Queensland Intertidal and Subtidal Ecosystem Classification Scheme Version 1.0

Module 1

Introduction and implementation of Intertidal and Subtidal Ecosystem Classification

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Queensland Wetlands Program

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Document outline

This ‘Queensland Intertidal and Subtidal Ecosystem Classification Scheme' (the scheme) was developed as part of the Queensland Wetlands Program (WetlandInfo 2016). The scheme was developed to provide a structured framework for classifying the intertidal and subtidal ecosystems of Queensland and surrounding waters using independent biophysical attributes, although it could also be used for other parts of Australia.

The scheme provides a logical process that harnesses the understanding of the factors that influence ecosystem types, allows for ecosystems to be described, and enables ecosystems to be identified based on biophysical attributes, at a range of different scales. This provides a common understanding and language of classification that will improve communication, ensure better integration, lead to more informed management outcomes, and provide the basis for any future mapping.

Four modules have been developed covering different aspects of the scheme:

- Module 1: Introduction and implementation of intertidal and subtidal ecosystem classification
- Module 2: Literature review of intertidal and subtidal classification frameworks and systems (in prep.)
- Module 3: Attributes, categories and metrics for the intertidal and subtidal ecosystem classification scheme (in prep.)
- Module 4: Mapping method and specifications for the intertidal and subtidal ecosystem classification scheme (in prep.)

Module 1 addresses the following topics:

Part 1 introduces the scheme and covers:

- the background on the need for an intertidal and subtidal (estuarine and marine) ecosystem classification scheme
- what the classification means and why it is useful
- the process used to develop the scheme
- the key concepts and principles of attribute-based classification
- the key features of the scheme and its uses
- the key issues identified through the development process and how they were addressed.

Part 2 describes the implementation of the scheme including:

- the process for applying the scheme
- how a classification system is developed
- how a typology is created
- how classes and ecosystem types can be mapped

Part 1: Introduction to intertidal and subtidal ecosystem classification

1 Introduction, scope and purpose of classification

The 'Queensland Intertidal and Subtidal Ecosystem Classification Scheme' has been designed to cover all ecosystems within Queensland state waters and is not confined to the 6-metre limit of the wetlands definition.

1.1 Background

The Queensland Wetlands Program (QWP) was established by the Australian and Queensland governments in 2003 to support projects and programs that enhance the wise use and sustainable management of Queensland's wetlands. The QWP is currently funded by the Queensland Government (www.wetlandinfo.ehp.qld.gov.au).

The QWP covers all aspects of wetlands management and has included the development of tools for assessing, classifying and mapping different kinds of wetlands. While a comprehensive classification scheme is in place in Queensland for terrestrial regional ecosystems (Sattler & Williams 1999, Neldner *et al.* 2012), freshwater wetlands (Environmental Protection Agency 2005) and groundwater dependent ecosystems (Glanville *et al.* 2016, Department of Science, Information Technology and Innovation (DSITI) 2015), there is no equivalent attribute-based classification scheme for intertidal and subtidal ecosystems.

As part of the QWP, this project was led by the Queensland Department of Environment and Heritage Protection (DEHP) in collaboration with the Queensland Departments of Agriculture and Fisheries (DAF), the Department of Science, Information Technology and Innovation (DSITI), the Department of National Parks, Sport and Racing (DNPSR), Gladstone Ports Corporation (GPC). Other organisations involved included: Queensland universities, the Commonwealth Scientific and Industrial Research Organisation (CSIRO), the Great Barrier Reef Marine Park Authority (GBRMPA) and natural resource management (NRM) bodies (see Appendix 6.2).

The Gladstone Ports Corporation provided financial assistance toward the development of this scheme as part of a fish habitat initiative required to meet fish habitat offsets associated with approved development conditions, with funding delivered through the Department of Agriculture and Fisheries (including part-funding under DAF 1498CQA-2 toward the Intertidal and Subtidal Habitat Mapping and Conservation Values Assessment for Central Queensland State Waters Project).

1.2 Scope and features of intertidal and subtidal ecosystems

Ecosystems are a dynamic complex of plant, animal and micro-organism communities and their non-living environment, interacting as a functional unit (Wetlands 2015; AETG 2012). Intertidal ecosystems are found between the high tide and low tide, experiencing fluctuating influences of land and sea, whereas subtidal ecosystems are permanently below the level of low tide, i.e. continuously submerged within tidal waters (OzCoasts 2015). The tidal waters inundating intertidal and subtidal habitats can be fresh, brackish, saline (usually oceanic) or even more saline than oceanic waters (hypersaline) (Ribbe 2014).

Thus, intertidal and subtidal ecosystems are composed of parts of both **estuarine** systems (freshwaters sometimes diluting oceanic waters, usually semi-enclosed by land) and **marine** systems (oceanic waters) (AETG 2012; Wetlands 2015; Cowardin *et al.* 1979).

Under normal meteorological conditions it is possible to delineate consistent intertidal and subtidal areas as characterised by organisms specialised to withstand tidal influence. In comparison, estuarine boundaries are variable and subject to weather and climatic variations associated with rainfall and river runoff (Woodroffe 2002). Thus the scope of the scheme addresses intertidal and subtidal ecosystems, which can then be applied to estuarine and marine frameworks if required.

Subtidal and intertidal ecosystems are dynamic and are influenced by a range of physical, chemical and biological variables that fluctuate and cycle at various scales across time and space. While no two intertidal or subtidal ecosystems are entirely the same, they are exposed to similar factors and have some similar features—this provides the basis for the scheme.

Within this scheme, **water column** refers to the vertical water mass between the surface of the water (Federal Geographic Data Committee 2012); and benthic is defined as pertaining to the seafloor (or bottom) of a river, coastal waterway, or ocean (modified from OzCoasts 2015b). Benthic material can refer to substrate or sediment and it can be used to describe the organisms that live on, or in, sea floor, or at the bottom of a water column (modified from Mount & Prahalad 2009).

While the project was developed through the QWP, the scheme extends beyond the definition of wetlands (Environmental Protection Agency 2005; Wetlands 2013b; AETG 2012) to cover all intertidal and subtidal ecosystems within Queensland waters (including those beyond the edge of the continental shelf), whereas the definition of wetlands does not extend below 6m depth in the marine environment (AETG 2012). The principles, methods and attributes of the scheme could also be applied to any Australian or international intertidal and subtidal ecosystems.

1.3 Why classify and map intertidal and subtidal ecosystems: ecosystem-based management

Intertidal and subtidal ecosystems annually deliver billions of dollars to the Queensland economy through the provision of many ecosystem services (Queensland Government 2017; Rolfe *et al.* 2005). However, many of these ecosystems are being impacted by a range of threats such as an increasing population, particularly along the coast. For example, catchment degradation and altered hydrology are impacting on fisheries and aquaculture productivity, as well as recreation and tourism opportunities (Queensland Government 2017). Appropriate management is critical for these ecosystems to remain healthy and productive and to continue to provide the services on which we depend.

Ecosystem-based management (EBM) is an integrated approach that considers the entire ecosystem, including humans (Leslie and McLeod 2007). The principle of EBM has been widely applied in Australia for managing ecosystems, species and resources (Sattler & Williams 1999; Kenchington & Hutchings 2012) and is at the core of the international Ramsar Ecological Character Framework (Department of the Environment, Water, Heritage and the Arts 2008). The EBM approach considers the relationships between systems and the consequences of impacts on systems and informs decision-making around initiatives and actions to successfully manage systems (Foley *et al.* 2013).

This scheme addresses the principles of EBM (as outlined in Leslie and McLeod 2007) by:

- addressing spatial components of ecosystems at hierarchical spatial levels and considering temporal variability
- identifying components of marine ecosystems that can be subsequently linked to processes, values and ecosystem services they deliver for human communities.
- creating a seamless ecosystem mapping framework compatible and connecting with land-based regional ecosystems and freshwater wetland mapping
- meaningfully involving stakeholders and managers collaborating in knowledge panels that build an understanding of ecosystem components and the biological, physical and chemical attributes that determine their nature and extent.

Fundamental to using the EBM approach is the documentation of the location (mapping) of the components of ecosystems and the characteristics of these components (classification) within a recognised framework (Galparsoro *et al.* 2017). While a wealth of coastal, marine and estuarine knowledge exists in various institutions and research bodies, a comprehensive and standardised classification and mapping of intertidal and subtidal ecosystems has remained a major gap in our knowledge for Queensland.

Classification provides a common language within a structured framework, enabling synthesis and understanding of the parts (components) and processes of different ecosystems, where these components (including ecosystems) may be grouped based on similar characteristics (Environmental Protection Agency 2005). By using a consistent and repeatable framework to classify the components of these complex and ever-changing systems, it is possible to better understand their nature, extent, distribution and structure. This information is necessary to investigate and understand how they function. This improves our knowledge of the effects of natural and human drivers and pressures and how to manage them.

In summary, the development of a standard intertidal and subtidal ecosystem classification scheme provides a foundation and structure which serves a wide range of applications (see Table 1) including:

- a framework for classification, data capture, storage and retrieval, mapping and monitoring
- assessing, understanding and communicating habitat values and processes
- informing a range of management and planning uses
- direct use in on-ground decision-making.

Table 1: Applications of Classification of Intertidal and Subtidal Ecosystem Classification Scheme

ISSUE	APPLICATION
FRAMEWORK for CLASSIFICATION, DATA CAPTURE, STORAGE, RETRIEVAL ,MAPPING & MONITORING	Maximising efficiency and transparency in decision making by having readily available frameworks, mapping and datasets on which to make decisions
	Providing the foundation for mapping (attributes and types)
	Consolidating knowledge into a consistent platform for intertidal and subtidal ecosystems
	Tracking changes in ecosystem extent and type and designing monitoring programs (e.g. for water quality & habitat condition – report cards)
	Providing the basis for the description of ecosystem types and the development of conceptual models (e.g. pictorial conceptual models can allow us to visualise how an ecosystem operates)
	Prioritising data acquisition activities
ASSESSING VALUES AND PROCESSES	Assessing the services and values of intertidal and subtidal ecosystems
	Assessing ecosystem representativeness/uniqueness for reserve systems and conservation assessment processes (e.g. representation for fish habitat areas, marine park zonings)
	Assessing connectivity and interactions between ecosystem types and identifying the key factors involved in these processes.
	Predicting species presence/absence based upon ecosystem types (e.g. Great Barrier Reef, Ramsar wetlands)
	Facilitating communication and reducing complexity about ecology, values and management for technical and non-technical audiences and stakeholders
MANAGEMENT POLICY & PLANNING	Developing management guidelines for intertidal and subtidal ecosystems based on key characteristics
	Informing resource utilisation, regulation, management and offsets
	Enabling integration of planning and policy for intertidal and subtidal habitats across agencies and jurisdictions
	Informing the identification of Matters of National and State Environmental Significance (MNES, MSES) (including Outstanding Universal Value of World Heritage areas and criteria under Ramsar)
	Informing water quality improvement initiatives e.g., future environmental values and water quality objectives, regional and state report cards
	Informing Marine Park and Fisheries planning and review; and initiatives to protect the Great Barrier Reef
	Assisting with the assessment of climate change impacts
	Assisting with the management of extreme weather and emergency management (e.g. prediction of impacts of oil spills, grounding etc.)
ON-GROUND DECISIONs	Assisting with development assessments and other management decisions (e.g. Environmental Impact Assessments, coastal approvals)
	Informing frontline services e.g. Field compliance
	Informing prioritisation and actions for on-ground works (e.g. for regional NRM groups and Non - Government Organisations)

2 Process of developing the classification scheme

The 'Queensland Intertidal and Subtidal Ecosystem Classification Scheme' was developed using a transparent approach involving literature review, extensive consultation with a range of experts (through workshops and correspondence), the use of a technical advisory group and peer review.

Figure 1: The process of developing the classification scheme.

2.1 Literature review

The literature review provided a foundational understanding of classification concepts and approaches, providing direction when developing an intertidal and subtidal classification scheme for Queensland.

In the development of the National Intertidal/Subtidal Benthic (NISB) classification (Mount & Prahalad 2009) and the Interim Australian National Aquatic Ecosystem (ANAE) Classification Estuarine-Marine Attribute Workshop Summary Report (AETG 2013), a number of issues were raised that needed further consideration. These included:

- resolving major themes and attributes important for characterising estuarine and marine ecosystems
- identifying specific thresholds/metrics for each agreed attribute
- clarifying terminology
- dealing with ecological timeframes (including variability of attributes, intermittent and episodic nature of environment)
- managing issues of scale.

Using the NISB and Interim ANAE Estuarine-Marine Attribute Workshop issues as an initial starting point, a comprehensive literature review (Module 2) was undertaken to ensure the above issues, and any others were considered when developing the scheme for Queensland. The review addressed:

- concepts and elements of schemes
- different approaches and examples of schemes
- issues requiring resolution when developing a classification scheme, for example considering biophysical attributes that correlate best with biodiversity patterns (surrogacy).

The review examined a broad range of existing classification schemes and frameworks. These included, but were not limited to, classifications from Queensland's Regional Ecosystems, ANAE (AETG 2012, AETG 2013), NISB (Mount & Prahalad 2009), Queensland freshwater wetland habitat classification scheme (Environmental Protection Agency 2005), Groundwater dependent ecosystem mapping (Glanville *et al.* 2016, Department of Science, Information Technology and Innovation (DSITI) 2015), Great Barrier Reef and Moreton Bay Marine Park zoning, academic studies, Queensland policy (e.g. Fish Habitat Areas), natural resource management groups and conservation groups and interstate and overseas examples.

2.2 Consultation

> *The scheme was only made possible through extensive participation by and consultation with prospective users including research institutions, scientists, managers, government officers, consultants and local experts with an understanding of intertidal and subtidal ecosystems.*
>
> *There was strong recognition and support from participants of the benefits of an attribute-based intertidal and subtidal ecosystem classification scheme to underpin future intertidal and subtidal management activities in Queensland*

A comprehensive collaboration and consultation process (including seventeen workshops, panels and technical working groups, two advisory groups and numerous one-on-one meetings) was undertaken to inform the development of the scheme. This involved policy makers, managers and scientists from state, local and federal government, natural resource management bodies and universities, with individuals from a wide range of disciplines. More than 120 representatives from over 30 organisations were involved during 2014-2017 (see Appendix 6.7 for consultation details).

The literature review, collaboration and consultation process informed the selection of attributes and categories (see Appendices 6.1, 6.2) and the development of draft typologies. Issues of scale, terminology and conceptual underpinning were also addressed. Beyond the initial examination of existing classifications, the collaborators continued to remain a reference group throughout the consultation and development of this scheme. This was to ensure the outputs were suitable for different purposes and optimised the potential to draw on existing information to ultimately compile a comprehensive account of Queensland's intertidal and subtidal ecosystems. Based on existing information, preliminary mapping of attributes was undertaken for two case study areas and was subsequently extended to several other areas of Queensland.

As the classification was intended to apply throughout Queensland and adjacent waters, workshops were held in Brisbane, Gladstone, Rockhampton and Townsville, locations selected to optimise opportunities for stakeholder involvement from a variety of organisations (see Appendix, section 6.7.1 and 6.7.2). The classification was then endorsed and applied at classification, typology and mapping workshops in the Great Sandy / Wide Bay area. Case study workshops where experts guided the application of the classification and typology to mapping demonstrated the applicability of the scheme, enabling stakeholders to provide feedback on, modify and subsequently support the scheme and products.

Stakeholder involvement was driven by a variety of interests including baseline data requirements, planning needs, regulation, monitoring, possibilities for future work, and integration of spatial and non-spatial data across jurisdictions and themes (e.g. vegetation and species records). The stakeholders included people from a range of different disciplines who use the terminologies, scale and conceptual frameworks of their own disciplines. For example, oceanographers, seagrass, and coral experts may deal with different scales and have different terminologies in their fields of expertise.

By the end of the workshop process, stakeholders had developed a mutual understanding of each other's fields and the value of collecting and sharing complementary data, thus contributing to the scientific understanding of habitats across disciplines. Through these workshops, there was a better awareness of knowledge gaps, thus opportunities for improving science and integration and information exchange with natural resource managers were identified.

It became apparent during development and implementation of the scheme that practical issues needed consideration such as data availability, systems for data management, how to apply classification and potential products and how different users would apply and interpret these.

Successive workshops built on the basic principles and underlying concepts of the classification scheme. For example, greater clarification was sought on what was meant by seascape scale, how the water column habitat would be addressed and whether information on human modifications of ecosystems would be captured. In particular, the water column classification panels highlighted the need to consider the mechanisms and concepts behind synthesising data over different timeframes and the four-dimensions of the water column. A strong conceptual and practical foundation for classification and mapping resulted from progressively addressing issues and resolving them with specialist advice.

The workshop series addressed four distinct focus areas, some of which required multiple workshops to resolve. The objectives for each focus area are listed in Table .

Table 2: Four focus areas addressed objectives which were to inform the structure and content of subsequent workshops

1. Benthic (sea floor) classification • Obtain mutual understanding and agreement on the scope, principles and structure of the classification scheme. • Consider components and processes of tidal and intertidal ecosystems at multiple scales. • Shortlist attributes for the classification scheme. • Identify categories to use for attributes. • Agree on the terminology of the classification scheme.
2. Geomorphology classification • Ensure geomorphic attributes and features able to be addressed by the classification scheme are appropriately characterised; and recognise processes which cannot be addressed by the scheme. • Enable consistency between classification of geomorphological features and the attribute-based classification system, where this is possible. • Enable '**cross-walking'** of geomorphological features between Queensland's intertidal and subtidal ecosystem classification scheme and other classification systems.
3. Water column classification • Ensure water column and oceanographic attributes are appropriately characterised in the scheme. • Consider appropriate dimensions for characterising the water column in space and time, with regard to its four-dimensional nature, including high temporal variability. • Enable consistency between classifications of the water column, water quality and the benthic attribute-based classification scheme. • Enable cross-walking of water column attributes between Queensland's intertidal and subtidal ecosystem classification scheme and other classification systems.
4. Typology and mapping • Development of draft intertidal and subtidal ecosystem typologies and mapping in south-east Queensland, Great Sandy/Wide Bay and Gladstone which address stakeholder needs using contemporary data sources. • Facilitate cross-walking of mapping attributes between Queensland's intertidal and subtidal ecosystem classification scheme and other classification systems.

2.3 Reference Panel and Peer Review

The project was overseen by a reference panel made up of representatives from:

- relevant divisions of the Department of Environment and Heritage Protection;
- other relevant Queensland Government departments (Agriculture and Fisheries; Science, Information Technology and Innovation; National Parks, Sport and Racing);
- Federal Government organisations including the CSIRO, Geoscience Australia, the Australian Institute of Marine Science, the Great Barrier Reef Marine Park Authority and the Department of the Environment; and
- the funding body, Gladstone Ports Corporation.

This panel's role was to provide governance, coordination and support strategic direction for the project. This included identifying complementary sub-projects, knowledge gaps and opportunities for integration. The panel reviewed the general direction of the project and provided valuable input at critical stages. In addition, a peer review was conducted by five external experts in intertidal and subtidal ecosystem classification. Comments have been incorporated into the revised documents.

3 Key concepts and principles of the Queensland intertidal and subtidal ecosystem classification scheme

3.0 Outline of concepts and principles

The following section provides details on the key principles and concepts that underpin the scheme and how these address issues raised during collaboration and consultation (Table 2).

The overarching principles include the following:

- Attribute-based classification provides a strong **integrating framework** for multiple disciplines e.g. ecology, oceanography, geomorphology, water quality and forms the basis for the classification scheme
- an attribute-based classification system can provide a **core knowledge base**, enabling the data collected by one group to be consistently used by others
- there is a **distinction between *attribute classification***, ***typology*** **and *mapping*** (see 3.1)
- there needs to be a **purpose** for attribute classification and the typology
- the attribute classification purpose should be **broad** to allow for multiple typologies and types to be generated from classified attributes
- the scheme **only deals with *components***, the processes and drivers are not generally part of the scheme (see 3.7)
- **estuarine and marine systems are actually typologies** made up of a number of attributes, as are geomorphological features—intertidal and subtidal ecosystem classification assists with the classification of these systems
- the process used to develop the scheme must be **transparent, documented with its confidence** explicitly defined (see 3.5, 3.9)
- **habitat condition is not dealt with** in the classification scheme but some attributes and qualifiers may be useful as an input to condition assessments (see 3.5)
- **data dimensions are reduced** (simplified) through data categorisation when implementing all stages of the scheme (attribute classification, typology and mapping) (see 3.6)

- as the attributes are the key feature which needs to be populated, the information used to populate the attribute is independent of the scheme and **not tied to any technology**.

Concepts include:

- **Benthic (seafloor**) **and water column classification are separate** but complementary parts of the scheme (see 3.3)
- **five scales (levels) apply** to the scheme (see 3.2)
- the **key terms of the scheme are defined** and described, with examples of their use:
  - attribute classification and typology – differences, purpose and use (see 3.1)
  - levels (scales) – use of five levels (see 3.2)
  - attributes – identifying, defining, selecting and discarding (see 3.4)
  - categories – nominating, defining, shortlisting, reviewing (see 3.4)
- during attribute classification, attributes can be classified into categories, **independent** of one another, but a typology must have a **hierarchy** in which rules for combination of the attributes are applied, based on the purpose of the typology
- **categories can exist in tiers,** enabling broad groupings or finer delineations at a level (see 3.4)
- **not all attributes and categories need to be applied** in attribute classification and typology
- **dataset assumptions, limitations and confidence** should be recognised and documented (see 3.5)
- **typologies** can be used to:
  - describe the nature of ecosystems in terms of their biophysical attributes (see 5.2)
  - apply decision rules using mapped attributes to define and delineate their extent (see 5.2.4)
- **spatial attributes** are applied to mapped components of the environment and are suitable for classifying geomorphological and other spatial features across different, nested levels and are available for a subsequent typology (see 3.4.1)
- mapping of ecosystems needs to recognise the **enduring nature of the attribute**—enduring attributes are considered more useful for mapping, the other attributes can be used as contextual information (see 3.4.2)
- some habitat types may exist but are **hard to map**, such as clines between water masses
- **morphology and bathymetry** are fundamental datasets to underpin benthic habitat mapping as they provide the core datasets to which other datasets relate
- **attribute qualifiers** add additional information including anthropogenic and temporal information (see 3.4.2)
- **repeated mapping of typologies can be used for assessing change and trend**. Strong persistence of an attribute or category may be due either to high resilience and/or capacity to adapt and/or low threat/variation in environmental condition.

3.1 Attribute Classification and typology

> ***Attribute classification** defines and categorises components of the environment into attributes and categories, and is not hierarchical within a level.*
>
> *A **typology** provides a **hierarchical** set of rules to apply to the attribute classification to identify types. Different typologies can be developed from the same attribute classification to fulfil different purposes. For example, a typology for managing coral reefs will use a different subset of attributes and combinations than a typology for identifying different types of landforms and substrates.*

Plants and animals are classified by grouping them (e.g. family, genus) according to shared characteristics. Generalisations may then be made across organisms and groups. A similar principle can be applied to ecosystems. There are many approaches to classification schemes, which vary both in structure and implementation, such as Delphic (expert-driven), statistical, self-organising, hierarchical, non-hierarchical and many more.

Classification involves simplifying complex, and sometimes continuous, data and information and converting these practical categories to make them more usable. When data and information are simplified, the detail is often lost (called dimension reduction), however, the ability to convey information is enhanced. These simplifications are used in everyday life. For example, while there are ranges of eye colours in humans we often refer to the colour of a person's eyes as brown, blue, grey etc. even though there is a continuum of colours.

Ecosystems can be similarly classified using measurable characteristics, variables or factors, referred to collectively as 'attributes'. The classification schemes mentioned in section 2.1 of Module 1 are all built on attribute-based classification principles. These classifications provide a set of biophysical (biological, physical and chemical) attributes for describing and defining ecosystem types. Examples of attributes include lithology, geology, substrate consolidation, water clarity, pH, and the presence and form of flora and fauna species (generally on the basis of the dominant species or species groups).

Biophysical attributes characterise intertidal and subtidal ecosystems, and together with their ecosystem processes, determine how they function as intertidal and subtidal ecosystems. Classifying intertidal and subtidal habitats ecosystems requires an understanding of which attributes (and their combinations) will shape, influence and maintain the habitats towards determining a recognisable ecosystem type.

Attribute classification provides definitions and categorisation of components of the environment, and their underlying **attributes,** and is the pre-cursor to a ***typology*** (see fig.2). The typology provides the rules to apply to attributes that group similar parts of an ecosystem into ***types*** for a particular purpose (AETG 2013). While attributes can be classified into categories, independent of one another, a typology must have a **hierarchy** in which the attributes are applied, based on the purpose of the typology.

An attribute-based classification scheme separates the classification of attributes (e.g. depth, sediment size) from the designation of types (i.e. combinations of attributes) for a particular purpose (e.g. habitats) (AETG 2013), and from the mapping of the attributes and types (see fig.2). Separating classifications, typologies and mapping provides structure while retaining the flexibility to adapt the system for multiple purposes.

This flexibility also enables the classification to deal with components of dynamic ecosystems and to incorporate relevant and readily obtained information so as to enable an understanding of their characteristics (e.g. incorporating relevant depths and leaf structure to understand potential distribution of deep water intermittent seagrass habitats versus shallow water more persistent seagrass habitats (Kilminster *et al.* 2015). Attribute-based classification provides an enhanced understanding of processes that cause change.

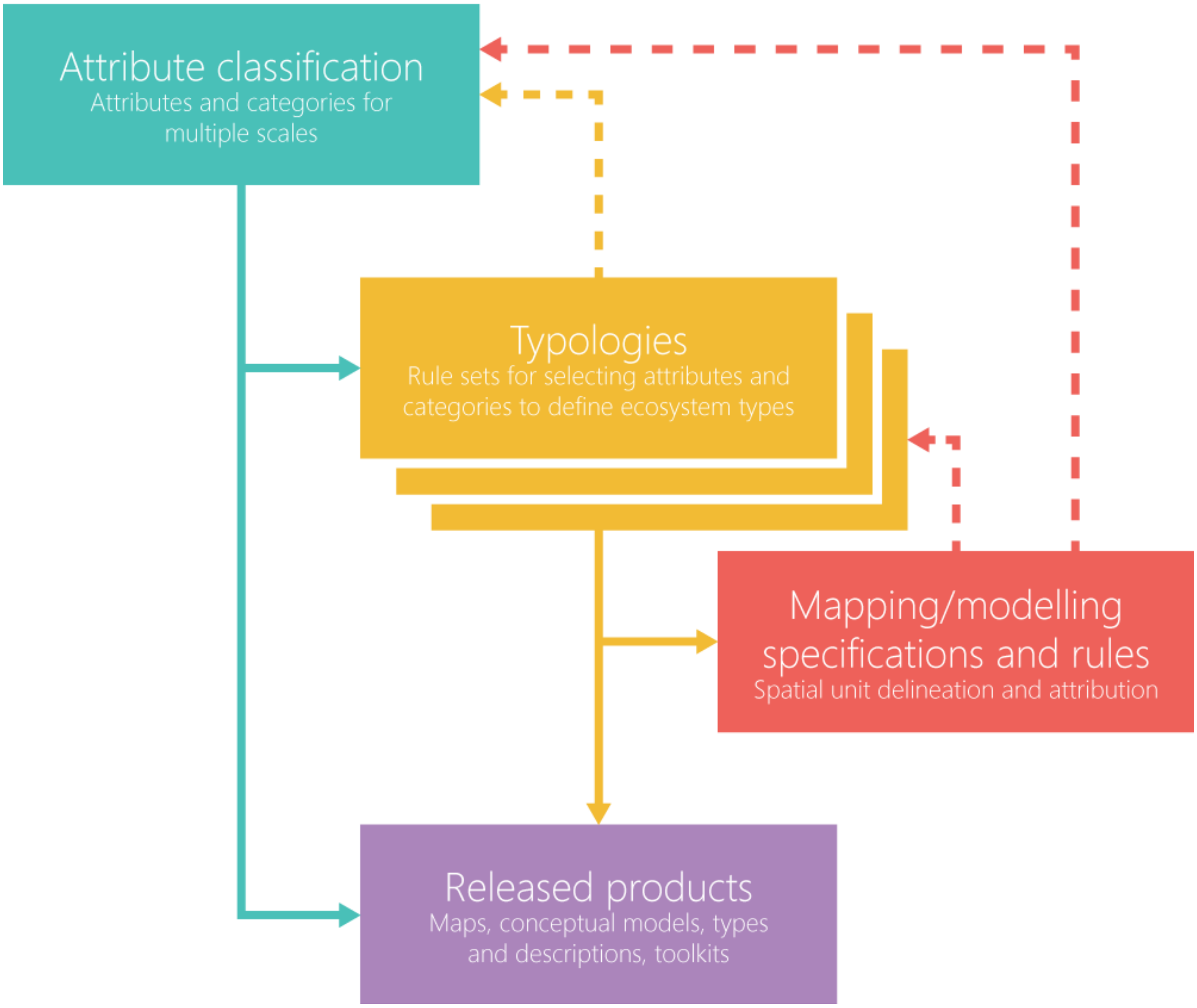


Figure 2: Relationships between attribute classification, typologies, mapping and products.

3.2 Levels (scale)

> ***Levels:*** *are the spatial hierarchy at which ecosystems occurs. The 'Queensland intertidal and subtidal ecosystem classification scheme' uses five levels of scale: region, subregion, seascape, habitat and community. The regional, seascape and habitat levels are compatible with the ANAE (national) classification.*

Attributes are applied to hierarchical, nested spatial scales called levels (see fig. 3). The scheme initially used the three hierarchical levels of the Australian National Aquatic Ecosystem, i.e. ANAE scales as per AETG (2012) that is, region, landscape (=seascape) and habitat.

However the consultation process identified an intermediate level was required between region and landscape, ‘subregion’, to better represent environmental complexity and to align with existing scales of marine management. This subregional level is compatible with the scale of bioregionalisation used by the Great Barrier Reef Marine Park Authority and the subregions of the Regional Ecosystems framework (Kerrigan *et al.* 2010; Sattler & Williams 1999). An additional fifth level of ‘community’ was subsequently added, to address the scale at which field inventory is conducted, and where people snorkel or dive, fish from boats etc. (see Done 1999; also compatible with CATAMI – Edwards *et al.* 2014).

Levels relate to **scale**, defined as ‘the parameter that describes the level of geographic resolution and extent, the context of space and time and helps define the positional accuracy’ (Quattrochi & Goodchild 1997). It is essential before any classification process to determine what the scale of the classification will be and this should be directly related to the purpose of the classification and the method of acquisition used to obtain the data used to conduct the classification.

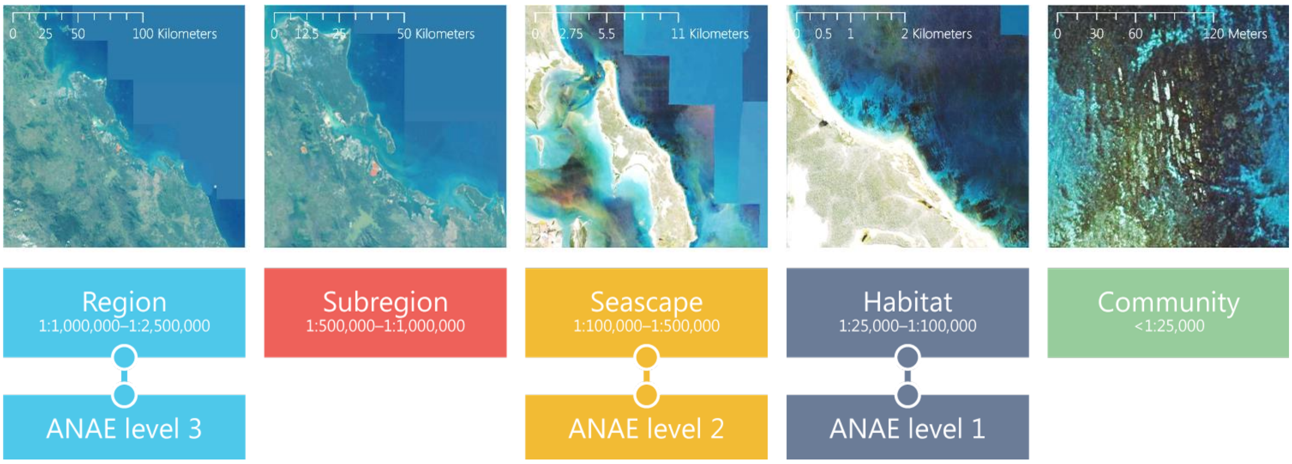


Figure 3: The Queensland Intertidal and Subtidal Ecosystem Classification scheme uses five scales (an additional two levels to the originally three adapted from the Australian National Aquatic Ecosystem classification scheme - AETG 2012).

When mapping attributes, each level corresponds to a given range of mapping scales and minimum mapping units (Table 3). For example, a subregion is mapped at scales between 1:500,000 and 1:1,000,000 with a recommended minimum mapping unit size of 25 hectares and width of 25 metres. As a guideline data used for classification and typology within a level should be at a scale compatible with its level (see inventory 3.5 and attribute mapping 5.3.2).

Table 3: Conceptual mapping scales and recommended minimum mapping unit for each level.

Level	Conceptual map scale	Recommended minimum mapping unit area / width
Region	1:1,000,000 – 1:2,500,000	400ha/1000m
Subregion	1:500,000–1:1,000,000	25ha/250m
Seascape	1:100,000–1:500,000	4ha/100m
Habitat	1:25,000–1:100,000	0.25ha/25m
Community	1:5,000 – 1:25,000	0.0025ha /2.5m

Attributes and their categories are related to spatial scales. Attributes may be related to one or more levels. Where an attribute is related to multiple levels then the categories of the attribute may vary between levels. The example of benthic depth (i.e. depth of the sea floor) shown in Table 4 demonstrates the use of different categories for different levels of the same attribute. In this case as the taxonomic resolution of the attribute decreases (from left to right in the table) the categories are grouped to a higher order category. Whilst this relationship of categories between levels is not mandatory it is advantageous as it allows higher resolution data to be easily reclassified for use at broader scales (higher levels).

Attributes used at multiple levels can be measured, thresholded and categorised independently from one another. For mapping, this means that different datasets may be used to map the same attribute at different scales.

Table 4: An example of different categories used for the same attribute (benthic depth) at each level.

<table>
<tr><th>Community</th><th>Habitat (m)</th><th>Seascape (m)</th><th>Subregion (m)</th><th>Region (m)</th></tr>
<tr><td>25cm divisions</td><td>0-1</td><td rowspan="5">0 -5</td><td rowspan="8">0 - 20</td><td rowspan="11">0m to 60m</td></tr>
<tr><td>25cm divisions</td><td>1-2</td></tr>
<tr><td>25cm divisions</td><td>2-3</td></tr>
<tr><td>50cm divisions</td><td>3-4</td></tr>
<tr><td>50cm divisions</td><td>4- 5</td></tr>
<tr><td>1m divisions</td><td>5 -10</td><td>5 - 10</td></tr>
<tr><td>1m divisions</td><td>10 - 15</td><td>10 - 15</td></tr>
<tr><td>1m divisions</td><td>15 - 20</td><td>15 - 20</td></tr>
<tr><td rowspan="2">.. Increment by 5m</td><td rowspan="2">.. Increment by 5 until 50</td><td>..Increment by 5 until 40</td><td>20 - 40</td></tr>
<tr><td>40 - 50</td><td rowspan="2">40 - 60</td></tr>
<tr><td>.. Increment by 5m</td><td>50 - 60</td><td>50 - 60</td></tr>
<tr><td rowspan="3">As for Habitat</td><td rowspan="3">...Increment by 10 until 200</td><td>60 - 100</td><td>60 - 100</td><td>60 - 100</td></tr>
<tr><td>100 - 150</td><td rowspan="2">100 - 200</td><td rowspan="2">100 - 200</td></tr>
<tr><td>150 - 200</td></tr>
<tr><td></td><td>200 - 220</td><td rowspan="2">200 - 300</td><td rowspan="2">200 - 300</td><td rowspan="3">200 - 500</td></tr>
<tr><td></td><td>... Increment by 20 until 300</td></tr>
<tr><td></td><td>300 - 400</td><td>300 - 500</td><td>300 - 500</td></tr>
<tr><td rowspan="2"></td><td rowspan="2">... Increment by 100 until 1000</td><td>500 - 700</td><td rowspan="2">500 - 1000</td><td rowspan="2">500 - 1000</td></tr>
<tr><td>700 - 1000</td></tr>
<tr><td></td><td>1000 - 1500</td><td>1000 - 1500</td><td>1000 - 1500</td><td>1000 - 1500</td></tr>
<tr><td></td><td>below 1500</td><td>below 1500</td><td>below 1500</td><td>below 1500</td></tr>
</table>

3.3 Separation of benthic (seafloor) and water column classifications

> *The Queensland Intertidal and Subtidal Ecosystem Classification Scheme recognises the need to separately classify the **water column** and the 'sea floor' (**benthic**) ecosystems, while acknowledging overlapping influences of each*

Through consultation and supported by the literature (e.g. Federal Geographic Data Committee 2012), the water column was identified as a system in its own right, possessing its own characteristics which influence, but are not solely dependent on, the drivers of benthic ecosystems. This led to the recognition of the importance of the water column as an ecosystem that needed to be classified separately from the sea floor (benthic) habitat, while acknowledging the influence of the water column on the benthos (fig. 4).

Although classification of the benthic and water column environments do share some similar attributes, there are sufficient differences (e.g. temporal variability, scale etc.) to separate them. There are some overlapping attributes, as the shape of the sea floor influences water column dynamics; and some water column attributes such as water clarity influence benthos.

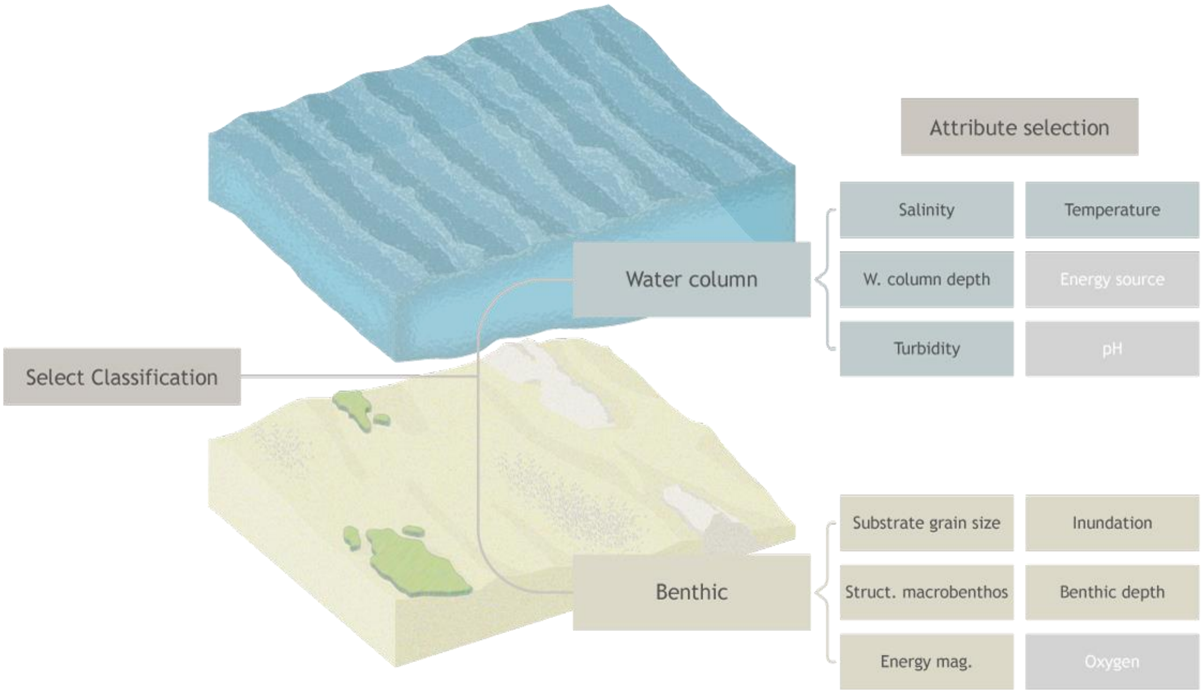


Figure 4: Benthic and water column ecosystems are classified using separate (but overlapping) attributes of the scheme. Overlapping water column attributes also influence the benthic classification and vice versa, especially close to the sea floor (grey boxes).

3.4 Terms of the Attribute Classification: *Themes, attributes, categories, tiers and metrics*

Terms of the Attribute classification *include:*

- ***Attribute themes*** *– broad groups used to describe attributes e.g. terrain, substrate, energy, hydrology (physical/chemical) and biota.*
- ***Attributes*** *are descriptive characteristics or features of aquatic ecosystems. An attribute may be a mathematical or statistical indicator, or characteristic used to describe characteristics of aquatic ecosystems in order to classify them (Aquatic Ecosystem Task Group 2012).*
- ***Categories*** *– A list of discrete values for an attribute, which provide for the complete domain of the attribute and are mutually exclusive.*
- ***Tiers*** *refer to the ecological resolution of a category depending on the resolution of ecological pattern at the relevant level and the extent to which it is delineated.*
- ***A Metric*** *is a specification for how an attribute will be measured. It may be binary ('yes' or 'no', 'present' or 'absent'), a ranking (high, medium, low), or a number (Aquatic Ecosystem Task Group 2012).*
- ***Threshold*** *is a 'cut-off' value that is applied to divide continuous metrics of an attribute into groups, creating discrete values for a category.*
- ***Inventory*** *involves the recording of standardised data about a taxonomic group, habitat or ecosystem from available data sources or through survey*

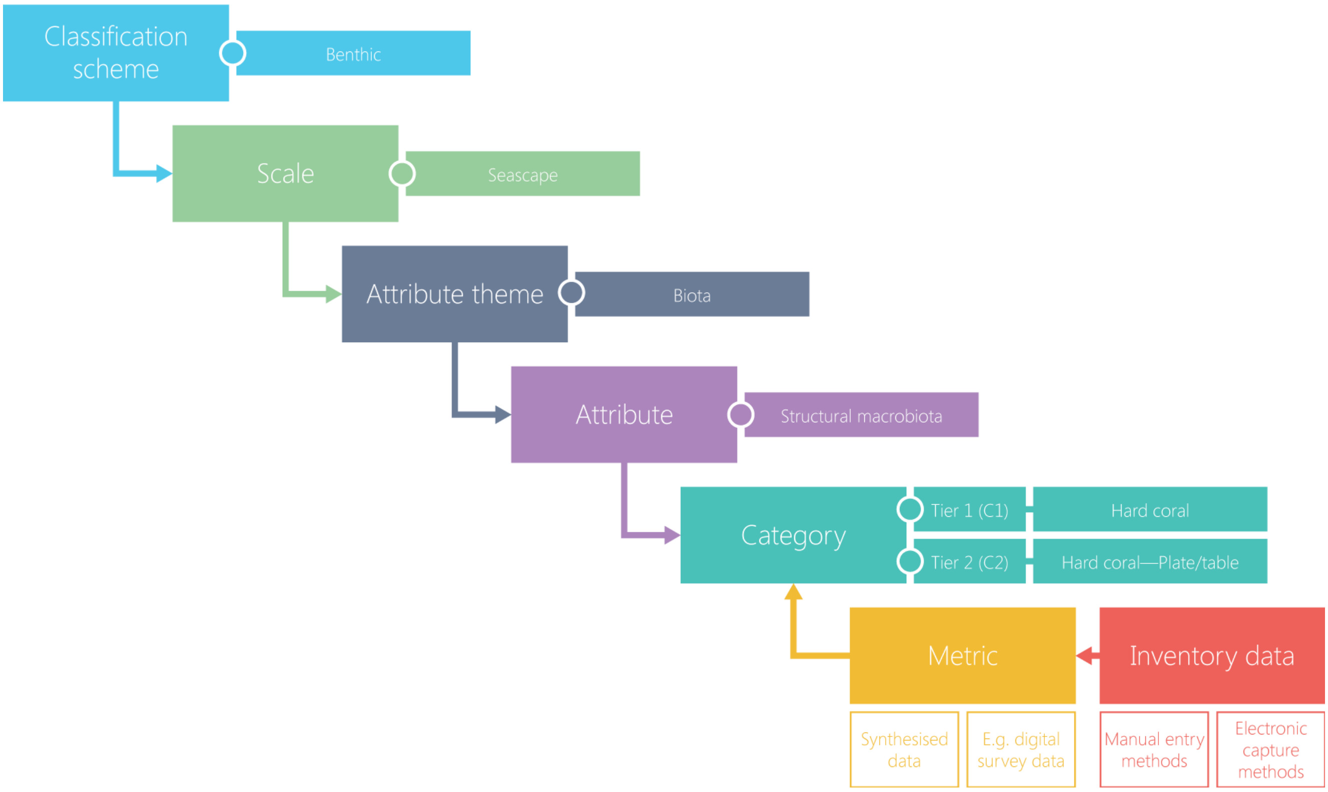


Figure 5: Structure of a benthic classification scheme and use of its terminology for the attribute of structural macrobiota. The tier 2 category selected in this case is 'plate coral', which fits hierarchically within the tier 1 category 'hard coral'.

Terms of the attribute classification are shown in Figure 5.

Attributes include measurable components of the environment that can be physical (e.g. tidal range, terrain slope), chemical (e.g. salinity, pH) or biotic (e.g. biotic cover, infauna). To organise and more broadly describe attributes, they are grouped into the attribute **themes**: e.g. terrain, substrate, energy, hydrology (physical/chemical) and biota.

The range of **categories** must provide for the complete domain of the attribute and should not overlap (they should be mutually exclusive). That is, a category must be available for any observed value (even if this is a category of 'other' or 'unknown').

Metrics can be continuous or categorical, qualitative or quantitative and are often informed by biological processes. In the case of continuous metrics the categories for a metric may be determined by applying **thresholds**. Where a category is made up of a number of number of parts this can be dealt with through the use of descriptors such as "contains" or through concatenation (i.e. joining with a separator '/' or '|'). For example a seagrass meadow type may represent a mixture of structural categories. Using concatenation, this becomes 'seagrass ovoid'|'strap-narrow'; or in a type descriptor, 'contains ovoid and / or narrow strap seagrasses'. For categorical metrics the values may be directly transferred to the appropriate categories or may be reclassified into relevant categories for the attribute. An attribute may utilise different metrics (based on available data) provided that it can be classified into the attribute categories in a consistent and comparable manner, however the assumptions and surrogate data used to derive the attributes and categories and the degree of confidence in these should be clearly documented.

Categories should be at a resolution appropriate to the **level** (or **scale,** see 3.2) to which the attribute is being applied and should be based on environmentally relevant thresholds where possible. Where the resolution of categories is decreased at higher levels, the categories should be derived from a grouping of categories at the lower level (see Appendix 6.3 Categories: Tiers and fig. 3). Categorisation can result in a loss of information but it summarises the data to a common standard to which typology can be applied (also see 'dimension reduction', section 3.6). For example, it is possible to classify certain water types based upon similar salinities, temperatures, depth in the water column etc. which enables a snapshot summarising complex three-dimensional attributes changing over time and at a particular scale, such as at a sub-regional level.

Categories may be further resolved into **tiers** – C1 master, C2 broad, C3 fine, C4 micro (see Appendix 6.3). How broadly or finely the category is resolved into tiers depends on how inventory was collected, the resolution of ecological pattern at the relevant level, and the need for the finer resolution**.** Applying tiers to categories enables a wide variety of available inventory data to be used, from broad to fine ecological and/or taxonomic resolution. In the attribute *structural macrobiota composition,* and within a category, ecological groups may be either split or grouped up based upon structural or taxonomic lines. Capturing categories of attributes in tiers enables grouping up of ecosystem types in the similar way to Broad Vegetation Groups of Queensland (Neldner *et al.* 2017). Tiers are relevant to certain **levels**, for example, a subregional typology may only require recognition of coral ecosystems, thus all categories are grouped up to 'coral'; while at the seascape scale it may be necessary to break these same ecosystems down into finer structural tiers, e.g. branching or massive hard corals; or Octocorallians (such as soft corals, sea fans). At the habitat scale it may be necessary to further distinguish between *Acropora* and other genera within these structural tiers. At the community level inventory schemas are directly relevant (e.g. CATAMI – Edwards *et al.* 2014; Althaus *et al.* 2015).

3.4.1 Spatial attributes

> ***Spatial attributes*** *describe the pattern of mapped attributes or types resulting from physical, chemical or biological processes. Spatial attributes address a defined ecological or geomorphological purpose across two or more levels (scales). Landscape ecology provides a suite of tools and metrics to map spatial attributes.*

Some attributes of the classification can only be applied to a mapped attribute or type. Once spatial pattern becomes apparent a further suite of attributes comes into play, which enables types to incorporate these various patterns. For a spatial attribute to be used to describe a pattern, often two or more spatial levels need to be investigated so that the pattern fits within a hierarchy of scales.

Geomorphology links formative processes to their resultant landforms (components), but the processes are difficult to map. However, the resultant components (i.e. their form, shape or morphology) and their patterns can be mapped and classified using a mixture of spatial and non-spatial attributes applied to the mapped features. Hydrological processes, through their interaction with topography, can transport sediment long distances, and sea floor morphology and topographic features also influence the water column (e.g. eddies, upwellings (Wolanski 2001; Steinberg 2007)), resulting in distinct areas or water types with a suite of similar water column attributes. Spatial attributes could be used to identify water types associated with distinct topographic features and attributes or to type estuaries.

When using spatial attributes, it is important to clearly define the ecological or geomorphological purpose including the scale or level(s), components or pattern of components that are being investigated, how they will 'nest' within those levels above, and the order that each spatial attribute will be applied.

Landscape ecology provides a suite of tools and metrics to map spatial attributes (see review by Lausch *et al.* 2015) including: "distance from"; "proportionate distance from"; "falls within"; "relative location"; "neighbourhood of"; "enclosure by"; "proportions of"; "relative proportions of". (See Appendix 6.5 for a list of spatial attributes and examples of their use).

If landscape tools and metrics are used to determine spatial attributes, the user needs to understand properties of the relevant metric. This is because autocorrelation may exist between certain metrics. Attributes may no longer be independent, or there may also be dependencies based on data resolution and study area extent, inventory scale, units and completeness (Kupfer 2012).

Spatial attributes are especially suitable for classifying geomorphological features, for example:

- **Coral reefs**. Some coral reef geomorphological typologies are based on spatial attributes of reef geomorphic zones (Hopley 1982; Hopley *et al.* 2007). Spatial attributes were applied on two levels by (Leon, Woodroffe 2013) to map and classify Torres Strait reefs into Hopley reef types, and by (Roelfsema *et al.* 2013) to classify coral reefs using a three level hierarchy - benthic communities to geomorphic zones to reef types.

- **The interim Waterhole classification for Queensland** (Department of Environment and Heritage Protection (DEHP) 2017) includes spatial attributes:
  - Spatial connectivity between waterhole and groundwater (type and direction of connection)
  - water source distance
  - proximity to any or similar waterhole
  - morphological dimensions (proportions of a feature)
  - erosional / depositional (typology of slope and repeated mapping of changes over time)**.**

3.4.2 Attributes and variability - qualifiers

Qualifiers *are descriptors of variability applied to an attribute. Several qualifiers have been identified: naturalness, trend, period, cover, biotic height and biomass. These qualifiers are not standalone attributes but should be implemented, where appropriate, by adding additional information to the categories of existing attributes.*

In relative terms and for mapping purposes, attributes can be considered as either **enduring** or **non-enduring** (Valesini *et al.* 2010). Enduring attributes are relatively more persistent over time (e.g. bedrock) and less mobile. Non-enduring attributes are more variable over time in terms of their persistence, duration and/or periodicity (e.g. seagrass meadows, mobile sand dunes). Enduring attributes are easier to map as they are unlikely to change during the mapping period. Whether an attribute is considered enduring or not for a particular application will depend upon the timeframe and scale at which the classification is applied and the purpose of the classification.

Attribute qualifiers provide extra information on the category of an attribute and are similar to modifiers in other classification schemes (Environmental Protection Agency 2005, Cowardin *et al.* 1979).
Changes in ecosystems may represent natural variations while at other times a change may constitute a shift in the state or type for an ecosystem (Done 1999). In classifying and mapping, consideration must be given to how the natural variability influences ecosystem structure and functionality of ecosystem processes and what can be used meaningfully in mapping. If possible the nature of these changes and their influence upon an attribute should be captured.

Dynamic processes such as erosion and accretion are important for shaping geomorphic features. Depending on the dynamics of the system, all habitats might not necessarily be able to be mapped. Geomorphological features resulting from erosion and accretion may either be mapped repetitively to show changes or spatial and non-spatial attributes and mapped type features can be applied in a typology to captures erosional or depositional surfaces.

These qualifiers are not standalone attributes but should be implemented, where appropriate, through adding information to the categories of existing attributes. For example, the ‘naturalness’ attribute qualifier describes the extent of human-induced change and for the attribute sediment size an area may have been classified as 'sand'. If this was the result of deposition from dredging activity, a category of 'modified natural’ or ‘artificial' could be assigned to the naturalness attribute modifier. In this way, the inherent category of the attribute does not change from 'sand' but the additional information may be used to interpret values or to classify components differently, which may be necessary for management purposes.

Naturalness
Considers the integrity of a component and the degree of anthropogenic influence. For example, two habitats might be characterised as 'mud' for the attribute 'sediment size' but one may be natural and one may be artificial (e.g. derived from dredge spoil). They may function in a similar fashion but for management or reporting purposes it may be necessary to characterise them differently.

In addition to the 'naturalness' of an attribute, qualifiers are also used to denote the variability of attributes and categories over time. Two qualifiers are available to describe temporal change. The 'trend' qualifier provides information on the nature of the variability of a component over time (e.g. constant, fluctuating, cyclic, and increasing, etc.). The 'period' attribute qualifier related to the period of time over which this variability is observed. For example, the attribute sea surface temperature may be observed to increase and decrease with seasons (cyclical variation over annual periods) but may also be observed to be increasing over longer periods (decadal). Both variations may be included in the data as attribute qualifiers.

Trend
Provides information on the persistence and variability of an attribute over time. Providing a summary of time-series information (e.g. average, maximum, percent exceedance) results in a loss of information about how systems are functioning. The trend modifier provides context on the observed trends in cycles and persistence for the period of data considered. This may be observed from data or sourced from experts who have observed and understand the processes functioning.

Period
The period qualifier can provide additional detail on the period over which temporal variation is considered e.g. Cyclic tidal or Fluctuates annually. Multiple qualifiers can be used e.g. to indicate a decadal increasing trend with seasonal cycles.

The qualifiers of cover, biotic height and biomass provide additional detail on the relative composition of categories. This is critically important where either attributes or categories are not mutually exclusive. This is often the case for such attributes as sediment grain size or structural macrobiota composition where components like boulders and pebbles or coral and algae may be present together in a habitat. These qualifiers can be used to determine the dominant category or whether a category will be used in a typology. Note: if a category is not used in the typology it may still be used to describe a habitat.

Cover
In mapping, the attribute qualifier 'cover' applies to mixed mapping units where more than one category is found within a mapping unit. In this instance, both Regional Ecosystems and Wetlands mapping methods apply the process of concatenation, that is, values are linked together in a chain or series (Neldner *et al.* 2012); (Environmental Protection Agency 2005). For example, the 'structural macrobiota' attribute categories of hard coral and soft coral may be both present in a mapping unit in proportions of 50% and 20%. The 'category' value would become concatenated as follows: 'Hard coral | Soft coral' (using '|'as a separator). Corresponding concatenation of the 'cover' field would be '50 | 20'. (Note that the total structural macrobiota cover may not add up to 100%, as non-living substrate such as sand may be present in the mapping unit).

Biotic height

Provides additional information about the height of structural macrobiota composition. Each broad category of structural macrobiota (tier C1) has its own height range – for example the height range of mangroves (metres) is not comparable with that of seagrasses (centimetres to millimetres).

Biomass is available where appropriate to characterise particular ecosystems where more information is required than height and cover to capture ecosystems (e.g. seagrasses where rhizome mass below the surface is a significant part of the ecosystem).

Appendix 6.4 lists qualifiers and their values.

3.5 Inventory information and data accuracy

> ***Inventory i****nvolves the recording of standardised data about ecosystems. Inventory data may be generated from available data sources (e.g. tenure, climate, population, land use) or collected through surveys (e.g. flora, fauna, water quality) involving the use of equipment and specialised field techniques.*
>
> *Inventory data may contribute to mapping and classification of the attributes, and inform their accuracy. By aligning to attributes and categories of the scheme, inventory can be better incorporated into classification, typology and mapping.*

Inventory can be undertaken for many reasons and can involve both field and remote sensing approaches. These data form the basis for all further classification, typologies, mapping and assessments – refer to fig.6. Attribute data consists of compilations of available inventory datasets that are '**cross-walked'** to the attribute schema (i.e. translated to the categories of the scheme), sorted by their confidence and scale, and allocated to qualifiers where necessary.

Examples of inventory include satellite imagery analysis and interpretation and /or field survey, modelling and interpolation based on field datasets etc. Inventory schema and Standard Operating Procedures (SOPs) can directly use the categories of the attribute schema, by incorporating them into SOPs to provide standard methods for data collection. In an Inventory project involving field investigation of intertidal seagrass distribution, the attribute schema qualifiers apply standard percentage cover intervals and biomass types that can be translated across different seagrass inventory projects, enabling seamless incorporation of attribute data.

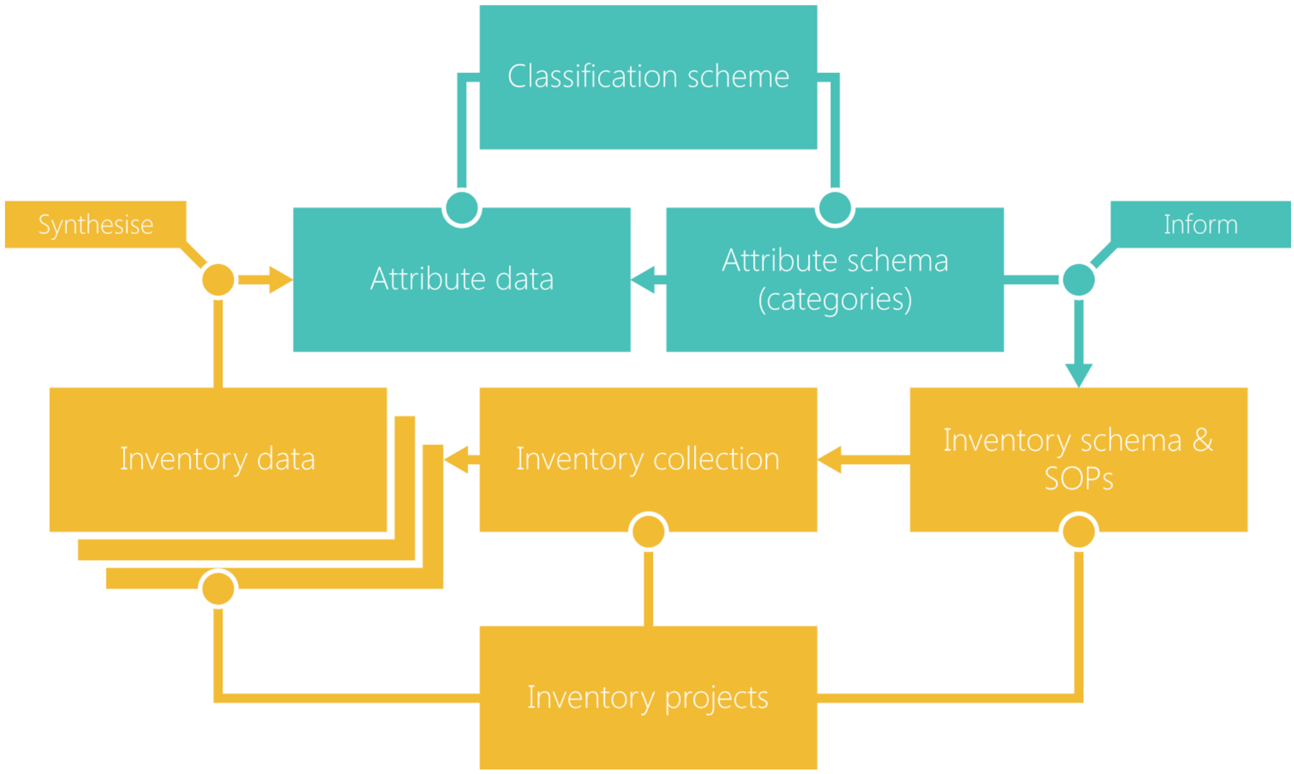


Figure 6: The collection of inventory data can be informed by attributes and categories within a classification scheme. Attribute data is compiled / synthesised based upon available **inventory data**, by cross-walking it based on the **attribute schema** (categories of the attribute within the Scheme).

An inventory may contribute to the mapping and the classification of the attributes directly or through modelling. For example, species records may be used to inform the mapping of the 'structural macrobiota' attribute or sediment records to inform modelling of the 'sediment grain size' attribute. Inventory schemas developed independently from the attribute schema may need an intermediate step to translate or cross-walk them across to the attribute schema categories within attribute datasets.

Inventory information may be used as supplementary information for descriptions of ecosystems. Examples include a list of species or typical assemblages observed to use habitat at a site or a broader summary of species usually observed to use this habitat.

Inventory information may also be used to assess the accuracy of a typology to determine whether the resulting types differentiate ecosystems as expected. If the inventory differs from what is mapped, the typology rules or the attribute datasets themselves may need to be modified. Once ecosystem types are mapped, additional inventory may target poorly known areas or poorly known attributes, identified as knowledge gaps. This inventory will provide more accuracy to the classification and mapped products.

Surrogate datasets are often used to infer where attributes and categories are present as it is not always possible to collect detailed field data. These surrogate datasets have a range of confidences, for example remote sensing methods can use field validation points to estimate overall accuracy for each class and this will be influenced by how many classes are in the map (Congalton 1991).

Confidence that inventory information has been applied correctly is influenced by many factors, usually listed in the metadata or methods section of the inventory project. The accuracy of inventory datasets needs to be evaluated and recorded when incorporated into the attribute dataset, with special consideration being given to its compatibility with the level (scale). This may affect confidence in a particular attribute and the final product, including its suitability for a particular level.

Mapping intensity is the number of field observations per hectares or is used to allocate an appropriate map scale and is essential to incorporate into confidence (see McKenzie *et al.* 2008). There are several different ways of recording confidence and accuracy and issues which need to be considered including

- **Spatial accuracy:** Spatial sampling methods determine how representative sampling will be to capture ecosystem extent. Where a particular field point sighting is situated will depend on the field method used (e.g. continuous, point, intercept), and how the location was captured, including whether sourced from another map. For example a trawl shot occupies several hundred metres, videos may be continuous, but stills from the video only sampled every 10m. GPS methods differ.
- **Attribute accuracy:** How accurately the attribute is identified and described will depend on the surveyor's expertise, the field method available or the interpretation of inventory data from remote sensing approaches. Field standards (or standard operating procedures – SOP's) are important to establish, and potentially attribute classification can help 'translate' field standards into useful attribute data.
- **Expert confidence in a model:** Using multiple lines of evidence and supported by attribute datasets, experts who understand interactions between attributes can use these datasets to model ecosystems and confidence in the resultant map. Gaps in knowledge may also be addressed by expert opinion where field data is absent. For example in groundwater dependent ecosystem mapping, rule-sets with field validation receive a high confidence while data determined by expert opinion only receive a low confidence (Glanville *et al.* 2016; Department of Science, Information Technology and Innovation, 2015).

Targeted inventory conducted for a particular purpose (such as seagrass monitoring or mapping) may incidentally collect additional data about other attributes or categories (such as sediment grain size and benthic macrobiota taxa). Inventory is generally expensive and resource intensive and the collection of multiple attributes and metrics when in the field provides better value for money. Collecting this additional information could inform ecosystem models and value or condition assessments.

The existence of a consistent attribute classification scheme can guide the collection of consistent data during inventory exercises (see fig. 6). The scheme's attributes and categories can be used as a base to better target field inventory to collect meaningful and useful data that can be easily translated into ecosystem attributes and types. This also facilitates better collaborative survey design, sharing and the standardizing of inventory methods to benefit many different users.

3.6 Simplification, dimension reduction and generalisation

*Classification **simplifies** the natural variability of ecosystems in several ways:*

- *During field **inventory** data collection*
- *Cross-walking inventory into **attributes, categories** and **levels** (scales)*
- *Applying **typology** rules to selected attributes to define a type*
- *Applying **qualifiers** to describe patterns of change*
- *During data assembly and GIS processes involved in mapping (generalisation)*

Classification of ecosystems simplifies their inherent variability in space and time and incurs dimension reduction.

Simplification may have already occurred during collection of inventory datasets and is also introduced through several stages of the classification process. The use of attributes, categories and levels (scales) is the foremost of these. Other stages of the classification implementation that simplify data are typology and mapping (including GIS operations).

The process of applying a typology to an attribute classification will simplify information by using rules to combine a selection of the available attributes to define types. A type is not expected to represent the totality of all the components and their variation. Rather, a typology draws on selected attributes for a specific purpose to organise and classify the environment into relevant types.

Dimension reduction occurs when datasets representing attributes that are continuous in space and time are represented in fewer dimensions. For example, dimension reduction occurs when:

- four-dimensional water column datasets are summarised into two dimensions ('time-slices', 'depth slices' or both)
- the extent of a biotic community (e.g. seagrass meadows) varies over time series and is compiled to represent the total extent of seagrass over the entire period. Applying temporal and cover qualifiers allows for the likelihood of the seagrass to be present.
- Data is in the process of assembly, resulting in abstraction, reduction and simplification of map scale and / or data points such as:
    - when cross-mapping source datasets to the classification attributes to ensure compatibility of different scales and methods of capturing data;
    - if re-sampling or interpolating the data to suit the categories and level; or
    - when resolving common boundaries of attributes and/or habitat type units.

All of these simplification processes, as well as the mapping process itself, may result in 'generalisation'. This GIS term involves a specific spatial kind of simplification, and is defined as the abstraction, reduction and simplification of features to accommodate change of scale or resolution (ESRI Support 2017). Other processes which can incur generalisation include the representation of attributes and types as maps and conceptual (or other) models.

Throughout the stages of classification, all information from the attribute classification should be retained in the final products if possible, retaining the ability to link back to the source datasets. The advantages gained by linking back to the attributes and source data are to provide a check against over-simplification and an information rich end product is available to provide contextual information and additional attributes beyond the classification of a type.

3.7 Components, processes and drivers

*The Scheme classifies **ecosystem components (**physical, chemical and biological parts, including spatial attributes). Ecosystem **processes** and **drivers** are generally better captured by models and are unsuitable for attribute classification.*

The scheme mainly deals with components or parts of an ecosystem (the physical, chemical and biological parts that make up the environment) and spatial attributes. Processes involve interactions between the components, and drivers are the reasons these interactions occur (AETG 2012, Wetlands 2013a). Processes or drivers are generally not appropriate for attribute classification and are better captured in models (such as hydrodynamic or conceptual models) or dealt with in other ways. In most cases the components are the result of the interaction of processes and drivers and other components. Ecosystems are the components which are able to be captured spatially or mapped through the interaction of certain components.

3.8 Mapping, feedback and improvement

***Mapping** of ecosystem attributes and types highlights key features of a classification and typology, providing feedback on its effectiveness.*
Depending upon the purpose of the application, it is possible to map the attributes alone, or combinations of the attributes in types.
***Inclusion of all attributes** enables experts to understand the underlying patterns that determine habitat types. Attributes can be used to group up or split out types for multiple typology purposes.*

Mapping of ecosystem attributes and types provided a visual reference for further consultation and feedback on the classification scheme, including the typology stage and some of the decision processes in this stage. Mapping results highlight the key features of the attribute based classification scheme by demonstrating the flexibility of typology rules and the information rich attributes within the data.

Inclusion of as much attribute information as possible provides the potential for re-examination with the option to either split out additional ecosystems, or amalgamate ecosystems for a specific purpose. Examples include:

- where a mapped typology shows insufficient resolution within a given type and experts agree there is a need to modify or split certain classified types based upon an attribute category;
- for a specific purpose and typology requiring a different scale of resolution, such as a typology for seagrasses only (splitting types based upon attributes), or a typology for broad scale marine park planning (grouping types based upon attributes with similar management requirements) .

As a generalised concept of an ecosystem, a map or conceptual model needs to have scope for continuous improvement and be represented in a variety of formats to communicate how an ecosystem works. Scope for inclusion of three-dimensional features to account for sea floor shape needs to be incorporated into attribute mapping. Linear features condense three or four dimensions into one to represent narrow elongated or steeply sloping features such as rivers, stream banks, intertidal rocky shores and subtidal coffee rock ledges (e.g. Environmental Protection Agency 2005; Sharples *et al.* 2009; Banks & Skilleter 2007). The topography or bathymetry of the sea floor may be presented as hillshades - displayed with the classified mapped features to represent the terrain of the features.

Other forms of representation (e.g. animated models, videos etc.) may display these components more accurately. In particular, water column ecosystem attributes and processes may be more easily explained by three and four-dimensional models illustrating change over time.

A key finding was that each time an additional attribute or category was added in a typology, the number of combinations of types significantly increased. Whilst desirable to include many attributes and categories within a habitat type, during the typology procedure it was necessary to continually check on whether further types were necessary – either by amalgamating very similar types (see S5.4 reclassification) or omitting 'impossible' types. The mapping procedure also refines the typology as the lack of data or the nature of the data sometimes precludes the development of some types, makes some others redundant, or reveals as yet unknown habitat types through unforeseen and unique attribute combinations.

All stages of the classification scheme allow for continuous improvement, and in general the whole scheme should be reviewed during implementation to ensure new data and methods and concepts are incorporated.

3.9 Transparency and documentation

The Scheme was developed through a transparent process involving documentation of relevant research guiding classification, workshop consultation incorporating participant feedback, fostering continuous improvement of elements of the Scheme during typology and mapping applications and confidence specifications

Transparency is critical to the development of any classification scheme as the ability to openly demonstrate the procedure used to derive classification, typologies and mapping increases acceptance of the final product. Transparency can be addressed in a number of ways:

- documenting the incorporation of research into the classification schemes and techniques
- documenting workshop consultation and outcomes, providing these to attendees and incorporating comments
- identifying potential issues and recommendations for the development of this scheme
- providing guidance on how to use the classification scheme
- capturing and refining successive typologies, attributes and mapping through versioning; and maintaining standard procedures, templates and mapping techniques
- providing information on the accuracy and confidence of the mapping

Documenting these issues will ensure that users can understand the implications and limitations of the classification and its outputs. In addition, clearly documenting issues and components that have *not* been incorporated or require further work provides a strong foundation for ongoing improvement in the classification scheme.

4 The 'Queensland intertidal and subtidal ecosystem classification scheme' in summary

The Queensland intertidal and subtidal ecosystem classification scheme provides a structured system for classifying intertidal and subtidal ecosystems.

The Scheme was developed through expert workshops involving policy makers and scientists from state, local and federal government bodies and universities, with individuals from a wide range of disciplines. It is effectively a synthesis of concepts and ideas that are currently being applied to specific areas and datasets with a narrower scope.

What distinguishes this scheme from many others is its applicability to a range of management issues and that it covers all intertidal and subtidal ecosystems at all scales in Queensland. Generally other research and management fields have developed methods and terminology specific to their disciplines, and though they may share commonalities, they are rarely completely compatible and individually do not cover the depth and breadth of this scheme.

In summary the scheme:

- provides a **transparent method** for classifying intertidal and subtidal ecosystems and developing types based on a clear rule based system
- adapts and extends the **ANAE framework** (AETG 2012) and Queensland's attribute-based classification and typology for freshwater ecosystems (Environmental Protection Agency 2005) and applies it to intertidal and subtidal ecosystems.
- as far as practicable, integrates with and complements other state and national mapping, datasets and classification schemes and allows for the **cross-walking of existing systems** to this scheme
- forms the basis for future mapping programs which will then be the **'point-of truth'** and the common data for managers, researchers and other stakeholders
- provides a **consistent platform** for **policy and planning** decisions, including offsets
- provides the basis for future **monitoring and assessment** programs
- incorporates existing data and knowledge into a **common framework** for classification, data capture, storage and retrieval, mapping and monitoring
- uses an approach that is **consistent, measurable, transparent, repeatable and flexible**
- allows for future **updates** and revisions as new information becomes available
- provides **consistent language and terminology** across the state and a consistent framework which can reduce overlap
- can be used to prioritise activities and **research to fill knowledge gaps**.

Part 2: Applying the 'Interim Queensland intertidal and subtidal ecosystem classification scheme' (scheme)

The following section outlines a generalised process and the stages and steps involved in applying the 'Queensland intertidal and subtidal ecosystem classification scheme'.

The four stages of the scheme were introduced in Part 1 s 3.1 (see fig. 2). Part 2 focusses on applying the scheme, where each of these stages are broken down into steps. Classification and typology stages are detailed to enable the user to apply them using the attributes and qualifiers available in Appendices (see 6.1 - 6.5). Mapping is briefly described to provide context for previous stages and steps.

The stages and their steps (shown in fig. 7) are:

- Stage 1 Classification
  - Step 1.1 —define the purpose, scale and outputs
  - Step 1.2—assemble the attributes (including categories, thresholds and qualifiers)
- Stage 2 Typology
  - Step 2.1 —define the purpose
  - Step 2.2 — shortlist attributes and categories and collapse / group categories
  - Step 2.3— define the attribute hierarchy
  - Step 2.4— define and run rule-sets (for combining attributes and categories
  - Step 2.5— review and refine typology (reclassification)
  - Step 2.6 — name types (based upon attributes)
- Stage 3 Mapping
  - Step 3.1 – align mapping purpose with classification and typology
  - Step 3.2 – map attributes (cross-walking inventory data into classification categories)
  - Step 3.3– map types (implementing typology rule-sets for combining attributes)
  - Step 3.4– review and refine mapping (progressively apply reclassification of typology)
- Stage 4 Product release
  - Step 4.1–release mapping and supporting products for consultation
  - Step 4.2–review feedback and release products

Not all steps need to be followed in applying the scheme, as there are potential products which can be generated at each stage (fig. 7). Also, while outlined as a series of steps, in reality several of the following steps can be combined and there is continuous feedback between different steps. Going through the stages can be an iterative process where each iteration of the mapping and typology is allocated a version number. For example, the development of mapping outputs may raise issues with some of the assumptions made at the attribute classification or typology stages and these may need to be revisited and documented.

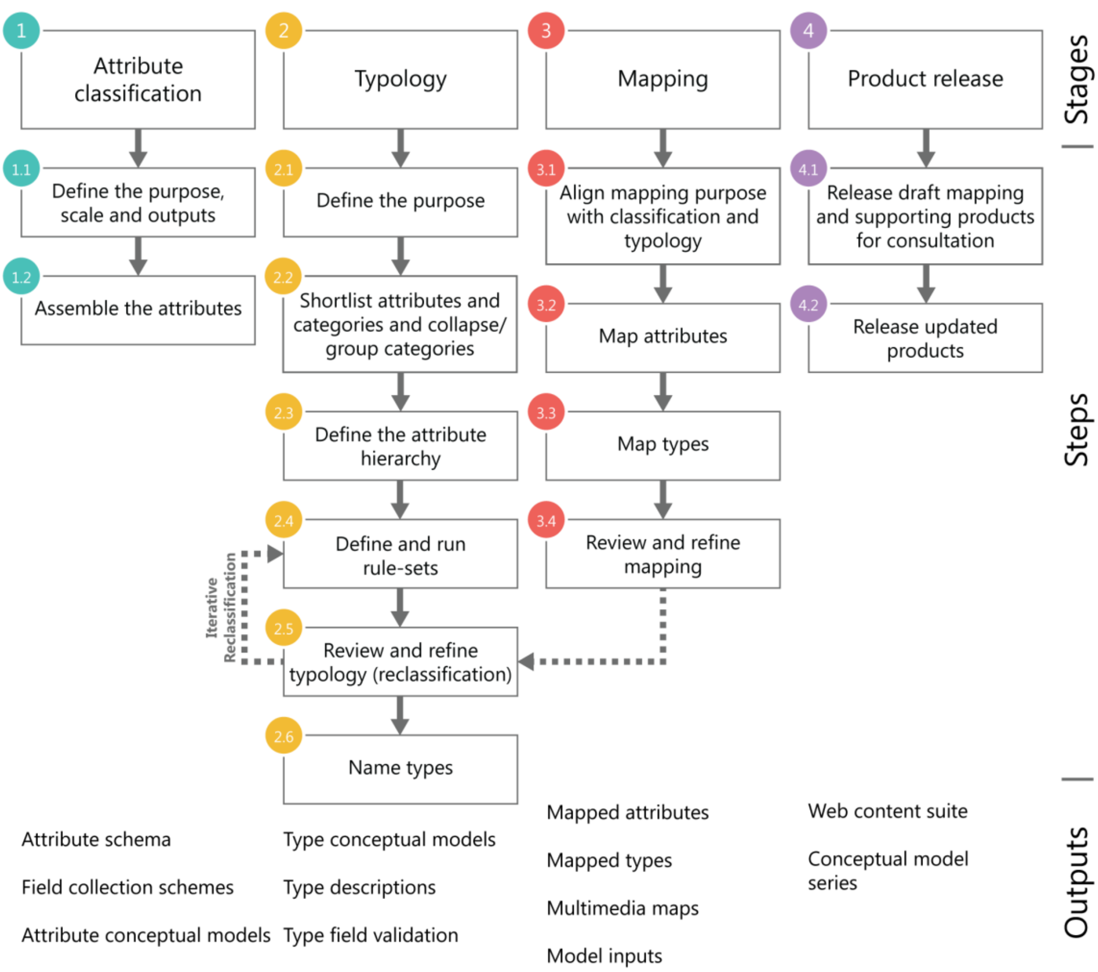


Figure 7: Stages and steps of a typology classification.

5.1 Stage 1 – Attribute Classification

During attribute classification the biological, physical and chemical attributes that determine the nature and extent of the ecosystems in question are assembled, evaluated and prioritised for a particular purpose.

5.1.1 Step 1.1— Define purpose, scale and outputs

The first step of any classification process is to determine the purpose of the classification and the outputs sought, as this will affect all subsequent steps. The purpose of the classification may be directed by a plan, strategy, research, funding, or legislation (e.g. for Ramsar information sheets - DEWHA 2008; for fish habitat under the Fisheries Act 1994 etc.). As part of the "purpose" step, the application must consider whether a **benthic or water column** classification (see section 3.3) is required and what **level** (scale - see 3.2) to which the application will apply.

Nevertheless, the **broadest possible scope for multiple purposes** should drive the attribute classification as its outputs can then be applied to many different typologies. For example one could categorise all existing inventory information in a region into the attributes, themes, categories and qualifiers and make this data and information available as a consolidated knowledge platform to stakeholders.

Conversely, attribute classification can be quite specific, for example:

- categorising limited attributes to create a typology for mapping of representative habitat in a marine park zoning plan
- classification and typology for seagrass to enable change in extent of different habitat types to be detected over time
- state-wide representative habitat typology for intertidal habitats at a habitat scale for use in offset policies
- habitat typology which might assist in the prediction of species associations.

A **collaborative process** involving multiple stakeholders and participative workshops is recommended. This will expose a broad range of people to the process and provide validation for any outputs.

The **final product** of attribute classification should also inform the purpose. Depending on the purpose, it may be determined that outputs of attribute classification suffice (see fig.7). Usually after attribute classification is completed the application proceeds to typology (stage 2), mapping (stage 3) and release (stage 4). For example, if a mapping product is required, it will be necessary to begin the compilation of the core inventory datasets as soon as possible as mapped attributes can inform attribute classification. This can be slightly problematic without the prior selection of attributes and categories, as data may be collected which does not later correspond to the scheme. The storage and indexing of these data also needs to be considered and can constitute a significant work load with resource implications. Outputs of attribute mapping (see 5.3.2 step 3.2) can be a useful companion product to accompany an attribute classification.

5.1.2 Step 1.2—Selection and documentation of attributes, categories, thresholds and qualifiers.

Once the purpose, outputs, level (scale) and nature of the classification scheme (water column, benthic) has been defined, the next step is to determine which attributes, categories, thresholds and qualifiers to use. The attribute classification step should use the scale, attribute themes, categories, metrics and qualifiers developed through the 'Queensland intertidal and subtidal ecosystem classification scheme' in appendices 6.1 and 6.2.

Most classification processes involve **facilitated workshops** with relevant experts from a range of disciplines. **Candidate attributes** are chosen which best respond and relate to the purpose, although these may be refined in future steps. The relevant categories within these attributes are then determined. Sometimes some categories are combined (referred to as '**collapsing down'**), to ensure that only those which are relevant for the purpose and have the underpinning ecological basis, are used (see fig. 8 in s5.2.2). The original categories should be retained in a list but are not used for the classification. Statistical analysis of datasets can also inform this step as some categories will become evident from this process. For many processes this step will also be influenced by the following steps, the availability of data and the final outputs.

This process should also consider the use of **attribute qualifiers** as an additional information source about the attributes. For example the attribute, 'sediment size' may be assigned the attribute qualifiers 'naturalness', 'period' and 'trend', or 'cover'. If a site was classified as 'sand' for the attribute 'sediment size' and its naturalness qualifier is classified as 'artificial' (e.g. derived from dredge spoil) then this is within the context of the 'sediment size' attribute and does not necessarily apply to the naturalness of attributes reflecting ecosystem water chemistry, vegetation etc.

This step should identify all of the relevant attributes and categories and not be constrained by known data sources. Sometimes an attribute is important but technology may not yet be available or data is not yet available to populate the mapped attribute. In many cases **surrogate datasets** can be used to populate classification schemes. Hasty elimination of ecologically relevant attributes or categories too soon in the process should be avoided as appropriate metrics, technology or data may subsequently become available.

All of the decisions on why attributes were chosen and the categories, thresholds and metrics used should be **documented and relevant tables** developed. The table and documentation should be provided to participants to clarify conceptual underpinning and logic.

A number of **future steps** are possible after this attribute classification stage. Stakeholders may want to use the attribute classification to consolidate disparate datasets, to spatially populate the classification system. The attribute classification can be used to identify knowledge gaps and allow stakeholders to seek funding to undertake work to fill these gaps. In most cases the steps associated with a typology are undertaken and further used for mapping purposes.

5.2 Stage 2 - Typology

The steps of the typology stage (fig. 7 and section 5.2.1–5.2.5) provide a process for applying the attribute classification, through the use of **rule-sets to define types**, linked to a clear purpose. Most typologies are developed through facilitated workshops with relevant experts from a range of disciplines and management and in combination with step 2 (attribute classification).

Typologies may be combined from a number of levels (scales). That is, having produced a typology at the 'region' level, it is possible to create multiple typologies at the next level down the scale, (i.e. subregion, seascape, habitat etc.) which can be applied to specific region types. Typologies at the region and sub-region level operate above the seascape level ecosystems, and their broad level attributes are relevant to and determine broad biophysical patterns of ecosystems at the seascape level. For example, a seascape level ecosystem 'shallow seagrass' from Torres Strait differs from that of South East Queensland. At the subregion level, both areas differ greatly in their water temperature, periodicity and volume of freshwater, and water source. For example, Torres Strait is a strongly monsoonal subregion with the Hiri current influence whereas South East Queensland is seasonal with the East Australian Current seasonal influence.

5.2.1 Step 2.1—Define the purpose

Unlike the attribute classification purpose, which should be broad enough to accommodate multiple typologies, the purpose for a typology needs to be **very specific and clearly defined**. Plans, policies, programs and projects referred to in s5.1.1 constrain the scope for typology i.e. confining the number of types and subsequently potential attributes and categories. By clearly defining the purpose future steps are easier to implement as stakeholder expectations are incorporated. For developing the purpose, scope and scale of the typology, selection of attributes should be a **subset** of those within the attribute classification. During this step, the purpose needs to determine the **level** of the typology. Generally, a typology uses attributes from the same level but it is also possible to include attributes from different levels as described in 5.2.

Different typologies can be applied to the same attribute classification to fulfil different purposes and for this reason the scope of the classification should be broader than for any single typology purpose. A typology does not need to use all of the available attributes from the attribute classification stage. For example, a geomorphic typology might use the attributes of terrain morphology, benthic depth, lithology and sediment grain size to classify the environment into geomorphic types.

5.2.2 Step 2.2— Shortlist attributes & categories, collapse / group categories

Candidate attributes are chosen which best respond and relate to the purpose, and the relevant categories within these attributes are determined. Sometimes the categories are '**collapsed down'** by combining a number of categories. Examples include combining 'other' 'none' and 'unknown', grouping up categories that are not relevant to the question (e.g. all hard corals other than branching - see fig. 8), or using a higher tier of the category (e.g. 'Mangrove' instead of 'Mangrove-Avicennia'). The collapsed group becomes a list of category values represented by a single name but the identity of the original category name is retained within this list. (e.g. 'Mangrove' can include 'Mangrove-Avicennia', 'Mangrove-Rhizophora' etc.). This reduces the potential number of types to a manageable number aligning to the purpose of the typology, while retaining the flexibility to distinguish these again if required for a different purpose, or if determined to be of use later in the process (see 5.2.5).

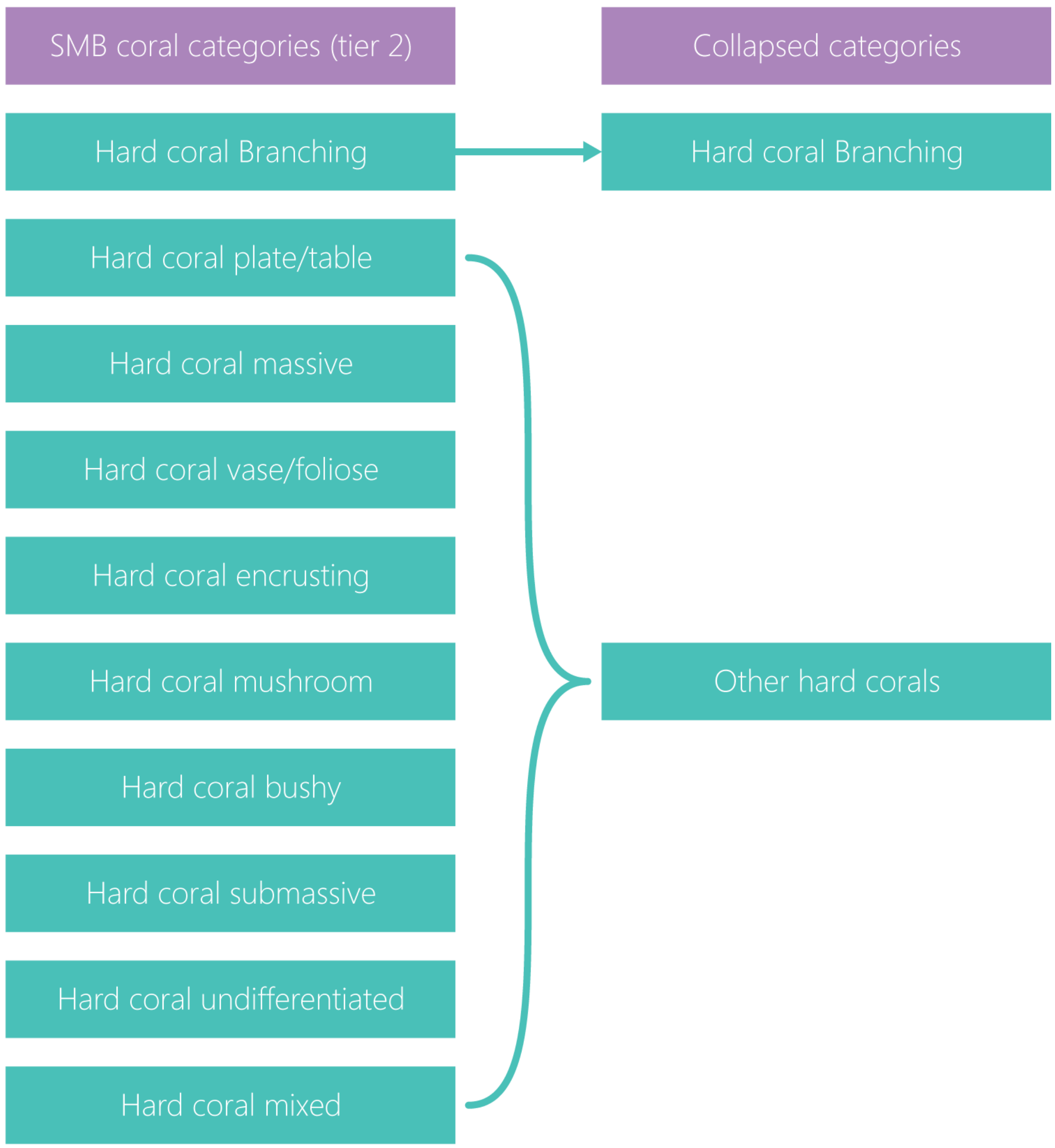


Figure 8: Collapsing down of hard coral structural types into 'branching' and 'other'

5.2.3 Step 2.3 —Determine attribute hierarchy

A **hierarchy of attributes** is required for each typology where subsequent attributes and their categories are assigned to differentiate types. It is important to determine which attributes are most crucial to the purpose of the typology as the order of attributes in the hierarchy influences distinctions between subsequent types. In a seascape typology for general biophysical purposes, it may be determined that the most important attribute in describing the nature of ecosystems is "benthic depth". If the typology purpose is to reflect biological variation, the next attribute selected may be "structural macro biota" and so on (see fig. 9).

Rank	Attribute
1	Depth
2	Struct. macro b.
3	Consolidation
4	Inundation
5	Morphology

Figure 9: During typology, attributes are assigned a rank in a hierarchy to allocate the order of each attribute decision rule in the filter table (table 5). In the above example, the first decision relates to depth, next comes structural macrobiota (Struct. Macro b.), then consolidation, inundation and morphology.

5.2.4 Step 2.4—Define and run rule-sets

Typology rules are developed to define 'types'. These rules are designed to be used in a specific order based upon the hierarchy established in step 2.3 (see section 5.2.3 and fig. 9).

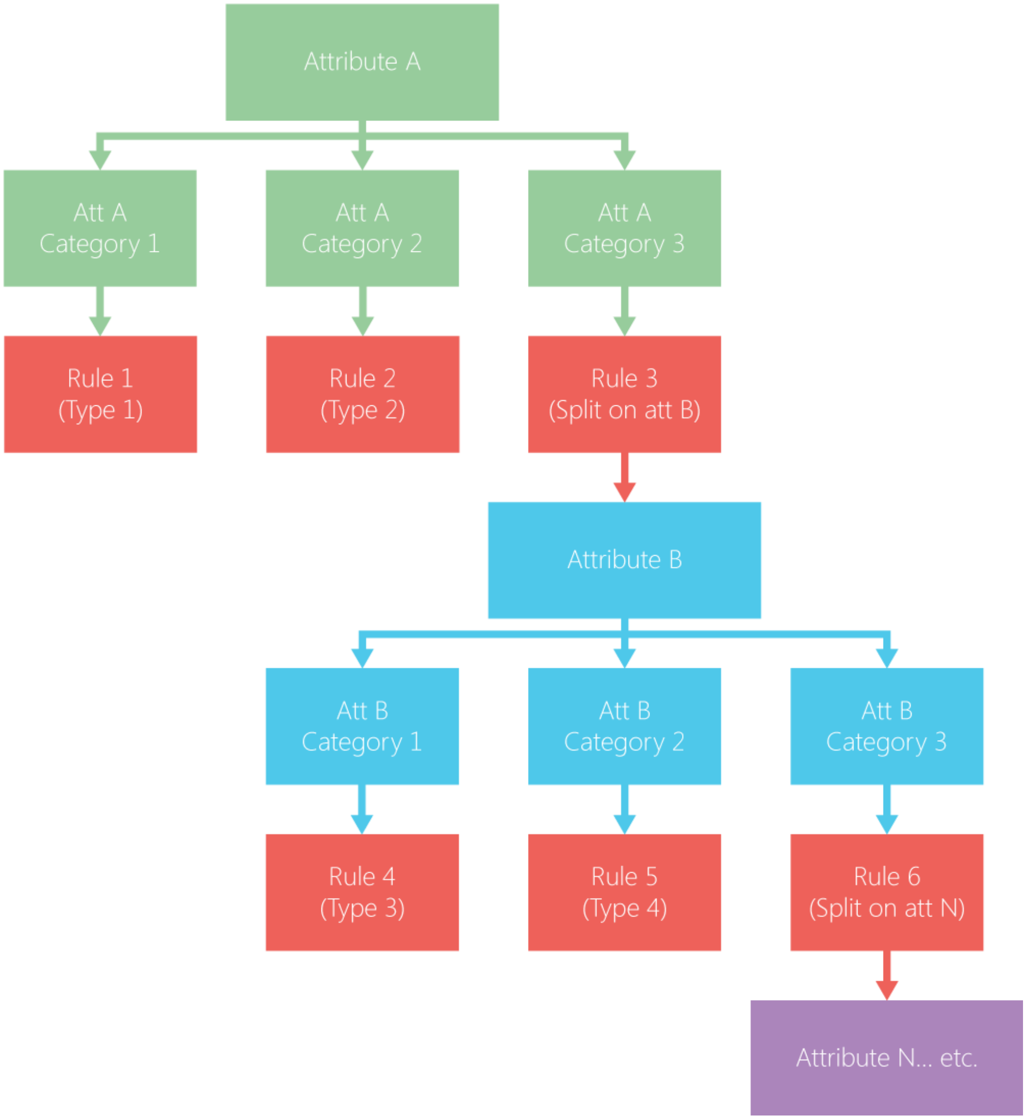


Figure 10: The hierarchy of attributes linking the types to each other in a sequence, splitting on different attributes in the hierarchy.

A **rule-set** consists of one or more rules necessary to define a type. These rule-sets determine specific combinations of attributes and their categories that define a particular type. Rules relating to one or more attributes and categories may be needed in combination to determine the type. Each rule tests whether the attribute category falls within a defined value as determined by the shortlisting or collapsing of attributes (see 5.2.2 set 2.2). Based on the outcome, this ‘filters’ or split the categories into two or more groups (e.g. “shallow” =benthic depth < -15m).

The outcome of this test will be either:

- the category meets the rule (e.g. it falls between 0 and -15m and is “shallow”)
- the category does not meet the rule (e.g. benthic depth > -15m “deep”)
- the category does not participate in the rule, because
    - it has already been filtered out by meeting a previous rule in the hierarchy where it was allocated to a type; OR
    - the rule is superfluous to needs or irrelevant (i.e. undifferentiated) .

Any remaining categories or groups of categories that were not filtered out are available for the next decision rule applying to the next attribute in the hierarchy (as in fig. 11). Decision rules are sequentially applied to ‘filter’ the remaining categories, and so on, gradually sifting through the categories left until all the types are ‘filtered out’.

All rules relating to types are compiled into a ‘decision filter table’ (e.g. Table 5). Every possible value for an attribute must be included in the filter table – including ‘unknown’ and ‘none’. This will ensure a comprehensive typology covering all possible biotic and abiotic ecosystems, even those which are poorly known, or for which there are little mapping data. These areas can be targeted later on for further investigation.

What is produced is a sequence of types that are related to each other by the hierarchy of attributes (explained in fig. 10.). Refer to Table 5 and fig. 11 for interchangeable views of a larger typology.

Table 5: 'Decision filter table' for example typology (see figure 11). Attributes are applied in the order of the hierarchy determined by fig. 8. When a habitat type decision rule is determined by an attribute, it is 'filtered out' i.e. no longer participates in any queries. This is why 'saltmarsh' and 'mangrove' remain undifferentiated for the Inundation attribute – see alternative 'typology sequence' in fig. 11. Despite this, the Inundation and Consolidation attribute information is still available to enrich the saltmarsh and mangrove datasets and type descriptors.

	Attribute												
	Depth				Structural macrobiota					Consolidation		Inundation	
Type	Shallow	Deep	Unknown	Very deep	Saltmarsh	Mangrove	Seagrass	Sponge, coral, other fauna	None	Consolidated	Unconsolidated	Intertidal	Subtidal
Very deep	✗	✗	✗	✓	Undifferentiated					Undifferentiated		Undifferentiated	
Saltmarsh	Undifferentiated			✗	✓	✗	✗	✗	✗	Undifferentiated		Undifferentiated	
Mangrove	Undifferentiated			✗	✗	✓	✗	✗	✗	Undifferentiated		Undifferentiated	
Intertidal seagrass	Undifferentiated			✗	✗	✗	✓	✗	✗	Undifferentiated		✓	✗
Subtidal seagrass	Undifferentiated			✗	✗	✗	✓	✗	✗	Undifferentiated		✗	✓
Reefal gardens	Undifferentiated			✗	✗	✗	✗	✓	✗	✗	✓	Undifferentiated	
Intertidal rocky shores and reefs	Undifferentiated			✗	✗	✗	✗	✓	✗	✓	✗	✓	✗
Subtidal rock and reefs	Undifferentiated			✗	✗	✗	✗	✓	✗	✓	✗	✗	✓
Bare intertidal on consolidated	Undifferentiated			✗	✗	✗	✗	✗	✓	✓	✗	✓	✗
Bare subtidal on consolidated	Undifferentiated			✗	✗	✗	✗	✗	✓	✓	✗	✗	✓
Bare intertidal on unconsolidated	Undifferentiated			✗	✗	✗	✗	✗	✓	✗	✓	✓	✗
Bare subtidal on unconsolidated	Undifferentiated			✗	✗	✗	✗	✗	✓	✗	✓	✗	✓

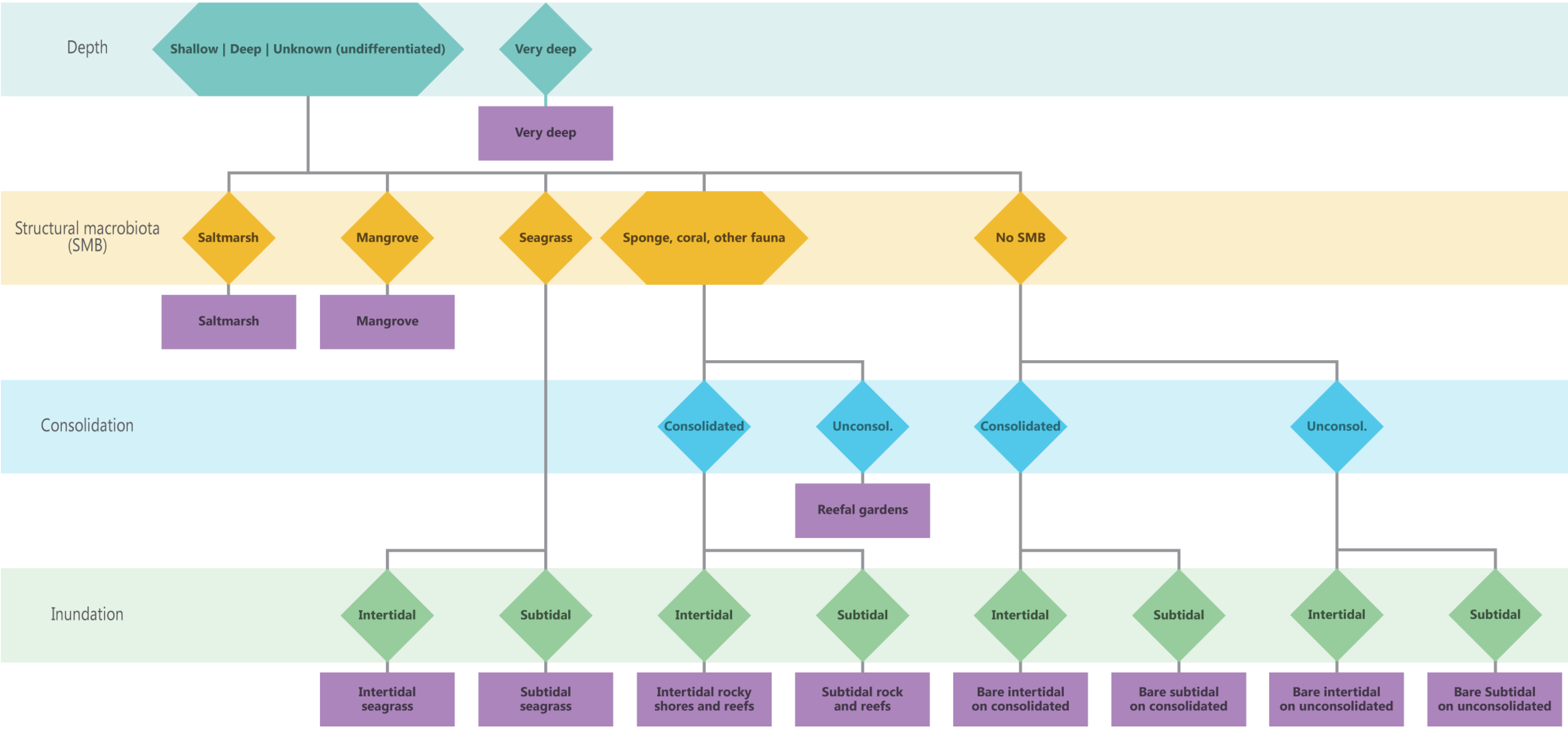


Figure 11: A typology sequence is another way of viewing a 'decision filter table'. It shows the hierarchy of attributes in a sequence of rules that determine each type ('rule-set') based on splitting on different attributes and the allocation of a type where no further splitting is required on an attribute. Diamonds represent categories of attributes and rectangles represent types.

5.2.5 Step 2.5— Review and refine typology (reclassification)

Once the attributes and categories have been combined the "preliminary types" can be **reviewed**. This is best done through a facilitated workshop process as participants bring a different perspective and allow for a robust review of the types, but must be guided by the initial **purpose**. Reclassification may be driven by the need to achieve a more balanced representation of ecosystems, to accommodate all stakeholders, or to suit particular stakeholder needs. Sometime the types are possible but not present in an area. Other times the differentiation of some types is inadequate and need to be split on a further attribute or category. Step 2.5 may also assist in identifying unique combinations of attributes and categories, which indicate unique or rare habitat types to be carefully considered as they may be anomalies of the process or they may genuinely exist. In some instances the findings from this step feeds back into the previous step, requiring rule-sets to be modified, re-defined and re-run. Mapping the types enables visualisation of the types and may also feed iteratively back between steps 2.3, 2.4 and 2.5. Based on a review of the resulting types or mapped products, a decision is made to further combine (lump or collapse down) or expand (split) based on an attribute or category.

Simplification via reclassification is needed when the retention of many attributes and categories results in a very large number of types. A typology using five attributes each with five categories yields 3125 possible permutations, differentiating far too many types for a particular management application. Conversely a type that was simplified too much by inclusion in a list during in the shortlisting and collapsing-down process (step 2.2) can be split back out.

The decision filter-table can be used reclassify types by re-adjusting the combinations of attributes and categories. A single biophysical classification (such as in Table 5) may serve multiple needs as well as specific needs. For example a seagrass scientist may be interested only in unconsolidated types and their position on the shoreline becomes irrelevant. In this case intertidal and subtidal are collapsed down into a single reclassified type (rocky shore and reef) making the inundation attribute 'undifferentiated' instead of 'intertidal' and 'subtidal'(fig. 12). Conversely the seagrass scientist may want to distinguish types based upon the differences in seagrass composition in shallow and deep water, splitting subtidal seagrass based upon the depth attribute, i.e. 'shallow seagrass' and 'deep seagrass' (fig. 13).

Reclassification can simplify the rules of a typology. This can simplify the initial creation of rules or simplify the rules after they have been generated. It is important to implement the following two principles during reclassification:

- It is critical to consider the **position of the attribute within the hierarchy** when splitting based on an attribute, so as to prevent the proliferation of subsequent types. When a decision is made to split on that attribute, the rule-sets must be re-run to check how many types will be produced. This may produce many more types than are required. Potentially it may be necessary to **re-order** the hierarchy which changes the entire typology and its rule-sets.

- Clearly identify the attributes used for splitting to ensure there are no gaps in the classification and the full suite of attributes and their combinations are represented in the final products. The principle of balanced representation of attribute combinations needs to be maintained so as to avoid creating a typology that is simply a list that reflects biases of the most vocal stakeholders.

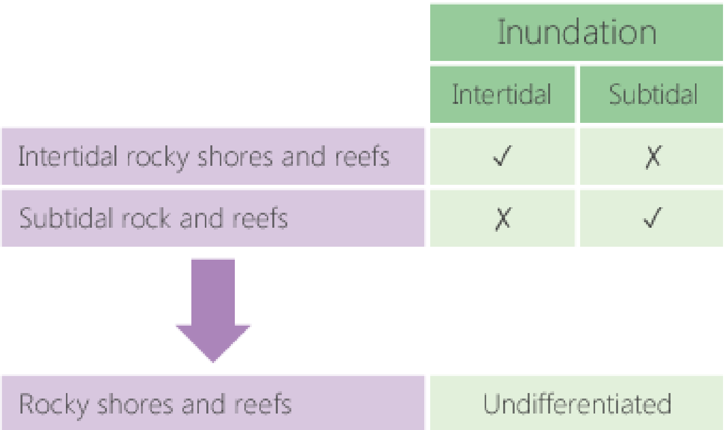


Figure 12: Example of 'collapsing down' during reclassification. Intertidal rocky shores and reefs and subtidal rock and reefs types are combined into one reclassified type Rocky shores and reefs using the Inundation attribute.

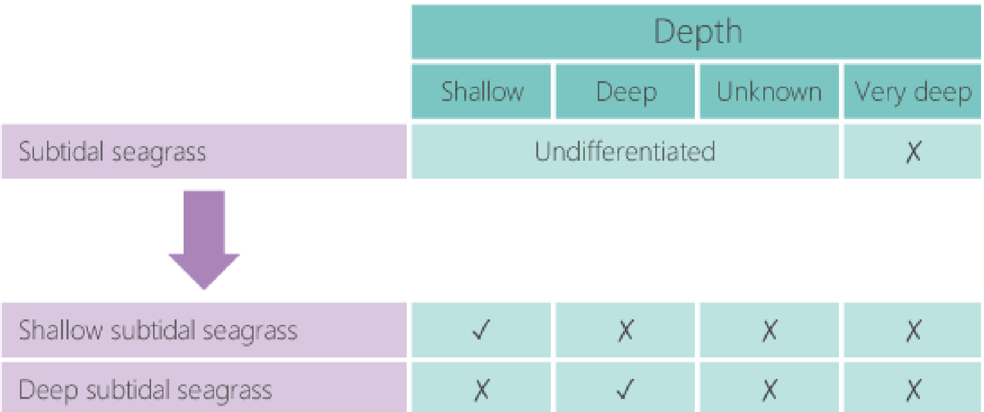


Figure 13: Example of splitting during reclassification. The Subtidal seagrass type is split into shallow and deep subtidal seagrass types based upon the attribute depth.

5.2.6 Step 2.6 — Name the types

The preliminary type should be documented in a table (e.g. Table 5) which clearly outlines the rules and the decisions made. The final **naming convention** for each type is dependent on the final users but it should reflect the key attributes used in the process.

Attributes and qualifiers not used for typology may be used as **supplementary information** for context or characterisation of a type (e.g. ecological character description). For instance, for the type 'intertidal seagrass on sand', the detailed categories of the inundation attribute are available to further describe a site as being positioned at the upper or lower region of the intertidal zone. Inventory point data can also provide supplementary information. Types may consist of short titles based on dominant attributes, or longer descriptions further enriched by the domain of all attributes within and listing species assemblages typically associated with the type. Mapping the types may inform the combinations of types available in the mapping unit and their dominance as an ecosystem (see 5.3.3).

Depending on the purpose of the typology, a decision may be made to produce outputs of type descriptions to enable validation of types in the field and conceptual models to understand how the attributes that determine the types interact. This information assists identification of the type in the field if mapping is unavailable. If a decision is made to map the types, the rule-sets are applied in Stage 3.

5.3 Stage 3 Mapping – assembling and mapping attribute datasets and applying attributes and categories to data

The following is a brief summary of the steps involved in mapping an attribute classification and typology. Mapping is a full method in itself, and only general principals, steps and logic are provided here (see fig. 7).

5.3.1 Step 3.1 — Align the mapping purpose with the attribute classification and typology

When undertaking mapping it is first necessary to align the purpose of the mapping with the typology (or typologies) and the attribute classification (step 3.1). A clearly defined purpose enables mapping of the correct attributes and their categories, and produces the number of types aligning with stakeholder needs. Retaining a broad classification provides the option to map multiple typologies within the one dataset simply by mapping reclassified types (see 5.3.3 and 5.2.5).

5.3.2 Step 3.2—Map the attributes

One of the primary purposes for developing a classification scheme or typology is to **map the attributes and the categories** (step 4.2) and ultimately the different types (step 4.3), which requires combining the individual mapped attributes and categories into a consistent product. Identifying this mapping output should be done **early in the process** as compiling, consolidating, and indexing the source inventory datasets is very time consuming. Ideally a selection of mapped attributes is available for workshop participants when shortlisting attributes (step 2.2) to view to envisage how types may be mapped.

One of the key activities involved in step 3.1 is locating inventory datasets to populate various attributes and categories. This process is difficult and can involve lengthy negotiations with data custodians where relevant open access datasets are unavailable. By collating inventory datasets and translating them to the relevant attribute and category of the Scheme, a 'stock-take' of data will identify data gaps and prioritise which additional inventory datasets to follow up with custodians. In many cases the inventory datasets are not in a format that can easily be translated to the attribute categories, or they do not have adequate metadata or do not cover the full area for which the mapping is being conducted.

Cross-walking of inventory datasets into the categories of the classification enables them to be translated into a common language so a single composite dataset can be compiled or 'stitched together' for each attribute.

It is important to retain a minimal subset of relevant attributes from inventory dataset information for later use, and maintain an inventory identifier to trace a mapped type back to its original dataset and record. For example include relevant attributes from regional ecosystem and wetland mapping (such as vegetation information – DSITI 2015). An identifier is a code to connect the inventory attributes back to mapped attributes and mapped types, and is important for visualisation, validation in product release and updating. Any mapping process needs to ensure that there is a provision for the recording of this code as queries in the final product may need to be related back to the inventory dataset.

Other important inventory data to retain concerns data about the category, stored as qualifiers. Examples of qualifier use include

- the cover qualifier percentage is used to identify the dominant category
- the naturalness qualifier is used to map an artificial type
- period and trend qualifiers are used to identify ephemeral habitat types

Scale is another significant consideration i.e. the scale of inventory data may not be consistent with its use or with other datasets (see s3.2, 3.5). Recording the **confidence** of the dataset will help determine its use in comparison to other datasets. It is recommended where possible to match inventory data scales with the level selected for the purpose of the typology (see Table 3), or if unavailable, its adjacent level. High confidence data should always overlay low confidence data when merging different data inventory data into an attribute layer. If only low confidence data (e.g. old and inaccurate bathymetry) is available in an area the resulting types should be interpreted with caution, and highlighted for future inventory collection.

5.3.3 Step 3.3 — Map the types

Once all inventory has been incorporated into their respective attribute datasets, they are available to be used in applying the rule-sets to mapping. The attribute datasets are combined by intersecting them with each other, retaining only the attribute and category data and identifiers.

The rule-sets are run to create a draft map of types, using the attribute datasets and guided by the decision filter-table (e.g. Table 5). Here the hierarchy of attributes becomes important as there may be potentially many different types in an area. Types that result from attributes towards the top of the hierarchy will determine the final type (e.g. 'saltmarsh' and 'mangrove' types in fig.11), overriding those types determined by other attributes below in the hierarchy ('co-types'). There may be unexplained overlaps between types, combinations of attributes and left-over types (e.g. where the majority of categories are 'unknown' or 'none') that do not match to the table of rule-sets, which may require re-examination of what additional attributes are available to describe these types. For example a lack of data in one attribute may be compensated for by splitting out another different attribute and category. This step feeds back into and inform Typology steps 2.3, 2.4 and 2.5.

It is possible to apply several different reclassified types (see 5.2.5) to the same combined attributes dataset simply by adjusting the combinations of categories in the rule-sets. A generalised typology can be produced from the same combined attributes dataset as a detailed typology.

When mapping types, a decision must to be made as to how to designate the type spatial unit, i.e. either (i) the intersection of the attributes, or (ii) assigned to some other kind of spatial unit (e.g. defined by an attribute such as morphology) or (iii) a hybrid of both approaches. This decision should be guided by the level and recommended minimum area / size for the corresponding mapping scale (Table 3) as well as the ecological resolution of types.

5.3.4 Step 3.4 — Review and refine the mapping

During this process it is possible that **initial assumptions** about attributes or categories will need to be **revisited** due to data limitations or the nature of the habitat types. This in turn can feed back to the classification and typology decisions – for example mapping step 3.4 provides feedback for typology steps 2.4 and 2.5. Expert panels should be convened at a second meeting to review how their decisions have been mapped, and to adjust the draft map where necessary. Minor adjustments may include selection or deletion of attributes, and / or amalgamation or splitting of types based upon category values. By linking mapped types and attributes back to inventory datasets via the identifier it is possible to test how the typology works in specific areas well-known to stakeholders. An attribute-based classification enables such fine-scale adjustments to be made. Major decisions such as changes in the attribute hierarchy will result in quite different rule-sets, requiring re-mapping of the types and re-running the rulesets. This would result in a new typology and map.

During this review and refinement step, stakeholders provide feedback as the initial part of the quality assurance process, evaluating the mapping decisions, types and scale. Workshop decisions need to be clearly documented and feedback obtained so that the workshop outputs can be implemented in the mapping. There are a number of tasks required to integrate workshop outputs into the mapping workflow within this step, which are outlined in figure 7.

5.4 Stage 4 Product release

Draft mapping in digital geodatabase form and cartographic products should be released for review, along with documentation of expert workshop decisions, metadata and technical procedures. Feedback is incorporated into subsequent products (see fig.7).

5.4.1 Step 4.1—Release mapping and supporting products for consultation

The attribute classification, typology or typologies, mapped attributes and mapped types are products which can be reviewed as part of a consultation process. Consultation may include limited release and testing with stakeholders with good local knowledge of types for a given area before releasing to a wider audience. This balances the feedback received during the wider quality assurance process with the resource requirements to implement those suggestions.

5.4.2 Step 4.2—Review feedback and schedule release of products

All mapped products are approximations that are only as accurate as their source inventory datasets, therefore are approximations to be sequentially updated over time as data and knowledge improve. Any identified errors from step 4.1 should be corrected in response to feedback but any major conceptual feedback will need to be documented to be addressed for updating in later versions (DSITI 2015).

At release, the final set of integrated intertidal and subtidal ecosystem mapping products is integrated with existing wetland mapping (e.g. for other study areas), individually versioned, and released through available delivery mechanisms.

6 Appendices

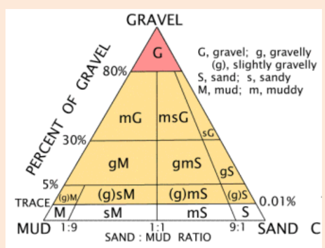
6.1 Attributes used in the scheme and relevance to each level showing whether they are benthic, water column or related to both, and the levels to which they should apply. [1]

Theme	Attribute	Benthic (B) Water column (WC) Both (B/WC)	Region[1]	Subregion[1]	Seascape	Habitat	Community[1]	
Terrain	Benthic depth	B	X	X	X	X	X	
	Terrain morphology	B	X	X	X	X		
	Terrain pattern	B	X	X	X	X		
	Terrain slope	B	X	X	X	X		
	Terrain relative relief	B			X	X		
	Terrain roughness	B	X	X	X	X		
Substrate	Lithology	B	X	X	X	X	X	
	Substrate consolidation	B		X	X	X	X	
	Substrate grain size	B		X	X	X	X	
	Substrate composition	B	X	X	X	X	X	
Hydrology: Physical	Energy source	B/WC	X	X	X	X		
	Energy magnitude	B/WC	X	X	X	X		
	Inundation	B		X	X	X	X	
	Tidal range	B/WC	X	X	X			
	Water column depth	WC	X	X	X			
	Hydrological morphology	WC	X	X	X			
	Exchange time	WC	X	X	X			
Hydrology: Chemical	Freshwater input source	B/WC	X	X	X			
	Freshwater input volume	B/WC	X	X	X			
	Mixing state	B/WC	X	X	X			
	Salinity	B/WC	X	X	X			
	Water clarity	B/WC	X	X	X			
	Temperature	B/WC	X	X	X			
	Air temperature	B	X	X	X			
	Oxygen	B/WC	X	X	X			
	pH	B/WC	X	X	X			
	Calcium carbonate	B/WC	X	X	X			
	Trace elements	WC	X	X	X			
Biota	Benthic rugosity	B				X	X	
	Structural Macrobiota Composition	B			X	X	X	
	Infauna utilisation	B				X	X	
	System metabolism	WC	X	X	X			
	Biotic size structure	WC	X	X	X			

[1] *Further development is required in subsequent versions of this document

6.2 Attributes and categories of the scheme

6.2.1 Seascape level

AttributeName	CategoryName	AttributeName	CategoryName
THEME: TERRAIN			
Benthic depth Depth of the seafloor using the Australian Height Datum (AHD) also referred to as absolute relief.	Unknown	**Terrain pattern:** Classifies a terrain morphology feature using the mixture of terrain morphologies from a lower scale. E.g. a planar feature at the seascape level may be made up of a sequences of habitat level ridges and channels (i.e. a dune field or delta).	Unknown
	>0m (above AHD)		None / Mixed
	0m to 5m		Ridges and Channels
	5m to 10m		Ridges and Planes
	10m to 15m		Ridges and Passes
	15m to 20m		Ridges and Pits
	20m to 25m		Ridges and Depressions
	25m to 30m		Peaks and Ridges
	30m to 35m		Peaks and Passes
	35m to 40m		Peaks and Channels
	40m to 50m		Peaks and Planes
	50m to 60m		Peaks and Pits
	60m to 100m		Peaks and Depressions
	100m to 150m		Crests and Depressions
	150m to 200m		Crests and Planes
	200m to 300m		Crests and Passes
	300m to 500m		Crests and Pits
	500m to 700m		Channels and Passes
	700m to 1000m		Channels and Pits
	1000m to 1500m		Channels and Planes
	below 1500m		Channels and Crests
Terrain morphology: The shape of the landform surface.	Unknown		Pits and Passes
	Plane		Pits and Planes
	Ridge		Passes and Planes
	Peak		Depressions and Passes
	Crest undifferentiated		Depressions and Planes
	Channel	**Terrain roughness:** Structural complexity of the terrain (measured across a morphological feature). May also be referred to as ruggedness. Generally a ratio of three-dimensional surface measurements to linear/planar measurements	Unknown
	Pit		None
	Depression (undifferentiated)		Very low
	Pass		Low
Terrain slope: Indication of the general or dominant slope of a morphological feature.	Unknown		Medium
	Level (<= 0°35')		High
	Very gently inclined (0°35' - 1°45')		Very high
	Gently inclined (1°45' - 5°45')	**Terrain Relative relief:** Related to the morphology features; the relative elevation is the general difference in elevation between a morphological feature and those features surrounding it.	Unknown
	Moderately inclined (5°45' - 18°)		None
	Steep (18° - 30°)		Very low
	Very steep (30° - 45°)		Low
	Precipitous (45° - 72°)		Medium
	Cliffed (> 72°)		High
	Overhang (>90°)		Very high
THEME: SUBSTRATE			
Consolidation:	Unknown	**Lithology:** Physical characteristics of rock.	Unknown
	Consolidated		Sedimentary – detrital
	Intermediate		Sedimentary – pyroclastic
	Unconsolidated		Sedimentary – chemical or organic
Substrate composition: Categorises the composition of unconsolidated substrates.	None (no sediment present)		Sedimentary – unspecified
	Calcareous – Biogenic - Coral		Igneous
	Calcareous – Biogenic - Shell		Metamorphic
	Calcareous – Biogenic - Halimeda		Other or unspecified
	Calcareous – Biogenic - Forams		
	Calcareous – Biogenic - Other or Unspecified	**Substrate grain size**: Categorises the size of unconsolidated substrates (regardless of composition). USE THESE CATEGORIES IN FOLK TYPOLOGY *BELOW  	Unknown
	Calcareous - Non-biogenic		None
	Calcareous -Undifferentiated		Other or unspecified
	Biosiliceous		Mud (clays and silts)
	Organic - Peat-beds		Sand
	Organic - Detritus (includes wood, detritus from mangroves, seagrass, etc.)		Pebbles
	Organic - Other or Unspecified		Cobbles
	Terrigenous (e.g. muds, sands and gravels derived from rock)		Boulders
	Terrigenous - Anthropogenic (e.g.concrete & metals)		Gravels (undifferentiated pebbles, cobbles and boulders)
	Other or unspecified		

HEME: BIOTA		
Structural macrobiota composition: Type of (sessile) structural macrobiota (SMB).	Grass/herb/sedge - undifferentiated	Coral –Octocorallian (incl. gorgonians, sea pens, sea whips)
	Grass/herb/sedge - grass or herb	Coral –undifferentiated
	Grass/herb/sedge - succulent	Hard coral - undifferentiated
	Grass/herb/sedge - sedge	Hard coral - Branching
	Algae - Encrusting	Hard coral - Massive
	Algae - Turf mat	Hard coral -Submassive
	Algae - Filamentous	Hard coral - Plate/table
	Algae - Blue-green	Hard coral - Bushy
	Algae - Erect macrophyte	Hard coral - Vase/foliose
	Algae - Erect calcareous	Hard coral - Encrusting
	Algae - undifferentiated	Hard coral -Mixture of structures
	Seagrass - Strap narrow	Sponge
	Seagrass - Strap broad	Mollusc - Oysters
	Seagrass - Ovoid	Mollusc - Scallops
	Seagrass - Fern-like	Mollusc - Other undifferentiated (e.g. bivalve, gastropod (limpet, worm shell))
	Seagrass - cylindrical	Ascidian (incl. tunicates, sea squirts)
	Seagrass - Other or unspecified	Crinoids (incl. feather stars, stalked crinoids)
	Mangrove - Avicennia	Tubeworm (Polychaetes and phoronids)
r	Mangrove - Rhizophora	Bryozoa (incl. moss animals, lace corals, sea mats)
	Mangrove - Ceriops	Barnacles
	Mangrove - Mixed	Other or unspecified fauna (incl. brachipods and kamptozoans)
	Mangrove -undifferentiated	Other or unspecified biota
	Other trees - Melaleuca, Casuarina	Unknown
	Other or unspecified flora	None

THEME:	HYDROLOGY (physical)
Tidal range: The difference between the height of water at high and low tides.	Unknown
	None (0m)
	Micro-tidal (0m to 2m)
	Meso-tidal (2m to 4m)
	Macro-tidal (>4m)
Energy source: Sources of energy driving water movement.	Unknown
	None
	Riverine
	Tidal
	Wave
	Current
	Upwelling
	Wind
	Overland flow
Energy magnitude: Relative strength of the energy source class.	Unknown
	None
	Very low
	Low
	Medium
	High
	Very high
Inundation: The tidal inundation regime.	Unknown
	Subtidal (below LAT)
	Lower Low (LAT to MLWS)
	Mid-Low (MLWS to MLWN)
	Upper Low (MLWN to MSL)
	Low - undifferentiated
	Lower Medium (MSL to MHWN)
	Upper-Medium (MHWN to MHWS)
	Medium - undifferentiated
	High (MHWS to HAT)
	Intertidal - undifferentiated

THEME: HYDROLOGY	(water chemistry)
Freshwater input source: Sources of freshwater runoff. Freshwater from the land contributes to the extent and degree of estuarine influence.	Unknown
	None
	River
	Groundwater
	Rainfall
	Overland flow
Freshwater input volume: Relative amount of the freshwater source.	Unknown
	None
	Low
	Medium
	High
Mixing state: Characterises the homogeneity of the water column.	Unknown
	Stratified
	Partially mixed
	Well mixed
Water clarity: Degree of transparency of water enabling penetration of light (not including the influence water depth i.e. light attenuation by the water column).	Unknown
	None
	Low
	Medium
	High
Temperature: Relative temperature of the water.	Unknown
	None
	Low
	Medium
	High
Salinity: Characterisation the amount of the dissolved salt content in water.	Unknown
	Fresh (<0.5 ppt
	Brackish (1-5 ppt
	Saline (34-36 ppt
	Hypersaline (>36 ppt)
pH: Characterises the acidity/alkalinity of water.	Unknown
	None
	Low
	Medium
	High
Calcium carbonate: Characterises the amount of dissolved calcium carbonate in the water.	Unknown
	None
	Low
	Medium
	High
Oxygen: Characterises the amount of dissolved oxygen in the water.	Unknown
	None
	Low
	Medium
	High

THEME: ATMOSPHERIC (PHYSICAL)	
Air temperature: The relative temperature of air acting upon the surface.	Low
	Medium
	High
	Unknown
	None

FOLK SEDIMENT TEXTURE TYPOLOGY - (FOLK CLASSIFICATION) PROPORTIONS of SUBSTRATE GRAIN SIZE – Folk (1974) - SEE SEDIMENT ATTRIBUTE *							
-	Unknown	B	BOULDER	O	None	M	MUD
(g)mS	(Slightly gravelly) muddy SAND	gmS	Gravelly muddy SAND	G	GRAVEL	sG	Sandy GRAVEL
(g)sM	(Slightly gravelly)sandy MUD	gM	Gravelly MUD	mG	Muddy GRAVEL	sM	Sandy MUD
(g)sM	(Slightly gravelly) SAND	gS	Gravelly SAND	mS	Muddy SAND	S	SAND

6.2.2 Habitat level

AttributeName	CategoryName	AttributeName	CategoryName
THEME: TERRAIN			
Benthic depth Depth of the seafloor using the Australian Height Datum (AHD) also referred to as absolute relief.	Unknown	Terrain pattern: Classifies a terrain morphology feature using the mixture of terrain morphologies from a lower scale. E.g. a planar feature at the seascape level may be made up of a sequences of habitat level ridges and channels (i.e. a dune field or delta).	Unknown
	>0: At 1m intervals (above AHD)		None / Mixed
	0m to 5m: at 1m intervals		Ridges and Channels
	5m to 50m: at 5m intervals		Ridges and Planes
	60m to 200m: at 10m intervals		Ridges and Passes
	200m to 300m: at 20m intervals		Ridges and Pits
	300m to 1000m: at 100m intervals		Ridges and Depressions
	1000m to 1500m		Peaks and Ridges
	below 1500m		Peaks and Passes
Terrain morphology: The shape of the landform surface.	Unknown		Peaks and Channels
	Plane		Peaks and Planes
	Ridge		Peaks and Pits
	Peak		Peaks and Depressions
	Crest undifferentiated		Crests and Depressions
	Channel		Crests and Planes
	Pit		Crests and Passes
	Depression (undifferentiated)		Crests and Pits
	Pass		Channels and Passes
Terrain slope: Indication of the general or dominant slope of a morphological feature.	Unknown		Channels and Pits
	Level (<= 0°35')		Channels and Planes
	Very gently inclined – 1 (0°35' - 1°)		Channels and Crests
	Very gently inclined – 2 (1° - 1°45')		Pits and Passes
	Gently inclined - 1 (1°45' - 3°15')		Pits and Planes
	Gently inclined - 2 (3°15' - 5°45')		Passes and Planes
	Moderately inclined - 1 (5°45' - 10°15')		Depressions and Passes
	Moderately inclined - 2 (10°15' - 18°)		Depressions and Planes
	Steep (18° - 30°)	**Terrain roughness:** Structural complexity of the terrain (measured across a morphological feature). May also be refered to as ruggedness. Generally a ratio of three-dimensional surface measurements to linear/planar measurements	Unknown
	Very steep (30° - 45°)		None
	Precipitous (45° - 72°)		Very low
	Cliffed (> 72°)		Low
			Medium
			High
			Very high
		Terrain Relative relief: Related to the morphology features; the relative elevation is the general difference in elevation between a morphological feature and those features surrounding it.	Unknown
			None
			Very low
			Low
			Medium
			High
			Very high

THEME: SUBSTRATE	
Consolidation:	Unknown
	Consolidated
	Intermediate
	Unconsolidated
Substrate composition: Categorises the composition of unconsolidated substrates.	None (no sediment present)
	Calcareous – Biogenic - Coral
	Calcareous – Biogenic - Shell
	Calcareous – Biogenic - Halimeda
	Calcareous – Biogenic - Forams
	Calcareous – Biogenic - Other or Unspecified
	Calcareous - Non-biogenic
	Calcareous -Undifferentiated
	Biosiliceous
	Organic - Peat-beds
	Organic - Detritus (includes wood, detritus from mangroves, seagrass, etc.)
	Organic - Other or Unspecified
	Terrigenous (e.g. muds, sands and gravels derived from rock)
	Terrigenous - Athropogenic (incl. concrete & metals)
	Other or unspecified
	Unknown

Lithology: Physical characteristics of rock.	Unknown
	Sedimentary – detrital
	Sedimentary – pyroclastic
	Sedimentary – chemical or organic
	Sedimentary – unspecified
	Igneous
	Metamorphic
	Other or unspecified
Substrate grain size: Categorises the size of unconsolidated substrates (regardless of composition). USE *either* THESE CATEGORIES *OR all* FOLK TYPOLOGY	Unknown
	None
	Other or unspecified
	Fine-medium clay
	Coarse clay
	Very fine silt
	Fine silt
	Medium silt
	Coarse silt
	Mud – undifferentiated (clays and silts)
	Very fine sand
	Fine sand
	Medium sand
	Coarse sand
	Very coarse sand
	Sand – undifferentiated
	Very fine pebbles (granules)
	Fine pebbles
	Medium pebbles
	Coarse pebbles
	Very coarse pebbles
	Pebbles – undifferentiated
	Cobbles
	Boulders
	Gravels (undifferentiated pebbles, cobbles and boulders)

OPTION to use all categories of **the FOLK TYPOLOGY** to apply GRAIN SIZE ATTRIBUTE

SEDIMENT TEXTURE (FOLK)	PROPORTIONS of SUBSTRATE GRAIN SIZE
-	Unknown
(g)mS	(Slightly gravelly) muddy SAND
(g)sM	(Slightly gravelly)sandy MUD
(g)sM	(Slightly gravelly) SAND
B	BOULDER
gmS	Gravelly muddy SAND
gM	Gravelly MUD
gS	Gravelly SAND
O	None
G	GRAVEL
mG	Muddy GRAVEL
mS	Muddy SAND
M	MUD
sG	Sandy GRAVEL
sM	Sandy MUD
S	SAND

THEME: BIOTA			
Structural macrobiota composition: Type of (sessile) structural macrobiota (SMB).	Grass/herb/sedge - undifferentiated	Coral –Octocorallian (incl. gorgonians, sea pens, sea whips)	
	Grass/herb/sedge - grass or herb	Coral –undifferentiated	
	Grass/herb/sedge - succulent	Hard coral - undifferentiated	Acropora
	Grass/herb/sedge - sedge	Hard coral - undifferentiated	Non-Acropora
	Algae - Encrusting	Hard coral - Branching	Acropora
	Algae - Turf mat	Hard coral - Branching	Non-Acropora
	Algae - Filamentous	Hard coral - Massive	Acropora
	Algae - Blue-green	Hard coral - Massive	Non-Acropora
	Algae - Erect macrophyte	Hard coral -Submassive	Acropora
	Algae - Erect calcareous	Hard coral -Submassive	Non-Acropora
	Algae - undifferentiated	Hard coral - Plate/table	Acropora
	Seagrass - Strap narrow	Hard coral - Plate/table	Non-Acropora
	Seagrass - Strap broad	Hard coral - Bushy	Acropora
	Seagrass - Ovoid	Hard coral - Bushy	Non-Acropora
	Seagrass - Fern-like	Hard coral - Vase/foliose	Acropora
	Seagrass - cylindrical	Hard coral - Vase/foliose	Non-Acropora
	Seagrass - Other or unspecified	Hard coral - Encrusting	Acropora
	Mangrove - Avicennia	Hard coral - Encrusting	Non-Acropora
	Mangrove - Rhizophora	Hard coral -Mixture of structures	Acropora
	Mangrove - Ceriops	Hard coral -Mixture of structures	Non-Acropora
	Mangrove - Mixed	Sponge	
	Mangrove -undifferentiated	Mollusc - Oysters	
	Other trees - Melaleuca, Casuarina	Mollusc - Scallops	
	Other or unspecified flora	Mollusc - Other undifferentiated (e.g. bivalve, gastropod (limpet, worm shell))	
		Ascidian (incl. tunicates, sea squirts)	
		Crinoids (incl. feather stars, stalked crinoids)	
		Tubeworm (Polychaetes and phoronids)	
		Bryozoa (incl. moss animals, lace corals, sea mats)	
		Barnacles	
		Other or unspecified fauna (incl. brachipods and kamptozoans)	
		Other or unspecified biota	
		Unknown	

Infauna utilisation Degree of habitation or use of the substrate by infauna.	Unknown
	None
	Low
	Moderate
	High

Benthic rugosity See terrain roughness - contribution of biota to the structural complexity of a surface (measured across a morphological feature). Generally a ratio of three-dimensional surface area to linear/planar area.	Unknown
	None
	Low
	Medium
	High

THEME:	HYDROLOGY (physical)
Tidal range: The difference between the height of water at high and low tides.	Unknown None (0m) Micro-tidal (0m to 2m) Meso-tidal (2m to 4m) Macro-tidal (>4m)
Energy source: Sources of energy driving water movement.	Unknown
	None
	Riverine
	Tidal
	Wave
	Current
	Upwelling
	Wind
	Overland flow
Energy magnitude: Relative strength of the energy source class.	Unknown
	None
	Very low
	Low
	Medium
	High
	Very high
Inundation: The tidal inundation regime.	Unknown
	Subtidal (below LAT)
	Lower Low (LAT to MLWS)
	Mid-Low (MLWS to MLWN)
	Upper Low (MLWN to MSL)
	Low - undifferentiated
	Lower Medium (MSL to MHWN)
	Upper-Medium (MHWN to MHWS)
	Medium - undifferentiated
	High (MHWS to HAT)
	Intertidal - undifferentiated
THEME: ATMOSPHERIC (PHYSICAL)	
Air temperature: The relative temperature of air acting upon the surface.	Low
	Medium
	High
	Unknown
	None

THEME: HYDROLOGY NB:	**Attributes not applied at the habitat scale:**
(water chemistry)	***Freshwater input source*** ***Freshwater input volume*** ***Mixing state*** ***Water clarity*** ***Temperature***
	Salinity ***pH*** ***Calcium carbonate*** ***Oxygen***

6.3 Categories: Tiers

	Tier	Description of resolution	Example1 corals	Example 2 Mangroves	Example 3 Seagrass
Category Degree of definition and delineation	C1	Master: the broadest ecological group required for reporting at the seascape scale– and the default if no further definition is possible	Co (corals)	Ma (mangroves)	Sg (seagrass)
	C2	Broad: a grouping clearly identifiable at the seascape scale	Co-Ha (hard corals)	Ma–Av (mangroves – *Avicennia*)	Sg–Str (seagrass – strap)
	C3	Fine: towards the limit of differentiation at that scale	Co-Ha-Br (branching hard corals – based upon structure)		Sg-Str-Br (seagrass – strap - broad)
	C4	Micro: identifiable group at the next scale down	Co-Ha-Br-Ac (branching *Acropora* hard corals – split based upon genus, family or order)		

The first tier of a category **C1** is the 'broad' resolution that can be delineated and defined at that scale or level (for a discussion of levels, see s3.2). Each tier with finer resolution is appended to the right, resulting in up to four tiers **C1C2C3C4**. Attributes to which tiers could apply include: lithology, sediment grain size, substrate composition, structural macrobiota composition (e.g. mangroves – example 2, seagrass – example 3, grass/herb/sedge, algae, etc. – see Appendix 6.2.1 and 6.2.2)

Example 1 explains the categories of 'coral' in tiers at the seascape and habitat scales:

- 'Corals' are mappable at a seascape scale – 'broad' delineation (tier **C1** "Co"),
- Hard coral can also be mapped at that scale (adding tier **C2** becomes "Co-Ha" – the other group not listed here would be "Co-Oc" – Octocorallians, sea fans, sea pens, sea whips).

- Structural growth forms of hard corals (e.g. ‘branching’) are a ‘fine’ resolution towards the limit of differentiation at that scale (adding tier **C**3 becomes “Co-Ha-Br”). See Appendix 1 for a full list of structural growth forms.
- The next tier must be applied at the scale below, with previous tiers used as a prefix. At the habitat scale, *Acropora* hard corals can be delineated and differentiated. Adding **C4**, the habitat level category becomes “Co-Ha-Br-Ac”

6.4 Qualifiers:

Naturalness qualifier

	Qualifier	Description	CODE
Naturalness	Unknown	Unknown	-
	Natural	Un-modified, negligible direct influence by humans	1
	Modified	Natural features or values modified directly by humans	2
	Artificial	Completely constructed, created or otherwise by humans	3

Temporal qualifiers

	Qualifier	Description
Period	unknown	unknown
	seasonal	variation linked to seasonal patterns
	tidal	variation with each tide
	lunar month	variation with greater tidal cycle of highs and lows
	annual	entire life cycle within a year
	Inter-annual	varies from year to year
	intra-annual	variation within a year that is aseasonal
	decadal	variation observed when considering periods over 10 years
	enso	El Niño Southern Oscillation
	diurnal	varies with day and night
	Unknown	Unknown
Trend	Fluctuating	Fluctuates over time without discernible cycles or trends
	Constant	Present/stable continually for most of the observed time
	Cyclic	Exhibits modal variation e.g. specific periods such as seasonal or tidal cycles
	Increasing	Tending to increase over the observed time
	Decreasing	Tending to decrease over the observed time

Cover qualifier

Cover: e.g. Percentage of surface covered by structural macrobiota.	Unknown
	0 - 3
	3 – 6
	6 – 12
	12 – 30
	30 – 50
	50 – 80
	80 – 100
	Unspecified - present

Biotic height qualifier

Biotic height: Dominant height of the structural macrobiota (includes flora and fauna).	Unknown
	0 – 0.01m
	0.01 – 1m
	1 – 2m
	2 – 10m
	>= 10m

Biomass qualifier

Biomass	Under development	USE SEAGRASS BIOMASS CLASSES AS STARTING POINT, COMPARE WITH OTHER MACROBIOTA

6.5 Spatial attributes

Spatial attributes are often applied to investigate a question or a process, often at the levels or scales above (see spatial attributes s3.4.1 and levels, s3.2). Spatial attributes can be used to map features or create typologies that depend on spatial interactions between attributes and patterns of mapped features at different scales (e.g. geomorphic features of a coral reef, fluvial features associated with estuary mouths etc.). Examples include:

- Distance from <a mapped feature> to <another mapped feature> , with applications:
    - distance from the shoreline;
    - distance from a depth contour (e.g. 200m approximates the shelf edge);
    - distance from a morphological feature (e.g. a channel etc.)
    - distance from an attribute threshold (e.g. steep slope)
- Relative location of <a mapped feature> between <a mapped feature> and <another mapped feature> ; with application:
    - a reef falls within 0.3 of the distance between the shoreline and the shelf edge e.g. 'inner reef' cf 'shelf edge reef'
    - a reef falls between a 5 year flood plume extent and a 100 year flood plume extent
    - defining and delineating geomorphological features by relative locations of mapped types. For example, in mapped types resulting from a typology of morphology, slope and terrain pattern, a 'level plane' beside a 'gently sloping plane' defines and delineates the 'ledge' IHO feature descriptor (refer to geofeature in Nichol *et al.* 2016)
- Neighbourhood of <a mapped feature>
    - Adjoins another <mapped feature> e.g. fringing reefs are adjacent to land; barrier reefs are located on the deep water side of a plane (continental shelf); reef crest is next to reef slope (Roelfsema *et al.* 2013)
    - The join length along <a mapped feature> and its adjoining <mapped feature>
    - Absence of <mapped feature> in proximity to <another mapped feature> e.g. seagrass is usually absent from areas adjoining reef matrix or rocky shore
- Enclosure of <a mapped feature> by <another mapped feature>; partial enclosure of <
    - A depression (lagoon) is enclosed by a ridge (reef crest) or within a plane (reef flat)
    - A ridge (reef crest) does not enclose a lagoon – for example ribbon reefs
- Proportions of <a mapped feature>
    - Ratio of length to width of a channel and depression as a measure of linearity
- Relative proportions between<a feature> and <a feature>
    - A feature is the largest of its type i.e. falls within the 95th percentile
    - In the above geomorphological typology, the relative width of a 'level plane' compared with its surrounding 'sloping plane' will determine whether the IHO feature descriptor is a plateau or knob (refer to geofeature in Nichol *et al.* 2016)
- Orientation
    - (parallel to / perpendicular to / oblique to)
    - (easterliness of/ northerliness of)
    - (direction of high energy) e.g. windward vs leeward

Examples of application of spatial attributes

Spatial attributes need expert guidance from specialists, such as geomorphologists, geographers and spatial analysts (detailed in Module 3). Examples:

1) Creating a Sub-regional typology of erosional and depositional surfaces

On the Great Barrier Reef, the outer-shelf coral reefs 'grow on the bones of their ancestors'. The inner-shelf reefs are typically covered with flood-borne (terrigenous) sediment from the land and the middle-shelf area is a mixing zone where wind driven wave action penetrates to the sea floor around 60m depth. The geomorphic processes of reef formation occurred during the ice ages when the shoreline was towards the edge of the continental shelf, and these are now in deeper waters on the shelf-edge (the antecedent Pleistocene surface) (see (Hopley,1982; Hopley *et al.* 2007). A sub-regional **typology** of the GBR needs to reflect these zones:

- the outer third of the shelf reflecting this antecedent (Pleistocene) surface of old coral reefs;
- the middle third of the shelf reflecting a mixing zone; and
- the inner third of the shelf reflecting the terrigenous sediment wedge [substrate composition].

This typology could be created using a mixture of spatial and non-spatial attributes.

Distance from shelf break. First, define morphology of the coastline, the continental shelf and the shelf-break at the subregional scale. Identify the shelf break where there is a change in slope and depth around 100-200m – a typology of *morphology, slope* and *depth* at a sub-regional level.

D***istance from mainland*** (or proportionate distance between the mainland and the shelf break). The width of the GBR Lagoon on the continental shelf varies from narrow in the north to wide in the south. Distances across the shelf break can be divided into thirds, and each third of the width across the continental shelf is delineated. Checking which section has terrigenous influence can be mapped by time series or zones of influence of riverine plumes (attributes of freshwater source / volume successively applied using qualifiers of period and trend) and substrate composition (terrigenous vs carbonate)

2) Creating an estuarine typology based on geomorphic features and water column attributes

Estuaries are difficult to define because they are a product of geomorphological and hydrological processes – not just tidal areas of freshwater influence, as some estuaries are blocked from marine influence from time to time and others may seldom receive freshwater. Defining their nature and extent will need a mixture of spatial and non-spatial attributes, applied to mapped type features.

- Potential attributes needed to create an *estuarine typology* (see OzCoasts, also Heap & Heap 2001) include: freshwater source, volume, mixing, morphology, inundation, benthic depth and spatial attributes applied to morphological features (e.g. distance) that result from key geomorphic processes (e.g. morphologies that modify energy thresholds related to erosion and deposition).
- Spatial attributes which could be applied include: degree of enclosure, deepness of lagoons (morphology and depth*)*, distance to shore, distance to sea level).

6.6 Glossary of terms

Attributes: are descriptive characteristics or features of aquatic ecosystems. An attribute may be a mathematical or statistical indicator, or characteristic used in the Interim ANAE Classification Framework to describe characteristics of aquatic ecosystems in order to classify them (Aquatic Ecosystem Task Group 2012).

Attribute Classification: defines and categorises components of the environment into attributes and categories, and is not hierarchical within a level.

Attribute Themes: are broad groups used to describe attributes e.g. terrain, substrate, energy, hydrology (physical/chemical) and biota.

Attribute-Based Classification: a set of biophysical (biological, physical and chemical) attributes for describing and defining ecosystem types. The step of attribute-based classification separates the classification of attributes (e.g. depth, sediment size) from the designation of types (i.e. combinations of attributes) for a particular purpose (e.g. ecosystems). Examples of attributes include lithology, geology, substrate consolidation, water clarity, pH, and the presence and form of flora and fauna species. (AETG 2013)

Benthic: Pertaining to the seafloor (or bottom) of a river, coastal waterway, or ocean (modified from OzCoasts 2015). Benthic material can refer to substrate or sediment and it can be used to describe the organisms that live on, or in, sea floor, or at the bottom of a water column (Modified from Mount & Prahalad 2009)

Categories: A list of discrete values for an attribute, which provide for the complete domain of the attribute and are mutually exclusive. That is, a category must be available for any observed value (even if this is a category of 'other', 'none' or 'unknown'). Categories need to be applied at a resolution appropriate to the level (scale) that the attribute is being applied and should be based on environmentally relevant thresholds where possible.

Classification: A process of simplifying complex, and sometimes continuous, data and information and converting it into practical categories to make it more usable. Through classification, attributes can be classified into categories, independent of one another, enabling synthesis of the parts (components) and processes of different ecosystems. (Environmental Protection Agency 2005)

Collapse down: occurs when a decision is made to 'group up' known categories that are not relevant to the question, in order to simply the detail during the initial stages of typology. This process needs to be guided by the purpose of the typology and final audience for the typology, so as to provide the appropriate number of types that can be easily understood.

Community: A level of the 'Queensland intertidal and subtidal ecosystem classification scheme' that is the scale at which field inventory is conducted, people snorkel or dive, fish from boats etc. (see (Done 1999))

Components: parts of an ecosystem (the physical, chemical and biological parts that make up the environment) and spatial attributes (Aquatic Ecosystem Task Group 2012).

Confidence: Degree of confidence that inventory information reflects what is present in the field. There are a number of measures of confidence: spatial accuracy (an object is where specified); attribute accuracy (an object is accurately identified); the surrogate's own confidence measures; or an expert's confidence in a model.

Cross-walking: A method or protocol for comparing and translating classification standards into a common language based upon common attributes (see AETG 2012). A **crosswalk** is a table that shows equivalent elements (or "fields") in more than one database schema. For example, the European Union has a crosswalk protocol to translate its EUNIS habitats classification to an ecosystem services classification, MAES (Mapping and Assessment of Ecosystems and their Services) see Evans *et al.* 2014.

Decision Filter Table: a sequence of rules for each type, based on the order of the attribute hierarchy.

Dimension Reduction: Where datasets representing attributes that are continuous in time and space are represented in fewer dimensions e.g. 'time-slices', 'depth-slices'. Dimension reduction can occur during inventory; during classification during data assembly, cross-mapping categories, thresholding, interpolating, reclassification, or when resolving common boundaries of mapped attributes and or ecosystem type units.

Drivers: the reasons interactions occur between components and processes of an ecosystem (Aquatic Ecosystem Task Group 2012)

Ecosystem-Based Management (EBM): A management approach that considers the relationships between systems, the consequences of impacts on systems and informs decision-making around initiatives and actions to successfully manage systems (Foley *et al.* 2013)

Ecosystems: are a dynamic complex of plants, animals and microorganisms and their non-living environment, interacting as a functional unit (Wetlands 2015; AETG 2012)

Enduring Attributes: attributes that are relatively more persistent over time and less mobile. Non-enduring attributes are more variable over time in terms of their persistence, duration and/or periodicity (see Valesini *et al.* 2010).

Estuarine: freshwaters sometimes diluting oceanic waters, usually semi-enclosed by land (AETG 2012; Cowardin *et al.* 1979).

Generalisation: the process of spatially simplifying information - by abstraction, reduction and simplification of features to accommodate change of scale or resolution (ESRI Support 2017).

Habitat: A level of the ANAE classification, defined as aspects of the landscape (or seascape) that are dependent on water, including the major aquatic systems based on Cowardin *et al.* (1979) for surface waters (marine, estuarine, lacustrine, palustrine, riverine and floodplain.) (AETG 2012)

Intertidal: part of the shoreline that is found between the high tide and low tide, experiencing fluctuating influences of land and sea (OzCoasts 2015b)

Inventory: involves the recording of standardised data about a taxonomic group, habitat or ecosystem from available data sources or through survey (Wetlands 2013c). *Inventory, WetlandInfo*, Department of Environment and Heritage Protection, Queensland, viewed 15 August 2017, <https://wetlandinfo.ehp.qld.gov.au/wetlands/assessment/inventory.html>.

Levels (Scales): The spatial hierarchy at which ecosystems occur is referred to as levels. The 'Queensland intertidal and subtidal ecosystem classification scheme' uses five levels of scale, referred to as levels; region, subregion, seascape, habitat and community. Region, seascape and habitat scales align to the national ANAE framework (AETG 2012)

Marine: oceanic waters (AETG 2012; Cowardin *et al.* 1979)

Metric: is a specification for how an attribute will be measured. It may be binary ('yes' or 'no', 'present' or 'absent'), a ranking (high, medium, low), or a number (Aquatic Ecosystem Task Group 2012). Metrics can be continuous or categorical, qualitative or quantitative and are often informed by biological processes.

Preliminary Types: An ecosystem created during typology, consisting of specific combinations of attributes and categories. A type description describes the nature of the ecosystem in terms of biophysical attributes.

Processes: interactions between the components of an ecosystem (AETG 2012)

Qualifiers: are descriptors of variability applied to an attribute. Several qualifiers have been identified: naturalness, trend, period, cover, biotic height and biomass. These qualifiers are not standalone attributes but should be implemented, where appropriate, by adding additional information to the categories of existing attributes.

Reclassification: occurs after rule-sets have been run or mapping undertaken to develop types during later stages of typology.

Region: A broad scale, high level of regionalisation to characterise aquatic ecosystems at a national /regional scale, broadly placing aquatic ecosystems into regions using an ecological underpinning. This provides an overall framework for subsequent finer scale levels (AETG 2012)

Rule-set: consists of one or more rules necessary to define a type during the typology process. These rule-sets determine the combinations of categories for each attribute that define a particular type.

Scale: the parameter that describes the level of geographic resolution and extent, the context of space and time and helps define the positional accuracy (Quattrochi and Goodchild 1997)

Seascape: Analogous level to landscape level of ANAE, defined as a finer-scale aquatic ecosystem regionalisation based on attributes that are relevant at a landscape scale (e.g. climate, landform, topography and water influence) (see landscape – AETG 2012)

Spatial Attribute: A spatial attribute is applied to a mapped feature, once an attribute classification and typology is devised and draft types are mapped. Spatial attributes often investigate a pattern across two or more spatial levels, and need to fit within a hierarchy of scales. Spatial attributes are especially suitable for classifying geomorphic features. Examples are: “distance from”; “proportionate distance from”; “falls within”; “relative location”; “neighbourhood of”; “enclosure by”; “proportions of”; “relative proportions of”.

Structural macrobiota: Sessile (attached) flora and fauna which increase spatial complexity (rugosity) and alter local environmental conditions of ecosystems, creating living space for other animal and plant species. Consequently ecosystems having structural macrobiota are biodiverse assemblages (after Lilley and Schiel, 2006 *in*: Mount *et al.*, 2007; AETG 2013)

Subregion: A level of the 'Queensland intertidal and subtidal ecosystem classification scheme' where a pattern of seascapes with consistently similar attributes is visible; falling between Regional and Habitat scales. This scale is compatible with the scale of bioregionalisation used by the Great Barrier Reef Marine Park Authority and the subregions of the Regional Ecosystems framework (Kerrigan *et al.* 2010; Sattler & Williams 1999).

Substrate: The sediment and other material that comprises the seabed (or floor) (OzCoasts 2015b).

Subtidal: permanently below the level of low tide, i.e. continuously submerged within tidal waters (OzCoasts 2015b)

Supplementary Information: attributes, categories and qualifiers not used for typology but also describe biophysical features of a type

Surrogate: a method used to collect, model or infer the value of field attribute data (e.g. remote sensing, interpolation of field values). Surrogates may improve or change, but the attribute does not alter.

Threshold: is a 'cut-off' value that is applied to divide continuous metrics of an attribute into groups, creating discrete values for a category. The 'cut-off' values need to reflect meaningful changes in biological and physical attributes at the scale or level of interest.

Tier: refers to the ecological resolution of a category. A category can be divided into 'tiers' depending on the resolution of ecological pattern at the relevant level and the extent to which it is delineated. Applying tiers to categories enables a wide variety of available inventory data to be used, from broad to fine ecological and/or taxonomic resolution in the similar way to Broad Vegetation Groups of Queensland (Neldner *et al.* 2017). Tiers available are: C1 master, C2 broad, C3 fine, C4 micro. The master 'tier' of a category is its broadest level of resolution (C1).

Type Naming Convention: how an ecosystem will be named and described in terms of its biophysical attributes

Typology: a set of rules that are applied in a hierarchy to the attribute classification to identify types for a specific purpose. Different typologies can be developed from the same attribute classification to fulfil different purposes. (AETG 2013)

Unique Or Rare Ecosystem Types : ecosystems that rarely occur, due to either a rare combination of biophysical attributes or reduced extent due to human changes.

Water Column: is the vertical water mass between the surface of the water and the substrate. Includes physical, chemical and biological attributes including water, including: water temperature and salinity conditions, biogeochemical features. These suite of attributes can vary concurrently, forming vertical layering or water masses (see also 'hydroforms' of the Coastal and Marine Ecological Classification Standard (CMECS) - Federal Geographic Data Committee 2012).

6.7 Classification scheme collaboration and consultation

6.7.1 Workshops held to develop the classification scheme

Panel topic	Southern Queensland	Wide Bay/Great Sandy	Central Queensland	Northern Queensland
Benthic classification	10-11 Feb 2014	16 Dec 2015	10-11 Dec 2013; Apr 26-27 2017	19-20 Feb 2014
Water column classification	20-21 June 2014			14-15 June 2014
Geomorphology	24 March 2014			
Technical groups	29 July 2014	*3 Feb 2016*	5 August 2014 26 Apr 2017	
Classification and typology	28 Jan 2015	*13 July 2016*	30 Jan 2015	Feb 2015
Coral classification			8 June 2017	

6.7.2 Stakeholders involved in developing the classification scheme

A total of 120 people attended the 17 workshops held 2014-2017, of whom twenty attended three or more workshops (see Acknowledgements)

NGOs, conservation groups and monitoring organisations

- Great Barrier Reef Foundation
- Mangrove Watch
- Reef Check Australia
- Seagrass Watch
- Wildlife Preservation Society of Queensland
- Gladstone Healthy Harbours Partnership[#]

Corporations and consultancies

- Auricht Projects
- BMT-WBM
- Gladstone Ports Corporation^
- Marine Conservation and Fisheries Management Consulting
- Nearshore Marine Science Pty Ltd*
- Vision Environment Queensland
- Infofish Australia
- Earth to Ocean

Australian Government

- Australian Institute for Marine Science (AIMS)
- Commonwealth Scientific and Industrial Research Organisation (CSIRO)^ +
- Department of the Environment^
- Geoscience Australia+#
- Great Barrier Reef Marine Park Authority (GBRMPA) ^*#

State Government (Queensland)

- Department of Natural Resources and Mines+
- Department of Agriculture, Fisheries and Forestry^#
- Department of Environment and Heritage Protection^+
- Department of National Parks, Recreation, Sport and Racing^
- Department of Science, Information Technology and Innovation^+
- Queensland Museum
- Museum of Tropical Queensland

Natural Resource Managers

- Burnett-Mary Regional NRM Group #>
- Fitzroy Basin Association>
- SEQ Catchments (including Healthy Waterways and Catchments) *
- Qld Water

Scientific organisations

- Central Queensland University
- Gladstone Healthy Harbour Partnership Independent Science Panel
- Griffith University
- James Cook University+#
- Macquarie University
- Queensland University of Technology
- Southern Cross University
- University of Queensland
- University of the Sunshine Coast
- University of Wollongong

^ representative on Reference Group – Estuarine and Marine Classification project
* representative on Technical Working Group – Estuarine and Marine Classification project
# representative on Advisory Group – Intertidal and Subtidal Classification CQ Project
+ representative on Project Team – Intertidal and Subtidal Classification CQ Project
> representative on Technical Advisory Group – Intertidal and Subtidal Classification CQ Project

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