Seamap Australia [Version 1.0] the development of a national benthic marine classification scheme for the Australian continental shelf

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Executive Summary

The Australian National Data Service (ANDS) High Values Collection (HVC) has funded the establishment of an Australian seabed habitat classification scheme and spatial database "Seamap Australia". Seamap Australia collates all national benthic habitat mapping data into one location on the Australian Ocean Data Network (AODN) complete with metadata records; syntheses these datasets into one spatial data product using a newly proposed national benthic marine classification scheme for the Australian continental shelf; and enables visualisation and download capacity via a web interface [http://www.seamapaustralia.org] of the Seamap Australia synthesis layer, all original collated benthic habitat mapping datasets, and a sample selection of biological data overlays.

The ongoing benefits of the Seamap Australia classification scheme and spatial data product will facilitate national collaborations for benthic research, establish a common seabed mapping vocabulary and encourage a nationally consistent approach for Australian seabed mapping into the future. We anticipate that Seamap Australia will facilitate national scale cross-disciplinary studies of continental shelf habitats. It is our intent that, by collating all the available marine habitat mapping datasets into a single viewing interface (http://www.seamapaustralia.org) and promoting and extending availability of these through the AODN Portal, institutions will work collaboratively to address nationwide solutions. This High Value Collection (HVC #19) provides a resource for researchers to share their marine habitat data through the AODN into the future, so that as the resource grows, there will be continuous improvement in the knowledge of Australia's marine estate.

Contents

1. Background and Introduction

In the last decade, there has been significant investment to collect seabed habitat data around the nation by each State and Territory. Government agencies, often in collaboration with University researchers, hold valuable spatial products of both habitat and bathymetric (depth) data that are of use for a variety of purposes including marine management and resource assessment. However, whilst the level of interest in and need for these datasets has grown significantly over the last 4-5 years, access to them is often difficult. The datasets are scattered throughout numerous agencies and institutions Australia-wide; information exists in a variety of different formats; critical metadata are often missing and, when located, the utility of these datasets is frequently limited by disparate spatial coverage and inconsistent classification schemes.

The Australian National Data Service (ANDS) High Values Collection (HVC) has funded the establishment of an Australian seabed habitat database – "Seamap Australia". This spatial database brings together data from a number of sources into a single national visualisation that can be easily accessed by potential users through a web browser interface. The Institute for Marine and Antarctic Studies (IMAS) has been well positioned to develop this spatial project. Previous IMAS projects like 'Seamap Tasmania', 'RedMap' and 'Reef Life Survey' have generated awareness of what is possible when spatial data are made publically available. These highly valued data assets have facilitated cross-disciplinary research and have permitted commercial, social, and economic values to be explored and assessed by the national marine community.

Seamap Australia (Version 1) has built upon other national seabed habitat mapping initiatives. The NESP Marine Biodiversity Hub (NMBH; http://www.nespmarine.edu.au) recently published a report that collated spatial data on benthic reef habitats on the continental shelf (Lucieer et al., 2016). Seamap Australia has expanded on this research, with the support of the national community, to additionally include benthic habitat data on the Australian continental shelf. These data were classified into a nationally consistent marine habitat classification scheme, which is detailed in Section 2 of this report.

The scope of the Seamap Australia project was to:

- Collate spatial data on benthic marine habitats on the Australian continental shelf into a single database, produce a compiled spatial data product, and make this layer available through the Australian Ocean Data Network (AODN).
- Establish a controlled vocabulary and associated governance for national classification of marine habitats.
- Where possible, demonstrate how these data could be complemented with other existing Australian spatial marine data such as BRUV (Baited Remote Underwater Video), AUV (Autonomous Underwater Vehicle), and RLS (Reef Life Survey) collections.
- To establish a Seamap Australia website which would create a national focal point that would improve discoverability of and access to data to collected already, maximise data reuse and provide a collection and synthesis point for future data.

The aim of this report is to address the first two points of the project scope and explain the workflow under which the benthic marine habitat classification vocabulary and associated governance structure were developed.

This report details a review of existing international and national classification schemes, and proposes the nationally extensive benthic habitat classification that was developed for Seamap Australia. It also includes an explanation of the choice of classes and the mechanisms behind the hierarchical structure.

1.1 What is classification and why is it important ?

Mapping and classification are a means to collect information and group data into meaningful and consistent categories. In the marine environment, mapping and classification are recognised as the foundation on which to build the tools required for effective marine management. With the increasing exploitation of the marine environment for recreational and commercial industries, it is clear that informed and effective management is fundamental to ensure marine resources are sustained and well managed into the future.

1.1.1 National approaches to habitat classification in Australia

In Australia, few attempts have been made to classify coastal and marine ecosystems at a national scale. One of the most widely used classifications involves the bioregionalisation of the Australian marine environment (IMCRA 2006). Bioregionalisation divides the environment into large (3000 – 240 000 km^2) units that are characterised by broad natural features and environmental processes that influence the function of the entire ecosystem. The purpose of IMCRA (2006) is to aid in regional scale planning, management and conservation; however, such coarse spatial resolution is unable to define habitats or detect change or loss of communities.

Mount and Bricher (2008) were the first to develop a nationally based habitat classification scheme that focused on characterising units at a finer resolution (10^1 - 10^3 m). The National Intertidal Subtidal Benthic (NISB) Classification Scheme defined broad habitat types in terms of substratum type and structural macrobiota (e.g. boulder, sand, rock, coral, seagrass, macroalgae) from the Highest Astronomical Tide (HAT) to the outer edge of the continental shelf (~200 m depth). The scheme was designed to be compatible with the mapping classification schemes used by mapping groups in Australia, however it was structured as an attribute-based system and so was not strictly hierarchical (Mount and Prahalad 2009). Thus it could not account for the nested scales of different mapping initiatives and this may explain why it was not readily adopted by the Australian seabed mapping community.

1.1.2 Australian regional and state-based approaches

The development of habitat classification schemes at the state level has received more attention. Influenced by funding for marine habitat mapping though schemes such as Natural Resource Management (NRM) or through local marine studies conducted by Universities or local government agencies and councils, there are a number of projects nationwide. Significant efforts by government and research agencies in Western Australia, South Australia, Tasmania and Victoria has seen the development of individual classifications in each area (Ferns et al. 2000, Bancroft 2003, SEAMAP 2006, DEH 2009, Edmunds and Flynn 2015). However, it is not currently possible to compare the distribution of habitats between these state waters due to inconsistencies in classification classes and differences in the primary focus of the schemes (e.g. substratum *vs* biology). Each system has been developed to meet a different purpose, and data have been collected using different technologies (acoustic single beam, multibeam sonar, or video, or AUV). The technology employed for data collection can be the determining factor in influencing how the classification is derived, structured (in terms of scale), and the characteristics of the class definitions.

As noted by Butler et al. (2001), there is no single best way to classify habitats, and the most appropriate structure will depend on the project objectives (e.g. conservation, resource evaluation, environmental impact or biodiversity assessment), and in some cases the technology used in data collection (e.g. remote sensing *vs in situ* methods). The consequence is that, although multiple, different classification approaches may be valid, existing classifications do not often align among states, territories, and regions.

1.2 The importance of a hierarchical structure in habitat classification

The structure and functioning of marine ecosystems is scale dependent, involving a myriad of processes operating at different scales in time and space. This must be taken into account when attempting to accurately classify the marine habitat at the snapshot in time in which the data are sampled.

The need for a hierarchical structure within a classification scheme is widely accepted (Green et al. 1999, Butler et al. 2001, Connor et al. 2004, Ball et al. 2006, FGDC 2012, Edmunds and Flynn 2015), and enables data collected at different resolutions to be incorporated, classified, and utilised within a single model. A successful hierarchical classification schemes will span multiple technologies, resolutions, and accuracies over time and reduce the liabilities of redundancy in classes or ontologies.

In a review of benthic marine habitat classification systems, Ball et al. (2006) identified general features required of a classification scheme, emphasising that it should:

- Be hierarchical to avoid overlap of definitions and duplication of categories.
- Be comprehensive and cover all marine habitats within a designated region of interest.
- Contain only mutually exclusive and exhaustive classes so that every feature should be able to be classified and should fall within only one class.
- Use a common language that is easily understood and interpreted.
- Be presented in a format that is clear and easy to understand and use.
- Be flexible to modification but stable to support ongoing work.
- Be of practical use for resource managers, field surveyors and researchers. This means it should be able to summarise the information at a range of scales, encompassing large scales (regional, state and national levels), as well as fine scales sufficient to assess local sites and observation studies.
- Be technology independent such that the same habitat classes can be identified regardless of sampling technique.
- Recognise time scales and accommodate habitat characteristics that may change over different temporal scales. Characteristics that may change over shorter time periods (e.g. biota) should be included at lower levels than those that change over much larger time periods (e.g reef substratum).

1.3 Existing hierarchical classification schemes

Of the marine habitat classifications that are in use today, the Coastal and Marine Ecological Classification Standard (CMECS; FGDC 2012) and European Nature Information System (EUNIS; Davies et al. 2004) schema are arguably the most thorough and well accepted schemes endorsed by the scientific community.

The CMEC Standard was based on the seabed classifications of Allee et al. (2000) and Madden and Grossman (2004). It was developed and applied in North America, however its flexible structure and comprehensive list of habitats has resulted in its uptake (to varying degrees) by mapping and classification projects internationally (e.g. Edmunds and Flynn 2015). CMECS classifies marine and coastal environments according to two settings (aquatic and biogeographic), and four components (water column, geoform, substratum and biotic). The settings partition the environment into broad categories/realms, while the components are designed to describe finer scale observations and sampling sites.

The EUNIS habitat classification scheme is based on recommendations from Davies and Moss (2004) and modifications of the Joint Nature Conservation Committee Classification scheme for Britain and Ireland (Connor et al. 2004). It was developed to describe terrestrial, freshwater, coastal, and marine habitats in the European region only, and differs from the CMEC Standard in its approach in that the marine section classifies biotopes, or '*areas with particular environmental conditions that are sufficiently uniform to support characteristic assemblages of organisms*'. The biotopes described by the EUNIS scheme are arranged in a single hierarchy, constituting six levels for the marine habitat branch. The upper levels focus on physical characteristics, while the lower levels describe biotic components of the habitat.

In Australia, a Victorian Marine Biotope Classification Scheme is under development (Edmunds and Flynn 2015). This classification is based on both the CMEC Standard and the EUNIS schema, and is intended for released in 2017. Other hierarchical schemes include the Nearshore Intertidal/Subtidal Benthic (NISB; Mount and Bricher 2008, Mount and Prahalad 2009) classification scheme, the Victorian Marine Biotope classification scheme (CBiCS; Edmunds and Flynn 2015). These provide broad classifications based on physical aspects of marine environment. Due to their coarse scale, lack of true hierarchical structure, and absence of thorough documentation, these schemas were deemed to not be relevant and were not considered further in developing an Australian classification scheme.

2. Development of the Seamap Australia Benthic Marine Habitat Classification Scheme

Benthic marine classification schemes used internationally were investigated to assess both the suitability and applicability of their structure and class units to the aims of the Seamap Australia National Benthic Marine Habitat Classification Scheme.

Schemes considered include the Coastal Marine Ecological Classification Scheme (CMECS; FGDC 2012), the European Nature Information System (EUNIS; Davies et al. 2004) classification, the Coastal Marine Classification for New Zealand (MFDC 2008), and the British Columbia Marine Ecological Classification (MSRM 2002).

The assessment was made through a review of each scheme in an Australian context (see Section 2.1). To aid in assessing the utility of each scheme, a classification crosswalk was performed between existing datasets (Appendix 1) and the candidate scheme in question. This involved passing classified units in the existing datasets through each of the above schemes as far as was possible using the information provided with the original classification. A comparison was made that related the resolution and accuracy of the original class to that of the 'new' class attributed in the candidate scheme. This procedure followed the guidelines for comparing classification systems outlined in FGDC (2012) (Table 2). It has allowed evaluation of each original classification term and enabled identifying the different aspects of each scheme that were suitable for reclassification, and those that were not.

Table 2. Definitions for the comparisons used to assess the suitability of candidate scheme structures and class definitions for development of the Seamap Australia Benthic Marine Classification Scheme.

Comparison	Definition
=	There is a 1:1 relationship between source unit and candidate unit. Unit names may differ.
≈	The source unit is almost equivalent to the candidate unit - there may be small threshold or concept differences.
>	The source unit is more broadly defined than the candidate unit. The threshold of the source unit may be higher or the concept broader, and the source unit fully contains the candidate unit.
<	The source unit is more finely defined than the candidate unit. The threshold of the source unit may be lower or the concept narrower, and the source unit is fully contained within the candidate unit.
><	The source unit is neither clearly broader nor finer than the candidate unit. Both units contain at least one common entity and each contains at least one entity that the other does not. Neither concept is fully contained within the other.
<>	The source unit does not have a clearly related unit in the candidate classification
?	The relationship between the source and candidate unit is unknown

Based on these definitions, the habitat classification model that was deemed the most suitable and broadly applicable was selected and reviewed with the aim of adopting it to form the foundation of the Seamap Australia Benthic Marine habitat Classification Scheme.

Adaptations from the original scheme were deemed necessary to ensure that the final Seamap Australia scheme was a) relevant to Australian benthic habitats, b) represented a true hierarchy with each class reached only through a single pathway, and c) ensured that all major benthic marine habitats were included in a clear and logical framework. Adaptations were made based on the aforementioned schema, and also from the broader habitat mapping and classification literature. Changes to classes and class definitions throughout the process were minimised so that habitats classified under the different schema could still be compared.

2.1 Review of classification schemes in an Australian context

European Union Nature Information System (EUNIS) and Combined Biotope Classification Scheme (CBiCS)

The EUNIS and CBiCS are both examples of hierarchical classifications with a shared aim to improve management and conservation of marine communities. The focus of these schemes is on biotope descriptions – biological communities that consistently occur within a defined set of physical environmental conditions/habitat features. Biotope classifications are advantageous in that they capture the full complexity of biotic communities and how they vary with gradients in environmental conditions, e.g. exposure, salinity, light. They also allow for classes to be described as much by dominant taxa as by frequently occurring but less abundant or rare species, which can be an important consideration for conservation and management of marine environments.

However the combination of both physical and biological attributes into a single hierarchy in this structure means that it is impossible to reclassify existing data, which often only map a single habitat characteristic, e.g. biota. Source units get 'stuck' at the higher levels of the hierarchy, resulting in reclassified units with concepts much broader than the original source concept. *Furthermore, the ecological meaning of biotope descriptions is not often intuitive, and labels are typically long and complicated, e.g. sublittoral mud in variable salinity (estuaries) (EUNIS).* In an attempt to avoid the loss of information that this could lead to, the Seamap Australia scheme has not adopted a biotope approach to classification of benthic marine habitats.

Nearshore Intertidal/Subtidal Benthic classification (NISB)

The NISB scheme was developed in 2006 with the aim of defining broad habitat types in Australia for use in management and planning. Habitats are described in terms of substratum type (e.g. boulder, rock) and structural biota (e.g. seagrass, coral) with the option of including a range of environmental attributes (e.g. depth, light availability, exposure) as additional descriptors.

The use of broad habitat types in the NISB scheme makes for clear and intuitive habitat classes. However, a limitation of this scheme is that the classes are not defined at a finer resolution. Many habitat mapping initiatives include data to species level, and the option to include classification at this level is necessary. Furthermore, while the NISB scheme captures the dominant habitat types, many commonly occurring and/or important habitat types are not described within the framework (e.g. rhodolith beds). This leads to an inability to adequately describe the diversity of marine ecosystems. When we reviewed the data that was provided for Seamap Australia, many data source units were often more finely described than the resulting reclassified unit in the candidate scheme. Although the structure of NISB means it is easy to alter and update the classification with new classes, this may lead to an extensive list of potential habitat terms, which may be impractical for application in the field.

The NISB scheme also departs from a hierarchical structure and instead adopts an attribute-based system where habitats are "described" through "tagging" spatially defined areas with the appropriate habitat label. This means that it is easy to reclassify existing data and many of the source and candidate classifications show a 1:1 relationship. However, the attribute-based structure does not clearly represent the different scales and levels of resolution that occur through use of different and commonly applied mapping methods. e.g. remote sensing *vs in situ*, and finer scale classifications cannot be collapsed into broader definitions. The collapsible nature of a hierarchical system is well recognised as an important feature of classification schemes (Ball et al. 2006, Edmunds and Flynn 2015), and this is the structure that has been adopted by Seamap Australia.

Coastal Marine and Ecological Classification Standard (CMECS)

The CMEC Standard was developed to describe habitat types in Northern America, and is arguably one of the most thorough and well-accepted systems endorsed by the scientific community. It classifies marine and coastal environments according to two settings – aquatic and biogeographic – and four components – water column, geoform, substratum, and biotic. The settings partition the environment into broad categories, i.e. realms, while the components are designed to describe observation data and sampling sites. Biological descriptions are based on the dominant taxa, with flexibility to include non-dominant species through application of a modifier.

The partition of the CMEC Standard into separate hierarchies requires that different ecosystem characteristics are scored and mapped in isolation. This flexibility is advantageous, because it allows the full complexity of ecosystems to be described in fine detail, and each characteristic can be described in complete absence of knowledge of any others. In contrast to a biotope classification (e.g. EUNIS, CBiCS), this approach is particularly useful in the context of a national scheme where the aims are to both provide a classification framework which can be used into the future to map broad and fine scale community level characteristics, and to accommodate historical data that may often only map one component, e.g. physical characteristics.

There is also a spatial hierarchy implied by the structure of the scheme, moving from broad descriptions of the Biogeographic and Aquatic Settings, to smaller scale Geomorphology classifications, and to finer descriptions of Substratum Type and the Biotic Community associated with the seafloor. This means that the scheme can be easily tailored to the specific needs of a project and the equipment available for mapping, facilitating its use by a variety of end-users.

2.2 Development of the structure for the Seamap Australia Benthic Marine Habitat Classification Scheme

Based on the review of habitat classification schemes in use internationally today (Section 2.1), the CMEC Standard is considered to provide the most suitable foundation for the development of the Seamap Australia Benthic Marine Habitat Classification Scheme. This next section provides a detailed review of the structure and content of the CMEC Standard, how this applies in an Australian context, and the methods and processes followed in the decision-making to establish the structure of the Seamap Australia Benthic Marine Habitat Classification Scheme.

2.2.1 Biogeographic Setting

The CMECS Biogeographic Setting (FGDC 2012) is a three-tiered hierarchy that partitions the environment into Realms, Provinces, and Ecoregions. Divisions are based on the Marine Ecoregions of the World (MEOW; Spalding et al. 2007) for estuarine and marine nearshore and offshore subsystems, the Global Open Oceans and Deep Seabed Biogeographic Classification (GOODS; UNESCO 2009) for marine oceanic subsystems, and Abell et al. (2008) for lacustrine systems. The bioregionalisations defined in these publications describe variation in biological communities across broad latitudinal and longitudinal gradients. These variations are functions of climatic, geologic and evolutionary processes, which act to influence the structure and functioning of regional and local ecosystems.

The levels of the CMECS Biogeographic Setting used in Seamap (Figure 1):

Level 1: **Realm** (e.g. Temperate Australasia)
Level 2: **Province** (e.g. Southeast Australian Shelf)
Level 3: **Ecoregion** (e.g. Bassian Ecoregion)

Seamap Australia adopts the use of the MEOW bioregionalisations (Spalding et al. 2007). This is a global system for coastal and shelf areas based on existing global and regional literature concerning taxonomic configurations, evolutionary history, patterns of dispersal, and degree of isolation. This approach has achieved wide acceptance internationally, and has many uses in management and conservation for assessing the effects of large-scale disturbances such as those associated with climate change and shifting species distributions. It is also useful in providing mapping units with a spatial context to fit within a larger, global framework. Although the GOODS (UNESCO 2009) and Abell et al. (2008) classifications may also apply to the Australian environment, incorporating these is beyond the scope of the Seamap Australia project.

In addition to using the MEOW, Australian marine environments have also been partitioned into finer scale bioregions under the Integrated Marine and Coastal Regionalisation of Australia (IMCRA) scheme (IMCRA 2006). IMCRA (2006) consists of two levels: Provinces which align approximately with the MEOW Ecoregion boundaries, and Meso-scale regions, or Bioregions. These Bioregions have been adopted widely for marine conservation and management purposes across Australia, and are a useful addition to the Biogeographic hierarchy. Including the IMCRA bioregions aligns the scheme with that of Edmunds and Flynn (2007).

With the additions of these subordinate levels, the modified CMECS Biogeographic Setting hierarchy adopted in the Seamap Australia scheme consists of 5 levels:

Level 1: **MEOW Realm** (e.g. Temperate Australasia)
Level 2: **MEOW Province** (e.g. Southeast Australian Shelf)
Level 3: **MEOW Ecoregion** (e.g. Bassian Ecoregion)
Level 4: **IMCRA Province** (e.g. Bassian Province)
Level 5: **IMCRA Bioregion** (e.g. Freycinet)

2.2.2 Aquatic Setting

The Aquatic Setting in the CMEC Standard comprises three hierarchical levels separating the ocean; (1) estuarine and lacustrine environments, (2) deep and shallow waters, and (3) submerged and intertidal areas.

Level 1 **System** (e.g. Marine)
Level 2 **Subsystem** (e.g. Nearshore)
Level 3 **Tidal Zone** (e.g. Intertidal)

Within this structure, Marine and Estuarine Systems and Subsystems are differentiated based on salinity, geomorphology and depth. Although salinity is a defining feature that strongly influences the biota that exist in these areas, it is rarely-recorded in habitat mapping initiatives. Without this information it become impossible to re-classify existing data, leading to large amounts of information loss.

Seamap Australia has redefined these classes to enable the re-classification of existing data. Although many types of estuarine and coastal waterway classifications exist (e.g. see Edgar et al. 1999) the majority use classes that are difficult to map using technologies common to habitat mapping projects (e.g. remote sensing, video transects). In re-defining the estuarine classes, Seamap Australia uses an established scheme for estuary mapping and classification within Australia (Heap et al. 2001, Ryan et al. 2003). This scheme is based on geomorphology, and has been used to identify and map 974 coastal waterways around Australia. A geomorphic classification is useful in the context of Seamap Australia because not only does geomorphology provide the basic framework upon which habitats are built, but it is also a readily mappable characteristic using a range of remote sensing and *in situ* methods. For a more thorough review of geomorphology for seafloor classification see Nichol et al (2017). The classes included in this scheme also allow for the inclusion of coastal lagoons as a coastal waterway type, a common and important feature of coastal environments across Australia.

Tidal zones within the CMEC Standard are defined using Mean Lower Low Water (MLLW), and Mean Higher High Water (MHHW). Seamap Australia instead considers the Lowest Astronomical Tide (LAT) and Highest Astronomical Tide (HAT), as defined by NTU (2010), (PCTMSL 2014), to represent these zones, and this also brings the classification in line with Australian chart datum (LAT).

The CMEC Standard uses the 30 m depth contour to describe Nearshore and Offshore Marine Subsystems. In regard to benthic habitat types, this is intended to represent abiotic boundaries such as the photic zone (Kleypas et al. 1999) and the depth to which surface conditions (e.g. wave energy) may influence the seafloor (Keen and Holland 2010). These boundaries have a significant effect on benthic habitat types, and using depth zone approximations of these boundaries facilitates classification over large areas. Seamap Australia adopts this level of classification, however in recognition that the exact depth at which these boundaries occur varies both spatially and temporally, Seamap Australia also includes a fourth level - Benthic Depth Zone - in the hierarchy. This describes depth zones according to tidal influence and photic zone and better characterises biotic boundaries such as the lower limits of vegetation. It also allows for compatibility with a wider range of classification systems where both depth zone and photic zone are described.

The Seamap Australia Classification only applies to benthic substrata between the HAT and 200 m depth contour, and definitions are modified to reflect this where necessary. The CMECS Aquatic Setting classes outside this zone (Marine Oceanic, Supratidal zones) are excluded.

The final levels of the Seamap Australia Aquatic Setting are:

Level 1	**System** (e.g. Marine)
Level 2	**Subsystem** (e.g. Nearshore)
Level 3	**Tidal Zone** (e.g. Subtidal)
Level 4	**Benthic Depth Zone** (e.g. Infralittoral)

2.2.3 Water Column Component

The CMECS Water Column Component divides the water column into subcomponents describing vertical layering, temperature, salinity, hydroforms and biogeochemical features. These subcomponents are designed to be stand-alone, and can be used either individually or in combination.

It is recognised that certain characteristics of the water column can influence benthic habitat types (e.g. currents, temperature, nutrients, oxygen content, etc.), and in the absence of other information (e.g. biota), these characteristics can be very informative as to potential habitat and community types. However, the information contained in this component is not regarded as a requirement to classifying benthic habitat, and thus the CMECS Water Column Component has not been considered for adaptation to the Seamap Australia Classification.

2.2.4 Geoform Component

The Geoform Component of the Seamap Australia Benthic Marine Habitat Classification Scheme is still under development (as at November 2017). In collaboration with Geoscience Australia we are currently developing a geomorphological classification based on the British Geological Society classification (Bradwell et al. 2016) that will be considered for adoption for this component of the Seamap Australia scheme. A full review of the CMECS Geoform Component and detail of the decision-making process to establish the Seamap Australia equivalent will be provided when this section is refined.

2.2.5 Substratum Component

The CMECS Substratum Component divides substrata into geologic, biogenic and anthropogenic classes. Geologic substrata are classified into consolidated and unconsolidated classes and further divided based on grain sizes according to the Udden-Wentworth (1922) and Folk (1954, 1974) standards for mineral grainsize scales. Biogenic substrata are classed first according to biota type with subsequent divisions describing either grain size, mineral composition, or species.

Anthropogenic substrata are classed according to material type/composition. The overall structure of the CMECS Substratum Component is as follows:

Level 1 **Origin** (e.g. Geologic)
Level 2 **Class** (e.g. Unconsolidated)
Level 3 **Subclass** (e.g. Coarse)
Level 4 **Group** (e.g. Gravel)
Level 5 **Subgroup** (e.g. Pebble)

The Substratum Component of the CMEC Standard is useful because it defines unique classes based on specific grainsizes or compositions, and the lower levels can be collapsed into higher-order groups as required by the resolution of mapping. However, it is not possible to collapse the lower levels into hard and soft categories, and this represents a disadvantage of the scheme. The distinction between hard and soft substrata is one of the simplest and most common distinctions made when mapping the seafloor, and can be estimated in all methods used for habitat mapping, including the use of satellite imagery, aerial photography, acoustic surveys and underwater video/photography. In terms of ecology, this characteristic also represents an important division between substratum types that are able to support reef ecosystems (hard), and those that cannot (soft). For these reasons we have made a modification to the CMECS classification, adding a node describing the hardness of the substratum at the highest level of the hierarchy, replacing the Origin (level 1) classifier. This modification is identical that proposed by Edmunds and Flynn (2015). Hardness refers to the physical properties of the substratum, and can be determined through knowledge of acoustic or optical reflectivity, as well as by the stability of the substratum. This means that habitats such as worm or shell reefs and rhodolith beds are all classified as hard substratum, despite not being hard in the literal sense, whilst pebble habitats are not considered hard because they are not sufficiently stable to support a reef ecosystem.

The CMECS Origin classifier provides valuable information, however, as identified by Edmunds and Flynn (2015), it can also be one of the more difficult characteristics to classify. The resolution required to clearly identify the origin of a substratum depends on the substratum in question. For example, rhodolith beds can be identified from acoustic surveys with simple *in situ* observation, e.g. camera drop, whereas determining whether a sand is dominated by a mineral composition or *Halimeda* sp. may require analysis of sediment samples. We include the information contained within the origin classifier, but include it as a 'floating' final level in the hierarchy. In the majority of cases this means that it will likely form the fourth or fifth level because this is typically the minimum level of resolution required to obtain the information. However, in cases where mapping resolution cannot resolve classification at the lowest levels of the hierarchy, but where the origin of the substratum is still discernible, this information can (and should) be included at an earlier level. This modification is similar to that proposed by Edmunds and Flynn (2015), where the origin classifier was placed at the final 6^{th} level in the hierarchy.

A further level of classification is added for substrata of geologic origin to describe the rock lithology (sedimentary, igneous, metamorphic). Rock lithology is important because it can influence the physical form of a reef through processes such as formation and erosion (Nichol et al. 2016). Lithology is also a category in the Australian Standard for the Geomorphological Classification of Reefs (Nichols et al. 2016), and its use in the Seamap Australia Classification ensures consistency at a national level.

The CMECS Class and Subclass classifiers are re-arranged and combined to form the second level of the Seamap Australia Classification. This is necessary to group substrata into appropriate categories within the modified Level 1 Hard/Soft classes. Hard substrata are identified as either consolidated, unconsolidated, or mixed. Boulders are considered a consolidated substratum in this instance because, while they can be susceptible to disturbance in large storms, such events are rare and stable boulder reefs are more common. Many existing datasets also include boulder (but not cobbles) as a reef forming habitat alongside bedrock, and thus including boulders under this node ensures compatibility when retro-fitting these classifications. Cobbles may also support reef ecosystems, however the longevity of these is circumstantial and depends on cobble size and disturbance levels. For this reason, cobble is considered separately as unconsolidated hard substrata. Soft sediments are also classified as unconsolidated substrata, and are divided according to broad grainsize categories (coarse or fine), similar to the CMECS Subclass classifier.

Classes within the lower levels (Levels 4 & 5) of the CMECS Geologic Origin substrata use grainsize classifications described by the Udden-Wentworth (1922) standard for straight sediment types, and the Folk (1954) classification for sediment mixes. Grainsize is one of the most commonly used characteristics to classify geological substrata, and this forms the basis for the structure and layout of many classification systems. It is one of the more readily obtained substratum characteristics, and can provide information on both the physical and biological environment. Both the Udden-Wentworth (1922) and Folk (1954) classifications have been widely accepted and are commonly used in marine science, and the Udden-Wentworth (1922) standard is also the foundation from which many subsequent grainsize classifications have been based, including the Folk (1954) classification. The Seamap Australia Classification adopts the Udden-Wentworth (1922) Standard for mineral grainsize classification. This ensures clear definitions for each sediment group, and enables compatibility with historical datasets. It also means that the Seamap Australia Classification is consistent with Geoscience Australia and the NESP Marine Biodiversity Hub standard for the Geomorphological Classification of Reefs (Nichol et al. 2016), both of which also use the Udden-Wentworth (1922) scale.

However, as noted by Blair and McPherson (1999), the Udden-Wentworth standard focuses on sand and mud fractions, where class boundaries are described in finer detail than those of the coarser components. This is despite the fact that gravel particles are dominant in many environments, e.g. high energy beaches. Seamap Australia adopts additional classes proposed by Blair and McPherson (1999), which partition the Udden-Wentworth gravel components into classes of equivalent resolution to those of the sand and mud fractions.

Seamap Australia does not adopt the Folk (1954) classification for mixed sediments. The focus of Seamap Australia is on classifying broader habitat types, and while the Folk (1954) classification provides useful information on physical habitat characteristics, it is more suited to grainsize description and analysis. The main drawback of Folk (1954) in regard to habitat classification is that the Gravel component consists of any/all of boulders, cobbles, pebbles, and granules. This makes it impossible to discriminate hard reef formed by boulders or cobbles from soft unconsolidated sediments, and major habitat types such as patch reefs could not be classified under this system. Instead, Seamap Australia includes mixed categories at each node within each level, but, once a mix is identified, and where the mapping resolution is adequate, the mix is further defined through stating the constituents of the mix. For example, a class might be Mixed Hard/Soft (Boulder/Pebble), Mixed Sediment (Silt/Sand), or Mixed Hard (Megaclast/Cobble/Boulder).

Defining a mix in this way is advantageous because, although it generates an extensive list of potential mixed classes, it is in keeping with a simple and intuitive classification, and can accommodate different classification schemes. One of the primary aims of the Seamap Australia Classification is to provide a scheme that can be used to unify seafloor habitats maps and classifications across the country, and the ability to retro-fit existing data is essential.

In modifying the CMECS hierarchy, Seamap Australia has developed a classification system structure to better represent the resolution at which it is possible to obtain information on specific substratum characteristics. However, while some levels from the CMECS have been rearranged, the vast majority of the CMECS class definitions are consistent with those defined in the Seamap Australia Classification, allowing CMECS units to be mapped into Seamap, and vice versa. This ensures that consistency is maintained in habitat mapping at national and international scales.

The revised Substratum levels of the Seamap Australia Classification are:

Level 1 **Hardness** (e.g. Hard)
Level 2 **Class** (e.g. Unconsolidated)
Level 3 **Group** (e.g. Cobble)
Level 4 **Subgroup** (e.g. Coarse)
Level X **Origin** (e.g. Biogenic)

The additional levels for the Origin classification are:

Level X.1 **Origin** (e.g. Biogenic)
Level X.2 **Origin Class** (e.g. Ooze)
Level X.3 **Origin Subclass** (e.g. Carbonate)
Level X.4 **Origin Group** (e.g. Foraminifera)

The CMEC Standard includes a list of standard modifiers that can be applied to units classified under the Substratum Component. These modifiers include anthropogenic, physical, physiochemical, spatial and temporal variables. Modifiers are useful in describing additional characteristics of mapped units, and allow users to adapt the classification to specific needs, but within a standard framework. **The scheme now needs to be tested and reviewed by the Australian habitat mapping community, and any further inclusion of modifiers could be addressed in Version 2 of the Seamap Australia spatial data product.**

2.2.6 Biotic Component

The Biotic Component of the CMEC Standard has five levels. The upper divisions reflect broad ecological groups and the lower levels of the hierarchy focus on identifying structural characteristics and dominant taxa.

Level 1 **Setting** (e.g. Benthic/Attached Biota)
Level 2 **Class** (e.g. Reef Biota)

Level 3 **Subclass** (e.g. Shallow/Mesophotic Coral Reef Biota)
Level 4 **Group** (e.g. Branching Coral Reef)
Level 5 **Community** (e.g. Branching *Pocillopora*)

The CMECS Biotic Component has a clear and usable structure that covers all major known ecosystems and all major biological groups. It is suitable for classification of historical datasets, and most of the existing Australian classifications can be retro-fitted. However, it does present some limitations in that some levels of the classification are not truly hierarchical, and the resolution required to map some levels is often similar (or finer) than the resolution required to map a lower level. For example, a Biotic Group within the Soft Sediment Fauna Class (Level 3) is the Larger Tube-Building Fauna. These are defined as having a tube width > 2 mm or length > 30 mm, yet to obtain an accurate measurement of tube length or width would require detailed diver surveys and sample analyses similar to what would be required to identify the dominant taxon listed under Community type. Moreover, partitions in the Biotic Class and Subclass levels can introduce dependency on substratum type (e.g. Soft Sediment Bryozoans, Attached Anemones, Burrowing Anemones). This may lead to the same class/species being reached by alternative paths, and therefore does not strictly adhere to a hierarchical system.

For the Seamap Australia Biotic Component we modified the CMECS partitions to define broad biotic groups and taxonomic classes, which more accurately reflect the spatial resolution at which the information is available. The divisions are based on phylogenetic groups, with the broadest grouping occurring at the higher levels. By using broad phylogenetic groups we remove any dependency on substratum type, and ensure a true hierarchical structure (each group can only be reached through a single path).

The lowest levels of the Seamap Australia Biotic Component corresponds to species level identification. Identification at species level is useful in many ecological studies, and is important for conservation and management purposes. It is also a common feature of many habitat mapping projects, particularly those concerning seagrass habitats. However, species identification can be difficult, particularly when data is in the form of still or video imagery. In such cases it is often more feasible to identify morphologies rather than species, and for this reason Seamap Australia also includes the option of a morphospecies classification.

There are a number of morphospecies classifications schemes that currently exist, but most are at a coarse resolution, focus on specific biotic classes, or describe morphology but do not relate it back to species (e.g. Boury-Esnault and Rützler 1997, Madin et al. 2016). Within Australia the CATAMI scheme (Althaus et al. 2015) represents the first attempt to establish a national standard for morphological classification, covering a range of different and commonly occurring phylogenic groups that can be identified from images. Although the CATAMI scheme has been criticised for its reliance on taxonomic distinctions leading to the inability to classify many images, it has been widely used across the country and with considerable success (e.g. Bewley et al. 2015, Cresswell et al. 2017, James et al. 2017). Seamap Australia considers this scheme to be the best currently available, and implements the use of this scheme as an alternative for when species identification is not possible.

Another limitation of the CMECS Biotic Component is that is does not include a classification for bare substratum (i.e. biota absent). Bare habitats are important to identify, as they can have important ecological implications and are also very common, e.g. bare sediment or rock. For this reason, we insert an extra level at the top of the Seamap Australia Biotic Component hierarchy to identify whether biota is present or absent.

Within CMECS, biotic units are defined by dominance measured as one of biomass, abundance or percentage cover. For example, a community that consists of 40% sponge, 30% macroalgae and 30% corals is classified as a Sponge habitat, just as a 35% sponge, 60% macroalgae habitat would be classed as a macroalgal habitat. Defining dominance by the most dominant biotic class is important because biota do not always cover 100% of the substratum surface or account for 100% of the biomass/abundance, and so the use of an arbitrary dominance threshold (e.g. 60%) will often lead to incorrect assessments of habitat types. A coral reef, for example, may only reach 30% surface coverage of corals, bit still constitute a healthy, biodiverse coral ecosystem.

Using this definition of dominance, there are no mixed categories within the CMECS classification structure, and non-dominant biota are instead recognised through Co-Occurring Elements. Co-Occurring Elements can be any unit already described in the component hierarchy, and can be used in cases where there might be two or more biotic classes that are at similar percentage cover/biomass/abundance to the dominant class, or when the user thinks it is important to record a non-dominant class. For example, for a unit where large areas of sponges co-exist in a habitat dominated by macroalgae, the classification might be:

- Classification: Benthic Biota -> Aquatic Vegetation Bed -> Benthic Macroalgae
- Co-Occurring Element: Benthic Biota -> Faunal Bed -> Attached Fauna ->Attached Sponges

Defining biotic classes within this structure is advantageous because it forces classification of the dominant biota allowing simplicity at a national/continental level, while still allowing the user to classify secondary units in a standardised way when required. However, Seamap also recognises that this may lead to arbitrary decisions regarding which is the dominant species when the cover/biomass/abundance of each is comparable. As a modification to this system Seamap Australia defines dominance by the most dominant biota, however in instances where dominance cannot be clearly established we include mixed classes within the main hierarchy framework. Although this approach allows for a relatively large number of possible mixed habitat combinations, this method reflects that natural assemblages are inherently multispecies, and ensures minimal information loss when re-classifying existing datasets. Seamap still includes a level for Co-Occurring species, leaving flexibility to include species of particular note or importance, e.g. threatened or rare species.

We have used the CMECS Biotic Component to build a classification for the benthic biota in Australia. The original structure has been modified to form a hierarchy that better reflects the spatial resolution of the identified biotic communities. While the base structure is different, the majority of class definitions are taken from the CMECS with little alteration, and mapped units from CMECS can be mapped into the Seamap Australia Classification and *vice versa*. The levels of the Seamap Biotic Classification are as follows:

Level 1 **Presence** (e.g. Biota Present)
Level 2 **Class** (e.g. Vegetation)
Level 3 **Subclass** (e.g. Macrophytes (Non-Wetland))
Level 4 **Group** (e.g. Macroalgae)

Level 5 **Species/Morphospecies** (e.g. *Ecklonia radiata*/Large canopy-forming: Brown)

Level 6 **Co-Occurring Element** (e.g. sponges)

The CMEC Standard includes a list of standard modifiers that can be applied to units classified under the Biotic Component. These modifiers include anthropogenic, biogeographic, physical, biological, physiochemical, spatial and temporal variables. Seamap Australia will address the biotic modifiers in Version 2.

3. The Seamap Australia Benthic Marine Habitat Classification Scheme

This section details the Seamap Australia Benthic marine Habitat Classification Scheme, including definitions for its use and classification units. Figures 1-4 illustrate the structure of the classification and the proposed terminology for Version 1 of the scheme.

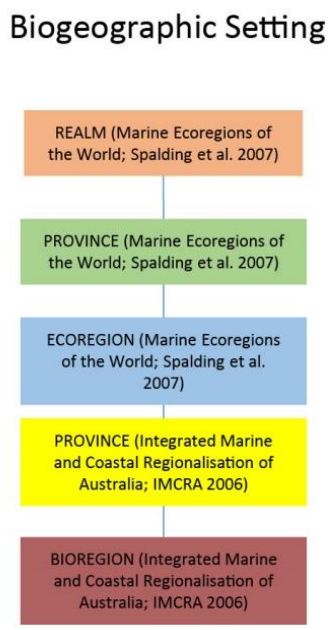

Figure 1. The Biogeographic Setting hierarchy. The Biogeographic Setting comprises 5 levels that partition the marine environment according to the bioregionalisations described in Spalding *et al.* 2007 and IMCRA 2006. Definitions of each level are found in Section 3.1.1 of this report, and lists and extents of individual regions can be found in the relevant publications.

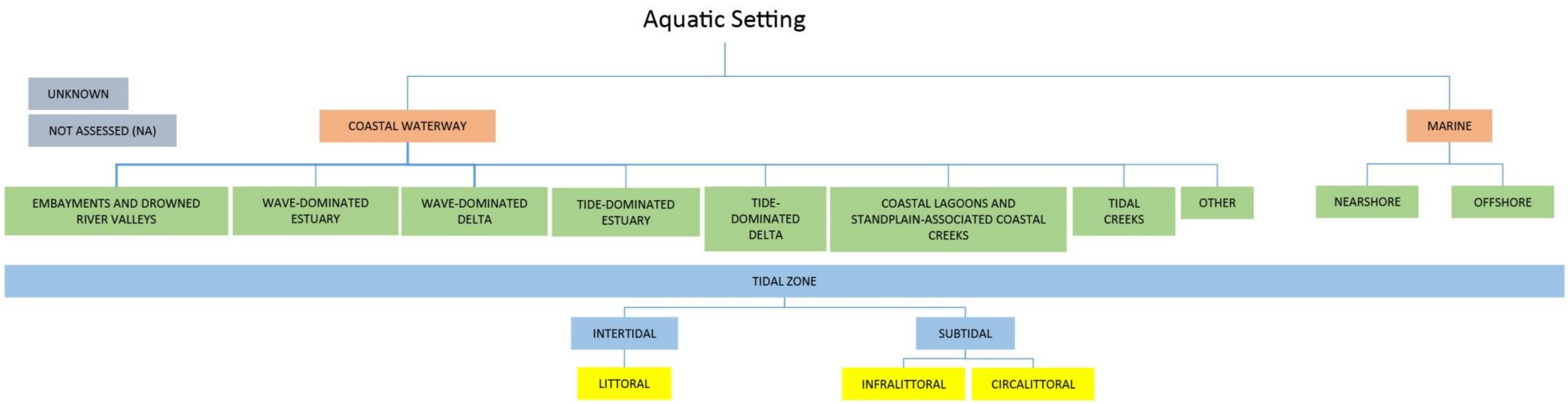

Figure 2. The Aquatic Setting hierarchy. The Aquatic Setting partitions the marine environment into four levels describing the freshwater influence, geomorphology, depth, tidal regime and benthic light environment. The third and fourth levels (blue and yellow) are nested (replicated) within each of the level 2 (green) classes. An Unknown or Not Assessed classification (top left) can be applied at any level within the hierarchy. Definitions for all terms can be found in Section 3.2.1 of this report.

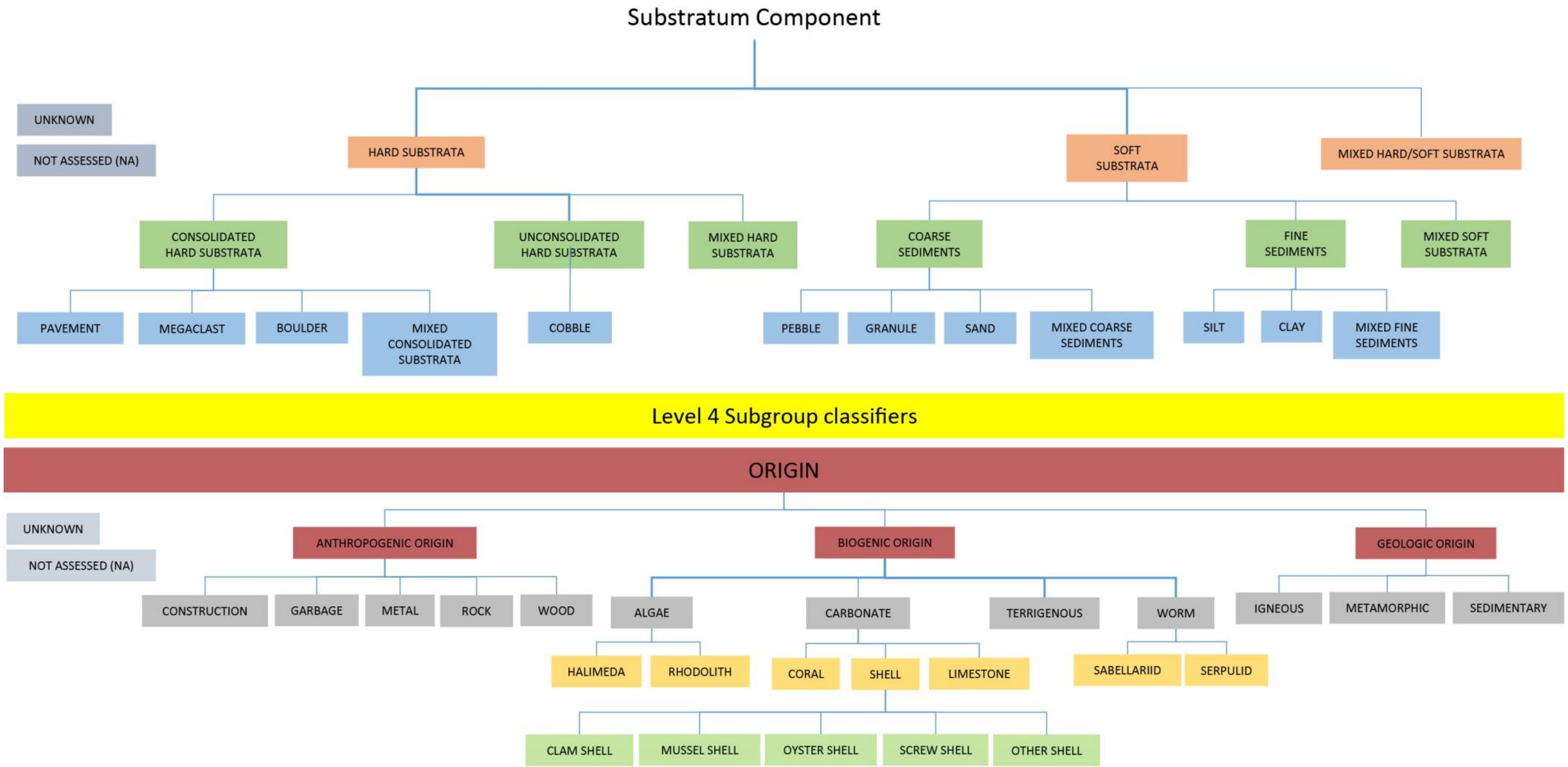

Figure 3. The Substratum Component hierarchy. The Substratum Component comprises 8 levels in two nested hierarchies – the first describing hardness and grainsize, and the second describing the origin (or composition) of the substratum. The Level 4 Subgroup classifiers (yellow) apply to all level 3 classes excluding Pavement and Granule. A detailed list of the level 4 terms and their definitions can be found in Section 3.4.1 of this report. The Origin hierarchy is nested within each final grainsize class (level 3 or 4, as appropriate). However it acts as a 'floating' level, and can be nested at higher levels (e.g. level 2, green) if the mapping resolution is inadequate to reach the third and fourth tiers. An Unknown or Not Assessed classification (top left) can be applied at any level within the hierarchy. Definitions for all terms can be found in Section 3.4.1 of this report.

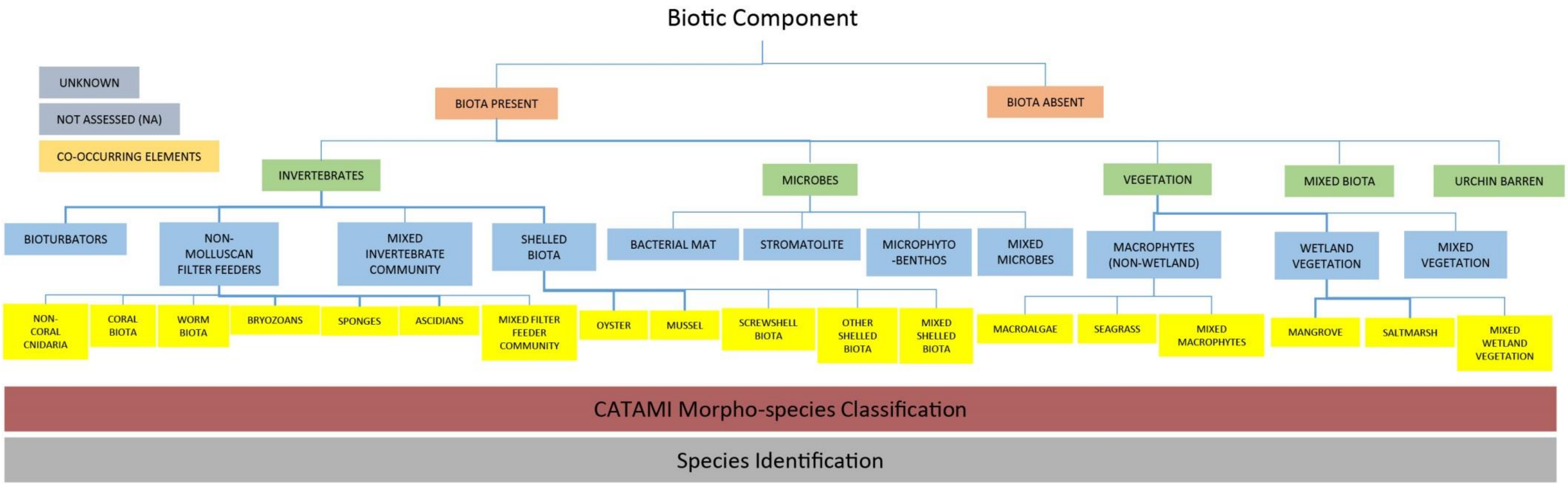

Figure 4. The Biotic Component hierarchy. This component used broad phylogenetic and taxonomic groups to describe living biota. The lowest levels of the hierarchy (level 5 and 6 – red and grey) classify individual morpho-types and/or species within each of the level 4 (yellow) classes. An Unknown or Not Assessed classification or a Co-Occurring Element (top left) can be applied at any level within the hierarchy. Definitions for all terms can be found in Section 3.5.1 of this report.

3.1 Biogeographic Setting

The Seamap Australia Biogeographic Setting partitions the marine environment according to the bioregionalisations outlined by the Marine Ecoregions of the World (Spalding et al. 2007) and Integrated Marine and Coastal Regionalisation of Australia (IMCRA 2006). These describe variation in biological communities across broad latitudinal and longitudinal gradients.

3.1.1 Biogeographic Setting class descriptions

The following descriptions are taken from Spalding et al. (2007).

- **Realm (MEOW)**
  Very large regions of coastal, benthic, or pelagic ocean across which biotas are internally coherent at higher taxonomic levels as a result of a shared and unique evolutionary history. Realms typically have high levels of endemism, including unique taxa at generic and family levels in some groups. Driving factors behind the development of such unique biotas include water temperature, historical and broad scale isolation, and the proximity of the benthos.
- **Province (MEOW)**
  Large areas defined by the presence of distinct biotas that have at least some cohesion over evolutionary time frames. Provinces will hold some level of endemism, principally at the level of species. Although historical isolation will play a role, many of these distinct biotas have arisen as a result of distinctive abiotic features that circumscribe their boundaries. These may include geomorphological features (isoloated island and shelf systems, semienclosed seas); hydrographic features (currents, upwellings, ice dynamics); or geochemical influences (broadest-scale elements of nutrient supply and salinity).
- **Ecoregion (MEOW)**
  Areas of relatively homogenous species composition, clearly distinct from adjacent systems. The species composition is likely to be determined by the predominance of a small number of ecosystems and/or a distinct suite of oceanographic or topographic features. The dominant biogeographic forcing agents defining the ecoregions vary from location to location but may include isolation, upwelling, nutrient inputs, freshwater influx, temperature regimes, ice regimes, exposure, sediments, currents and bathymetric or coastal complexity.

Class definitions for the IMCRA provinces and bioregions are not specifically described in the original IMCRA documentation (IMCRA Technical Group 1998, IMCRA 2006). The following definitions explain the terms in the context of Seamap Australia and outline how the regionalisation was implemented.

- **Province (IMCRA)**
  Provincial-level regionalisations are based on a classification of demersal fish species diversity and richness. They are grouped by climate characteristics into tropical, subtropical, warm temperate, and cold temperate waters.
- **Bioregion (IMCRA)**
  A regionalisation of the continental shelf into meso-scale bioregions based on biological and physical characteristics, including the distribution of demersal fishes, marine plants and invertebrates, seafloor geomorphology, sediments, and oceanographic features and characteristics.

Note that although the positioning of the region borders within the MEOW and IMCRA schema allows for the majority of IMCRA Provinces to be nested almost perfectly within the MEOW Ecoregions, there are some exceptions where boundaries do not perfectly align. These instances are noted below, and care has been taken to assign the appropriate class to habitat units in these regions.

- Minor misalignment between the MEOW *Tweed-Moreton/Manning-Hawksbury* Ecoregion boundary and the IMCRA *Central Eastern Transition/Central Eastern* Province boundary.
- Minor misalignment between the MEOW *Exmouth to Broome/Ningaloo* Ecoregion boundary and IMCRA *Central Western Transition/West Central Australian Shelf* Province boundary.
- The border between the MEOW *Exmouth to Broom/Bonaparte Coast Ecoregion* differs to the *Northwest Province/Northwest Transition* such that a large section of the IMCRA *Northwest Province/Northwest Transition* crosses into the *Exmouth to Broom Ecoregion.*
- The border between the MEOW *South Australian Gulfs/Western Bassian* Ecoregions differs to that of the IMCRA *Spencer Gulf/Western Bassian Transition*, such that the IMCRA *Coorong Bioregion* sits entirely within the Spencer Gulf Province (IMCRA) and the Western Bassian Ecoregion (MEOW).
- The IMCRA *Victorian Embayments Bioregion* sits within two IMCRA Provinces (Bass Strait Province and Southeast Transition) and two MEOW Ecoregions (Bassian and Cape Howe). The borders of the IMCRA/MEOW regions are the same, it is simply that the IMCRA bioregion is not nested in the IMCRA Province in the first place.

3.2 Geoform Component

The Geoform section of the scheme is still under development. In collaboration with Geoscience Australia we are currently developing a geomorphological classification based on the British Geological Society classification (Bradwell et al. 2016) that will be considered for adoption for this component of the Seamap Australia scheme.

3.3 Substratum Component

Substratum in the Seamap Australia Classification refers to the surface of any non-living material upon or within which biota can attach and grow. This typically consists of natural rock or mineral sediment of various grain sizes, but also includes materials such as organic debris, man-made surfaces such as plastic, concrete or metal, and non-living biota (e.g. shells). Seamap Australia recognises that not all substrata are 2-dimensional habitats, and in some cases, e.g. soft sediments or veneers, habitats may extend below the surface. In these situations Seamap Australia considers the uppermost 15 centimetres of the substratum.

3.3.1 Dominance

Dominance for all physical (hardness/grain size) classes is defined as ≥ 80 % of cover, weight or composition. For Origin classes, dominance is assigned to the class that has the highest percentage cover/weight/composition. Whether cover, weight, or composition is used will depend on the size class and the technology used to map them. For example, boulders would be assessed by percent cover but sand categories may be either percent cover or weight depending on whether a sediment grab or underwater video was used to record the information, while biogenic classes may be assessed by composition.

3.3.2 Mixed categories

Mixed categories refer to substrata composed of a mixture of classes where no single class is dominant (i.e. no single class accounts for ≥ 80 % of cover, weight or composition). Mixed classes occur within each node of each level (Figure 1). Where mapping resolution is adequate, the constituents of the mix should be specified using the classes already defined within the classification, for example Mixed Hard Substrata (Cobble/Boulder), or Mixed Coarse Sediments (Pebble/Sand). In the interest of brevity, all possible permutations of mixed classes are not shown in the hierarchy map (Figure 2), nor described in the class definitions (Section 2).

3.3.3 Grainsize definitions

The categorisation of Subgroups (Level 4) in the Substratum classification is based largely on grainsize classes. Seamap Australia has used the combined the classifications of Udden-Wentworth (1922) and Blair and McPherson (1999) to determine grainsize classes. These are presented in Table 1.

3.3.4 The Origin Classifier

Nested within the Substratum Hierarchy is the Origin Classifier. This is itself another hierarchy, describing the origin of the substratum, and acts as a 'floating' level that is applied to <u>all</u> classes at the finest level of classification that is achieved within the standard substratum grainsize classification. The Origin should be identified to the highest level of resolution possible. Where the Substratum Origin is classified, the naming convention should place the class in brackets following the grainsize classification. e.g. Pebble (Rhodolith), Boulder (Geologic). If the Origin cannot be resolved, the brackets should be removed.

Table 1. Grain Size classes used by Seamap Australia for the Substratum component of the classification. Class names and sizes are adopted from Udden (1914, 1998), Wentworth (1922), and Blair & McPherson (1999). Grain size classes are described in units of either mm or Phi (Krumbein 1934, Krumbein 1938).

Class	Grain Size (mm)	Grain Size (Phi)
Clay	0.0039 – 0.00006	8 - 14
Silt	0.0039 – 0.0625	4 - 8
Very Fine	0.0039 – 0.0078	7 - 8
Fine	0.0078 – 0.0156	6 - 7
Medium	0.0156 – 0.0310	5 - 6
Coarse	0.0310 – 0.0625	4 - 5
Sand	0.0625 – 2.0	1 - 4
Very Fine	0.063 – 0.125	3 - 4
Fine	0.125 – 0.250	2 - 3
Medium	0.250 – 0.500	1 - 2
Coarse	0.5 – 1.0	0 - 1
Very Coarse	1.0 – 2.0	-1 to 0
Granule	2.0 – 4.0	-2 to -1
Pebble	4.0 – 64.0	-6 to -2
Fine	4.0 – 8.0	-3 to -2
Medium	8.0 – 16	-4 to -3
Coarse	16 – 32	-5 to -4
Very Coarse	32 – 64	-6 to -5
Cobble	64 – 256	-8 to -6
Fine	64 – 128	-7 to -6
Coarse	128 – 256	-8 to -7
Boulder	256 - 4096	-12 to -8
Fine	256 – 512	-9 to -8
Medium	512 – 1024	-10 to -9
Coarse	1024 – 2048	-11 to -10
Very Coarse	2048 – 4096	-12 to -11
Megaclast	4.096 – 1049 m	< -12
Blocks	4.096 – 65.5 m	-16 to -12
Slabs	65.5 – 1049 m	-20 to -16
Pavement*	> 1049 m	< -20

* Pavement is equivalent to the Blair and McPherson (1999) monolith and megalith classes

3.3.5 Substratum Hardness

Substratum hardness describes the physical properties of the substratum. It can be determined through acoustic or optical reflectivity and/or its stability, and thus its potential to maintain a stable reef ecosystem. Hardness is subdivided into Hard, Soft, and Mixed Hard/Soft categories.

- **Not Assessed (NA)**
  An NA classification can be applied at any level of the hierarchy. An area with an NA classification is a region where mapping has occurred, but where the given characteristic was not assessed. An NA classification is distinct from an Unknown classification in that an Unknown implies an assessment was made however a classification was not possible (e.g. due to inadequate resolution, or poor quality data).

- **Unknown**
  An Unknown classification can be applied at any level of the hierarchy. An Unknown is an area where an assessment was made, however a classification was not possible at the given level. This could be due to any reason, including inadequate resolution, or poor quality or ambiguous data.

- **Substratum Hardness: Hard Substrata**
  Substrata of any origin where ≥ 80% of the substratum surface is hard (i.e. acoustically or optically hard and/or stable enough through time to be able to maintain a reef ecosystem of some form).

  - **Substratum Class: Consolidated Hard Substrata**
    A Hard Substratum where the dominant (i.e. ≥ 80 %) grainsize is ≥ 256 mm in any dimension.
    - **Substratum Group: Pavement**
      Consolidated Substrata where individual particles are > 1049 m in any dimension and comprise ≥ 80 % of the consolidated component. This forms a more or less continuous rock formation, and is equivalent to the monolith and megalith categories of Blair and McPherson (1999) grain size classes.
      - **Substratum Origin: Origin***
    - **Substratum Group: Megaclast**
      Consolidated Substrata where individual particles between 4.096 -1049 m in any dimension are dominant (i.e. comprise ≥ 80 % of the consolidated component).
      - **Substratum Subgroup: Slab**
        A megaclast-dominated substratum where ≥ 80 % of the megaclasts are between 65.5 – 1049 m in any dimension.
        - **Substratum Origin: Origin***
      - **Substratum Subgroup: Block**
        A megaclast-dominated substratum where ≥ 80 % of the clasts are between 4.1 – 65.5 m in any dimension.
        - **Substratum Origin: Origin***
    - **Substratum Group: Boulder**
      Consolidated Substrata where individual particles between 256-4096 mm in any dimension are dominant (i.e. comprise ≥ 80 % of the consolidated component).
      - **Substratum Subgroup: Very Coarse Boulder**
        A boulder-dominated substratum where ≥ 80 % of the boulders are between 2048-4096 mm in any dimension.
        - **Substratum Origin: Origin***
      - **Substratum Subgroup: Coarse Boulder**
        A boulder-dominated substratum where ≥ 80 % of the boulders are between 1024-2048 mm in any dimension.
        - **Substratum Origin: Origin***

- **Substratum Subgroup: Medium Boulder**
  A boulder-dominated substratum where ≥ 80 % of the boulders are between 512-1024 mm in any dimension.
  - **Substratum Origin: Origin***
- **Substratum Subgroup: Fine Boulder**
  A boulder-dominated substratum where ≥ 80 % of the boulders are between 256-512 mm in any dimension.
  - **Substratum Origin: Origin***

- **Substratum Group: Mixed Consolidated Substrata**
  Consolidated Hard Substrata composed of a mixture of two or more of Pavement, Megaclasts and Boulders, but where no individual component exceeds ≥ 80 % of the substratum component.

- **Substratum Class: Unconsolidated Hard Substrata**
  A Hard Substratum where the dominant grainsize (i.e. ≥ 80 %) is < 256 mm in any dimension.
  - **Substratum Group: Cobble**
    Unconsolidated substrata where individual particles between 64-256 mm in any dimension are dominant (i.e. comprise ≥ 80 % of the unconsolidated component).
    - **Substratum Subgroup: Coarse Cobble**
      A cobble-dominated substratum where ≥ 80 % of the cobbles are between 128-256 mm in any dimension.
      - **Substratum Origin: Origin***
    - **Substratum Subgroup: Fine Cobble**
      A cobble-dominated substratum where ≥ 80 % of the cobbles are between 64-128 mm in any dimension.
      - **Substratum Origin: Origin***
- **Substratum Class: Mixed Hard Substrata**
  A Hard Substratum composed of a mix of Consolidated Hard Substrata and Unconsolidated Hard Substrata where neither class is dominant (i.e. does not exceed ≥ 80 % of the substratum component).

- **Substratum Hardness: Soft Substrata**
  Substrata of any origin where ≥ 80% of the substratum surface is soft (i.e. acoustically or optically soft and/or not stable enough through time to be able to maintain a reef ecosystem of some form). This is equivalent to a substratum where < 20 % of the substratum is hard.
  - **Substratum Class: Coarse Sediment**
    A Soft Substratum where the dominant (i.e. ≥ 80 %) grainsize is 0.0625 – 64 mm in any dimension.
    - **Substratum Group: Pebble**
      A Coarse Sediment where individual particles between 4-64 mm in any dimension are dominant (i.e. comprise ≥ 80 % of the sediment component).
      - **Substratum Subgroup: Very Coarse Pebble**

A pebble-dominated substratum where ≥ 80 % of the pebbles are between 32-64 mm in any dimension.

  - **Substratum Origin: Origin***

- **Substratum Subgroup: Coarse Pebble**
  A pebble-dominated substratum where ≥ 80 % of the pebbles are between 16-32 mm in any dimension.
  - **Substratum Origin: Origin***
- **Substratum Subgroup: Medium Pebble**
  A pebble-dominated substratum where ≥ 80 % of the pebbles are between 8-16 mm in any dimension.
  - **Substratum Origin: Origin***
- **Substratum Subgroup: Fine Pebble**
  A pebble-dominated substratum where ≥ 80 % of the pebbles are between 4-8 mm in any dimension.
  - **Substratum Origin: Origin***

- **Substratum Group: Granule**
  A Coarse Sediment where individual particles between 2-4 mm in any dimension are dominant (i.e. comprise ≥ 80 % of the sediment component).
  - **Substratum Origin: Origin***
- **Substratum Group: Sand**
  A Coarse Sediment where individual particles between 0.0625-2 mm in any dimension comprise ≥ 80 % of the sediment component.
  - **Substratum Subgroup: Very Coarse Sand**
    A Sand where particles between 1-2 mm in any dimension are dominant (i.e. comprise ≥ 80 % of the Sand).
    - **Substratum Origin: Origin***
  - **Substratum Subgroup: Coarse Sand**
    A Sand where particles between 0.5-1 mm in any dimension are dominant (i.e. comprise ≥ 80 % of the Sand).
    - **Substratum Origin: Origin***
  - **Substratum Subgroup: Medium Sand**
    A Sand where particles between 0.25-0.5 mm in any dimension are dominant (i.e. comprise ≥ 80 % of the Sand).
    - **Substratum Origin: Origin***
  - **Substratum Subgroup: Fine Sand**
    A Sand where particles between 0.125-0.250 mm in any dimension are dominant (i.e. comprise ≥ 80 % of the Sand).
    - **Substratum Origin: Origin***
  - **Substratum Subgroup: Very Fine Sand**
    A Sand where particles between 0.0625-0.125 mm in any dimension are dominant (i.e. comprise ≥ 80 % of the Sand).
    - **Substratum Origin: Origin***

- **Substratum Group: Mixed Coarse Sediment**

A Coarse Sediment composed of a mixture of any combination of Pebble, Granule and Sand, but where no individual component exceeds ≥ 80 % of the substratum component.

- **Substratum Class: Fine Sediments**
  A Soft Substratum where the dominant (i.e. ≥ 80 %) grainsize is 0.0039 - 0.0625 mm in any dimension.
  - **Substratum Group: Silt**
    Fine substrata where individual particles between 0.0039-0.0625 mm in any dimension are dominant (i.e. comprise ≥ 80 % of the Silt)
    - **Substratum Subgroup: Coarse Silt**
      A Silt where particles between 0.0310-0.0625 mm in any dimension are dominant (i.e. comprise ≥ 80% of the Silt).
      - **Substratum Origin: Origin***
    - **Substratum Subgroup: Medium Silt**
      A Silt where particles between 0.0156-0.0310 mm in any dimension are dominant (i.e. comprise ≥ 80% of the Silt).
      - **Substratum Origin: Origin***
    - **Substratum Subgroup: Fine Silt**
      A Silt where particles between 0.0078-0.0156 mm in any dimension are dominant (i.e. comprise ≥ 80% of the Silt).
      - **Substratum Origin: Origin***
    - **Substratum Subgroup: Very Fine Silt**
      A Silt where particles between 0.0039-0.0078 mm in any dimension are dominant (i.e. comprise ≥ 80% of the Silt).
      - **Substratum Origin: Origin***
  - **Substratum Group: Clay**
    Fine substrata where individual particles between 0.00006-0.0039 mm in any dimension are dominant (i.e. comprise ≥ 80 % of the sediment component).
      - **Substratum Origin: Origin***
  - **Substratum Group: Mixed Fine Sediments**
    A Fine Sediment that comprises a mixture of Silt and Clay, but where neither component exceeds ≥ 80% of the substratum component.

- **Substratum Class: Mixed Soft Substrata**
  A Soft Substrata that is composed of a mixture of Coarse and Fine Sediment such that neither component exceeds ≥ 80% of the substratum component.

- **Substratum Hardness: Mixed Hard/Soft Substrata**
  Substrata of any origin where the substratum is composed of a mix of Hard and Soft Substrata such that neither class is dominant (i.e. neither class comprises ≥ 80 % of the substratum).

- ***Substratum Origin: Origin**
  - **Not Assessed (NA)**
    An NA classification can be applied at any level of the hierarchy. An area with an NA classification is a region where mapping has occurred, but where the given characteristic was not assessed. An NA classification is distinct from an Unknown classification in that an Unknown implies an assessment was made however a classification was not possible (e.g. due to inadequate resolution, or poor quality data).

  - **Unknown**
    An Unknown classification can be applied at any level of the hierarchy. An Unknown is an area where an assessment was made, however a classification was not possible at the given level. This could be due to any reason, including inadequate resolution, or poor quality or ambiguous data.

  - **Substratum Origin: Geologic**
    Where the substratum is composed of a greater percentage of geologic materials than either biogenic or anthropogenic. Geologic substrata can be igneous, metamorphic or sedimentary particles of any grain size class.
    - **Geologic Class: Igneous**
      A geologic substratum that is dominated by igneous rock.
    - **Geologic Class: Metamorphic**
      A geologic substratum that is dominated by metamorphic rock.
    - **Geologic Class: Sedimentary**
      A geologic substratum that is dominated by sedimentary rock.

  - **Substratum Origin: Biogenic**
    Substratum where a non-living biogenic origin is evident and comprises the dominant constituent over either geologic or anthropogenic substrata.
    - **Biogenic Class: Worm**
      Biogenic substrata that are dominated by partially or fully cemented calcareous or muddy/sandy tubes of polychaetes or other worm-like fauna.
      - **Biogenic Subclass: Sabellariid**
        Worm substrata that comprise tubes composed of shell and sand fragments that have been constructed by sabellariid worms (e.g. *Idanthyrsus pennatus*)
      - **Biogenic Subclass: Serpulid**
        Worm substrata that comprise tubes composed of calcium carbonate that have been constructed by serpulid worms (e.g. *Serpulid sp., Galeolaria caespitose*).

    - **Biogenic Class: Algae**
      A Biogenic Substratum that is dominated by non-living crustose and calcareous algae. Living algae may be present, but these are described under the Biotic Component.
      - **Biogenic Subclass: Rhodolith**

A biogenic substratum that is primarily composed of rhodoliths, a crustose algae that forms rounded calcareous nodules.

- **Biogenic Subclass: *Halimeda***
  Biogenic Algae Substrata that are primarily composed of *Halimeda sp.,* a calcareous marine alga that can form extensive algal sands once it has died.

- **Biogenic Class: Carbonate**
  - **Biogenic Subclass: Limestone**
    A consolidated hard substratum formed by the accumulation of organic remains, predominately calcium carbonate (e.g. shells, corals).
  - **Biogenic Subclass: Coral**
    A biogenic substratum that is dominated by non-living scleractinian coral. Living coral may be present, but these are described under the Biotic Component.
  - **Biogenic Subclass: Shell**
    Biogenic substratum that is constructed from cemented/self-adhered non-living shells and shell fragments. These are typically (but not exclusively) molluscs. Living shelled fauna may be present but these are described under the Biotic Component.
    - **Biogenic Group**: **Screw Shell**
      Biogenic substrata dominated by screw shells (*Maoricolpus roseus*).
    - **Biogenic Group: Oyster Shell**
      Biogenic substrata dominated by oysters.
    - **Biogenic Group: Mussel Shell**
      Biogenic substrata dominated by mussels.
    - **Biogenic Group: Clam Shell**
      Biogenic substrata dominated by clams.
    - **Biogenic Group: Other Shell**
      Biogenic substrata dominated by other shell types not otherwise classified.

- **Biogenic Class: Terrigenous**
  A Biogenic Substratum that is composed of sediments from a terrigenous origin, e.g. soils and other organic materials eroded from the land.

- **Biogenic Origin: Anthropogenic**
  Substratum that has a greater percentage cover, weight or composition of anthropogenic material than of either geologic or biogenic material. Anthropogenic material can be anything that is man-made, or which has been intentionally or accidentally placed by humans.
  - **Anthropogenic Class: Rock**
    An Anthropogenic Substratum that is dominated by natural mineral materials. This includes breakwaters and artificial reefs made of natural stone. If the origin

cannot be identified, it is assumed to be natural and classed under Geologic Origin.

- **Anthropogenic Class: Wood**
  An Anthropogenic Substratum that is dominated by wood and woody materials that were constructed and deposited in the marine environment by humans.
- **Anthropogenic Class: Construction**
  An Anthropogenic Substratum that is composed of unnatural mineral materials used in construction that have been assembled and deposited by humans, e.g. concrete, plastic, fibreglass, porcelain, rubber.
- **Anthropogenic Class: Metal**
  An Anthropogenic Substratum that is dominated by metal that was manufactured by humans.
- **Anthropogenic Class: Garbage**
  An Anthropogenic Substratum that is typically composed of plastic, but can include any amounts of rubber, glass, wax, metal and other rubbish materials, that has been manufactured and discarded by humans.

3.4 Biotic Component

The Seamap Australia Benthic Habitat Classification Scheme is designed to characterise seafloor habitats, and within this context, biota are defined as the living organisms that are attached to or closely associated with the seafloor. This can be any benthic plant, alga, or animal. The Biotic Component of the Seamap Australia Classification characterises the benthic biota based upon the dominant phylogeny. The first level of the hierarchy identifies whether biota is present or absent, and the subsequent levels separate out different phylogenies and taxonomic groups. The lowest levels of the hierarchy identify individual species or morphospecies (depending on information available). It is recognised that not all extant phylogenetic classes are represented in the middle levels of the hierarchy, however an exhaustive list would be impractical, and missing classes are those considered unlikely to occur as a mappable habitat type.

3.4.1 Dominance

Dominance in the Biotic component of Seamap Australia is defined as the most dominant biotic class measured as one of biomass, abundance or percentage cover. Which out of biomass, number of individuals or percentage cover is used will depend on the biota type and the methods used to collect the data. For example, mapping using underwater video footage might use percentage cover, whilst *in situ* surveys and sample analyses might use biomass.

3.4.2 Mixed categories

Mixed categories are defined at each node in each level of the hierarchy. A mixed class is identified where the percentage cover/biomass/abundance of the two or more most dominant classes are separated by ≤ 30% (relative to the percentage cover/biomass/number of individuals of the most dominant class). For example a community that consists of a 35% sponge, 60% macroalgae habitat would be classed as macroalga-dominated, while a community of 45% sponge and 60% macroalgae would be classed as a mixed macroalgae/sponge habitat.

3.4.3 Co-Occurring Elements

The Seamap Australia Benthic Marine Habitat Classification Scheme is a dominance-based classification, i.e. the classes are defined based on the dominant biota, or a mixture of one or more dominant species. In many cases sparse or rare species are of particular importance, and the Co-Occurring Elements descriptor provides a standard structure within which these can be recorded. A Co-Occurring Element can be any unit already described in the Biotic Component hierarchy.

3.4.4 Biotic Component class descriptions

Classes are defined according to descriptions in Edgar (2008), Allaby (1991), Allaby (1994) and Lawrence (2005), unless otherwise noted. Class definitions are consistent with all CMECS units such that direct comparisons can be made.

It should be noted that in the following definitions, the taxonomy of certain classes is often stated. While is recognised that taxonomic definitions are not always possible without detailed *in situ* observation, they have been included here for completeness.

3.4.5 Biota Presence

This describes the presence or absence of biota, and also separates areas where macrobiotic components have not been recorded. It allows bare habitats to be identified, and importantly enables these to be differentiated from areas where macrobiotic classes have not been mapped.

- **Not Assessed (NA)**
  An NA classification can be applied at any level of the hierarchy. An area with an NA classification is a region where mapping has occurred, but where the given characteristic was not assessed. An NA classification is distinct from an Unknown classification in that an Unknown implies an assessment was made however a classification was not possible (e.g. due to inadequate resolution, or poor quality data).

- **Unknown**
  An Unknown classification can be applied at any level of the hierarchy. An Unknown is an area where an assessment was made, however a classification was not possible at the given level. This could be due to any reason, including inadequate resolution, or poor quality or ambiguous data.

- **Biota Presence: Absent**
  An area where there is no evidence of living biota within the observational unit, either attached or closely associated with the seafloor, or where living biota account for a total of < 5% of the substratum surface/composition/biomass of the observational unit.

- **Biota Presence: Present**
  Areas where benthic biota are present in the observational unit and account for a total ≥ 5% of the substratum surface/composition/biomass.

  - **Biotic Class: Vegetation**
    This describes a habitat where the dominant biota are plants or algae.
    - **Biotic Subclass: Wetland Vegetation**

This describes vegetation that exists exclusively in areas that are permanently water logged, but may only be inundated with saline or brackish water periodically or occasionally. This includes areas such as marshes, tidal flats and river estuaries, but excludes oceans. At the Highest Astronomical Tide (HAT) mark, vegetation in this class is never fully submerged and typically only the roots are immersed.

- **Biotic Group: Mangrove** (as in Edgar 2008)
  Areas dominated by mangroves, a tree or shrub that occurs in saline and brackish water in coastal and estuarine environments between low and high tide levels on sheltered shores. Mangroves are typically considered a tropical species, however in Australia some species occur in temperate regions as well. They typically have a tangled, above ground root system, and can form extensive swampy forests.
- **Biotic Group: Saltmarsh** (as in Edgar 2008)
  Areas dominated by saltmarsh plants (halophytes). These typically occur on sheltered intertidal mud and sand flats. They are easily distinguished from other plants in that their roots are (semi-) regularly inundated by saltwater, and from mangroves based on their smaller size.
- **Biotic Group: Mixed Wetland Vegetation**
  A habitat where the dominance of a single Wetland Vegetation group (Mangroves, Saltmarsh) cannot be identified, or where the surface/composition/biomass coverage of the second-most dominant group lies within 30% margin of the most-dominant group.

- **Biotic Subclass: Macrophytes (Non-Wetland)**
  This describes vegetation that exists in areas that are inundated either permanently or with regular tidal flow. At the Highest Astronomical Tide (HAT) mark, this vegetation is fully submerged.
  - **Biotic Group: Macroalgae**
    Areas dominated by macroalgae, a multicellular algae that are capable of attaching to the seafloor. Macroalgae are commonly referred to as seaweeds, and consist of the phyla Chlorophyta and Rhodophyta, and class Phaeophyceae.
  - **Biotic Group: Seagrass**
    Areas dominated by seagrass, a flowering plant (angiosperm; Phylum Magnoliophyta) that typically occurs in sheltered intertidal or subtidal environments, and has elongated green and grass-like leaves.
  - **Biotic Group: Mixed Macrophytes**
    A habitat where the dominance of a Macrophyte group (Macroalgae, Seagrass) cannot be identified, or where the surface/composition/biomass coverage of the second-most

dominant group lies within 30% margin of the most-dominant group.

- **Biotic Subclass: Mixed Vegetation**
  A habitat where the dominance of a single Vegetation subclass (Wetland Vegetation, Macrophytes) cannot be identified, or where the surface/composition/biomass coverage of the second-most dominant subclass lies within 30% margin of the most-dominant subclass.

▪ **Biotic Class: Invertebrates**
A habitat dominated by benthic macrofauna that do not have a backbone, i.e. are not vertebrates.

- **Biotic Subclass: Non-Molluscan Filter Feeders**
  A filter feeder habitat is characterised by biota dominated by organisms that feed by drawing water through a specialised structure and filtering out small particles and organisms in the water column.
  - **Biotic Group: Coral Biota**
    An area dominated by coral, a colonial marine Cnidarian from the Order Scleractinia, Antipatharia, Alcyonacea or Pennatulacea, where colonies are composed of individual polyps that are connected by living tissue. In some, corals polyps excrete an exoskeleton and are embedded within this structure, while others possess large amounts of gelatinous tissue and are much softer.
  - **Biotic Group: Non-Coral Cnidaria**
    Areas dominated by anemones, hydroids, hydrocorals or other benthic Cnidaria that are not corals.
  - **Biotic Group: Bryozoans** (as in Edgar 2008, FGDC 2012)
    A colonial animal of the Phylum Bryozoa that consists of numerous zooids, small box-like units about 1 mm long. They generally have a chitinous or calcareous covering that adds structural support, and feed by extending tentacles from an orifice in the upper sidewall. They may occur in many growth forms, including as flat encrusting, branched, fenestrate, soft dendroid and fouling communities.
  - **Biotic Group: Sponges**
    Areas dominated by sponges, simple multicellular animals of the Phylum Porifera that live attached to the seafloor. Their soft and porus body structure is supported by a framework of fibrous proteins, and spicules of calcium carbonate or silica. Sponges are morphologically diverse, but all draw in a current of water using specialised flagella and extract nutrients and oxygen from the flow.
  - **Biotic Group: Ascidians**
    Areas dominated by ascidians (also known as seasquirts or tunicates; Class Ascidiacea), a diverse group of solitary or colonial animals, the adults of which are sessile. Ascidians are bag-like filter feeders, drawing water in and out through separate inhalant and

exhalent siphons. They occur from intertidal to deep (> 2000 m) subtidal waters, and can reach high abundances.

  - **Biotic Group: Worm Biota**
    Areas dominated by sessile marine worms, in particular tube dwelling polychaetes. These sedentary polychaetes have highly differentiated bodies and most live in secreted tubes attached to the seafloor.
  - **Biotic Group: Mixed Filter Feeder Community**
    A habitat where the dominance of a single Non-molluscan Filter Feeder group (Non-coral Cnidaria, Corals, Worms, Bryozoans, Sponges, Ascidians) cannot be identified, or where the surface/composition/biomass coverage of the second-most dominant group lies within 30 % margin of the most-dominant group.

- **Biotic Subclass: Bioturbators**
  Bioturbation refers to the signs and traces formed by the activity of macro- and meiofauna living in soft sediment habitats. This can include evidence of burrows, feeding or crawling traces and mounds from a hugely diverse group of organisms. While direct observations of the fauna may not be common, the existence of these traces and the type of trace can help inform which types of bioturbators might be present in an area.
- **Biotic Subclass: Shelled Biota**
  - **Biotic Group: Oyster Biota**
    Areas dominated by accumulations of living oysters attached to a substratum.
  - **Biotic Group: Mussel Biota**
    Areas dominated by accumulations of living mussels attached to a substratum.
  - **Biotic Group: Screw Shell Biota**
    Areas dominated by accumulations of living screwshells attached to a substratum.
  - **Biotic Group: Other Shelled Biota**
    Areas dominated by accumulations of living shells other than oysters, mussels, clams of screwshells, that are attached to the substratum.
  - **Biotic Group: Mixed Shelled Biota**
    A habitat where the dominance of a single Shelled Biota group (Oyster, Mussel, Screwshell, Other) cannot be identified, or where the composition/biomass/surface coverage of the second-most dominant group lies within 30% margin of the most-dominant group.
- **Biotic Subclass: Mixed Invertebrate Community**
  A habitat where the dominance of a single Invertebrate subclass (Non-molluscan Filter Feeders, Bioturbators, Shelled Biota) cannot be identified,

or where the composition/biomass/surface coverage of the second-most dominant subclass lies within 30% margin of the most-dominant subclass.

- **Biotic Class: Microbes** (as in FGDC 2012)
  Areas dominated by microbes that form a soft or hard structure visible to the eye. Soft structures are usually formed through accumulations of conspecifics and other microbes into a matrix that appears as strands, a thin film, or a thicker mat. Hard structures generally form through secretions and entrapment of minerals and sediments.
  - **Biotic Subclass: Stromatolite** (as in FGDC 2012)
    An area dominated by stromatolites, a microbial community forming a hard layered and mound-like structure, sometimes of considerable size. They occur only in specific areas in warm shallow water, and comprise of secretions of cyanobacteria.
  - **Biotic Subclass: Bacterial mat** (as in FGDC 2012)
    Areas dominated by colonies of bacterial decomposers and other decay organisms. These colonies can range in appearance from delicate and filamentous to a dense mass that may blanket the sediment surface.
  - **Biotic Subclass: Microphytobenthos (MacIntyre et al. 1996)**
    Unicellular eukaryotic algae and cyanobacteria that grow within the upper several mm of illuminated sediments, typically appearing as only a subtle brownish or greenish shading.
  - **Biotic Subclass: Mixed Microbes**
    A habitat where the dominance of a single microbial subclass (Stromatolites, Bacterial Mat, Microphytobenthos) cannot be identified, or where the surface/composition/biomass of the second-most dominant subclass lies within 30% margin of the most-dominant subclass.

- **Biotic Class: Mixed Biota**
  A habitat where the dominance of a single biotic class (Vegetation, Microbes, Invertebrates or Urchin Barrens) is unclear, or where the surface/composition/biomass coverage of the second-most dominant class lies within 30% margin of the most-dominant biotic class.

- **Biotic Class: Urchin Barren**
  An area where the absence of fleshy seaweeds on hard substratum is attributed to over-grazing from sea urchins. These areas are largely devoid of fleshy macroalgal cover where seaweeds would otherwise be expected to occur, and sea urchins are typically present at high densities, although once formed an urchin barren can be maintained by relatively low densities of urchins.

4. Reclassifying national data to the Seamap Australia Habitat Classification Scheme

The final Seamap Australia spatial product was generated by first reclassifying datasets in the newly established database (Appendix 1) using the Seamap Australia Benthic Marine Habitat Classification Scheme, before aggregating and assembling the layers into a single product. The reclassification used all relevant information that was provided with the original dataset to ensure that it was appropriately relabelled in the Seamap Australia Benthic Marine Habitat Classification Scheme. This ensured the newly attributed classes achieved the highest resolution possible and minimised the amount of data lost in the transfer process. The original class given to each polygon was retained as an attribute in the final dataset, along with the source dataset URL, allowing for comparison and analysis of the accuracy of reclassification.

In assigning polygons in the National layer to the appropriate IMCRA Province and Bioregion classes, some of the data did not fall within the clipping bounds of the IMCRA shapefile e.g. habitat was too far inland or too close to an island. These polygons were assigned the nearest neighbouring Province/Bioregion, and such cases were noted in the data table in square brackets, for example as *Bass Strait Province [extended inshore].*

The aggregation of all habitat layers into a single product was performed using ArcGIS software (ESRI). Overlapping polygons were assimilated if their classifications related to different Components (e.g. Substratum and Biotic). Where spatial overlap occurred between polygons with a classification from the same Component (e.g. Biotic Component) priority was assigned by taking into account the date the data were collected (more recent data prioritised over older data), the method of data collection (finer resolution prioritised over coarser) and the information provided in the metadata (thoroughly documented methods, dates, sources etc. took priority over poorly documented information).

The result was a single data layer, the Seamap Australia National Habitat Layer, which includes all known information for each level in each of the hierarchies described within the Seamap Australia Benthic Marine Habitat Classification Scheme. Also included is the classification from the original dataset, the source dataset URL, and selected metadata (date, data collection methods, location).

5. Discussion

A nationally consistent benthic marine habitat spatial layer is as important for management of Australia's marine estate as terrestrial cadastre maps are for land use management. To address this need Seamap Australia has collated existing marine habitat data from across the nation, and created a new benthic marine habitat classification scheme that assimilates all existing relevant national habitat data in to a single and publically accessible resource. The Seamap Australia National Benthic Marine Habitat Classification Scheme is a preliminary product to be used and developed into in the future to ensure consistency in the classification of benthic marine habitats at a national scale.

Tasmania was, through the Seamap Tasmania project, the first state to embark on broad-scale marine habitat classification in the year 2000 (Barrett et al. 2001). The history of Seamap Tasmania has demonstrated the unparalleled ability of benthic habitat maps to reach out to a number of stakeholders including biodiversity assessment, marine aquaculture planning, fisheries research and management, oil spill response and marine hazard management (e.g. tsunami modelling).

The exercise of producing a nationally consistent benthic habitat spatial layer has highlighted those parts of our marine estate where three are significant gaps in understanding of marine resources. Mapping these data voids allows strategic investments to be made in field surveys, which are expensive to conduct.

We anticipate that the ongoing benefits of the Seamap Australia classification scheme and spatial data product will reach far into the future. Seamap Australia will facilitate national-scale cross-disciplinary studies of continental shelf habitats. Collating all available marine habitat mapping datasets into a single viewing interface (http://www.seamapaustralia.org) and promoting and extending the availability of these through the AODN Portal by highlighting the parties responsible for each data collection, should encourage institutions to work collaboratively to address nationwide solutions. The real benefit of this High Value Collection will emerge in the future as researchers share their marine habitat data through the AODN so that the resource grows and the improved knowledge of our marine environment is accessible to all.

There are many different approaches to habitat classification (see review, section 1.3), and Seamap Australia has had to choose one. Although we consider this to be the best suited to the aims of the project, like all schemas there are limitations to its design and implementation. The design of the Seamap scheme uses four (with an intention of eventually refining five) separate hierarchies, each mapping different habitat characteristics, e.g. substratum and biota. This design is well suited to accommodating historic datasets, as it allows each characteristic to be described in complete absence of knowledge of any others. However, this method has the potential to yield multiple maps for any given area, the interrogation of which will require some form of GIS analysis. If combined, the classifications from each of the hierarchies may also lead to many (possibly hundreds of) derived classes, the meaning of which may not be intuitive.

Using a classification scheme driven by dominance also has limitations. Although dominant taxa are ecologically important, sparse and rare species can also be informative, and recording them may be important for change/condition assessment and management purposes. In any mapping project the question of what information the classification might miss or down-weight through use of the dominant species classification should be considered, and where necessary any extra information can be recorded through the Co-Occurring Elements descriptor.

The proposed Seamap Australia National Benthic Marine Habitat Classification Scheme should be considered a “living document” in the hope that, by widespread national adoption of the scheme the design will be refined and improved. There are several considerations for future development. The inclusion of simple biotope classes that combine biotic and physical descriptions is likely to be useful, e.g. ‘seagrass on soft sediment’. Priority should be assigned to developing and implementing these first for commonly occurring combinations. This kind of classification provides a short and intuitive description of habitat type, and may also be of more use from a management and reporting perspective.

The Seamap Australia Aquatic Setting uses the Geoscience Australia classification for estuarine and costal waterways (Heap et al. 2001, Ryan et al. 2003). This is an established scheme and its use has enabled a classification to be applied to many mapped habitat units. However, the use of this scheme has some limitations, such as the difficulty in defining the boundaries to some classes such as 'tidally influenced waters', which is a definition applied to coastal waterways. This will require further review in future versions of the classification scheme.

The biotic component of the scheme does not yet capture the diversity of mappable biotic units. We have tried to ensure the broad and/or commonly mapped habitat types are included (Level 4), and while we include the flexibility to retain classifications at a finer resolution (species/morphospecies), these levels need to be further developed. The extent to which each class is developed should depend on the level of diversity of each individual biotic class, e.g. macroalgae encompasses a huge diversity of organisms (fleshy, coralline, canopy-forming, rhodoliths etc.) whilst finer detail for shelled biota (e.g. oyster, mussel) may not be considered necessary. As more mapping is completed, and the scheme is adopted and tested, the biotic component can be modified and additional classes added as required.

The final Seamap Australia spatial product (version 1) is published to the Australian Ocean Data Network (AODN) with a fully interactive visualisation available through the Seamap Australia website [www.seamapaustralia.org]. The webpage architecture allows for other data, such as Baited Remote Underwater Video (BRUV), Autonomous Underwater Vehicle (AUV), and Reef Life Survey data collections to be overlaid onto the Seamap Australia product via Web Mapping Services. Some of these collections were previously available and accessible online (e.g. RLS, some AUV), while others (BRUV) are only now being made available through the activities of separate projects. While the inclusion of this BRUVs data into the public domain will be a valuable addition, the majority of Australia's BRUV data holdings remain inaccessible (the BRUVs data from AIMS is a notable exception). However, a number of BRUVs collections will be made available through a component of the NMBH D3 project to be completed in the 2017-08 financial year. Thus, within the life of this HVC project, a much broader collection of national BRUV data will be made available through the activities of national service for BRUV analyses established under RDS Marine Data Services, and can be published as complementary ecological data alongside the Seamap Australia product.

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Appendix 1. Custodians and contact details for the source data of Seamap Australia

Region	Custodian	Data Collection	Contact
NSW	Department of Primary Industries, New South Wales	NSW Estuarine Macrophytes	
NSW	Office of Environment and Heritage, New South Wales	NSW Marine Habitats 2013	Tim Ingleton Tim.Ingleton@environment.nsw.gov.au
NSW	Office of Environment and Heritage, New South Wales	NSW Marine Habitats 2002	Office of Environment and Heritage data.broker@environment.nsw.gov.au
NSW	Office of Environment and Heritage, New South Wales	NSW Estuarine Inventory	Office of Environment and Heritage data.broker@environment.nsw.gov.au
NSW	Office of Environment and Heritage, New South Wales	NSW Ocean Ecosystems 2002	Office of Environment and Heritage data.broker@environment.nsw.gov.au
NSW	Office of Environment and Heritage, New South Wales	NSW Estuary Ecosystems 2002	Office of Environment and Heritage data.broker@environment.nsw.gov.au
QLD	Department of National Parks, Sport and Racing, Queensland	Moreton Bay Broadscale Habitats	Department of National Parks, Sport and Racing Spatial.Services@npsr.qld.gov.au
QLD	Chris Roelfsema, University of Queensland	Eastern Banks seagrass, Moreton Bay	Chris Roelfsema c.roelfsema@uq.edu.au
QLD	Department of Natural Resources and Mines, Queensland	QLD Reefs and Shoals	LSISDMTTopoDataTeam@dnrm.qld.gov.au
QLD	Centre for Tropical Water & Aquatic Ecosystem Research, James Cook University National Environmental Science Program	GBRWHA Seagrass Composite	Alexandra Carter Alexandra.Carter@jcu.edu.au
QLD	Centre for Tropical Water & Aquatic Ecosystem Research, James Cook University	Dugong and Turtle Seagrass Habitats in NW Torres Strait	Alexandra Carter Alexandra.Carter@jcu.edu.au

	National Environmental Science Program		
QLD	Centre for Tropical Water & Aquatic Ecosystem Research, James Cook University	Torres Strait Seagrass Mapping Consolidation	seagrass@jcu.edu.au
QLD	Centre for Tropical Water & Aquatic Ecosystem Research, James Cook University	Low Isles Seagrass	Len McKenzie Len.McKenzie@jcu.edu.au
QLD	Department of National Parks, Sport and Racing, Queensland	Moreton Bay Coral 2004	Matthew Nash-Arnold Matthew.Nash-Arnold@npsr.qld.gov.au
QLD	Great Barrier Reef Marine Park Authority	Great Barrier Reef Features	gis@gbrmpa.gov.au
QLD	Environmental Protection Agency University of Queensland	Moreton Bay seagrass 2004	data.coordinator@epa.qld.gov.au
QLD	Environmental Protection Agency University of Queensland	Moreton Bay seagrass 2011	Environmental Protection Agency data.coordinator@epa.qld.gov.au
QLD	Guy Castley, Griffith University	Gold Coast Seagrass	Guy Castely g.castely@griffith.edu.au
QLD	Department of Science, Information Technology and Innovation, Queensland	Queensland Wetland data version 4.0	queensland.herbarium@qld.gov.au
QLD	Stuart Phinn, University of Queensland	Heron Reef Benthic Communities & Geomorphic Zones	Stuart Phinn S.Phinn@uq.edu.au
QLD	Department of Primary Industries, Queensland	Queensland Coastal Wetland Resources	

QLD	Chris Roelfsema, University of Queensland	PLEA Point Lookout Reefs	Chris Roelfsema C.Roelfsema@uq.edu.au
SA	Department of Environment, Water and Natural Resources, South Australia Adelaide, 5001	SA State Benthic habitats	Matthew Royale Matthew.Royal@sa.gov.au
TAS	Tasmanian Aquaculture and Fisheries (TAFI)	Seamap Tasmania	Vanessa Lucieer Vanessa.Lucieer@utas.edu.au
NT	Department of Environment and Natural Resources, Northern Territory	Mangrove Mapping Bynoe Harbour	datarequests.denr@nt.gov.au
NT	Department of Environment and Natural Resources, Northern Territory	Mangrove Mapping of Darwin Harbour	datarequests.denr@nt.gov.au
NT	Department of Environment and Natural Resources, Northern Territory Department Primary Industries, Queensland	Seagrass meadows of Arnhem Land and Gulf of Carpentaria	datarequests.denr@nt.gov.au
NT	Geoscience Australia (GA)	Oceanic Shoals geomorphology	sales@ga.gov.au
NT	Geoscience Australia (GA)	Petrel Sub-Basin geomorphology	sales@ga.gov.au
NT	Geoscience Australia (GA)	Mapping and classification of Darwin harbour seabed	sales@ga.gov.au
NT	Department of Environment and Natural Resources, Northern Territory	Darwin Harbour Marine Habitats	datarequests.denr@nt.gov.au
NT	Department of Environment and Natural Resources, Northern Territory	Ludmilla Creek Vegetation Survey	datarequests.denr@nt.gov.au

NT	Department of Environment and Natural Resources, Northern Territory	Mangroves of the Northern Territory	datarequests.denr@nt.gov.au
WA	Department of Water, Western Australia	WA Seagrass Synthesis 2013	Kieryn Kilminster Kieryn.Kilminster@water.wa.gov.au
WA	University of Western Australia Oceans Institute	Marine Futures Reef	Jessica Meeuwig Jessica.Meeuwig@uwa.edu.au
WA	University of Western Australia Oceans Institute	Marine Futures Biota	Jessica Meeuwig Jessica.Meeuwig@uwa.edu.au
WA	CSIRO Oceans & Atmosphere	MOU74 Marine Resources	Tim Skewes Tim.Skewes@csiro.au
WA	Department of Parks and Wildlife, Western Australia	DPAW Marine Habitats	Geoffrey Banks Geoffrey.banks@dpaw.wa.gov.au
WA	Cockburn Sound Management Council DAL Science & Engineering Pty Ltd	Mapping selected areas of Cockburn Sound	
WA	University of Western Australia	Changes in Seagrass in Cockburn Sound	Gary Kendrick Gary.Kendrick@uwa.edu.au
WA	CSIRO Oceans & Atmosphere Department of Environment, Western Australia	NW Shelf ecosystem characterisation	
NATIONAL	Geoscience Australia	Geomorphic feature of Australia's margin	sales@ga.gov.au
NATIONAL	CSIRO	CAMRIS benthic substrate	CSIRO.enquiries@csiro.au
NATIONAL	CSIRO	CAMRIS seagrass	CSIRO.enquiries@csiro.au
NATIONAL	Geoscience Australia	National Coastal Geomorphology updates	sales@ga.gov.au
NATIONAL	Geoscience Australia	Coastal waterways geomorphic habitat mapping	sales@ga.gov.au