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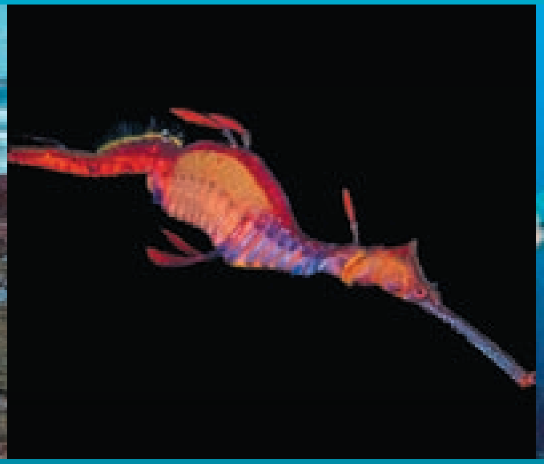

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Parks Victoria Technical Series No. 26

Review of Marine Habitat Classification Systems

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February 2006

EXECUTIVE SUMMARY

The aim of this report was firstly to review and compare the interim marine habitat classification scheme for Victoria presented in Ferns & Hough (2000) with relevant Australian and international examples of marine habitat classification systems. The second aim was to present a revised marine habitat classification system to support mapping of shallow habitats at Victoria's Marine National Parks and Sanctuaries.

The classification schemes investigated in this report could be divided into those that presented a hierarchical framework for classifying marine environments at all geographical scales from continents to local areas (*e.g.* IMCRA Technical Group 1998, Allee *et al.* 2000, CMR & DEP 2002, Madden & Grossman 2004), and those that presented a classification scheme for describing marine habitats or communities at a local-level (*e.g.* Mumby & Harborne 1999, Bancroft in prep., Tasmanian SEAMAP). Local-level habitat classification schemes provide a means of describing the lowest levels of the national/continental schemes and are typically in the form of a matrix or hierarchy of habitat modifiers. This review did not attempt to re-define national classification schemes for Australia (*e.g.* IMCRA Technical Group 1998, CMR & DEP 2002), but rather it focused on presenting a revised matrix of modifiers for local-level habitats.

A two-stage approach to habitat classification was adopted for the marine mapping whereby a primary habitat classification scheme was used to classify observations from underwater video and a reduced set of modifiers was used to classify habitats mapped from the aerial photography in the GIS. The primary habitat classification scheme (Table 19) was a modification of the interim MHC scheme presented in Ferns & Hough (2000). The GIS mapping classification scheme (Table 20) included those categories from the primary classification scheme that could be interpreted from aerial photography.

The primary classification scheme is divided into five levels of modifiers (Table 19). The first level (substratum type) is a simple differentiation between rock/reef and sediment, with the additional category of rock/reef – sediment for patchy reef. The second level differentiates between substratum types based on relief for rocky reef and presence of vegetation for sediment. The third level is substratum structure and discriminates between continuous and patchy for reef systems and physical profile for sediment. The fourth level describes the substratum texture for both reef and sediment. The fifth level relates to dominant biota and provides two modifiers for reef (biota type and dominant canopy species) and three modifiers for sediment (biota type, density and dominant species).

The GIS mapping classification scheme (Table 20) consists of two levels of modifiers. The first level (substratum type) is consistent with the primary classification table. The second level is divided into intertidal and subtidal habitats and features elements of the substratum category and texture for reef and dominant biota for sediments. The habitat polygons mapped from the aerial photography were only classified according to these modifiers.

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1. INTRODUCTION

This report reviewed and documented the relationship between relevant Australian and international local-level marine habitat classification systems and the Victorian interim marine habitat classification scheme (see Ferns & Hough 2000). A revised marine habitat classification system is presented to support mapping of shallow habitats at Victorian Marine National Parks and Sanctuaries.

Throughout Australia and internationally, remote sensing techniques have been employed to characterise and map the marine environment. Interpreting and translating remotely captured data into ecologically meaningful maps requires a classification system that operates at an appropriate scale given the available data and is representative of the habitats in question.

Most international and Australian marine habitat classification systems use some form of hierarchical classification of ecosystem components that are a mixture of geomorphological and biological information which can be aggregated into successively higher levels of organisation. At the upper levels of classification the scale and classification is typically coarser and is predominantly based on geomorphological attributes, while at finer-scales classification moves more towards biological attributes (ANZECC TFMPA 2000).

1.1 Background

Large-scale mapping of marine habitats in Victoria commenced in 1995 as part of the *Environmental Inventory of Victoria's Marine Ecosystems* (Ferns & Hough 2000). The Inventory employed a range of remote sensing techniques, including aerial photography, Landsat TM imagery and single-beam hydro-acoustics to map shallow-substrata (mostly <20 m) at scales of approximately 1:100,000. The remote sensing was supplemented in places with ground-truthing observations from SCUBA spot dives, underwater video and collection of substratum samples (Ferns & Hough 2000). This mapping was primarily designed to assist in the selection and evaluation of candidate representative marine protected area locations.

Parks Victoria commissioned Primary Industries Research Victoria (PIRVic) Marine and Freshwater Systems in 2004 to map shallow habitats at Victoria's Marine National Parks and Sanctuaries at a scale of 1:25,000. The spatial extent of habitat to be mapped at each Park in this project was limited to seabed habitats that could be interpreted from aerial photography, which was typically up to depths of 5-10 m along the open coast of Victoria, depending on sea conditions. The mapping was designed to allow a more accurate description of the spatial extent and distribution of shallow seabed habitats and to provide more detailed biological information on the Parks to support assessment of management performance. A separate project to map the deeper areas at selected Parks (beyond depths that can be interpreted from aerial photography) with acoustic systems commenced in 2005.

1.2 Aim of Review

The aim of this review was firstly to compare the Victorian interim marine habitat classification scheme presented in Ferns & Hough (2000) to relevant Australian and international marine habitat classification systems. The second aim was to present a revised marine habitat classification system to support mapping of shallow habitats at Victoria's Marine National Parks and Sanctuaries.

2. CLASSIFYING MARINE HABITATS FOR MAPPING

2.1 What are Marine Habitats?

There are multiple definitions of what constitutes a habitat through the scientific literature, with each definition typically being dependent on the aims of the particular study. A review of methods for ecosystem mapping for the National Representative System of Marine Protected Areas (NRSMPA) (ANZECC TFMPA 2000) presented the following hierarchy of ecological definitions derived from the IMCRA Technical Group (1998) and ANZECC TFMPA (1999):

Bioregion: an ecologically based regionalisation at a particular scale (i.e., IMCRA meso- to provincial scale).

Ecosystem: a dynamic complex of plant, animal and microorganism communities and their non-living environment interacting as a functional unit.

Habitat: a specific type of environment inhabited either permanently or temporarily by organisms.

Community: an assemblage of species occupying a particular habitat or area.

Population: a grouping of living organisms of a species.

Species: a group of organisms capable of interbreeding freely with each other but not with members of other species.

Individual: a single organism of a species.

Under these definitions habitat implies a strong structural dimension in defining a feature, while a community is the biological assemblage that occupies that habitat. Put simply, benthic habitat can be defined as a place where a plant or animal ordinarily is found (Diaz *et al.* 2004).

2.2 Marine Habitat Mapping

Diaz *et al.* (2004) found that there is no universal definition for what constitutes benthic habitat mapping and that this is partly as a result of the wide range of instruments and survey techniques that have evolved for characterising the seabed. In the case of mapping studies, habitat is typically defined in terms of spatial concepts, as it is the definition of the distribution and spatial extent of those features that will determine how they can ultimately be represented on a habitat map. Coastal habitats are also seen as manageable units and large-scale maps allow managers to visualise the spatial distributions of these habitats (Mumby & Harborne 1999).

The extension of acoustic mapping technologies to seabed mapping has enabled effective collection of data on seabed substrata and has led many mapping studies to equate benthic habitat with bottom sediment or substratum type (Diaz *et al.* 2004). These mapping approaches emphasise the concept of benthic habitat as a ‘dwelling place’ or ‘preferred substratum’ for biota, from species to entire communities, with the biota representing a form of cover overlying the physical bottom features (Diaz *et al.* 2004). This approach can be limiting as it equates habitat with the physical properties of seabed topography and sediment textural characteristics that are typically independent of biological processes (Diaz *et al.* 2004). However, many of these habitat mapping studies also include biological sampling or observations (*e.g.* underwater video) to verify and identify presumed connections between physical characteristics and distribution of biota. Efforts are also being made to develop means to apply acoustic mapping systems to not only differentiate between physical substrata, but also to identify presence of associated biota.

2.3 Characteristics of Marine Habitat Classification

The characteristics of any marine habitat classification system will depend upon the objectives of the study, but some general features of classification systems include:

- The classification system should be hierarchical to avoid overlap of definitions and duplication of categories at different levels of the system, and ensure that ecologically similar types are placed near to each other and at an appropriate level.
- A classification scheme should be mutually exclusive and exhaustive so that every feature to be classified should fall within one class only.
- Be comprehensive, accounting for all the marine habitats within the region to be mapped.
- Habitats should be identifiable, repeatable environmental units, divided into types or classes.
- Provide a common and easily understood language for the description of marine habitats.
- Be practical in format and clear in its presentation.
- All types of sampling techniques should result in the same habitat classes or community definitions, although the level to which a habitat can be classified in a hierarchy will be dependent on the resolution of the sampling technique.
- The classification should recognise time scales over which variables may change. Habitat variables that change over shorter time scales (*e.g.* biota) should be incorporated at a lower level in the hierarchy than variables that change over longer time scales (*e.g.* reef substratum).
- It should include sufficient detail to be of practical use for resource managers and field surveyors, but be sufficiently broad (through hierarchical structuring) to enable summary habitat information to be presented at national and international levels or be used by non-specialists.
- It should be sufficiently flexible to enable modification resulting from the addition of new information, but stable enough to support ongoing uses. Changes should be clearly documented and where possible, newly defined types need to be related back to types in earlier versions of the classification (Congalton 1991; Booth *et al*. 1996; Kvitek *et al*. 1999; Connor *et al*. 2004).

2.3.1 Hierarchical Systems

It is generally agreed that marine habitat classification systems should be hierarchical (Congalton 1991; Booth *et al*. 1996; Kvitek *et al*. 1999; Connor *et al*. 2004). Congalton (1991) highlighted the advantage of the collapsible nature of categories in a hierarchical scheme, which allows the formation of more general categories higher in the classification scheme. The top levels of a hierarchy should be based on characteristics that can be mapped at a large-scale using remote sensing methods, and will define the boundaries within which other levels are classified (Booth *et al*. 1996; Kvitek *et al*. 1999).

3. INTERNATIONAL CLASSIFICATION SCHEMES

Multiple classification schemes have been developed internationally in an attempt to systematically classify habitats in different marine environments. The following provides a brief discussion of selected international habitat classification schemes.

3.1 United States of America

The National Oceanic and Atmospheric Administration (NOAA) has supported the development of two marine and estuarine habitat classification systems in recent years. These classification systems were developed in response to the need for natural resource managers and scientists to have a common language and a single classification standard for identifying and managing marine communities (Allee *et al*. 2000, Madden & Grossman 2004). The first of the NOAA classification systems proposed by Allee *et al* (2000) has largely been superseded by the scheme presented by Madden & Grossman (2004), but as Allee *et al.* (2000) has been widely cited in the marine classification literature we have summarised both schemes below.

The classification system proposed by Allee *et al.* (2000) consisted of a 13 level hierarchy (Table 1). The position in the hierarchy of some of the variables was selected arbitrarily and was based on the probability of information being available (Allee *et al*. 2000). Levels 11–13 (Table 1) in the hierarchy presented categories that were applicable to local areas. The concept of eco-types was introduced at Level 12 and represented a relatively coarse-level description of biological community associated with the physical variables (including substratum type) and were named for the dominant, readily-visible biotic element (*e.g.* seagrass, kelp beds) (Allee *et al*. 2000).

Eco-units sat at the lowest level of the hierarchy (Level 13) and represented the biological community or assemblage that is the product of the physical and biotic variables above it (Allee *et al*. 2000). Other local modifiers were also applied to the eco-types at this level in lieu of adding more levels to the hierarchy.

In response to the ongoing need for a standard ecological classification that would be universally applicable for coastal and marine systems, NOAA funded NatureServe to produce a revised classification scheme (Madden & Grossman 2004). NatureServe reviewed existing schemes, including Allee *et al.* (2000) and hosted a series of technical workshops. The resulting hierarchical framework, for a Coastal/Marine Ecological Classification Standard (CMECS), featured eight nested levels (Table 2).

The CMECS framework was designed to be applicable on spatial scales of less than one square metre to thousands of square kilometres and to be used in littoral, benthic and pelagic zones of estuarine, coastal and open ocean systems (Madden & Grossman 2004). Level 3 of the hierarchy divides into five systems; estuarine, estuarine-influenced, nearshore marine, neritic and oceanic. Levels 6–8 in CMECS (Table 2) are similar to Levels 11–13 in the scheme presented by Allee *et al.* (2000, Table 1). Figure 1 illustrates the entire CMECS hierarchy for the nearshore-marine system and includes examples of habitat units (macrohabitat and habitat) and biotopes for that system.

Modifiers are integral components of all levels of CMECS, but sit outside the hierarchy itself. Modifiers provide additional information about a classification unit and general classes of modifiers include substrate type, water mass characteristics, physical attributes, and biological attributes. Modifiers are particularly relevant at the habitat and biotope levels. Substrate modifiers are typically required to define habitat units, while modifiers that describe the spatial distribution, patchiness or density of vegetation or colonizing fauna are important distinguishing features for biotopes (Madden & Grossman 2004).

3.2 Canada

Roff & Taylor (2000) developed a classification system for marine habitats in Canada including the very different environments of the Arctic, Atlantic and Pacific Ocean regions. The system was based on five classification levels representing “enduring” and recurrent geophysical features of the marine environment (Table 3).

Roff & Taylor (2000) argued that the boundaries of marine communities are more dynamic than their terrestrial ecosystems, but that it should be possible to define representative communities in terms of their related “enduring features”. Features were considered enduring in this context over time-frames of hundreds to thousands of years. Furthermore, since many parts of the world have a paucity of biological marine data, using geophysical features as surrogates for marine communities should be widely applicable, and in some cases may be the only practical approach (Roff & Taylor 2000). Roff & Taylor (2000) considered that the use of mixed physical and biological features (usually indicator species) was a weakness of some classification schemes, especially where the same indicators were used at several levels of a hierarchy.

The broadest level of the classification scheme presented by Roff & Taylor (2000) was based on geographic/temperature regions (*i.e.* Arctic, Atlantic and Pacific Ocean) with the next level dividing between the benthic and pelagic realms. The remaining levels of the scheme differentiated habitats based on depth/light, substratum and exposure/slope. The temperate (Atlantic) benthic component of the system is presented in Table 3.

3.3 Britain and Ireland

The UK government’s wildlife advisory body, the Joint Nature Conservation Committee (JNCC) developed a marine habitat classification system as a tool to aid the management and conservation of marine habitats in Britain and Ireland (Connor *et al*. 2004). The classification was presented in a hierarchical format comprising six levels (Table 4).

At the top of the JNCC hierarchy was a simple distinction between marine, terrestrial and freshwater systems. In distinguishing the next levels in the hierarchy Connor *et al.* (2004) identified a broad range of environmental factors that influence community structure including substratum, zonation, exposure, oceanography, water quality and other physical parameters. While the importance of each of the environmental factors will vary for each community, Connor *et al.* (2004) identified substratum and vertical gradient or zonation as the factors that appeared to play a significant role in all communities. These are also the most easily and reliably recorded attributes in the field and are readily able to be mapped (Connor *et al.* 2004). As a consequence, substratum and zonation were considered the most appropriate for structuring the upper levels of the classification.

A primary habitat matrix of substrata (rock and sediment) versus zonation (littoral, infralittoral and circalittoral) was developed to provide a general framework for the JNCC classification and identified the habitat types for levels 2 & 3 in the hierarchy (Table 5). The categories presented in Table 5 were developed after an assessment of how best to classify biological data at lower levels of the hierarchy (Connor *et al.* 2004).

The lower levels of the hierarchy (levels 5 & 6) were defined by biotopes and sub-biotopes (Table 4). Biotopes were the combination of an abiotic habitat and its associated community of species and were distinguished by a combination of both presence and abundance of the most “obvious” species in a community (Connor *et al.* 2004). Sub-biotopes were a further classification of the biotopes and were defined using less conspicuous species. Biotopes typically exist at scales of at least 25 m^2 and can cover many km^2, while sub-biotopes exist at the scale of metres (Connor *et al.* 2004). It was envisaged that multivariate analysis of data from field surveys would group these data into clusters that had similar characteristics and that this would form the basis for defining these biotopes and sub-biotopes.

3.4 Tropical Reef Classification

Mumby and Harborne (1999) proposed a systematic approach to habitat classification for tropical coral reefs in the Caribbean. This regional level classification scheme defined habitats in terms of both geomorphological structure and benthic cover. The hierarchy of classes within the geomorphological component of the classification scheme is presented in Table 6 while a summary of the benthic component is presented in Table 7.

Mumby and Harborne (1999) defined coral reef habitats in terms of geomorphological structure and benthic cover as these attributes were known to exert a combined influence on the spectra recorded by remote sensors applied in the reef mapping. As a consequence, the hierarchical structure of the classification scheme also reflected the capabilities of different remote sensors for habitat mapping.

Mumby and Harborne (1999) defined benthic classes (Table 7) through quantitative analysis (hierarchical multivariate analysis and SIMPER) of field data identifying percentage cover of benthic species in quadrats collected throughout the study area.

The classification system proposed by Mumby and Harborne (1999) resulted in each polygon in a habitat map or GIS layer being assigned a geomorphological (Table 6) and/or benthic (Table 7) class. The advantage of this approach was that it allowed some areas to be mapped in greater detail than others within the same classification system, depending on the available information.

Table 1. Proposed USA Marine and Estuarine Ecosystem Classification System. Source: Allee et al. (2000)

Level	Sub-levels
1. Life Zone	1a. Temperate 1b. Tropical 1c. Polar
2. Water/Land	2a. Terrestrial 2b. Water
3. Marine/Freshwater	3a. Marine/Estuarine 3b. Freshwater
4. Continental/Non-Continental	4a. Continental 4b. Non-Continental
5. Bottom/Water Column	5a. Bottom (Benthic) 5b. Water Column
6. Shelf, Slope, Abyssal	6a. Shallow – on or over the continental shelf; <200 m. 6b. Medium – on or over the continental slope; 200–1000 m. 6c. Deep – on or over the rise and deeper features; >1000 m.
7. Regional Wave/Wind Energy	7a. Exposed/Open – open to full oceanic wave or wind energies. 7b. Protected/Bounded – protected from full wave or wind energies.
8. Hydrogeomorphic or Earthform Features	8a. Continental - Nearshore (surfzone); Inshore (rest of shelf); Straight or partially enclosed shorelines; Lagoons; Fjords; Embayments; Estuaries - Shore zone; Off shore zone; Delta; Carbonate settings; Outer continental shelf; Upper continental slope; Upper submarine canyon. 8b. Non-Continental - Island (Volcanic; Low); Atoll; Submerged reef types.

Level	Sub-levels
9. Hydrodynamic Features	9a. Supratidal – above high tides. 9b. Intertidal – extreme high to extreme low water. 9c. Subtidal – below extreme low water. 9d. Circulation features – *e.g.*, eddies.
10. Photic/Aphotic	10a. Photic (above the depth for photosynthesis). 10b. Aphotic (below the depth for photosynthesis).
11. Geomorphic Types or Topography	Cliff; Bench; Flat; Reef flat; Rock platform, Spur-and-Groove; Sand bar; Crevice; Slump; Rockfall; Terrace; Ledge; Overhang; Steeply sloping; Riverine; Fringe; Inland; Beach face; Dunes.
12. Substratum and Eco-type	12a. Substratum (Not limited to this list) - Cobble; Pebble; Sand; Silt; Mud; Bedrock; Peat; Carbonate; Boulder; Biogenic; Organic; Anthropogenic. 12b. Eco-type (Not limited to this list) - Coastal; Soft bottom; Hard bottom; Water column; Beach; Mangrove; Wetland; Seagrass bed; Coral reef; Kelp bed; Mud flat.
13. Local Modifiers and Eco-unit	13a. Modifiers (Not limited to this list) - Temperature; Local energy regimes – waves, tides, current; Salinity; Nutrients; Alkalinity; Roughness/relief; Dynamism; Edge effects – from adjacent areas; Anthropogenic disturbances; Biological interactions; Extreme events – history. 13b. Eco-units - Unlimited representation of species resulting from modifiers applied at the above hierarchical levels.

Table 2. Coastal/Marine Ecological Classification Standard (CMECS) for the USA. Source: Madden & Grossman (2004)

Level	Scale	Description
1. Ecological Region	100 km^2 to > 1,000 km^2	Large regions of the coasts and oceans defined by similar physical and/or biological characteristics.
2. Regime	10 km^2 to > 1000 km^2	Areas defined by the presence or absence of fresh water.
3. System	1 km^2 to > 1000 km^2	Areas that form estuaries, estuarine-influenced areas, or marine waters of shallow, deeper, or very deep-water columns.
4. Hydroform/Geoform	10,000 m^2 to 100 km^2	Large physical structures formed by either water or solid substrate within systems.
5. Zone	100 m^2 to 10,000 km^2	Major zones are the water column, littoral or sea bottom.
6. Macrohabitat	100 m^2 to several 1000 m^2	Large physical structures that contain multiple habitats.
7. Habitat	1 m^2 to 100 m^2	A specific combination of physical and energy characteristics that creates a suitable place for colonization or use by biota.
8. Biotope	1 m^2 to 100 m^2	The characteristic biology associated with a specific habitat.

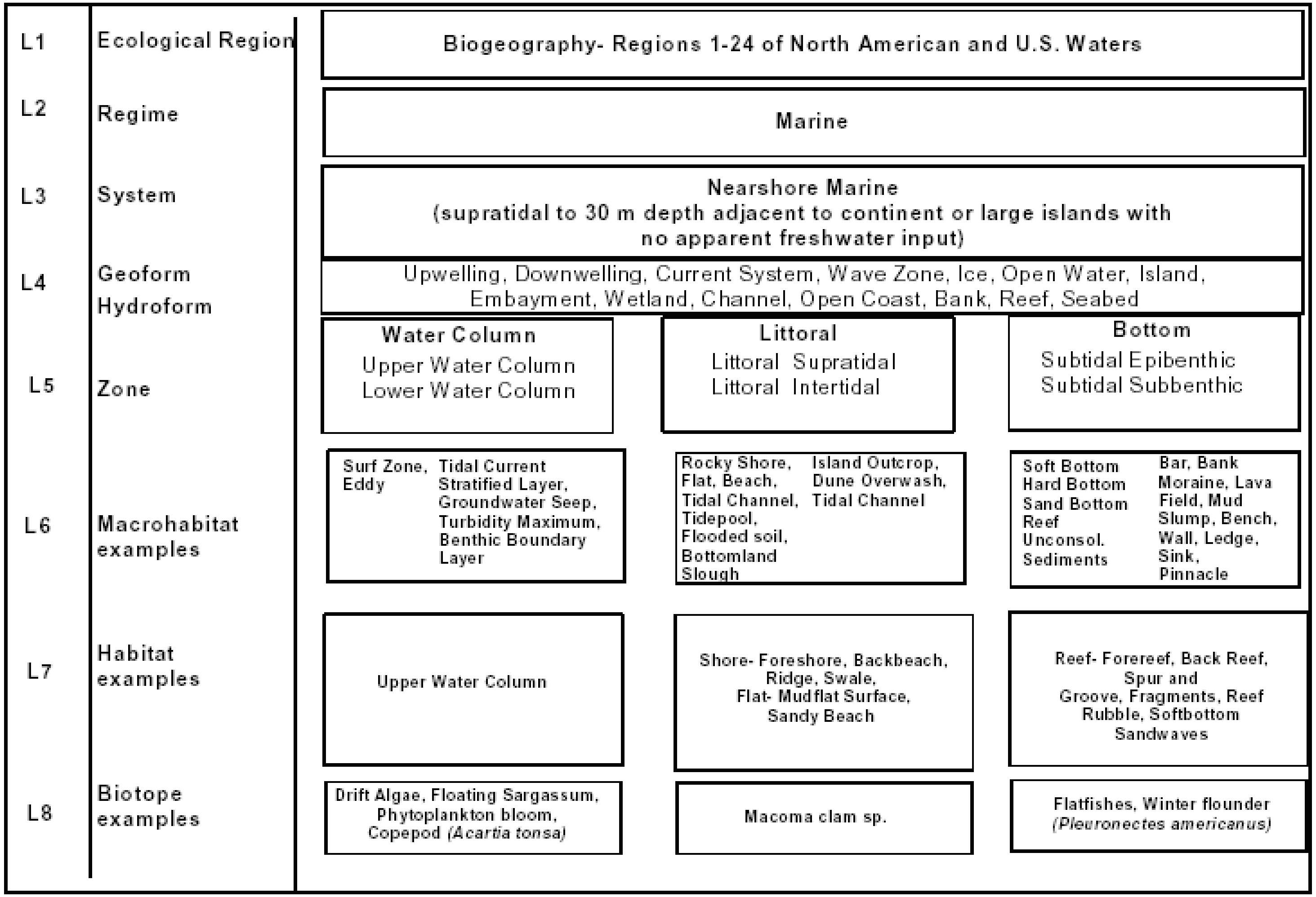

Figure 1. Coastal/Marine Ecological Classification Standard (CMECS) example hierarchy for nearshore marine environments. Source: Madden & Grossman (2004).

Table 3. Temperate benthic component of hierarchical classification scheme for Canada. Source: Roff & Taylor (2000)

Level 1. Geographic/ temperature	Level 2 Benthic	Level 3. Depth/light	Level 4. Substrate type	Level 5. Exposure/slope
Temperate Atlantic	Benthic	Littoral (intertidal)	Rock/boulders Pebbles/gravel/ coarse sand Fine sand Mud/silt	Exposed/very exposed Moderately exposed Sheltered/very sheltered
		Sub-littoral euphotic (0–50 m)	Rock/boulders Pebbles/gravel/ coarse sand Fine sand Mud/silt	Exposed/very exposed Moderately exposed Sheltered/very sheltered
		Sub-littoral dys/aphotic (50–200 m)	Gravel/sand Mud/silt	Low slope High slope (shelf edge/sea mounts/gulleys/ canyons)
		Bathyal (200–2000 m)	Gravel/sand Mud/silt	Low slope High slope (shelf edge/sea mounts/gulleys/ canyons)
		Abyssal/hadal (>2000 m)	Not applicable	

Table 4. National marine habitat classification scheme for Britain and Ireland. Source: Connor et al. (2004)

Level	Description
1. Environment (marine)	Single category to distinguish marine from terrestrial and freshwater environments.
2. Broad habitat types	Broad habitat divisions; littoral rock, littoral sediment, infralittoral rock, infralittoral sediment, ciralittoral rock and sublittoral sediment (Table 5).
3. Main habitats	Broad habitat divisions that reflect major differences in biological character and can be used as national mapping units.
4. Biotope complexes	Groups of biotopes with similar overall physical and biological character. Relatively easy to identify by non-specialists or coarser survey methods and provide better units for mapping than the component biotopes.
5. Biotopes	Distinguished by different dominant species or suites of conspicuous species. The majority of available biological sample data can be attributed to this level. Equivalent of communities defined in terrestrial classification systems.
6. Sub-biotopes	Defined on basis of less obvious differences in species composition, minor geographical and temporal variations, subtle variations in habitat or disturbed and polluted variations of a natural biotope.

Table 5. The UK's Joint Nature Conservation Committee (JNCC) framework for habitat classification; the primary habitat matrix. Source: Connor et al. (2004).

SUBSTRATUM		**ROCK**				**SEDIMENT**					
ZONE		**High energy rock** (wave exposed or very tide-swept)	**Moderate energy rock** (moderately wave-exposed or tide-swept)	**Low energy rock** (wave sheltered & weak tidal currents)	**Features on rock** (rockpools, caves)	**Coarse sediment** Mobile cobble & pebble, gravel, coarse sand	**Sand** Clean sands & non-cohesive muddy sands	**Mud** Cohesive sandy muds & muds	**Mixed sediment** Hetero-geneous mixtures of gravel, sand & mud	**Macrophyte-dominated sediment**	**Biogenic reefs**
LITTORAL	**LITTORAL** (splash zone, strandline & intertidal)	High energy littoral rock	Moderate energy littoral rock	Low energy littoral rock	Features on littoral rock	Littoral coarse sediment	Littoral sand	Littoral mud	Littoral mixed sediment	Littoral macrophyte-dominated sediment	Littoral biogenic reefs
SUBLITTORAL	**INFRA-LITTORAL** (shallow subtidal)	High energy infralittoral rock	Moderate energy infralittoral rock	Low energy infralittoral rock	Features on infralittoral rock	Sublittoral coarse sediment	Sublittoral sand	Sublittoral mud	Sublittoral mixed sediment	Sublittoral macrophyte-dominated sediment	Sublittoral biogenic reefs
	CIRCA-LITTORAL (nearshore deeper & offshore subtidal)	High energy circalittoral rock	Moderate energy circalittoral rock	Low energy circalittoral rock	Features on circalittoral rock						

Table 6. Hierarchy of classes within the geomorphological component of the classification scheme for Caribbean coral reefs. Source: Mumby and Harborne (1999)

First tier			Second tier		
Code	**Label**	**Characteristics**	**Code**	**Label**	**Characteristics**
1	Backreef				
2	Reef crest				
3	Spur and groove		3.1	Low relief spurs and grooves	Spurs <5 m in height
			3.2	High relief spurs and grooves	Spurs >5 m in height
4	Forereef	Reef with <45° slope			
5	Escarpment	Reef or lagoon with >45° slope			
6	Patch reef		6.1	Dense patch reef	Aggregated coral colonies (living or dead) where colonies cover >70% of the benthos.
			6.2	Diffuse patch reef	Dispersed coral colonies (living or dead) where colonies cover *ca* <30% of the benthos.
7	Lagoon floor	Lagoon floor with <45° slope	7.1	Shallow lagoon floor	Depth <12 m
			7.2	Deep lagoon floor	Depth >12 m

Table 7. Hierarchy of classes within the benthic component of the classification scheme for Caribbean coral reefs. Source: Mumby and Harborne (1999)

First tier		Second tier		Third tier	
Code and label	**Characteristics**	**Code and label**	**Characteristics**	**Code and label**	**Characteristics**
1. Coral classes	>1% hard coral cover	1.1. Branching corals	*Acropora* spp. visually dominate		
		1.2. Sheet corals	*Agaricia* spp. visually dominate		
		1.3. Ribbon and bare corals with green calcified algae	*Agaricia tenuifolia* visually dominant		
		1.4. Massive and encrusting corals		1.4.1. Sparse massive and encrusting corals	1–5% hard coral cover
				1.4.2. Dense massive and encrusting corals	>5% hard coral cover
2. Algal dominated	>50% algal cover; <1% hard coral cover	2.1. Green algae			
		2.2. Fleshy brown algae and sparse gorgonians	= 3 gorgonians m^{-2}		
		2.3. *Lobophora*	Monospecific *Lobophora* beds		
		2.4. *Euchema* and *Amphiroa*	Rare assemblage dominated by red algae with encrusting sponges		
3. Bare substratum dominated	Dominated by bare substratum; <1% coral	3.1. Bedrock/rubble and dense gorgonians	>3 gorgonians m^{-2} (usually >8 m^{-2}) and *ca* 30% algal cover		
		3.2. Bedrock/rubble and sparse gorgonians	= 3 gorgonians m^{-2} and little algal cover		
		3.3. Rubble and sparse algae	No gorgonians		
		3.4. Sand with sparse algae	>90% sand		
		3.5. Mud			
		3.6. Bedrock	No gorgonians		
4. Seagrass dominated	>10% seagrass cover	4.1. Sparse seagrass	Standing crop 1–10 $g.m^{-2}$; cover <30%		
		4.2. Medium density seagrass	Standing crop 11–80 $g.m^{-2}$; cover 30-70%		
		4.3. Dense seagrass	Standing crop >80 $g.m^{-2}$; cover >70%		
		4.4. Seagrass with distinct coral patches	Seagrass visually dominant, coral cover may reach 3%, gorgonians may be present		

4. AUSTRALIAN CLASSIFICATION SCHEMES

4.1 Ecosystem mapping for National Representative System of Marine Protected Areas

A review of methods for ecosystem mapping for the National Representative System of Marine Protected Areas (NRSMPA) summarised and outlined methods for describing and mapping ecosystem components for all Australian jurisdictions (ANZECC TFMPA 2000). The review did not attempt to develop a national standard habitat classification system, rather it focused on the classification systems used to develop the NRSMPA and presented information on the following:

- ecological units used as the basis for mapping (ie ecosystem, habitat, community),
- definitions of terms for ecological units,
- mapping methods being used by other agencies (CSIRO, AIMS, AGSO etc.),
- scale of map for which ecosystems are digitised (input and output),
- tolerances used in digitising and creating a boundary for an ecosystem, and
- accuracy of base/source maps and digitising.

The ANZECC review is online at: http://www.deh.gov.au/coasts/mpa/nrsmpa/action8/index.html and as a consequence we have not attempted to reproduce the information in this report. Instead we present below a selection of more recent Australian mapping studies and the classification systems developed as part of these studies.

4.2 Interim Marine and Coastal Regionalisation

An Interim Marine and Coastal Regionalisation for Australia (IMCRA) was developed through a collaborative effort of State, Northern Territory and Commonwealth marine management and research agencies (IMCRA Technical Group 1998). The identification of an ecosystem-based regionalisation of Australia's marine and coastal environments was seen as a major task to support establishment of a National Representative System of Marine Protected Areas (NRSMPA).

A hierarchical structure of biogeographic terms was adopted for IMCRA to allow classification of ecological patterns and processes at continental, regional, local and site scales (IMCRA Technical Group 1998). The IMCRA hierarchical structure is shown in table 8.

One of the key outputs from the IMCRA process was the development of the meso-scale regionalisation for Australian marine environments extending from the coastline to the limit of State territorial waters. In Victorian waters, five meso-scale regions were identified consisting of the Otway, Central Victoria, Flinders, Twofold Shelf and Victorian Embayment regions (IMCRA Technical Group 1998). The IMCRA Technical Group (1998) did not attempt to develop a classification system for micro-scale regions or smaller units as this was beyond the scope of its project. In assessing the need for micro-scale regionalisation, the IMCRA Technical Group (1998) identified the importance of site-based marine surveys to support definition of local scale ecological units through spatial multivariate statistics and marine habitat mapping to define the spatial extent and boundaries of ecological units.

Table 8. IMCRA hierarchical structure. Source: IMCRA Technical Group 1998.

Region	Scale	Size
Continental provinces	Macro-scale	>1,000s of km
Regions	Meso-scale	100s – 1,000s of km
Local units	Micro-scale	10s – 100s of km
Sites	Pica-scale	<10 km

4.3 CSIRO Marine Research

CSIRO Marine Research developed a hierarchical scheme to classify the structure of marine habitats for the North West Shelf Joint Environmental Management Study (CMR & DEP 2002). The scheme was developed having regard to other published classification schemes but was adapted for Australian needs. The scheme featured 7 levels in the hierarchy and is summarised in Table 9. Levels 1–3 of the hierarchy were applied to a deepwater bioregionalisation of Australia's south-east marine region to support identification of candidate areas for a regional representative system of marine protected areas (CMR *et al.* 2003).

To assist mapping marine habitats at Levels 4–6 of the hierarchical scheme, CSIRO Marine Research undertakes seabed classification with marine acoustic and underwater video systems. Table 10 presents an example of a seabed scoring system for interpreting underwater video developed by CSIRO for seabed habitat mapping on the south-east continental shelf (http://www.marine.csiro.au/sefmapping/about/index.htm).

Table 9. CSIRO Marine Research hierarchical scheme for habitat mapping and classification. Source: CMR & DEP 2002.

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 southeastern Australia 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 distribution of animal communities, which may have narrow depth ranges.
	2c Mesoscale units	Along-slope subdivisions within, *e.g.*, mid-slope unit, typically dictated by faunal distributions. For example IMCRA identified 12 mesoscale units on the continental shelf in the SE Australia, 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 10’s 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 that *size* is not a criterion for level in the above 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 there are some indicators of spatial extent (CMR & DEP 2002).

Table 10. CSIRO Marine Research underwater video classification system. Source: Bruce Barker pers.comm.

Substratum	Geomorphology	Fauna	Abundance
Mud	Un-rippled	None - no apparent epifauna or infauna	Low / sparse (<10%)
Fine sediments	Current rippled / directed scour	Gardens - large sponges	Medium / intermediate (<50%)
Coarse sediments	Wave rippled	Gardens - small sponges	High / dense (>50%)
Gravel / pebble	Highly irregular	Gardens - mixed. (sponges , seawhips , ascidians)	
Cobble/ boulder	Debris flow / rubble banks	Crinoids	
Igneous / metamorphic rock	Subcrop	Octocorals (gold corals / seawhips)	
Sedimentary rock	Outcrop (low <1 m); no holes/cracks	Small encrustors / erect forms (including bryozoans)	
	Outcrop (low < 1 m); with holes/cracks	Sedentary: *e.g.* seapens	
	Outcrop (high > 1 m); no holes/cracks	Mobile: *e.g.* echinoids / holothurians / asteroids	
	Outcrop (high > 1 m); with holes/cracks	Distinct infauna bioturbators	

4.4 Tasmania

Tasmania is undertaking a comprehensive seabed habitat mapping program known as the SEAMAP Tasmania project. The SEAMAP project is applying multiple mapping techniques including aerial photography interpretation, acoustic sounding and underwater video. The following information was derived from the SEAMAP web page (http://www.utas.edu.au/tafi/seamap/).

The subtidal seabed habitat classifications in the SEAMAP Tasmania project are defined within a hierarchical scheme that uses the framework outlined in Allee *et al.* (2000) (Section 0). It is based on either physical or biotic structuring variables, or a combination of the two, and is often related to the method and scale of the habitat mapping. The four levels in the hierarchy were defined as:

- Geomorphic type.
- Bio-geomorphic type
- Substratum/Eco-type.
- Eco-units.

The SEAMAP Tasmania classifications are presented in Table 11 and correspond to levels 11–13 in the NOAA scheme (Allee *et al.* 2000; Table 1). The geomorphic and bio-geomorphic levels in the hierarchy present habitats defined through acoustic mapping techniques in the SEAMAP Tasmania project. The ecotype and ecounit modifiers were identified in the field by underwater video and diver observations.

The physical and biological factors defined in the scheme were not considered to be exhaustive, but represented those used so far in the SEAMAP Tasmania project. More modifiers and eco-units may be added, relevant to the objective and/or scale of the mapping project and as further data becomes available.

Table 11. Tasmanian SEAMAP subtidal habitat classification scheme. Source: URL: http://www.utas.edu.au/tafi/seamap & A.Jordan pers. comm.

Geomorphic type					
Reef		Unconsolidated			
Biogeomorphic type					
Unvegetated & Vegetated		Unvegetated		Vegetated	
Attributes	**Modifiers**	**Attributes**	**Modifiers**	**Attributes**	**Modifiers**
Substratum texture	Solid Broken Cobble Boulder	Substratum texture	Hard (high shell content)	Substratum texture	Hard (high shell content)
Structure	Continuous Patchy Guttered	Relief	Hills Waves Ripples Flat	Bed structure	Continuous Patchy Sparse
Profile	High Low			Sediment type	Sand Mud
Slope	slight vertical sloping overhang steep	Slope	slight sloping steep	Slope	slight sloping steep
Swell/wave exposure	*e.g.* high exposure	Swell/wave exposure	*e.g.* sheltered	Swell/wave exposure	*e.g.* very sheltered
Sponge morphological groups	*e.g.* branched, encrusting				
Rock type	*e.g.* Dolerite, Granite				
Substratum/Ecotype					

Unvegetated		**Vegetated**		**Unvegetated**		**Vegetated**	
Attached epifaunal groups	Dense sponge	Attached floral groups	Macroalgae (kelp)	Sediment type	Sand Silt	Attached floral groups	Seagrass Algae

Ecounits							
Attached epifaunal species	*e.g. Pyura australis*	Attached floral species	e.g *Ecklonia radiata, Macrocystis pyrifera*	Attached epifaunal groups	Sparse sponge	Attached floral species	e.g. *Posidonia australis* *Caulerpa trifaria*
Unattached faunal groups	*e.g.* Fish seastars	Unattached floral groups	*e.g.* Red algae	Attached epifaunal species	*e.g. Sarcoptilus grandis*	Attached epifaunal groups	*e.g.* Ascidians
Unattached faunal species	*e.g. Asterias amurensis*	Unattached floral species	*e.g. Enteromorpha compressa*	Unattached faunal groups	*e.g.* Brittle stars Fish	Attached epifaunal species	*e.g. Polycarpa viridis*
Unattached floral groups	*e.g.* Red algae	Attached epifaunal groups	*e.g.* Sponge Bryzoans Ascidians	Unattached faunal species	*e.g. Asterias amurensis*	Unattached faunal groups	*e.g.* Fish
Unattached floral species	e.g *Laurencia majuscula*	Attached epifaunal species	*e.g.* Pyura australis	Emergent epifaunal groups	*e.g.* Bivalves Polychaetes	Unattached faunal species	*e.g. Neoodax balteatus*
		Unattached faunal groups	*e.g.* Fish seastars	Emergent epifaunal species	*e.g. Maoricolpus roseus*	Emergent epifaunal groups	*e.g.* Bivalves Ghost shrimps
		Unattached faunal species	*e.g. Asterias amurensis*	Unattached floral groups	*e.g.* Red algae	Emergent epifaunal species	*e.g. Corbula gibba*
				Unattached floral species	*e.g. Enteromorpha compressa*	Unattached floral groups	Red algae
				Attached floral groups (low % cover)	*e.g.* Seagrass Macroalgae Filamentous algae	Unattached floral species	*e.g. Colpomenia sinuosa*
				Attached floral species (low % cover)	*e.g. Zostera tasmanica* *Caulerpa trifaria*		

4.5 South Australia

Two current projects in South Australia will address marine habitat classification; the Adelaide Coastal Waters Study and Marine Protected Area (MPA) surveys.

The Adelaide Coastal Waters Study aims to examine the causes of seagrass loss along the Adelaide metropolitan coastline. SARDI, in conjunction with Adelaide and Flinders Universities is conducting the biological component of the study, which focuses on assessing the response of seagrasses to various anthropogenic stressors, including stormwater inputs and elevated nutrient levels (from www.sardi.gov.au). This project incorporates mapping of seagrass beds with a CASI hyperspectral airborne imagery system and ground-truthing with underwater video.

In conjunction with the SA Department of Environment and Heritage (DEH), SARDI is also involved in mapping marine habitats using remote video and acoustic techniques to assess potential areas for MPAs. Currently this work is focussed on Encounter Bay and Backstairs Passage, which is the site for the MPA pilot (www.environment.sa.gov.au/coasts). This project is in progress at the moment and the actual habitat classification scheme is yet to be finalised. At present, DEH is generally following the Tasmanian SEAMAP classification system (Table 11) with a view to developing a habitat classification system that is hierarchical and consistent with other States at a broad-scale, while refining the final classes at a morphological level to meet local habitats (B. McDonald, pers. comm.).

A representative system of MPAs in South Australia is being developed with a statewide recognition of the following 12 broad habitat categories (B. McDonald, pers. comm.).

- Reef
- Surf beach
- Seagrass meadow
- Unvegetated soft bottom
- Sheltered beach
- Tidal flat
- Tidal creek
- Estuarine river
- Coastal lagoon
- Mangrove forest
- Saltmarsh
- Freshwater spring

The above habitat classes were derived from Bryars (2003).

4.6 Western Australia

The WA Department of Conservation and Land Management Marine Conservation Branch (MCB) is undertaking a program of marine habitat mapping to support planning and management of marine protected areas. As part of its marine mapping and conservation work the MCB is developing a shallow-water marine habitat classification scheme (SMHC). The SMHC classifies shallow-water marine habitats according to a range of environmental and physical factors, including bathymetry, tidal range, exposure, geomorphology, biology, lithology, density and other spatial characteristics (Bancroft in prep.). The upper levels of the draft hierarchical structure for the SMHC are shown in Figure 2. The lower levels of the draft hierarchy, not shown in Figure 2, classify biota by functional or species groups and physical features by geomorphological/geological characteristics.

4.6.1 Recherche Archipelago

The University of Western Australia is undertaking a project funded by the Fisheries Research Development Corporation (FRDC 2001/060) to provide baseline information about the distribution of benthic habitats within the Recherche Archipelago to assist in planning the management and use of the area (Baxter 2003). The Recherche Archipelago marine habitat mapping project is investigating different sources of information including satellite (Landsat), aerial photography, acoustic imagery (side-scan and multi-beam), underwater video and divers (Baxter 2003). The Recherche Archipelago project was integrated into a larger coastal water habitat mapping project being undertaken by the Coastal CRC to develop and apply technology for the rapid and cost effective assessment of shallow marine habitats around Australia (http://www.coastal.crc.org.au/cwhm/index.html).

A hierarchical marine habitat classification scheme was developed for the different habitats observed in the initial video survey of April 2002. The classification scheme was based on physical descriptions of the observed habitat (*e.g.*, depth, substrate and relief), dominant habitat type and degree of cover (Table 12).

Various survey techniques were used to derive detailed information that was fed into the classification scheme and mapping projects (Baxter 2003). Underwater video was used to assess the dominant biological components present and also to validate the differences observed on side-scan sonar surveys. Aerial photography and satellite imagery was primarily used to derive habitat boundary information, whilst acoustic information was used to classify relief (slope and aspect) and surface roughness. To avoid misleading representations of the complex distribution of habitat types in between the video drops, other indicators of spatial extent of habitats, such as side-scan sonar or aerial photography, were used to map habitats. The classification scheme was then used to draw together physical factors, such as depth, relief, substrate and exposure, as well as dominant biological components observed by the video, to develop rules by which habitats are identified, classified and predicted (Baxter 2003).

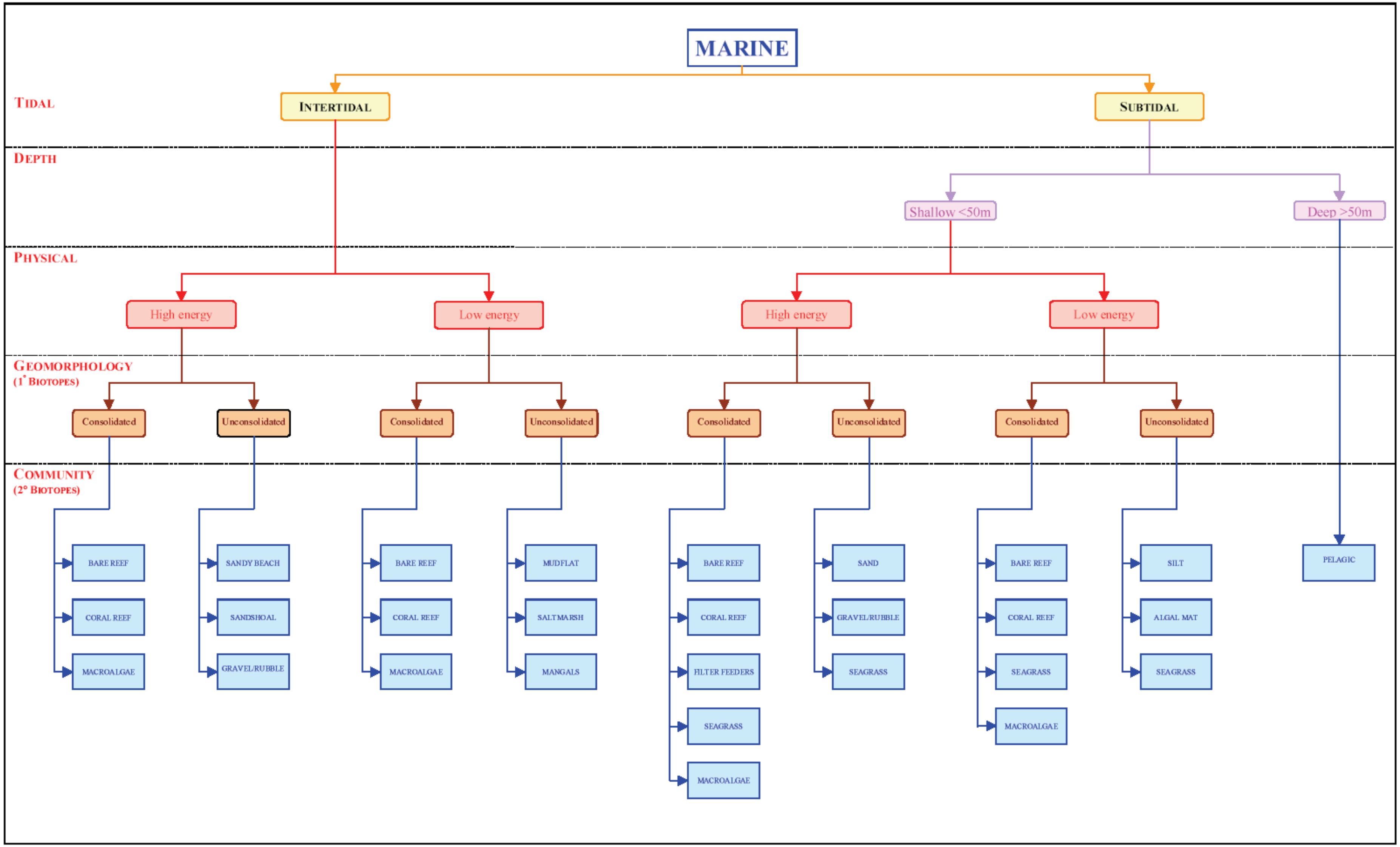

Figure 2. Western Australian shallow-water marine habitat classification (after Bancroft in prep.)

Table 12. Benthic classification scheme for the Recherche Archipelago, Western Australia. Source: http://www.marine.uwa.edu.au/recherche/Research/classification.htm

Substrate type	Major Habitat	Biotic Components
S1. sand	H1. Seaweeds	Canopy 1. Kelp (*Ecklonia / Scytothalia*) (Can1)
S2. mud	H2. Seagrasses	Canopy 2. *Cystophora / Sargassum* (Can2)
S3. gravel/maerl	H3. Filterfeeders	Rhodophyta (rho)
S4. reef	H4. Unvegetated	Phaeophyta (pha)
S5. mixed	H5. Rhodoliths	Chlorophyta (chl)
		Posidonia sinuosa, australis, angustifolia (psin)
		Posidonia ostenfeldii (4 spp.) (post)
		Halophila/*Heterozostera* / *Syringodium* (hhs)
Qualifiers: Relief	**Qualifiers: Cover**	*Amphibolis* sp. (amph)
R1. flat/ gently sloping (5–35°)	C1: Sparse (5–25%)	Thallasodendron (thal)
R2. steeply sloping (35–70°)	C2: Medium (25–75%)	Sponges (spg)
R3. vertical walls (70–90°) and overhangs/caves	C3: Dense (>75%)	Ascidians (asc)
R4. pinnacles	C4: Bare	Hard coral (hcr)
R5 sand mega-ripples (>20 cm)		Soft coral (scr)
R6. sand flat		Gorgonians (gor)
		Crinoids (crn)
		Hydroids (hyd)
		Bryozoans (b)
		Scallops (scp)
		Rhodoliths (rot)
		Anenomes (ane)

4.7 Queensland

Intertidal habitat mapping in coastal Queensland was undertaken as part of the process of designing a representative system of Marine Protected Areas in the State (Banks & Skilleter 2002). The classification system used to describe these areas was based on a detailed evaluation of substratum geomorphology along the shoreline. The classification levels are outlined in Table 13. The more detailed secondary classification including features such as shoreline slope, boulders, cobbles, gravel, sand, *etc*. were identified using stereo aerial photography.

Table 13. Classification scheme for intertidal habitats in Queensland. Source: (Banks & Skilleter 2002).

Classification level	Classification attributes
Level 1	Broad Geomorphology (consolidated, unconsolidated, artificial, reef).
Level 2	Substratum type. Consolidated (Bedrock, Beach Rock, Boulder). Unconsolidated (Cobbles, Gravel, Sand, Mixed fines). Reef (wide or narrow). Artificial (jetty, marina, rock wall).
Level 3	Slope (Steep, inclined, flat).
Level 4	Habitat type or local modifiers including wave exposure and tidal range.

5. VICTORIAN HABITAT CLASSIFICATION SYSTEMS

5.1 Interim marine classification scheme for Victoria

An interim marine classification scheme for Victoria's nearshore marine waters was presented in Ferns & Hough (2000) and described marine biodiversity at "habitat" and "community" levels. Marine Habitat Classes (MHCs) classified intertidal and subtidal marine habitats with qualitative attributes collected with remote sensing (satellite imagery and vessel based hydro-acoustics) and field survey techniques (SCUBA, underwater video and grab samples) that described their dominant physical type (*e.g.*, reef or sand) and dominant biota (*e.g.*, seagrass or kelp). MHCs aimed to function as surrogates for describing marine biodiversity at scales of 1:25,000 to 1:100,000 (Ferns & Hough 2000). Dominant biota was included as an important habitat component as some large common species, such as kelp and seagrass, may provide habitat for other species.

In developing the MHCs, a separate definition for Marine Ecological Communities (MECs) was identified which consisted of distinct biological communities inhabiting the marine habitats (Ferns & Hough 2000). While the MHCs were defined by qualitative and semi-quantitative methods, primarily from remote sensing, MECs were derived from numerical classification (*e.g.* cluster analysis) of systematic quantitative sampling data (*i.e.* Victorian subtidal monitoring program).

5.1.1 Subtidal Classification

The interim subtidal MHCs presented by Ferns & Hough (2000) were based on combining substratum attributes with dominant biota (Table 14). The substratum categories were developed as part of the underwater mapping project described by Roob (2000). Biota attributes were derived from dominant species commonly described on both reef and soft sediment substrata (Roob *et al*. 1998; Ferns & Hough 2000). Additional attributes also described co-dominant species, dominant understorey species and seagrass density. The descriptions of dominant algae, seagrass or sessile invertebrates used for MHC mapping were largely qualitative.

The interim MHCs presented in Ferns & Hough (2000) also incorporated seagrass classifications developed during the Victorian seagrass mapping program (Roob & Ball 1997; Roob *et al*. 1998; Blake *et al*. 2000; Blake & Ball 2001a,b).

5.1.2 Intertidal Classification

Due to the different attributes of intertidal and subtidal habitats, a separate classification system was developed for intertidal habitats (Ferns & Hough 2000). The intertidal categories were similar to the subtidal categories, but provided for shore features (*e.g.* rock platform) and biota (*e.g.* mangroves) (Table 15). The interim classification of Victoria's intertidal MHCs was based on an initial classification of Victoria's intertidal substratum types (Roob *et al*. 1997) and classification of intertidal habitats for the Victorian component of the Oil Spill Response Atlas (Marine and Freshwater Resources Institute 2000).

Table 14. Interim subtidal marine habitat class (MHC) categories for Victoria. Source: Ferns & Hough (2000).

Description	Sub-tidal MHC Attributes			
Substratum type	Reef		Sediment	
Substratum relief	Low profile (reef) (< 1 m high) High profile (reef) (> 1 m high)		Flat (sand / mud) Ripples (sand) Gently undulating ridges (sand) Steeply undulating ridges (sand)	
Substratum texture	Solid (not broken into fragments) Broken (boulders / slabs / bommies) Gutters (gutter-like depressions or chutes) Outcrops (reef breaking the surface)		Coarse sand (0.5–1.0 mm) Medium sand (0.25–0.5 mm) Very fine / fine sand (0.125–0.25 mm)	Muddy Sand Mud / silt (< 0.031 mm) Shelly rubble / grit
Substratum consistency	Continuous	Patchy		
Lithology	Basalt Sandstone Granite		Limestone Calcarenite	
Dominant reef biota	Kelp – *Phyllospora* dominated Kelp – *Macrocystis* dominated Kelp – *Durvillaea* dominated Kelp – *Ecklonia* dominated Kelp – Mixed *Phyllospora* / *Ecklonia* Mixed algae – Brown algae dominated Mixed algae – other		*Cystophora* Red algae dominated *Acrocarpia* Urchin barrens *Seirococcus* *Amphibolis* *Cystophora* / *Amphibolis* Sessile invertebrates (*e.g.* sponges)	
Reef understorey biota	Encrusting coralline algae Mixed red algae Sessile invertebrates		*Caulerpa* dominated Mixed algae *Plocamium* dominated	
Dominant sediment biota	*Halophila* *Posidonia* *Amphibolis* *Zostera*	*Heterozostera* *Ruppia* Mixed seagrass / algae *Caulerpa* dominated	Mixed *Zostera* / *Posidonia* / *Halophila* Mixed *Posidonia* / *Halophila* Mixed *Zostera* / *Posidonia* Mixed *Zostera* / *Halophila*	
Seagrass density	Sparse	Medium	Dense	

Table 15. Interim intertidal marine habitat class (MHC) categories for Victoria. Source: Ferns & Hough (2000).

Description	**Intertidal MHC Attributes**		
Shoreline category	Dune Beach Platform	Beach / Platform Reef Cliff (steep or inclined)	Lagoon Flat Artificial seawall
Intertidal area/zone	Coastal/Backshore Supralittoral	Littoral Infralittoral fringe	
Substratum type	Bedrock Bedrock (broken) Bedrock/rock Cobble	Boulder/cobble Sand Sand/Gravel Sand/Bedrock	Mud Mud/Sand Artificial structure (i.e. Concrete/Wood/ Metal)
Lithology	Basalt Sandstone Granite	Limestone Calcarenite	
Wave Energy/Exposure	Low	Moderate	Moderate – High
Dominant structural biota	Coastal scrub Coastal heath Mangrove Saltmarsh Seagrass	Fleshy algae – mixed greens Fleshy algae – mixed browns Durvillaea Hormosira Turf algae	Coralline algae Pyura Mussels Barnacles

5.1.3 Seagrass Classification

Victoria's interim MHCs (Table 14) adopted seagrass species and density values developed during the Victorian seagrass mapping program (Roob & Ball 1997; Roob *et al*. 1998; Blake *et al*. 2000; Blake & Ball 2001a; 2001b) and were defined as follows.

5.1.3.1 Seagrass Species

The main seagrass species identified during the seagrass mapping program for Victorian marine embayments were *Zostera muelleri*, *Heterozostera tasmanica*, *Halophila australis*, *Posidonia australis* and *Amphibolis antarctica.* Other species, including *Ruppia spp*. identified in the interim MHCs are unlikely to be encountered during the shallow habitat mapping study.

The previous seagrass mapping in Victoria adopted the species definitions of *H. tasmanica* and *Z. muelleri* (Blake *et al*. 2000; Blake & Ball 2001a; 2001b). In these studies, the two species were grouped into a single category of "*Zostera/Heterozostera*", as while *H. tasmanica* is generally subtidal and *Z. muelleri* is generally intertidal, it was not possible to differentiate these species by visual observation in the field. In the period since these studies there has been a re-assessment of the taxonomy of Zosteraceae in Australia and New Zealand (Les *et al*. 2002).

5.1.3.2 Seagrass Cover

Seagrass cover or density was initially derived from the aerial photography through interpretation of the "darkness" of vegetated areas and the amount of seabed visible through the vegetated areas. These density categories were verified in the field through visual observations along transects. The density values recorded during field surveys were described as follows:

For *Zostera/Heterozostera* and *Posidonia australis*:

- Dense: Thick enough to hide the sediment underneath from view.
- Medium: Thick enough for leaves to touch but sediment could be discerned beneath.
- Sparse: When plants were present but at a density where leaves of individual plants did not touch each other.
- For *Halophila australis*:
- Dense: The base sediment could always be seen, but the leaves were within touching distance of each other.
- Medium: Present but leaves did not touch, although within close proximity to each other.
- Sparse: Leaves did not touch and individual plants clearly dispersed.

The same principles were applied to estimating macroalgal densities on sediment.

For *Amphibolis antarctica:*

Amphibolis antarctica typically grows in association with reef and this presents difficulties in interpreting *Amphibolis* distribution and densities from aerial photography as an underlying dark reef substrata can disguise the plant densities. As a result the previous seagrass mapping studies did not attempt to interpret *Amphibolis* densities from aerial photography or in the field.

5.2 Bunurong Marine National Park Mapping

"High-resolution" marine habitat mapping of the Bunurong Marine National Park (Ferns & Hough 2002) was the first Victorian mapping study to apply the interim MHCs presented by Ferns & Hough (2000). This study made use of different mapping techniques including aerial photography, single beam acoustic sounder, side-scan sonar, underwater video and quantitative SCUBA transects. The resulting habitat maps reflected the different levels of the interim MHCs hierarchy that could be differentiated with the different mapping techniques. The aerial photography interpretation classified habitats as sand and reef while the acoustic techniques were able to further differentiate between substratum relief and texture (*e.g.* low profile and high profile reef).

5.3 Port Phillip Bay Mapping - University of Melbourne

Postgraduate students at The University of Melbourne, Department of Geomatics, undertook mapping of selected Marine National Parks and Sanctuaries in Port Phillip Bay (Sutherland 2003; Vuyovich 2003).

Vuyovich (2003) investigated seabed mapping with aerial photography, satellite imagery and side-scan sonar at Point Lonsdale Marine National Park. Underwater video was used to ground-truth the remote sensing imagery. A simple classification of sand and rocky reef was applied to the remote sensing, while underwater video was classified according to the categories presented in Table 16.

Table 16. Underwater video classification system for Port Phillip Heads Marine National Park - Point Lonsdale (University of Melbourne, Department of Geomatics). Source: Vuyovich (2003)

Cover Type	Cover Density
Seagrass & *Amphibolis*	Sparse Moderate Heavy
Mixed	
Ecklonia	Sparse Moderate Heavy
Rubble	
Sand	
Rock	

Sutherland (2003) investigated benthic mapping techniques from aerial photography at Point Cooke and Jawbone Marine Sanctuaries. A simple classification scheme consisting of six categories was adopted to delineate the seabed (Table 17).

Table 17. Seafloor bottom classes for Point Cooke and Jawbone Marine Sanctuaries (University of Melbourne, Department of Geomatics). Source: Sutherland (2003)

Bottom Type Classes	Definition
Rock and Algae:	Combination of bare rock and algae (non-seagrass vegetation) that grows in this environment.
Bare Sediment:	Sand of all grades and shades as well as mud, with no vegetative cover.
Macroalgae and Sediment:	Non-seagrass categories of vegetation, with a sparse coverage over sediment.
Macroalgae:	Areas dominated by non-seagrass vegetation.
Sparse Seagrass:	Patches of seagrass where individual plants are grouped, but sediment is clearly visible beneath.
Dense Seagrass:	Patches of seagrass where little or no bare sediment is visible beneath.

5.4 Victorian Subtidal Reef Monitoring Program

The Victorian subtidal reef monitoring program has collected extensive data on reef communities based on presence and abundance of fish, benthic invertebrates and macrophytes (Edmunds & Hart 2003). While not aimed at mapping reef communities, the monitoring program has particular emphasis on the Marine National Parks and identifies general categories of macrophyte communities derived from quantitative data collection and analysis. Macrophyte communities identified by the subtidal reef monitoring program to date, are generally compatible with the dominant reef biota categories presented in the interim MHCs.

6. DISCUSSION

6.1 Classification Schemes

The classification schemes outlined above can be divided into those that presented a hierarchical framework for classifying marine environments at all geographical scales from continents to local areas (*e.g.* IMCRA Technical Group 1998, Allee *et al.* 2000, CMR & DEP 2002, Madden & Grossman 2004), and those that presented a classification scheme for describing habitats or communities at a local-level (*e.g.* Mumby & Harborne 1999, Bancroft in prep., Tasmanian SEAMAP). Connor *et al.* (2004) presented both a national level hierarchical classification and a local-level habitat scheme for marine systems in England and Ireland. Madden & Grossman (2004) also presented a continental/national classification scheme with examples of how the different levels in the hierarchy could be applied to different marine systems including local-level habitats.

Describing both continental/national level and local habitat/community level classification schemes as marine habitat classification schemes can cause some confusion. The national/continental schemes provide broad hierarchical frameworks for describing all levels of the marine environment. The local-level habitat classification schemes provide a means of describing the lowest levels of the national/continental schemes and these are typically in the form of a matrix or hierarchy of habitat modifiers. A matrix of habitat modifiers for local-level habitats may be in a hierarchical format and applying the different levels of the classification typically requires an increasing level of field-survey and intensity of data collection as you move down through the hierarchy or levels of modifiers. By contrast the different hierarchical levels of the national/continental schemes correspond to the different spatial scales of the habitat units represented by each level.

This review did not attempt to re-define categories in the national classification schemes for Australia (*e.g.* IMCRA Technical Group 1998, CMR & DEP 2002), but rather it focused on presenting a revised matrix of modifiers for local-level habitats. While different terminology is used by all the classification schemes, the shallow habitat mapping study addressed habitats that sit at the lower levels of the national level hierarchical frameworks. These habitats are variously described as eco-types and eco-units by Allee *et al.* (2000, Table 1), primary and secondary biotopes and biological facies by CMR & DEP (2002, Table 9), and main habitats, biotope complexes and biotopes by Connor *et al.* (2004, Table 5).

Despite significant differences in the coverage and the diversity of habitats they attempted to classify, a number of common themes emerged from the international examples of classification schemes, (*e.g.* Mumby & Harborne 1999, Roff & Taylor 2000, Connor *et al.* 2004, Madden & Grossman 2004). Most classification schemes employed elements of geomorphology (*e.g*. rock reef, sediment, crevice, spur, *etc.*) and benthic biota or species assemblages. There were some subtle variations for local environments (*e.g.*, nutrients, salinity) or specific habitat types (*e.g.*, coral reefs) where additional modifiers are employed, but the general themes across the schemes are relatively consistent.

The classification scheme presented by Mumby & Harborne (1999) was developed for a tropical marine environment (Table 6 & Table 7), but it is illustrative of how geomorphological and benthic biota can be combined in a classification structure. It is also illustrative of how consideration of mapping techniques and capabilities of remote sensing can be addressed in developing a classification scheme.

Benthic biota classes in Mumby & Harborne (1999) were developed objectively using agglomerative hierarchical classification of field data and Similarity Percentage analysis of resulting clusters (Mumby & Harborne 1999). This method was similar to the statistical analysis employed in the development of the Victorian Interim Marine Ecological Communities (MECs) and allowed differentiation of dominant reef biota presented in the MHCs (Ferns & Hough 2000).

There were subtle differences between the marine habitat classification schemes across Australia, but in general the differences were related to local environmental differences or different mapping aims. The review by ANZECC TFMPA (2000) identified the following reasons for some of the differences between the mapping and marine habitat classification schemes in different Australian States:

- nature of the marine environments (*e.g.*, shallow / turbid waters or high wave action coastline) which may limit the remote sensing or field survey techniques which are applicable,
- differences in ocean uses, management issues, management agencies and responsibilities, and resources (human and financial) for marine research and management (including mapping), and
- conceptual differences in defining mapping elements and mapping scale hierarchies of ecosystem components.

The interim Victorian MHCs presented by Ferns & Hough (2000) were generally consistent with other Australian classification systems. All of the identified Australian classification systems use a hierarchical approach with geomorphic classifications forming the top level of the hierarchy with different types of qualifiers or modifiers at lower levels of the hierarchy describing substratum relief, cover and biotic components.

The marine environment of Tasmania is most similar to the ecosystems of Victoria and consequently the habitat classification schemes of both areas are consistent. The Tasmanian SEAMAP classification scheme gave consideration to the interim Victorian MHCs during its development (A. Jordan *pers. comm.*) and not surprisingly it is also the scheme most compatible with the interim Victorian MHCs.

Both the Victorian and Tasmanian habitat classification systems distinguished between broad geomorphological and biotic characteristics including sand, seagrass and reef as these characteristics could be derived from aerial photographic mapping techniques. Both systems also allowed for the possibility of higher resolution classification of dominant species using underwater video. However, underwater video can only effectively sample a small proportion of an area. For example, a polygon classified as reef, may have a continuum of several different dominant biota communities that cannot be effectively mapped without extensive ground-truthing. Consequently, SEAMAP habitat maps did not apply dominant biota attributes and classifications to polygons, but rather applied point-source video as hyperlinks on electronic maps.

6.2 Habitat Modifiers

Some of the continental/national hierarchical classification schemes outlined above recognised the need for modifiers to describe habitats at lower levels of the hierarchy (*e.g.* Allee *et al.* 2000, Connor *et al.* 2004, Madden & Grossman 2004). These local modifiers should be defined in such a way as to capture functional as well as structural aspects of a habitat type (Allee *et al*. 2000). Modifiers can also be applied to habitats at lower levels in lieu of adding more levels to the classification hierarchy. Madden & Grossman (2004) identified the key modifiers and grouped them into six categories (Table 18).

Different combinations of the modifiers outlined in Table 18 were adapted to produce the local-level classification schemes discussed above.

Table 18. Marine habitat modifiers. Source: Madden & Grossman (2004)

Modifier Category	Modifiers
Water Mass / Physico-chemical	Salinity Oxygen Temperature Turbidity
Physical	Energy (*e.g.* currents, waves) Tidal range Depth Photic regime
Spatial	Physical structure and complexity
Geomorphological	Profile Slope Relief Substratum type and composition Geology Grain size
Biological	Trophic status (*i.e.* oligotrophic, mesotrophic and eutrophic) Cover type (vegetation and fauna) Cover class (degree of cover)
Anthropogenic	Physical modification Pollutants

6.3 Geomorphological Versus Ecological Classes

Local-level marine classification schemes typically include categories based on geomorphological and ecological attributes. Ecological definitions of habitat may be based on assemblages (communities) of plant and animal species or widened to include species and substrata which together comprise the upper layer of the seabed (Mumby 2000).

Mumby & Harborne (1999) stated that geomorphological features are generally simpler to map with remote sensing data than ecological assemblages for three principal reasons. Firstly, identifying geomorphological classes is relatively straightforward and various classification schemes are available to characterise these features. Benthic assemblages are less amenable to development of standardised classification schemes because of their great variation, even within geomorphological zones. Secondly, geomorphological features typically have more distinct boundaries than benthic assemblages, which tend to exhibit change along gradients (*e.g.* species variability with depth). These gradients make the classification of ecological habitats inexact and the placement of boundaries can be rather arbitrary unless there are sharp boundaries in environmental conditions. Thirdly and most significantly for mapping studies, geomorphological features can usually be interpreted from remote sensing in the absence of field survey (Mumby & Harborne 1999).

Even with high-resolution remote sensing, some habitat classes are difficult to differentiate (*e.g.*, bare reef versus reef with macroalgae or dense seagrass) and may have similar reflectance spectra (pixel values) which can also be confounded by depth. While geomorphological features are typically simpler to map, particularly when defining boundaries of consolidated substratum (*e.g.* reef), boundaries within unconsolidated substratum are generally less distinct.

Mumby (2000) made the point that the lack of precise boundaries makes classification of ecological assemblages somewhat inexact and the question needs to be asked about how different two habitats need to be before they are considered separate. Hierarchical classification schemes have been developed in response to this uncertainty to enable complex habitats to be described at increasing levels of complexity depending on the available information.

6.4 Mapping Techniques Versus Classification

For the most part, what will constitute the description of marine habitats will be dictated by the resolution of the mapping methods being employed (Diaz *et al.* 2004). Many classification schemes fail to draw this link between classification scheme categories and the mapping method required to distinguish different classification levels in the hierarchy. This is an important consideration in the development of a classification hierarchy as the upper levels of a hierarchy must be able to be differentiated by the simplest available mapping technique, which in the shallow habitat mapping study was aerial photography interpretation.

In defining their coral reef classification scheme, Mumby & Harborne (1999) gave consideration to the combined influence of geomorphological structure and benthic fauna and flora on the spectra recorded by the remote sensors to be used in their reef mapping. Allee *et al.* (2000) also recognised that in mapping ecosystems we are limited to what the available technology allows us to see or interpret. For example, coral species cannot be identified from current airborne remote sensing, so in the absence of species data from the field, a generic term of coral was adopted for mapping (Allee *et al*. 2000). Baxter (2003) and the Tasmanian SEAMAP project are local examples that examined mapping techniques in developing marine classification systems.

The shallow habitat mapping study needed to differentiate between classification of habitat categories possible from aerial photography versus those requiring acoustic systems (*e.g.*, single-beam and multi-beam sounders and side-scan sonar). It is not possible to differentiate seabed relief or dominant biota from aerial photography alone, so habitats derived from aerial photography are typically restricted to the upper levels of a marine habitat classification hierarchy (*i.e.,* reef, unvegetated sediment, vegetated sediment). By contrast, acoustic-mapping systems can provide a complete 3-dimensional picture of the seabed allowing habitat classification to incorporate seabed relief and structural characteristics not possible from aerial photography.

Differentiating between habitat classes based on dominant biota (*e.g.*, bare reef versus reef with macroalgae or dense seagrass) remains problematic even with high-resolution imagery, due to the possibility of similarity in their reflectance spectra (pixel values). A recent study on the application of hyperspectral airborne imagery (CASI) to map intertidal rock platform vegetation at Boags Rocks, Victoria, highlighted the complexity of differentiating reef communities even with high-resolution remote sensing (Dekker *et al*. 2003).

6.5 Mapping Scale and Habitat Definition

The question of mapping scale is an important influence on any system of habitat classification. In developing a hierarchical marine classification scheme for Australia's North West Shelf, CSIRO Marine Research noted that the structure and function of marine ecosystems is a multi-scale process (CMR & DEP 2002). The property of scale that distinguishes different hierarchical levels in natural systems is a continuously varying function and as a consequence sharp, unequivocal boundaries are the exception rather than the rule. However, within the complexity of the natural world, different hierarchies can be identified (CMR & DEP 2002).

The levels in habitat classification schemes cannot usually be specified simply in terms of a spatial scale, as it is difficult to place a scale on units being mapped without them being placed in the context of the hierarchical level above it (CMR & DEP 2002). Sizes of features though, will typically decrease from upper levels to lower levels in a continental/national hierarchy.

Roff & Taylor (2000) suggested that the scale at which a feature has its dominant effect is where it should be placed in a hierarchical classification system. In the Canadian example, Roff & Taylor (2000) considered that this meant only using physiographic and oceanographic features for their large-scale national-level classification, due to the difficulty in obtaining sufficient biological data for mapping community types at smaller scales.

As an alternative to specifying mapping scales, Mumby & Harborne (1999) adopted the concept of “descriptive resolution” which identifies the level of habitat detail to which a remote sensing method describes the benthos. Under this approach a coarse descriptive resolution would differentiate coral reefs from seagrass beds, whereas a finer resolution would differentiate between coral species assemblages and seagrass standing crops (Mumby & Harborne 1999).

The shallow habitat mapping study employed aerial photography and underwater video. Aerial photography and underwater video techniques operate at two different scales, which needed to be considered with respect to the minimum mapping units for the shallow habitat mapping study. Underwater video is a micro-scale sampling technique that is useful for identifying features in a narrow field of view, whereas aerial photography is useful for differentiating between macro-scale features (Finkbeiner et al. 2001). Diver or video observations typically occur over distances of metres and it should be remembered that observers in the field are likely to see small habitat changes within an area given a single habitat category in the mapping (Finkbeiner et al. 2001). Field surveys of marine systems are time-consuming and expensive and as a consequence remote sensing can also be used to “scale-up” these field observations (Mumby et al. 2004).

6.6 Dominance in Defining Habitats

In developing a classification system, an ideal situation would be an environment characterised by homogeneous geomorphological and/or biological features that occur over a geographic scale that equates to the minimum mapping unit of the mapping approach. However, in reality the marine environment exhibits considerable diversity and complexity even at the mapping scale of 1:25,000 adopted for the shallow habitat mapping study. Classification of the marine environment must therefore adopt an approach whereby the classification system seeks to represent the visibly “dominant” feature within a mapping unit. In this approach dominant equates to those features with the greatest spatial coverage within a mapping unit.

Our definition of habitat for the shallow habitat mapping study was based on structural variables for both geomorphological and biological features and as a result the dominant features to be identified during the mapping related to these structural variables. Aerial photography interpretation allowed identification of dominance of geomorphological features (*i.e.* reef versus sediment) with confirmation of the classification from underwater video. Dominance of biological features was based on observations of the visible coverage from an underwater video system towed approximately 1.5 m above the seabed and with a field of view of approximately 1.5–2 m.

The subtidal reef monitoring program for Victoria (Edmunds & Hart 2003) implements a systematic methodology for identifying coverage of macrophytes within quadrats spaced along set transects. It is not possible to undertake this level of quantification of species numbers or areal coverage from underwater video alone and a reduced number of species and estimate of coverage was recorded during the interpretation of the video. It is often only the canopy species (*e.g.*, kelps) that are clearly visible in the underwater video, so while a site may feature an extensive understorey it may not be possible to observe it with a towed underwater video.

6.6.1 Patchiness

Only some marine habitats have obvious dominant species (*e.g.* kelp forests), while many support a mosaic of species none of which may appear to be visually dominant and which may exhibit a degree of patchiness over the seabed and variability over time (Connor *et al.* 2004). The problems in clearly identifying dominant habitats can be partly addressed by applying patchy habitat categories to account for the variability. Patchiness of habitats is used in many marine classification schemes (*e.g.* Mumby & Harborne 1999, Table 6, Tasmanian SEAMAP, Table 11), but is not always well defined.

Patchiness can apply to both geomorphological and biological features. Madden & Grossman (2004) defined patch reef as a discontinuous reef growing in small areas, separated by bare areas of sand or debris, often part of a larger reef complex. Similarly, a patchy vegetation cover was defined as a distribution of vegetation that is non-heterogeneous resulting in large spatial variation in density of cover (Madden & Grossman 2004). This patchy cover definition could also be applied to colonising fauna that forms a habitat structure.

6.7 Contextual Editing

The accuracy of habitat maps can be improved by “contextual editing”, *i.e.* segmenting an environment according to predictable decision rules (*e.g.*, area A favours cover type 1 but not cover type 2) (Mumby *et al*. 1998). Contextual editing accounts for known patterns or distributions of habitat types and can be an effective way to improve the accuracy of habitat classification provided the decision rules are applicable throughout an image (Mumby *et al*. 1998). Classification from remote sensing can be edited to take account of generic patterns of habitat distribution such as the location or context of habitats within the environment (Mumby *et al*. 1998). For example, Mumby *et al.* (1998) were able to identify an area at the Turks and Caicos Islands which had been misclassified as seagrass from remote sensing and re-code it to the appropriate reef category based on its location on the forereef slope.

Contextual editing is most effective where identifiable patterns or zonation (geomorphological or biological) can be identified in the environment. Where such patterns exist, logical decision rules can be created which reflect the transition of one habitat into another. Tropical coral reef systems, for example, exhibit a distinctive pattern of geomorphological zonation, and since these zones (*e.g.*, forereef, back reef, lagoon, *etc.*) are associated with characteristic depth and community structures that occur at scales of ten to hundreds of metres, they are amenable to detection by remote sensing (Mumby *et al*. 2004).

Existing knowledge of a marine system can further assist in developing habitat classifications and decision rules. The presence of reef versus seagrass is an example of how classification of remote sensing can be enhanced through existing knowledge (*e.g.*, seagrass distribution at Corner Inlet was mapped previously (Roob *et al*. 1998) and the distribution of seagrass species was similar during the current study).

6.8 Spatial Representation of Habitats

Ultimately, most habitat classification systems will be used to produce some form of map output that aims to visually represent the spatial distribution of habitats at a study area. Most map outputs are produced from Geographic Information Systems (GIS). The principal method of representing discrete geographic features in a vector based GIS is in the form of points, lines or polygons (Mitchell 1999). Points are a single x,y location and in marine habitat mapping can be used to represent habitat characteristics at underwater video or dive sample sites. Lines represent a series of points in a sequence and can be used to represent underwater video or depth profile transects. Polygons define the areal extent of spatial features and are represented by a closed line that represents the boundary of features such as a reef or seagrass bed.

Factors including the selection of mapping technology and complexity of the environment will determine at what level in a classification hierarchy features can be represented by the geographic features of points, lines or polygons. Section 0 outlined some of the issues that determine how mapping techniques influence the ability to classify different levels in a hierarchy.

Aerial photography interpretation typically allows differentiation of reef, sediment and seagrass as polygon features. The boundaries of these features will be “fuzzy” in nature though, as the dynamic nature of marine systems through tidal variations, movement of sand, seasonal variations in macrophytes etc. mean that the location of these boundaries will be constantly varying.

Discrimination of substratum relief and/or dominant biota typically sits at lower levels of a local-level classification hierarchy. These categories are more difficult to define as separate polygons in a GIS as, in most cases, there will not be a visible boundary between the habitats that can be identified through remote sensing approaches such as aerial photography interpretation. Acoustic systems such as multi-beam or side-scan sonar can provide total coverage of the seabed and thereby enable discrimination of differences in substratum and relief that can be readily translated into polygons. It is more difficult to differentiate between dominant reef biota and there may not necessarily be clear boundaries defining the transition between different biota. The underlying reef also typically prevents visual discrimination of different biota within a single reef polygon. Seagrass beds on sediment can more readily be defined as polygons than biota on reef as the boundary between bare and vegetated sediment can be discriminated from aerial photography.

7. REVISED CLASSIFICATION SCHEME

The shallow habitat mapping study for Victoria's Marine National Parks used aerial photography interpretation as its primary mapping technique supported by underwater video ground-truthing. Some of the limitations of aerial photography interpretation for marine habitat mapping were outlined in Section 0. The level of habitat information that could be derived from the ground-truthing method (underwater video) was greater than could be defined spatially by the primary mapping technique (aerial photography interpretation). As a consequence, we adopted a classification approach that allowed us to work at the scale covered by the field of view for the underwater video and also allow us to extrapolate or "scale-up" this information to the level of habitat differentiation possible from aerial photography interpretation.

A two-stage approach to classification was adopted whereby a primary habitat classification scheme was used to classify observations from the underwater video and a reduced set of modifiers was used to classify the habitats mapped from the aerial photography in the GIS. The primary habitat classification scheme (Table 19) was a modification of the interim MHC scheme presented in Ferns & Hough (2000). The GIS mapping classification scheme (Table 20) included those categories from the primary classification scheme that could be interpreted from aerial photography.

7.1 Primary Habitat Classification Scheme

The interim MHC scheme (Table 14) was generally consistent with Australian and international local-level classification schemes examined in this review and only small changes were made for the revised primary classification scheme presented in Table 19. One of the principal changes was the addition of a rock/reef – sediment substratum category as a classification for patchy and cobble/rubble reef systems. The table was also re-structured to more clearly distinguish the relevant modifiers for rock/reef versus sediment. These amendments provided greater consistency with the Tasmanian SEAMAP hierarchy (Table 11).

The revised primary classification scheme included cobble and rubble as substratum modifiers for the substratum type rock/reef - sediment. This diverged from some of the classification schemes outlined above which treated cobble and rubble as sediment categories. We included cobble and rubble in the rock/reef - sediment category as we treated it more as a functional classification whereby the cobble substratum may provide a more similar habitat to rocky reef than sandy sediment.

The primary classification scheme is divided into five levels of modifiers (Table 19). The first level (substratum type) is a simple differentiation between rock/reef and sediment, with the additional category of rock/reef – sediment for patchy reef. The second level differentiates between substratum types based on relief for rocky reef and presence of vegetation for sediment. The third level is substratum structure and discriminates between continuous and patchy for reef systems and physical profile for sediment. The fourth level describes the substratum texture for both reef and sediment. The fifth level relates to dominant biota and provides two modifiers for reef (biota type and dominant canopy species) and three modifiers for sediment (biota type, density and dominant species). The key elements of the primary classification scheme are outlined below.

7.2 GIS Mapping Classification Scheme

We were only able to consistently classify aerial photography for the Marine National Parks to the first level of the primary classification scheme (Table 19). However, there were elements of the lower levels of the primary classification scheme that could be applied to the aerial photography (*e.g.* intertidal substratum categories and subtidal seagrass categories). As we could not consistently apply all levels of the primary classification scheme to mapping from the aerial photography, we devised a second classification table (Table 20) that only included those elements that could be classified from the imagery.

The GIS mapping classification scheme (Table 20) consists of two levels of modifiers. The first level (substratum type) is consistent with the primary classification table. The second level is divided into intertidal and subtidal habitats and features elements of the substratum category and texture for reef and dominant biota for sediments. The habitat polygons mapped from the aerial photography were only classified according to these modifiers. These habitat polygons could be further classified in the future with shallow acoustic mapping systems and additional ground-truthing to include all levels of the primary habitat matrix.

The categories in the GIS mapping classification scheme are consistent with classification systems for existing mapping at Marine National Parks (Roob *et al*. 1998; Blake & Ball 2001a; 2001b; Ferns & Hough 2002; Sutherland 2003; Vuyovich 2003). The key elements of the GIS mapping classification scheme are outlined below.

7.3 Physical Modifiers for Habitat Classification

The following sections provide a description of the main modifiers included in the primary classification scheme (Table 19) and the GIS mapping classification scheme (Table 20). Only substratum type was used to classify both the underwater video and GIS mapping.

7.3.1 Substratum Type

- Rock/Reef: consolidated substratum where the substratum structure was *continuous* and the substratum texture was either *solid*, *broken*, *boulders* or *pavement/gutters*.
- Sediment: substratum type was *sediment* (unconsolidated substratum).
- Rock/Reef-Sediment: where the Rock/Reef substratum structure was *patchy* or if the substratum texture was either *cobble* or *rubble*.

7.3.2 Substratum Categories

- Low profile reef: flat subtidal rocky reef with a profile predominantly <1 m (low profile category also applied to intertidal platform).
- High profile reef: rugose subtidal rocky reef with a profile predominantly >1 m (high profile category also applied to intertidal platform).
- Unvegetated sediment: no visible vegetation growing in the sediment.
- Vegetated sediment: vegetation visible with at least a sparse coverage growing in the sediment. Primarily seagrass species *Zostera* spp., *Posidonia australis*, *Halophila australis* and *Amphibolis antarctica*.

7.3.3 Substratum Structure

For Rock/Reef:

- Continuous: areas of reef visible on the video transect, uninterrupted for distances greater than approximately 20 m*.
- Patchy: small discontinuous areas of reef that often form part of a larger reef complex. Typically no larger than approximately 20 m* in width, separated by bands of sediment and/or cobble/rubble. These reef patches may be highly variable with waves/currents causing the patches to be continually buried and exposed, and for the sand separating them to be washed away on occasion to form continuous reefs.

For Unvegetated Sediment:

- Flat: no discernible patterns present.
- Ripples: sediment shaped into a pattern of ripples, generally no larger that 30 cm in height in the nearshore region.
- Mounds: not observed in the shallow mapping surveys.
- Hills: not observed in the shallow mapping surveys.

* Distance travelled by the underwater video was derived from the GPS position or the time and boat speed recorded in the video log file.

7.3.4 Substratum Texture

For Rock/Reef:

- Boulders: rocks with diameter >256 mm.
- Cobble: smooth rounded rocks 64 – 256 mm in diameter.
- Rubble: irregularly shaped rock fragments up to approximately 256 mm in diameter (often associated with patchy, broken low profile reef).
- Solid: reef that was not broken or fragmented.
- Broken: reef that was fractured and fragmented.
- Pavement: describes flat smooth very low profile reef, usually associated with sandstone, limestone and clay reefs.
- Gutters: describe smooth channels eroded into sedimentary reefs such as limestone and sandstone.
- Ripple sand veneer: a category devised to describe an unusual reef structure observed at Point Addis MNP. The habitat was characterised by a relatively flat reef intruding through an overlying veneer of sand ripples.

For sediment:

- Gravel/Pebble: loose rocks with a grain size 2 – 64 mm.
- Shelly sand: sediment that is dominated by small pieces of broken shell remnants.
- Sand: sediment of a predominantly sandy texture with a grain size of 0.063 – 2 mm. Very little, if any silty plume is observed when the video sled touches the seabed.
- Silt: very fine sediment with an approximate grain size of 0.004 – 0.062 mm. Readily forms fine plumes when the video sled touches the seabed.
- Clay: very fine and highly cohesive sediment (grain sizes <0.003 mm).

Where the vegetation cover was too dense to see the underlying sediment, the sediment characteristics were identified from an adjacent area.

7.3.5 Substratum Biota Density

Substratum biota density was only applied to seagrass species. The following section outlines the approach adopted for classifying macroalgae. Biota density categories developed for previous seagrass mapping studies in Victoria (Section 5.1.3.2) were adopted for the current study. Density values previously applied to the *Zostera/Heterozostera* category were applied to the new category of *Zostera* sp. (Section 0).

For *Zostera* sp. and *Posidonia australis*:

- Dense: plants dense enough to hide most of the underlying sediment from view.
- Medium: plants dense enough for leaves to be touching, but underlying sediment is visible through the leaves.
- Sparse: plants present, but at a density where leaves of individual plants did not touch each other.

For Halophila australis:

- Dense: leaves were within touching distance of each other.
- Medium: present but leaves did not touch, although within close proximity to each other.
- Sparse: leaves did not touch and individual plants clearly dispersed.

For patchy seagrass:

At some sites seagrass patches or clumps (diameters <10 m) separated by narrow bands of bare or sparsely vegetated sediment (<5 m in width) may form a continuous seagrass bed. The density of seagrass within individual patches may be sparse, medium or dense according to the above definitions. At these sites a classification of dense patchy, medium patchy or sparse patchy was used.

For *Amphibolis antarctica*:

A. antarctica typically grows in association with reef and this presents difficulties in interpreting its distribution and densities from aerial photography as an underlying dark reef substrata can disguise the plant densities. As a consequence we did not attempt to interpret *A. antarctica* densities where it was growing in association with reef. At sites where *A. antarctica* was growing on sand it was almost always dense, *i.e.* leaf canopy hid the underlying sediment.

7.3.6 Dominant Biota

Dominant biota species identified with the underwater video were primarily the dominant canopy species. The species outlined below represent those observed during the marine mapping field-work or known to occur in the Marine National Parks.

It was beyond the scope of this project to identify ecological assemblages that occur in association with the dominant biota. Analysis of macroalgae community structure at sites both in and around the Marine National Parks was undertaken as part of the Victorian Subtidal Monitoring Program (Edmunds & Hart 2003).

Only some of the dominant biota was observed in monospecific stands and most of the species were found in complexes with other species. There were limitations on the level of quantitative information that could be extracted from the underwater video on the relative abundance and percentage cover of the different biota species. As a consequence we adopted a simple system based on quartiles for classifying the dominant biota observations from the underwater video. This is best explained with the use of the examples below:

- Phyllospora: Approximately >75% cover of Phyllospora (there may be mixed brown algae also present but will be only approximately <25% of the cover).
- Phyllospora/Mixed brown algae: Approximately 50% of each class.
- Phyllospora with mixed brown algae: Approximately 75% Phyllospora with approximately 25% mixed brown algae.
- Mixed brown algae with Phyllospora: Approximately 75% mixed brown algae with approximately 25% Phyllospora.

Using the quartiles system (above) resulted in multiple combinations of the following biota categories.

Amphibolis: *Amphibolis antarctica*. This species was generally present over areas of sediment or low profile patchy broken and rubble reef. It tended to form dense monospecific beds over sand and occurred with mixed algaes over reef areas.

Ascidians: While ascidians or sea squirts may have been present, they were not always readily visible in the video because of overlying kelps or difficulties in distinguishing them from the underlying reef.

Cystophora spp. several species of the genus *Cystophora* are present along Victoria's open coast. It was not possible from the video to differentiate between species so this general class was used.

Durvillaea: *Durvillaea potatorum*. This species mainly occurred in dense bands at the seaward edge of the intertidal zone on both high and low profile reefs exposed to high wave energy. It was however, also observed down to depths of up to 10 m.

Ecklonia: *Ecklonia radiata*. This was one of the more commonly observed species of macroalgae. It was often associated with *P. comosa*, becoming more dominant in areas of deeper water or greater exposure.

Halophila: *Halophila australis*. This species was only recorded at a single site in the northern section of Corner Inlet Marine National Park.

Hormosira: *Hormosira banksii*. The distribution of this species was restricted to intertidal rock platforms. As a consequence it was only recorded infrequently by the video due to the boat not being able to safely access the intertidal reef even on high tide.

Macrocystis: *Macrocystis angustifolia*. This species was not observed very frequently and occurred in small stands that were generally quite sparse.

Mixed algae: represented a mixture of brown, red and green algae and no one class appeared dominant. Also used where the class of algae could not easily be distinguished due to poor visibility.

Mixed Brown Algae: where brown algaes were the dominant biota type, but it was unclear which species were present or no species could be identified as being dominant.

Mixed Green Algae: where green algaes were the dominant biota type but it was unclear which species were present.

Mixed Red Algae: where red algaes were the dominant biota type but it was unclear which species were present. Identification of red algae to species level generally requires physical examination of samples, so it was not possible to identify species with the video survey methodology used.

Phyllospora: *Phyllospora comosa*. This was the most readily observed species of macroalgae during the video surveys. It often formed monospecific beds, but was also regularly associated with *E. radiata*.

Posidonia: *Posidonia australis*. This species of seagrass was only recorded at the Corner Inlet Marine National Park. It formed dense monospecific beds on the sandbanks in this inlet (predominantly at the northern site).

Sponges: sponges are a diverse class of fauna but these species were mostly observed from the video at depths beyond the limit of the shallow habitat mapping *e.g.,* sponges observed at depths of approximately 20 m in Point Hicks MNP.

Turf algae: categories of algae that form a "mat' over the reef substratum.

Urchin Barren: sites where large grazing aggregations of urchins denude the reef of erect algal species (Edmunds *et al.* 2005). Urchin barrens were only observed at Cape Howe MNP and have previously been identified by Edmunds *et al.* (2005) as being formed by *Centrostephanus rodgersii*.

Zostera sp.: In previous seagrass mapping studies in Victoria (Section 5.1.3.2) we adopted a combined Zostera/Heterozostera category for *Heterozostera tasmanica* and *Zostera muelleri*. In the period since these studies, a re-assessment of the taxonomy of Zosteraceae in Australia and New Zealand addressed the problem of species recognition (Les *et al*. 2002). Les *et al.* (2002) recommended a revised taxonomic scheme that included the sub-genera of *Heterozostera* with a single species *Z. tasmanica* to replace the previous definition of *H. tasmanica.* We adopted the taxonomic scheme recommended by Les *et al.* (2002) which recognised *Zostera marina* and *Zostera tasmanica*. While *Zostera marina* and *Zostera tasmanica* inhabit the intertidal and subtidal zones respectively, it was not possible to distinguish the two species by visual observation in the field. As a consequence we adopted this combined category of *Zostera* sp.

7.3.7 Mapping Categories

The categories for most of the substratum/biota class in the GIS mapping classification scheme (Table 20) were consistent with the modifier descriptions outlined above. Additional categories included:

Artificial rock wall: sea walls constructed to protect the backshore are present at some Marine National Parks and Sanctuaries. This category relates to barriers created from rock boulders present at Point Nepean.

Mangroves: the white mangrove *Avicennia marina* is the only mangrove species found in Victoria and forms broad bands seaward of the saltmarsh in the intertidal zone. Mangroves were only present at the Corner Inlet (south) MNP in this study.

Patchy reef: where multiple small patches of reef (<20 m diameter) formed continuous spatial features. This category was also used where there was no clear boundary between small areas of reef and the adjacent sediment or reef due to factors such as depth or sediment in the water.

Saltmarsh: Saltmarsh occupies the upper intertidal to middle intertidal zone typically between coastal scrub and mangroves. Saltmarsh only occurred at Corner Inlet (south) MNP in this study. Shrubby Glasswort *Sclerostegia arbuscula* and Beaded Glasswort *Sarcocornia quinqueflora* usually dominate the seaward edge of the Corner Inlet/Nooramunga salt marsh community. Other species in this community include Black-seeded Glasswort *Halsarcia pergranulata*, Trailing Hemicroa *Hemichroa pentrandra* and Austral Seablite *Suaeda australis* (Frood 1986).

Sand flat (beach)/Low profile platform: sites where a rocky intertidal platform is likely to be continually buried or exposed by mobile sand under the influence of strong wave energy. These sites were usually classified where aerial photography was available for more than one time-period allowing comparison of changes to the beach structure or where ground-truthing highlighted changes in platform size relative to the aerial photography.

Seagrass / Reef – Sediment: sites where extensive beds of seagrass grew over reef and amongst sandy sediment between patches of reef. The seagrass in this category was predominantly *A. antarctica*, but small stands of *Zostera* spp. were also observed in sheltered areas at Mushroom Reef and Nepean Bay. This category applied to areas where it was not possible to accurately delineate separate seagrass and reef features from the aerial photography, particularly where the *A. antarctica* extended from the reef into the adjacent sediment.

Seagrass species: the spatial extent of a seagrass species category was assigned with a combination of contextual editing and extrapolation from the ground-truthing.

Table 19. Primary shallow habitat classification scheme. Abbreviated titles in brackets correspond to data fields in the GIS.

<table>
<tr><td colspan="4">Substratum Type (Sub_type)</td></tr>
<tr><td>Rock / Reef</td><td colspan="2">Rock / Reef – Sediment</td><td>Sediment</td></tr>
<tr><td colspan="3">Substratum category (Sub_cat)</td><td>Substratum category (Sub_cat)</td></tr>
<tr><td>Low profile reef/platform (<1 m)
High profile reef/platform (>1 m)</td><td colspan="2">Low profile reef/platform (<1 m)
High profile reef/platform (>1 m)</td><td>Bare sediment
Vegetated sediment
Sand beach
Sand flat
Sand-mud flat</td></tr>
<tr><td colspan="3">Substratum structure (Rock_struc)</td><td>Substratum structure (Sed_struc)</td></tr>
<tr><td>Continuous</td><td>Continuous</td><td>Patchy</td><td>Flat
Ripples
Mounds
Hills</td></tr>
<tr><td colspan="3">Substratum texture (Rock_tex)</td><td>Substratum texture (Sed_tex)</td></tr>
<tr><td>Solid
Boulders
Broken
Gutters</td><td>Cobble
Rubble</td><td>Boulders
Cobble
Rubble
Solid
Broken
Gutters
Pavement
Ripple sand veneer</td><td>Gravel/Pebble
Shelly sand
Sand
Silt
Clay</td></tr>
</table>

Table 19. Cont.

Substratum biota type (Rock_bio)	**Dominant biota (Rock_dom)**	**Substratum biota type (Sed_bio)**	**Substratum biota density (Sed_dens)**	**Dominant biota species (Sed_spec)**
Bare	*Phyllospora*	Bare	Dense	*Halophila*
Seagrass	*Macrocystis*	Seagrass	Medium	*Posidonia*
Macroalgae	*Durvillaea*	Macroalgae	Sparse	*Amphibolis*
Seagrass / Macroalgae	*Ecklonia*	Seagrass / Macroalgae	Dense patchy	*Zostera* sp.
	Cystophora spp.	Mangrove	Medium patchy	*Caulerpa* spp.
	Amphibolis	Saltmarsh	Sparse patchy	Mixed green algae
	Hormosira			Mixed brown algae
	Mixed brown algae			Drift algae
	Mixed green algae			
	Mixed red algae			Combinations of above categories
	Mixed algae			
	Urchin barren			
	Sponges			
	Ascidians			
	Turf algae			
	Combinations of above categories (Section 0)			

Table 20. GIS mapping shallow habitat classification scheme. Abbreviated titles in brackets correspond to data fields in the GIS.

Substratum Type (Sub_type)						
Rock/Reef		Rock/Reef - Sediment		Sediment		
Substratum/Biota category (Map_cat)				**Substratum/Biota category (Map_cat)**		
Subtidal	**Intertidal**	**Subtidal**	**Intertidal**	**Intertidal**	**Subtidal**	
Reef	Low profile platform (<1 m) High profile platform (>1 m) High profile platform – boulder Low profile platform – cobble / boulder Rock pile	Reef – patchy Seagrass / Reef – Sediment	Low profile platform – cobble Rock pool Sand beach/Boulder Sand beach / Low profile platform Sand flat / Low profile platform Sand flat / Boulder	Sand beach Sand flat Sand beach / flat Sand-mud flat Mangrove Saltmarsh Seagrass Artificial rock wall	Bare sediment ***Seagrass density*** Dense Medium Sparse Dense patchy Medium patchy Sparse patchy	***Seagrass species*** *Zostera sp.* *Posidonia* *Halophila* *Amphibolis* (no density value applied)

7.4 Other Data Fields

The following data fields (Table 21) were also recorded for each underwater video observation, but did not form part of the modifiers in the classification table (Table 19).

Table 21. Additional data fields recorded for video observations.

Attribute	Description
Site id	Unique code assigned to each video clip. Syntax for id is based on a two letter abbreviation for park name, transect number and sequential clip number (*e.g.* site id BB_T1_1 corresponds to Barwon Bluff Marine Sanctuary, transect 1, site 1).
Vessel position	Latitude/Longitude of the vessel position. Coordinates are from the vessel GPS in the AGD66 datum.
Sled position	Latitude/Longitude for corrected position of towed video sled relative to vessel position. Coordinates are in the GDA94 datum.
Date/Time	Date/Time of video.
Depth	Depth in metres measured by the vessel sounder (not corrected for tide or swell).
Comments	Other observations from video that did not fit in the classification table structure.
Observer	Name of PIRVic scientist who completed video interpretation.
DVD/Video file	DVD reference and name of digital video file (mpg or vob format).
Video still	Name of any still images extracted from the video (jpg format).

7.5 Other Modifiers

Table 18 summarised the range of possible modifiers that could be applied to describe and classify marine habitats. The revised shallow habitat classification categories (Table 19 & Table 20) only incorporated elements of the geomorphological and biological modifiers and we did not include modifiers for lithology (rock geology) or wave energy/energy. This approach was taken, as the selected elements were consistent with the initial information requirements of park managers and were within the scope of the aims of the shallow habitat mapping study. The decision to focus on this group of modifiers does not exclude adding more modifiers to the classification structure over time or prevent further classification of the identified habitat categories in the future. This is one of the advantages of the modifier approach that allows for more modifiers to be added, or for the modifiers to be translated to other classification systems in the future.

Other possible modifiers that could be added to the classification table, and which would not necessarily require additional field measurements, include exposure/energy, tidal range and geology. While some other modifiers would need additional data collection and/or specialist equipment *e.g.* seabed profile, slope, relief and water chemistry, some of the existing modifiers already include elements of these other modifiers in their categories. Energy/exposure for example, is implicit in the biota modifiers as some of the kelp species are found in high-energy environments (*e.g. D. potatorum*), while some seagrass species are only found in relatively sheltered environments (*e.g. P. australis*).

The classification categories presented above only relate to shallow habitats. The identification of classification categories for deeper habitats that could be added to the classification table will be undertaken as part of the deep-water component of the marine national park mapping being undertaken as a separate project for Parks Victoria.

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