Queensland Intertidal and Subtidal Ecosystem Classification Scheme Version 1.0

Module 4

A method for providing baseline mapping of intertidal and subtidal ecosystems in Queensland

September 2020

Queensland Government
Queensland
Wetlands Program

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Contents

Document Outline

This Queensland Intertidal and Subtidal Ecosystem Classification Scheme (the scheme) was developed as part of the Queensland Wetlands Program (DES, 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 are available 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
- Module 3: Attributes, categories, and metrics for the intertidal and subtidal ecosystem classification scheme (online as web pages on Wetland*Info)*
- Module 4: A method for providing baseline mapping of intertidal and subtidal ecosystems in Queensland (current document).

Module 4 applies the framework of Module 1 to mapping, addressing the following topics:

- key concepts and principles of attribute-based mapping
- stages and steps of mapping (including spatial database design principles)
- mapping classified attributes, including:
    - how to choose attributes for mapping using the scheme
    - how to align source attribute datasets to the scheme
    - how to capture information about anthropogenic changes (naturalness)
    - how to compile a spatial attribute dataset from source datasets
    - how to compile source datasets into a spatial attribute layer, based on confidence.
- capturing expert technical advice to inform classification and mapping
- mapping ecosystem types
- developing typology rule-sets in a way that can be mapped
- product release and finalisation
- quality assurance:
    - confidence, including method and source data limitations
    - continuous improvement, including knowledge gaps and inventory standards.

1. Introduction, scope, purpose, and rationale of the intertidal and subtidal classification scheme

1.1 Background and rationale for the approach

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.des.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. Comprehensive classification schemes are in place in Queensland for terrestrial regional ecosystems (Sattler & Williams, 1999; Neldner *et al.*, 2012), freshwater wetlands (EPA, 2005), groundwater dependent ecosystems (Glanville *et al.*, 2016; DSITI, 2015), waterholes (DES, 2020a) and intertidal and subtidal ecosystems (DEHP, 2017a).

Although there is a classification scheme for intertidal and subtidal ecosystems, and there are many mapping datasets available, there are no integrated core datasets on which to make management decisions. The most optimal approach to mapping would have been to gather new inventory to populate the attributes, but this would have been very costly and time consuming. The most effective approach, and the one adopted, was to gather and collate existing datasets and translate them into the common language of the classification scheme to develop the mapping and supporting spatial dataset. While this approach harnessed the considerable resources, which had already been expended in mapping, it also resulted in significant resources being spent in obtaining data, negotiating collaborative agreements, and integrating the datasets.

As part of the QWP, this project was led by the Queensland Department of Environment and Science (DES) in collaboration with the Queensland Department of Agriculture and Fisheries (DAF), the former Department of Science, Information Technology and Innovation (DSITI), the former Department of National Parks, Sport and Racing (DNPSR), and the 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 Module 1, Appendix 6.2, DEHP, 2017a).

The GPC provided some of the financial assistance toward the development of the scheme as part of a fish habitat initiative required to meet fish habitat offsets associated with approved development conditions. Funding was delivered through DAF, including part-funding under DAF 1498CQA-2 toward the Intertidal and Subtidal Habitat Mapping and Conservation Values Assessment for Central Queensland State Waters Project (DEHP 2017a, DEHP 2017b).

1.2 Scope and feature of intertidal and subtidal ecosystems

Ecosystems are a dynamic complex of plants, animals and microorganisms and their non-living environment, interacting as a functional unit (DES, 2015b; AETG, 2012). Intertidal ecosystems are found between the high tide and low tide limits, experiencing fluctuating influences of land and sea, whereas subtidal ecosystems are permanently below the level of low tide, that is continuously submerged within tidal waters (OzCoasts, 2015a). The tidal waters inundating intertidal and subtidal ecosystems can be fresh, brackish, saline (usually oceanic) or even more saline than oceanic waters (hypersaline) (Ribbe, 2014).

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; DES, 2015a; 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 (see Box 1).

Box 1

The Queensland Intertidal and Subtidal Classification Scheme has been designed to cover all ecosystems within Queensland state waters and is not confined to the six-metre limit of the wetlands definition (DEHP, 2017a).

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

While the project was developed through the QWP, the scheme extends beyond the definition of wetlands (DES, 2013a) 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 six metres depth in the marine environment (reflecting the original Ramsar convention's emphasis on waterfowl – Ramsar Convention on Wetlands, 1971, AETG, 2012). The principles, methods and attributes of the scheme could also be applied to any Australian or international intertidal and subtidal ecosystem.

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, 2017a; 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, 2017a). 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 & 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 (DEWHA, 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).

The scheme addresses the principles of EBM (as outlined in Leslie & 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 the 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 by 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 EPA, 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, establishing a current understanding of the system to inform

In summary, the development of a standard intertidal and subtidal ecosystem classification scheme provides a foundation and structure that serves a wide range of applications including:

- a framework for classification, data capture, storage and retrieval, mapping and monitoring

- assessing, understanding, and communicating ecosystem values and processes
- informing a range of management and planning uses
- direct use in on-ground decision-making.

For further information refer to Table 1 in Module 1 (DEHP, 2017a).

1.4 Advantages of applying attribute classification and typology to mapping

To understand the nature and extent of an ecosystem, it is necessary to describe its characteristics or features (attributes). In classifying an ecosystem, the user applies a set of biophysical (biological, physical, and chemical) attributes that describes ecosystem types. The scheme was developed in stages that separate the assembly of the attributes of an ecosystem (attribute classification e.g. depth, sediment size) from typology, a set of rules applied in a hierarchy to the attribute classification to identify types for a specific purpose.

Accurate mapping of attributes and types supports the following outcomes:

- provides an information resource for natural resource management and planning process
- guides investment in natural resource management
- guides research into intertidal and subtidal ecosystems
- guides investment for further survey and inventory to fill gaps in the distribution of intertidal and subtidal ecosystems
- provides an information resource for education and communication about intertidal and subtidal ecosystems, their functions, and values
- informs the assessment of the impact of proposed development on intertidal and subtidal ecosystems.

1.5 Purpose and use of this document

Purpose

The purpose of this document is to provide an operational approach to attribute-based mapping and spatial database design, based on the attribute-based classification framework and implementation principles of the Queensland Intertidal and Subtidal Ecosystem Classification Scheme as outlined in Module 1. While this method can be applied at any scale, the seascape scale examples within the document are drawn from the Central Queensland mapping project (DES, 2019b). The document does not provide the specific detail to operationalise the method.

Who should use this document and why?

The document is designed for scientists, citizen scientists, NRM groups, First Nations people and managers who are proposing to map intertidal and subtidal ecosystems in Queensland, or who may intend to map parts of these ecosystems as part of broader projects. By using this document and the attribute-based approach outlined in Module 1, spatial information will be produced from projects in a form which will allow for future integration into state-wide ecosystem mapping and databases. Projects may take many forms, such as inventory or monitoring programs, research projects to inform an ecological or management question or projects to address specific knowledge gaps.

Typical questions for projects may include:

- what biophysical factors are influencing the nature and extent of ecosystems?
- what ecosystems may be impacted by a development and what monitoring may be required to assess and monitor these impacts on ecosystems?
- what rehabilitation should be undertaken and what ecosystems may need rehabilitation?

- how are species using different ecosystems and how are they moving between these systems?
- how do fish use different ecosystems and how do the ecosystems support fisheries production?
- what is the current known nature and extent of ecosystems?
- where should new field data be collected and what kind of biophysical data should be collected?
- what standards are there for field and monitoring data?
- where monitoring sites should be located to represent ecosystem extent and type?
- have some biophysical attributes changed?

Module 4 is designed for people who understand how to design a mapping program. Spatial professionals will need to translate these scientific and ecological terms into software-specific terminology and processes required. See Glossary Appendix A1 which provides scientific terms and abbreviations, with equivalent terms for spatial analysts

2. Overview: Guiding principles and the stages

This section outlines the overall approach and stages of classification, typology, mapping, product release and the elicitation of spatial information from various technical working groups and experts.

2.1 Mapping approach – integration of datasets – opportunities and constraints

Existing ecosystem classification and mapping frameworks in Queensland, including regional ecosystems, wetlands, and groundwater dependent ecosystems, have required the integration and processing of a limited number of foundational base layers to develop standalone mapping products of ecosystem types. For example, soils and landzone mapping reconciled with geology and vegetation structure mapping informed early versions and the approach for Regional Ecosystem mapping (Sattler & Williams, 1999).

A very different situation exists across Queensland's intertidal and subtidal disciplines. Decades of independent mapping, monitoring and inventory of reefs, corals, mangroves, seagrass etc. for various projects, purposes, locations, and scales have resulted in multiple datasets. Spatial knowledge is located widely across government, consultancies and academia, in scientific journals, reports or grey literature, in data files that include a variety of monitoring, modelling datasets and in spatial databases, in online repositories, government servers, researchers' hard drives and digital video discs (DVDs). In this document these various data files are referred to as **source datasets**.

The Queensland Intertidal and Subtidal Ecosystem Classification Scheme provided the common unifying framework to collate these disparate datasets (DEHP, 2019b). However, a balance was necessary between integration effort and the usefulness of source data. Expectations are that, if a dataset exists, an effort should be made to integrate it, unless an improved or updated dataset is available for that attribute, otherwise an opportunity is wasted, or duplication may occur.

Occasionally, the resources required to integrate a dataset may exceed its applicability to the attribute or compatibility with the scheme.

Core datasets cannot be routinely assumed to exist. Routine collection of core data is seldom undertaken during specialised field inventory and some core data may only be a partial component of the field data. Most field projects only collect a subset of applicable attribute data, leaving gaps in core data (unless they contribute to a central repository of data if available). It is difficult to expect field scientists to add core attribute information when designing new survey work if the focus of their investigation is for a different purpose.

Due to the need to consolidate and integrate existing data, consultation was critical and required excellent communication and cooperation with data providers, fostering goodwill and an open sharing attitude. Activities focussed around group consultations, bringing together custodians from different disciplines to understanding attributes in common, the gathering of and sharing of datasets and contacts, and individual consultation between the expert and spatial analysts to ensure datasets aligned to the common language of the scheme. This approach was very time-consuming, involving lengthy negotiations to establish data sharing agreements, often with uncertainty as to the suitability of the final product. Benefits include a shared vision with collaboration opportunities.

There was also a need to work across many different disciplines with different terminologies and expectations, and deal with the different license conditions of datasets. Transparency when processing and/or merging datasets enabled the integrity and intellectual property of source datasets to be protected, without breaching license conditions. A good relational spatial data model ensured both transparency and confidentiality were maintained (refer to section 2.4 and Box 5 for more on data models and relational databases).

2.2 Classification stages and spatial considerations, mapping terms and outputs

Classification stages are briefly summarised from Module 1 (section 3.1 page 16, DEHP, 2017a) where the basis, concepts and features of attribute-based classification were introduced, including alignment between the scheme and Regional Ecosystem and freshwater wetlands classifications. Key features and principles of attribute-based classification were explained, notably that an attribute-based classification is applied through separate **classification, typology, mapping, and product release stages** (Figure 1 and 2). Module 1 Part 2 (DEHP, 2017a) provides a detailed description of the classification and typology stages and terminology which are a prerequisite for mapping (Figure 3). These stages and terminology are reiterated below, where relevant to mapping and spatial data synthesis (Figure 3 and Boxes 2, 3 and 4).

The concept of **attribute classification** was introduced, where biophysical factors or attributes were assembled that underpin the nature and extent of ecosystems addressing a particular scale and purpose. At the initial stage, an attribute classification is a simple list of independent attributes and categories. During the mapping stage, **a mapped attribute** is created from the assembly of spatial datasets associated with an individual attribute. This is done for each attribute, thereby creating the **set of mapped attributes associated with an attribute classification** (defined in Box 2). An attribute classification when compiled into a spatial synthesis database is a versatile product, suitable for developing a number of different **typologies**, depending on the purpose for each typology and the combinations of attributes used.

Box 2

*A **mapped attribute** is a map of an attribute, with its levels, categories, metrics, and thresholds spatially defined and described (see section 5.3.2, page 47 in Module 1, DEHP, 2017a).*
*A **set of mapped attributes associated with an attribute classification** is a series of collectively mapped attributes that correspond to an attribute classification, with their levels, categories, metrics and thresholds spatially defined and described (see section 5.3.2, page 47 in Module 1, DEHP, 2017a).*
*A **mapped typology** is a map of ecosystem types based on specified combinations of mapped attributes according to hierarchical rule-sets, which describes the order in which each attribute is used in the typology mapping (see section 5.3.3 , page 48 in Module 1 'Map the types', DEHP, 2017a).*
*A **typology 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 (from Module 1 glossary page 67, refer to section 5.2.4 page 41, DEHP, 2017a).*
*Note: a typology rule set becomes a **typology mapping rule set** when the typology rules are applied to attribute datasets to create a mapped typology.*

Although mapping is represented as the third stage of a classification and typology application (Figure 1 and 2), there are mapping considerations at all stages and these are further detailed from a mapping perspective in Figure 2.

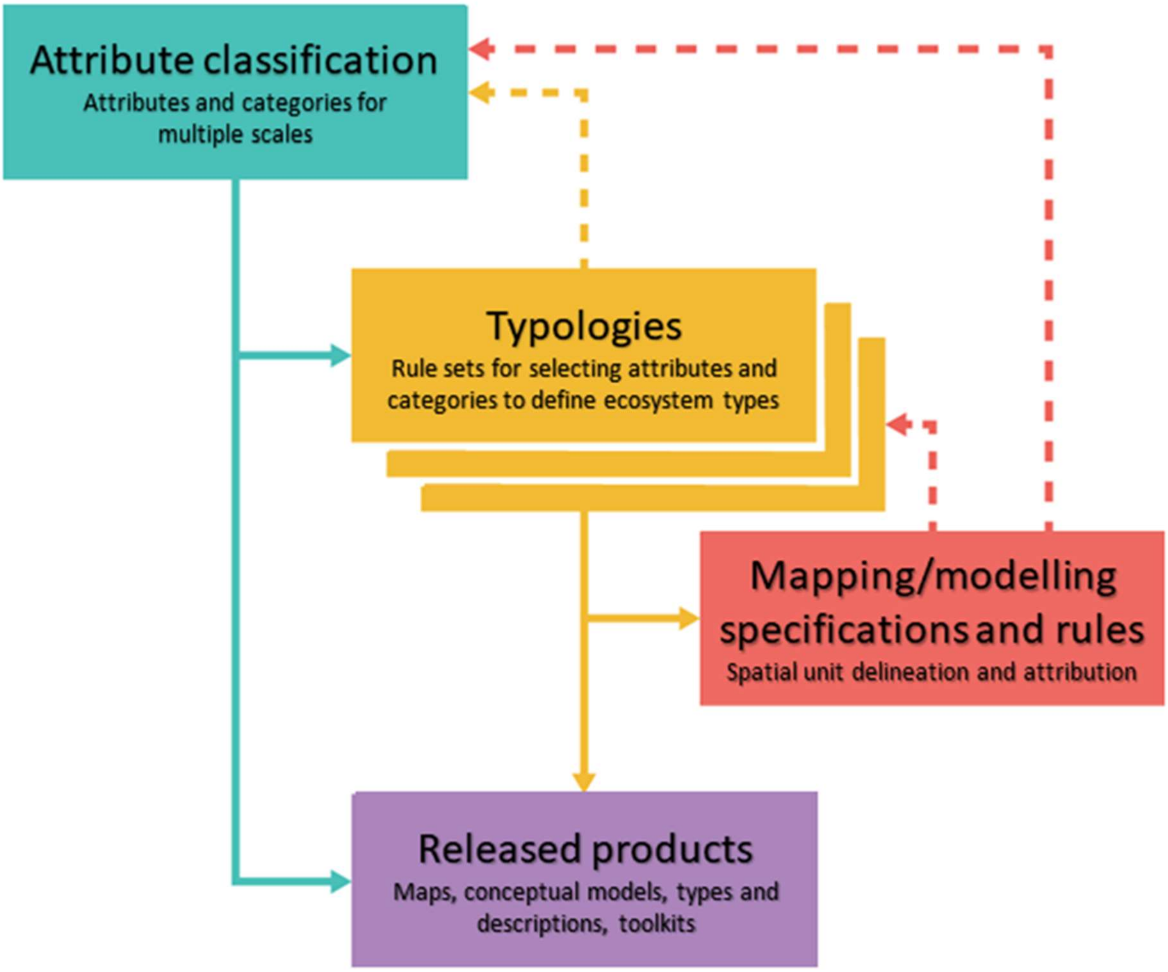


Figure 1: Stages of attribute-based classification. Relationships between the stages of attribute classification, typologies, mapping, and product release, taken from Module 1 (DEHP, 2017a).

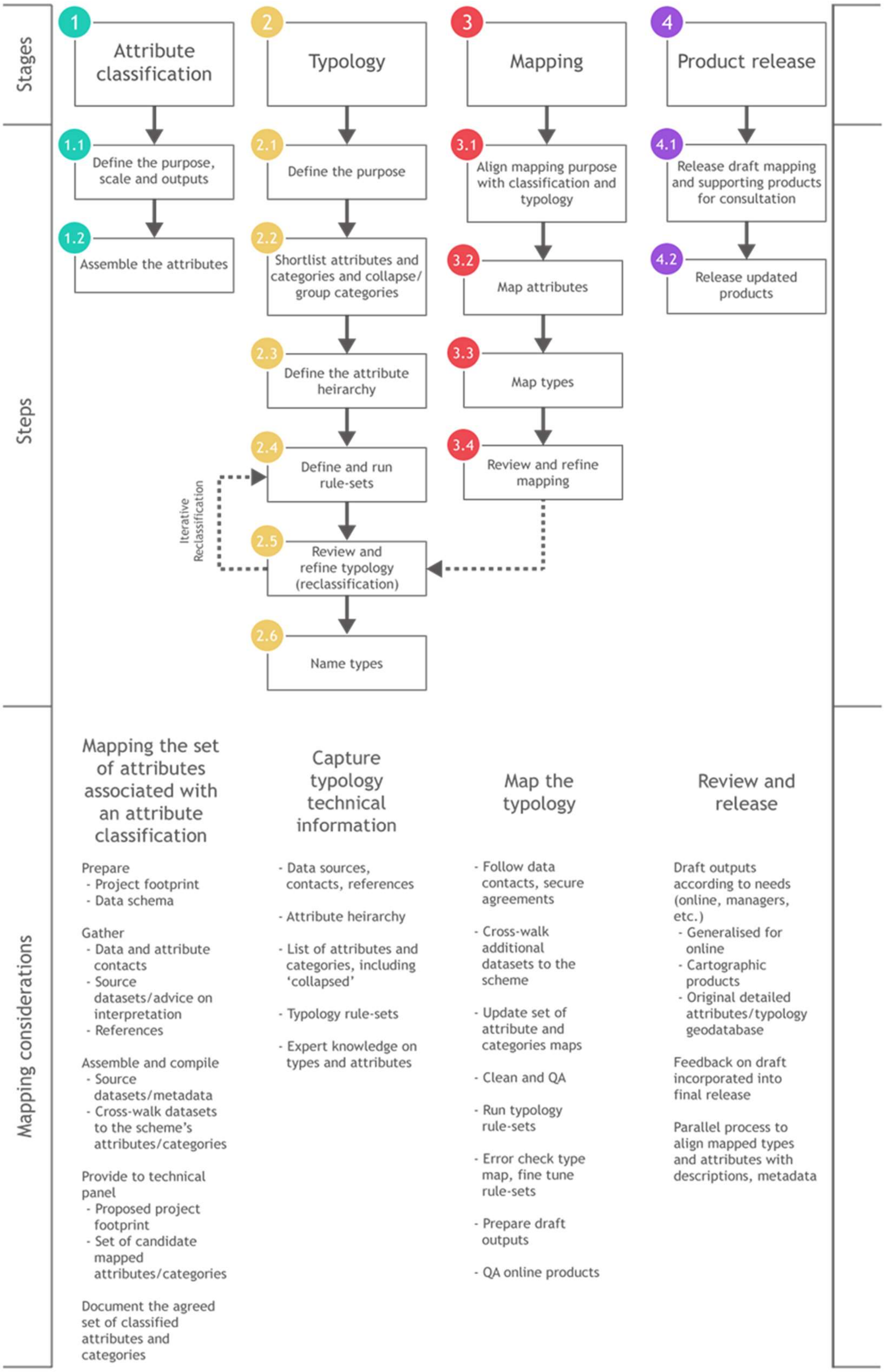


Figure 2: Stages and steps of attribute-based classification. Expanded from Figure 1.

Stages of classification are expanded into a series of steps (boxes, Figure 2) and possible outputs from each stage. There are mapping considerations at each of these stages.

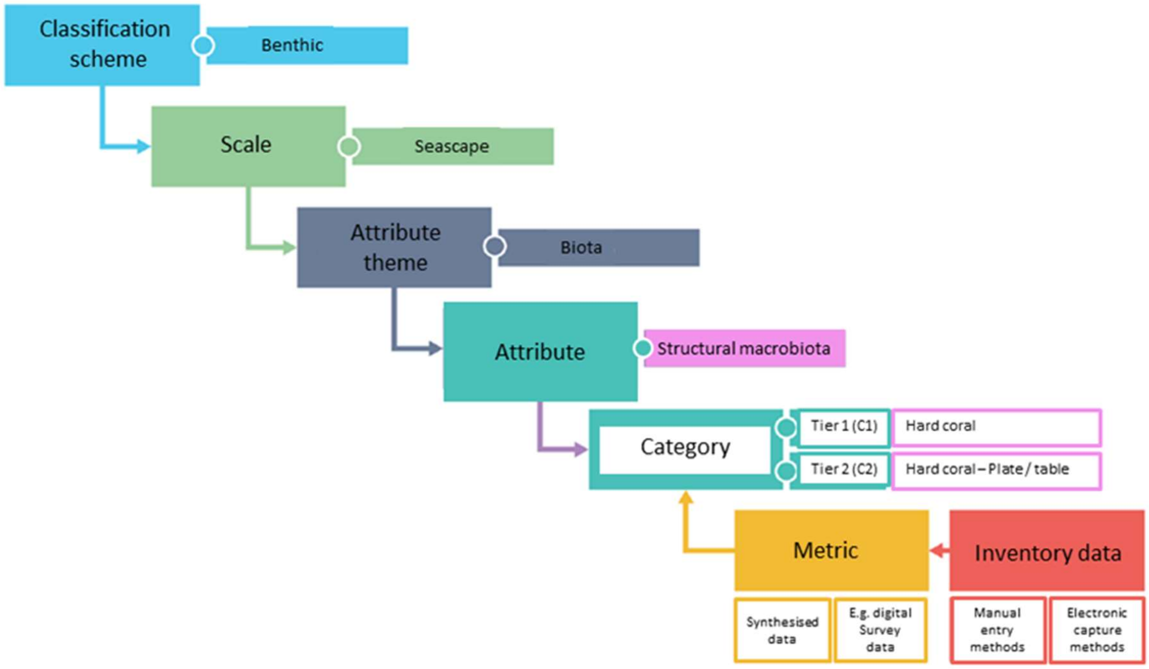


Figure 3: Terms of an Attribute Classification - (Box 3 and section 3.4 Module 1, DEHP, 2017a). In this example, the attribute structural macrobiota has a category 'coral', either hard coral (tier 1) or if inventory data is available, plate/table (tier 2).

Box 3

Attribute classification terms *(see section 6.6 Glossary for definitions page 65 Module 1, DEHP), 2017a):*

- ***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*
- ***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 (AETG, 2012)*
- ***Categories*** *are 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 (from Module 1 page 22 section 3.4, DEHP, 2017a)*
- ***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 (AETG, 2012). Metrics can be continuous or categorical, qualitative, or quantitative and are often informed by biological processes*
- ***A surrogate*** *may be a method or dataset 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 ('surrogate' means 'substitute', from the Macquarie Dictionary).*

Metrics are spatially defined and delineated using surrogates. Surrogate methods or datasets are often used to infer where attributes and categories are present as it is not always possible to collect detailed field data (Module 1 page 28, DEHP, 2017a). Examples of surrogates are provided in Figure 11 and 12.

Box 4

Typology terms – reference *(see section 6.6 Glossary for definitions page 65 Module 1).*
A ***typology*** *is 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; also DES, 2017a, glossary – note 'rule-set' and 'a set of rules' are equivalent terms – see Box 2).*
The following definition relates to a ***mapped typology*** *and its products:*

- ***Mapped co-types*** *result where typology rule-sets match more than one type, when applied to a set of mapped and classified attributes associated with an attribute classification. (Mapped co-types are derived from the second field value in concatenated type fields).*

The following is a brief outline of the typology process. Refer to Module 1 for a more detailed description of typology, section 5.2, pages 37 to 49. Mapping of types is introduced in sections 5.3.3 to 5.3.5, pages 48 to 49 (DEHP, 2017a).

Typology takes an attribute classification, applying its attributes and categories in a defined sequence similar to a flowchart or a dichotomous key (an example is shown in Figure 4 as an inverted tree – see also Module 1, Figure 10, page 41, DEHP, 2017a). The attribute classification on which this typology was based would include four independent attributes, depth, structural macrobiota, consolidation and sediment texture, with no implied relationship between these attributes. The rule-sets check specific categories of chosen attributes, which can be used to describe a type (see Box 2 and Figure 4).

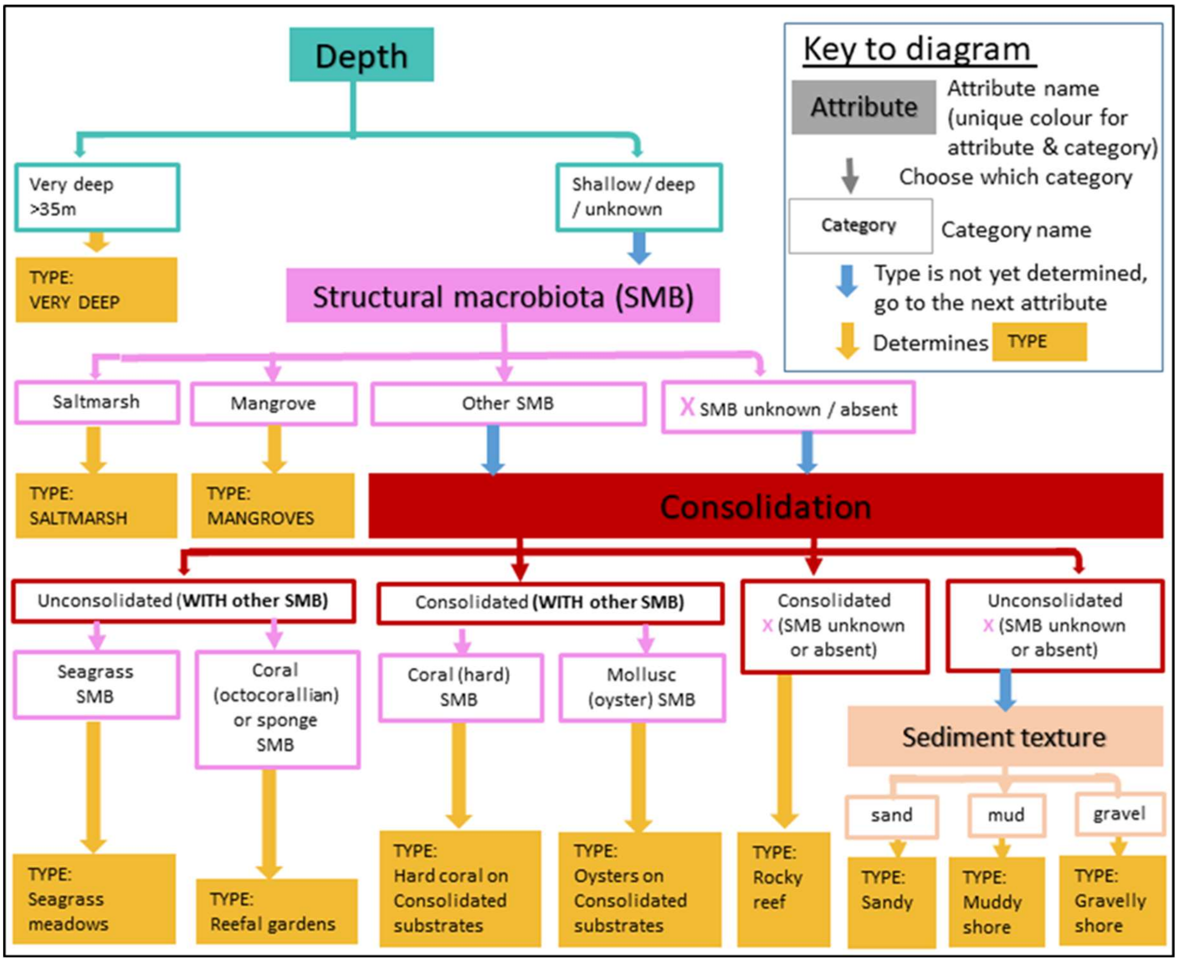


Figure 4: An Example of a Typology Tree. A typology provides a hierarchical set of rules to apply to the attribute classification to identify types. This typology is based on four attributes, each with its own colour codes – depth, green, structural macrobiota, pink, consolidation, red-brown and sediment texture, skin tone. Typically, there are many more available combinations (e.g. hard corals or oysters could grow on unconsolidated substrates, etc.) not included here. Types are determined by choosing a category from one or more attributes – if the type is not determined by the first attribute category, then follow the blue arrow through to the next attribute.

2.3 Capturing technical advice to inform mapping

The incorporation of expert advice is a fundamental activity in the application of the scheme. This collaboration and consultation process provides robustness, transparency, and a scientifically defensible level of quality assurance in the final products. Expert technical advice is used in the scheme, throughout the process (see Figure 5).

Experts may include prospective users, scientists, managers, government officers, Traditional Owners, consultants, industry, and local experts with an understanding of intertidal and subtidal ecosystems. Technical experts should provide input through a working group of scientists and managers, during facilitated workshops, prior to and during the application of the scheme, out-of-session, and in reviewing draft products. Different experts will require different consultation process, based on the nature of the advice required and the individual expert involved.

Scope of technical advice required - technical experts should be encouraged to provide broad spatial advice and make specific decisions during the facilitated workshops and specialist working groups. Experts should also review draft products of the typology and mapping process (see section 6).

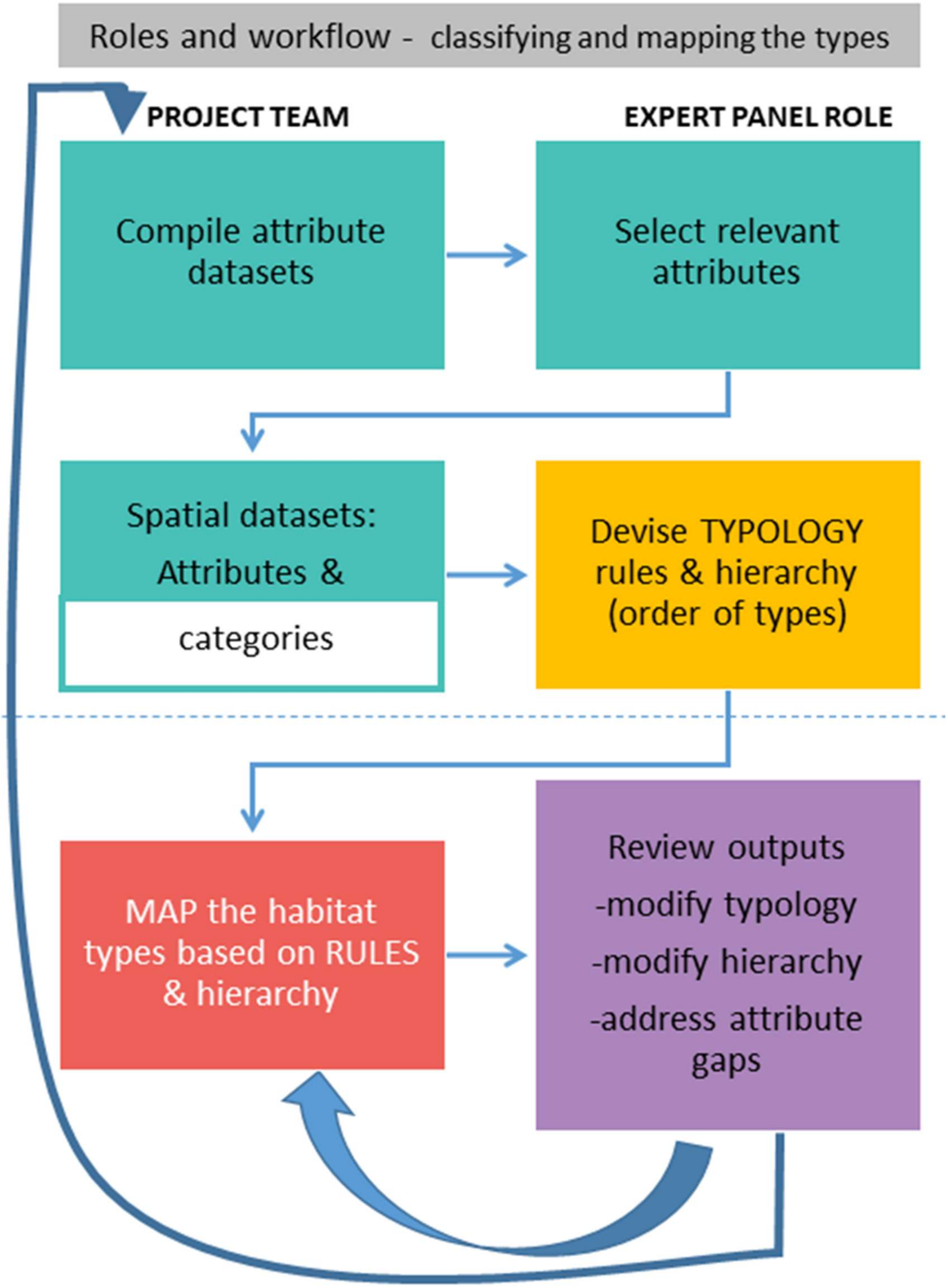


Figure 5: Technical Advice and Mapping Roles - Workflow. The project team and the technical experts collaborate in defining attributes and categories, devising a typology, and reviewing mapped outputs.

2.4 Classification scope and implications for mapping

Scope decisions all have spatial (mapping) implications, such as which datasets and resources will be required for spatial analysis, the design of the spatial information system and relational data model, and which output products are required (see Box 5). Scope decisions should include:

- **defining the project purpose** by clearly articulating the classification and mapping intent in terms of project objectives, potential users and outputs required. Will a set of mapped attributes associated with an attribute classification suffice (no integration of attributes with other attributes to form types), or is a mapped typology also necessary? While a set of mapped attributes associated with an attribute classification is resource intensive, the development of mapped attribute datasets builds collaboration across many disciplines and provides products for multiple purposes and stakeholders.
- the **boundaries of the area** should reflect boundaries of biophysical attributes as far as possible, although often studies are constrained to human boundaries (e.g. state, council or NRM regions). Suitable attributes to delineate an area of interest include inundation (e.g. the intertidal extent based on tidal planes, subtidal extent etc.), benthic depth (e.g. depths aligned to photic depth, the continental shelf etc.), tidal range (e.g. macrotidal, microtidal), energy (e.g. high vs low wave energy) or climatic zones.
- whether a **benthic** or **water column** classification is required. Water column attributes may require modelled outputs that need to be summarised over time.
- the **scale** or **level** of the classification (i.e. the spatial hierarchy at which ecosystems occur) that aligns to the agreed purpose. A different suite of attributes and categories will operate at different levels. For example, regional and subregional attributes and patterns will influence levels below (e.g. seascape, habitat and community; see Table 1 and Figure 6). The scale or level determines:
    - attributes to be mapped and the combinations of attributes to create types
    - the degree of spatial representation required, for example at a finer scale or level (e.g. habitat, community) available spatial datasets are of a higher resolution and need significantly more resources to process (see Table 1 and Box 5, also Module 1, section 3.2, (DEHP, 2017a).
- defining the temporal scope of the typology and how variation within a period should be treated (e.g. application of period and trend qualifiers – see section 3.4).

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	1:25,000 – 1:5,000	0.005ha/0.25m

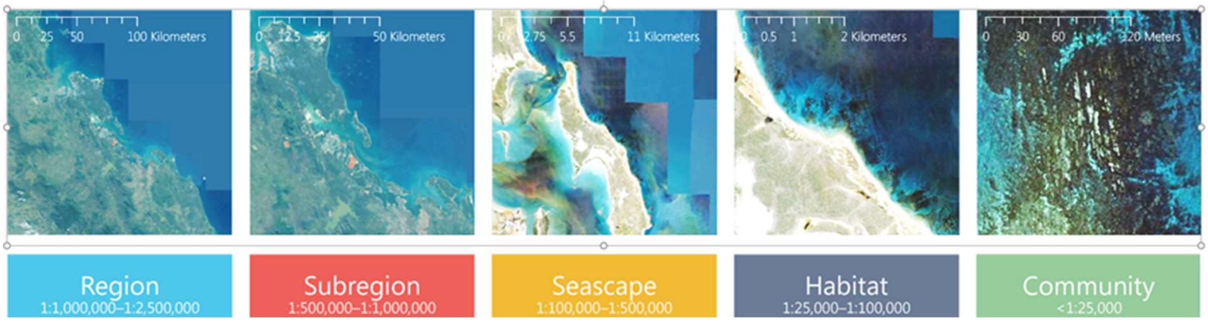


Figure 6: Five Scales (Levels) of the scheme. (As listed in Table 1, taken from Module 1, DEHP, 2017a).

Box 5

***A data model** is a way of defining and representing real world surfaces and characteristics in Geographic Information System (see definitions at Humbolt State University, 2019).*
*There are two primary types of **spatial data models**:*

- ***vector** data represents features as discrete points, lines, and polygons*
- ***raster** data represents features as a rectangular matrix of square cells (pixels).*

*A **relational data model** uses data tables to group elements into relations. The relations are linked by the use of keys (i.e. numeric codes used as an index), with the primary key used as an identifier to link multiple tables (i.e. a code common across all tables).*

3. Producing a set of mapped attributes associated with an attribute classification

A key purpose of the scheme is as a standard that can 'crosswalk' (translate) to other mapping or classification systems or datasets. Once datasets have a common language, they can be merged or translated into common biophysical attributes.

Depending on the purpose of attribute classification, a set of **mapped attributes associated with an attribute classification** may suffice if the purpose is to integrate datasets and identify gaps in attribute inventory. A set of mapped attributes associated with an attribute classification can be stand-alone or an essential prerequisite to mapping a typology (as in section 5.2). To produce maps of a set of attributes, spatial datasets that correspond to each attribute need to be assembled. For each attribute dataset, a specific **sub-method** or mapping approach may need to be developed based on the categories of the attribute available for crosswalking (see Box 6) and the surrogate datasets available to match (for the terms see Module 1 section 3.4 page 23, DEHP, 2017a). For a full list of the attributes see Module 1 Appendix 6.1 (DEHP, 2017a).

Once translated, the source datasets are then amalgamated in a way that best reflects their **scale and accuracy** (section 3.5, informing also quality assurance section 7.1.1).

> *Box 6*
>
> ***Crosswalking** is a method or protocol for comparing and translating classification standards into a common language based upon common attributes (AETG, 2012). A **crosswalk** is a table that shows equivalent elements (or 'fields') in more than one database schema (also written as cross-walk or cross walk).*

When crosswalking source datasets, their variability over time needs to be captured in separate **qualifier** fields (i.e. naturalness, period and trend, percent cover) that correspond to a record in the source data table (refer to section 3.4 and Module 1 section 3.4.2, page 25, DEHP, 2017). Datasets matched to a category need to be based on the best available metric at the time, given that metrics will change over time with improved technology.

3.1 Considering source datasets for a set of mapped attributes

It is important to understand the degree to which source datasets align with the scheme's attributes and categories. If the purpose and structure of source datasets differ greatly from the scheme, they may require pre-processing to produce data that will match. This section compares the structure of the scheme with potential source datasets of various purposes, schemas and structures, offering options for how to identify which information to crosswalk. Information about source datasets should be discoverable in metadata, which should adhere to appropriate standards to ensure they are discoverable and record sufficient detail to be useful (e.g. ISO metadata standards such AS/NZS ISO 19115.1:2015 Metadata, ANZLIC, 2015, DCAT2, W3C, 2020).

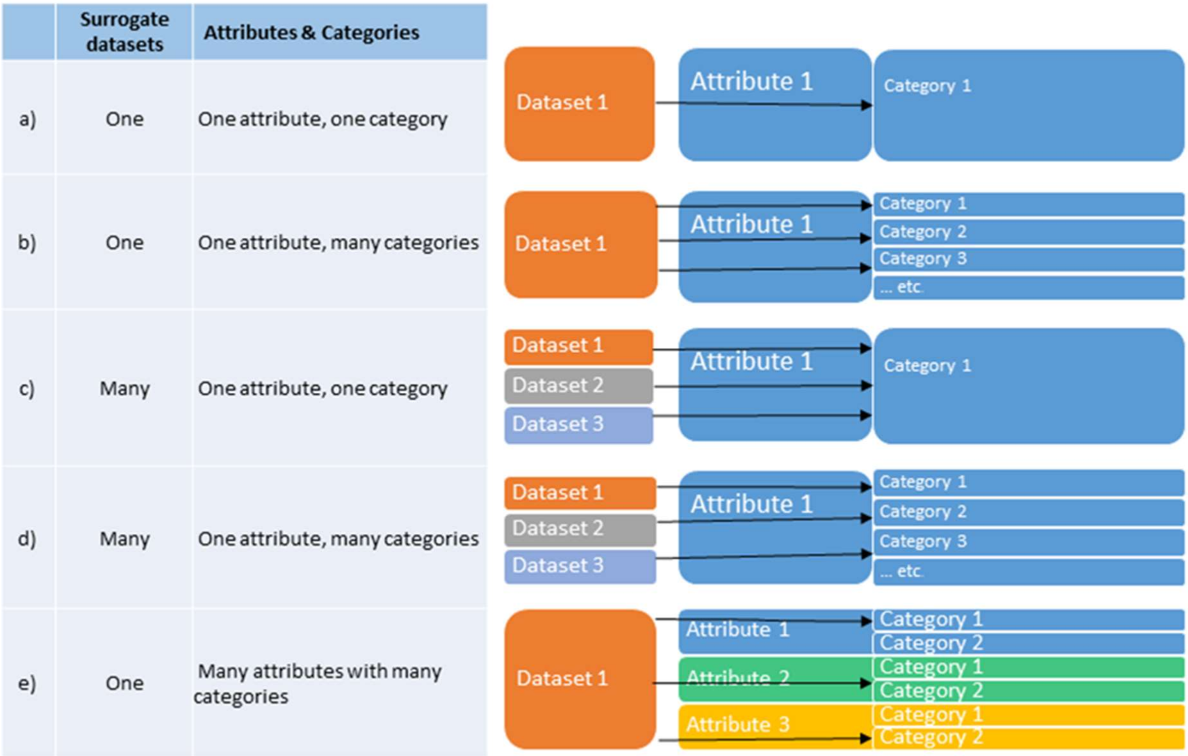
Matching the scale or level of the source dataset to the scheme - within the scheme, the categories of an attribute are assembled to reflect the way a biophysical attribute works in the real world. Matching the resolution of source datasets to the desired level or scale of the classification is achieved by applying the appropriate categories of the scheme corresponding to that **level** (see Figure 6 above, and refer to Module 1 page 50, appendices 6.1 listing available attributes, 6.2 seascape level and 6.3 habitat-level attributes and categories, (DEHP, 2017a)). Usually only a few categories are required for broader levels (regional, subregional), being progressively split into more categories at finer spatial scales (seascape, habitat, community) (see Figure 3 and the definition of

Tiers in Box 4). These decisions will ensure that, once assembled into a set, each of the attribute compilation datasets will be compatible with each other and with the purpose of the attribute classification.

For example, in the attribute of terrain slope, metrics include degrees, percentage slope or a ratio of height change to length change. Available surrogates may include a mix of field inventory including point sounding data, chart contours, modelled interpolations between data gaps, intertidal LiDAR (Light detection and ranging) datasets and multi-beam (MBES) surveys. Surrogates do not always provide the final attribute data required and may need to be processed. Each of these surrogate datasets has limitations in terms of sampling density, spatial and temporal resolution etc. which flows through to the accuracy of the mapping. Better field inventory will provide more precise surrogate datasets (further detailed in section 3).

Source dataset alignment with attribute-based approach - few intertidal and subtidal ecosystem mapping and classification datasets to date have used a fully attribute-based classification approach (refer to Module 2 for a review of classification schemes (DES, 2019c)). However, in Queensland, the Regional Ecosystem mapping (Neldner *et al.,* 2012) provides a good match to two attributes, inundation (tidal land zone 1) and structural macrobiota, enabling Regional Ecosystems (REs) to seamlessly integrate with the scheme. Datasets that are not fully attribute-based require more effort to identify which parts of the data will potentially crosswalk to attribute categories. Some vector data e.g. line or point data, may be useful to identify what category is present, but a different spatial dataset may be needed to delineate the feature. The metadata and lineage (workflow) of source datasets should be examined in detail before use.

Ways to apply source datasets to categories - the categories of a biophysical attribute are a human construct and are not always discrete in the natural world and classifying them can result in loss of information (dimension reduction, Module 1 section 3.6, DEHP, 2017a). Some datasets may be typologies that will need to be broken down into their core biophysical attributes before they can be used. Often biophysical attributes exist as mixtures (Module 1 section 3.4, DEHP, 2017a). The mixtures present in source datasets may reflect how the source data was captured in space and time, thus it is important to select the correct categories appropriate to the level or scale (Module 1 section 3.2, DEHP, 2017a). Crosswalking options are shown in Figure 7.



	Surrogate datasets	Attributes & Categories
a)	One	One attribute, one category
b)	One	One attribute, many categories
c)	Many	One attribute, one category
d)	Many	One attribute, many categories
e)	One	Many attributes with many categories

Figure 7: Ways to Crosswalk Source Datasets to Attributes and Categories. Various ways of crosswalking source datasets to attributes and categories, examples a, b, c, d and e, are described below.

There are several different data crosswalking options for an attribute:

- **one surrogate dataset** provides one category of one attribute (example a in Figure 7)
- **many surrogate** datasets contribute to a category of one attribute (example c in Figure 7), e.g. many datasets used for the 'consolidated' category in the Central Queensland project (see Figure 13 below, DEHP, 2017b)
- **one dataset provides many attributes and many categories** (see example e in Figure 7). A single source dataset may provide several different attributes and/or categories, which need to be extracted and stored separately. For example, a Landsat image has a 25 metres pixel and a source data thematic map derived from it (by classifying its reflectance, patterns etc.), can be used to identify areas of coral, rock, sand, macroalgae, seagrass, rubble and mud. This source thematic dataset will provide information for three different attributes and their respective categories:
    - consolidation 'consolidated' (the extent of hard coral and rock)
    - sediment grain size (or texture) 'sand', 'mud' and 'gravel' (i.e. rubble) providing components of a mud, sand, and gravel Folk typology (Folk, 1974, 1954)
    - structural macrobiota ('coral', 'seagrass', 'macroalgae').
- **different category datasets that overlap** need to be stored separately. In the above Landsat example, the polygons of coral, macroalgae and seagrass will each become part of a composite layer for structural macrobiota that is combined with other attribute datasets during the process of mapping a typology
- **multiple timescales or temporal summaries** from dynamic models represent mixtures of spatial biophysical data which change over time. Depending upon their format, temporal datasets need to be reclassified or need additional processing before they can be incorporated into an attribute dataset (e.g. reclassified to a summary statistic per time

interval such as mean, standard deviation, number of presences vs absences and so on). For further discussion on temporal changes, see period and trend qualifiers in section 3.4:

  - **one dataset within an attribute can provide many categories** (one dataset, one attribute, many categories, example b in Figure 7) such as different temporal summaries of a surrogate inventory dataset across time. For example, the 'data cube' derived Intertidal Extents Model (ITEM, Sagar *et al.*, 2017) and later National Intertidal Digital Elevation Model (NIDEM, Bishop-Taylor *et al.*, 2019) dataset show average tidally inundated areas where alternating tidal and water pixels are detected. In the Inundation attribute, outer ITEM pixel boundaries were used as tidal extent
  - **an extract from a dynamic model** such as wave or tidal current energy can provide the metric that best reflects ecological differences (example b in Figure 7). For example, in the structural macrobiota attribute for a coral map of the Capricorn Bunker Group, different wave energy metrics were used to model the distribution of various coral growth forms (e.g. branching, massive, plate). Six of the best available wave energy magnitude predictors of coral growth form (e.g. significant wave height), were summarized from different scaled wave models (Roelfsema *et al.*, 2018)
  - **many inventories over the mapping period** (e.g. several different seagrass surveys) will require each dataset in a time series to be intersected, summarising combinations of attribute categories, number of presences/absences standardised by number of surveys; with cover or biomass summary statistics **if available**. This summary dataset is available to apply period and trend qualifiers as necessary, identifying ephemeral versus persistent, which may warrant different types and different management approaches. Gaps in inventory can be targeted for the future.
- **many categories within an attribute may be sourced from many datasets** (example d in Figure 7). While many surrogate datasets can be used to populate an attribute and the categories within an attribute, the best mapping surrogate available at the time for each category should be used. An example where many different surrogate datasets populate one attribute for many categories is this one from the Central Queensland Project (DEHP, 2017b), for the limits of tidal influence (Highest Astronomical Tide, HAT), the best available dataset to populate the metric was a modelled HAT line dataset DNRM, 2013):
  - the lower tidal levels were sourced from NIDEM (Bishop-Taylor *et al.*, 2019) data, but this was only applicable where vegetation did not obscure the water signal, and where terrestrial LiDAR elevation models show land
  - tidally influenced vegetation, such as saltmarsh and mangrove mapping, was used within the intertidal zone, above mean sea level, where vegetated cover obscures the water signal
  - high resolution aerial photography from various timelines were used to delineate extreme low tidal emergence (i.e. 'lower low tides').
- **combinations of categories can be used in a typology** that represents different mixtures. An example of categories that have been applied in a typology is the Folk classification of sediment texture (Folk, 1974; Folk, 1954). The attribute of substrate grain size provides categories of the Wentworth classification, which are then combined in a typology. The categories of mud 'M' and sand 'S' are compared with that of gravel 'G' (amalgamation of the cobble, pebble and boulder grain sizes). Mud, sand and gravel each become an axis of a triangle that represents their relative proportions in the sediment (sediment texture, USGS,

2005). A notation of brackets, lower case, and upper case represents relative percentages, for example, (g)sM is ‘slightly gravelly sandy mud’, where brackets denote ‘slightly gravelly’, lower case ‘s’ denotes a smaller proportion of sand than upper case M, ‘mud’

- **datasets that are typologies** need to be broken down into the attributes and categories underpinning each type. For example, the attribute of terrain morphology can be crosswalked from shoreline geomorphic types only if each geomorphic type contains information that can be broken down into the terrain morphology categories of peaks, pits, planes, depressions, and ridges. Datasets that are typologies without discoverable attributes based on assumed knowledge, or where scale is not specified may not be to be reclassified to an attribute or crosswalked into the categories of the scheme. For example, the International Hydrographic Organisation (IHO) (n.d.) defines the undersea features ‘hill’, ‘peak’, ‘mound’, ‘knoll’, ‘pinnacle’, ‘seamount’, ‘salt dome’ and ‘mud volcano’ which include all peaks at different scales, however, their definitions do not always specify scale of the feature. Definitions may include processes.
- **concatenation of different categories -** where two categories are present in the one unit or polygon, these can be concatenated with a separator (e.g. ‘/’ or ‘|’). For example, the RE mapping uses concatenation to show different mixtures of REs (Neldner *et al.,* 2012). Using a separator enables each to be later broken down into separate fields, if necessary. Usually the dominant category is listed first in order. Where possible the qualifiers of cover, biotic height or biomass should also be captured for each of the categories to determine the dominance of the category. The order of a concatenated category field needs to reflect the order of its corresponding qualifier field. In a mixed seagrass meadow, ovoid seagrass may be 70 per cent of the biomass and strap seagrass 30 per cent, represented in the category field as ‘Ovoid seagrass | strap seagrass’ and in the biomass field as ’70 | 30’. Comment fields may be necessary to preserve original data
- **spatial boundaries** and attribute categories can come from different source datasets (see Figure 12). For example, for the Consolidation attribute in the Central Queensland Project (DEHP, 2017b):
    - geological mapping of rock types was used to define lithology, but the coarse scale of mapping was insufficient for the finer level or scale of the set of mapped attributes associated with an attribute classification
    - at finer resolution, roughness visible on LiDAR data overlaid with high-resolution aerial photography, helped delineate boundaries of rocky (consolidated) polygons
    - additional polygon boundaries can be manually delineation by a spatial analyst, based on what is visible within LiDAR/aerial photography.
- **spatial boundaries and the identity of a category** may be provided by different data sources, for example one data source is used to delineate the boundary of an area, and another to determine the category within the boundary, or vice versa. For example, polygon linework to determine the limits of tidal influence may be a HAT line dataset overlaid with elevation data. To confirm the category for these polygons, orthophotos can be used to show that some HAT polygons lack marine plants, and LiDAR showed barriers that exclude tidal flow. The category can be updated as being outside tidal influence i.e. terrestrial or freshwater.

Assessing the accuracy of primary source data - in assembling an attribute classification, ranking mapping surrogates by their confidence is described in this section to ensure the best available surrogate is used. Implications for confidence are detailed in section 7. Refer also to Module 1 section 3.5 (DEHP, 2017a) for definitions and a discussion of inventory (defined as the recording of standardised data about ecosystems), surrogates, confidence, and data accuracy.

The assessment and review of confidence information is informed by the source metadata, including:

- currency (an object is present in a location within the mapping timescale)
- reliability (an object repeatedly identifies the feature it specifies)
- consistency (an absence of conflicts within the mapping and values)
- extent (the mapping covers as much of the project area as is possible).

Source data spatial accuracy, methodology, surrogate base datasets and field mapping intensity are often interrelated (see Figure 18 in section 7, relating confidence of source data with, spatial accuracy and mapping scale, and Figure 11, applying an overlay order to data sources for a mapped attribute, consolidation). The order to overlay spatial datasets in an attribute classification needs to consider the following:

- **methods involving field work** vary in spatial accuracy, from statistically averaged points to georeferenced field surveys, through to interpolated models and sophisticated thematic maps (e.g. supervised classification of remotely sensed base data, based on field training and validation, with accuracy assessment). Statistical methods often average valuable spatial data to a central survey site, which should be used at a broad spatial scale.
- **thematic mapping** derived from remotely sensed surrogates reflect the sensor resolution:
    - sensor **spatial resolution** is associated with thematic map spatial accuracy (e.g. Landsat derived thematic maps 30 metres versus Quickbird 5 metres)
    - sensor **radiometric resolution** affects the attribute accuracy (e.g. green, blue, and purple bands passing through water effectively detect benthic habitats
    - **temporal resolution** of a sensor may inform the currency/consistency.
- **measurable accuracy -** some source datasets provide an accuracy assessment, e.g. a confusion matrix, Kappa statistic, user's accuracy, producer's accuracy, and overall accuracy (see Congalton, 1991). Methods that incorporate field training/validation data have measurable accuracy (e.g. supervised classification) unlike methods that don't use field data (e.g. unsupervised).
- **mapping intensity** (number of field observations per hectare, see section 3.2 and section 3.5) needs to match the classification or level selected. If no alternative exists except a dataset with a broader scale than intended, highlight this area as a data gap to be addressed by further inventory.

Recording the confidence of the dataset will help determine its use in comparison to other datasets. High confidence data should always take precedence over 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 (see section 7.2 Field inventory and field validation).

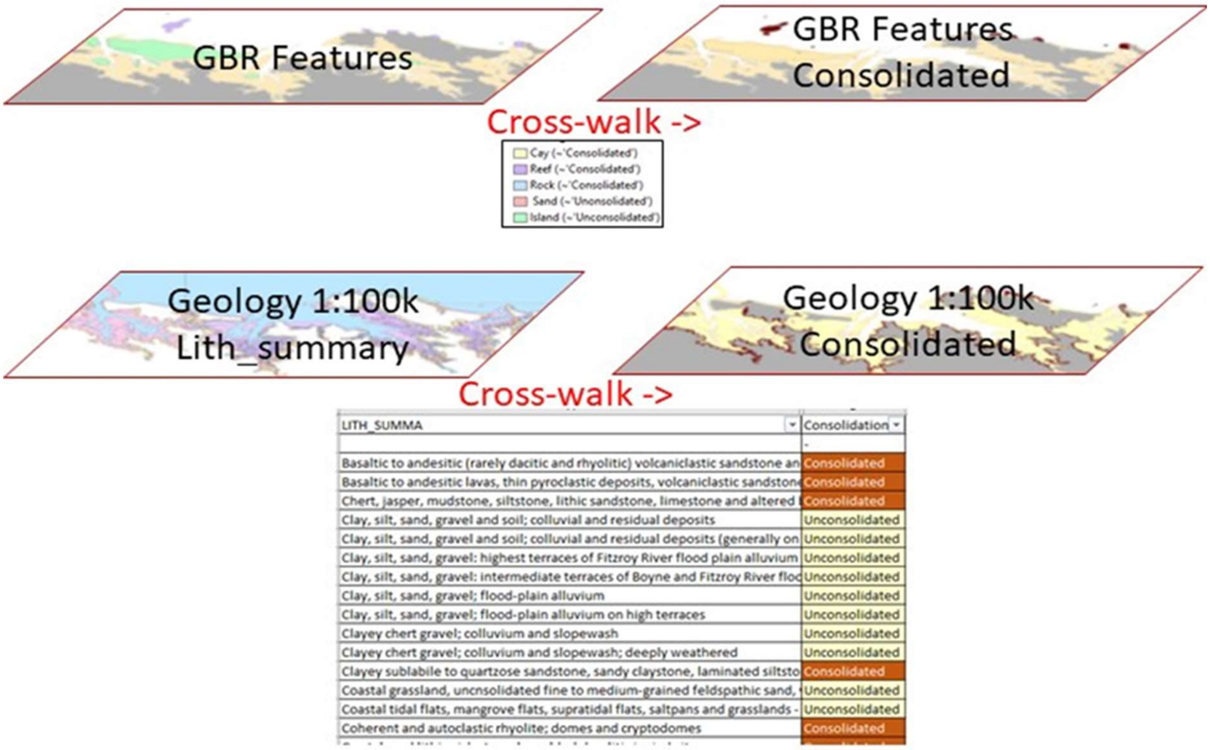
3.2 Designing the data schema for an attribute classification

As this mapping method is primarily based on the integration of existing datasets, the data schema for the set of mapped attributes needs to be able to accommodate and record the ways in which the attribute datasets are integrated. This provides a transparent linkage from each of the attribute datasets back to the source data. Essential steps for designing the schema of an attribute dataset are:

1) **design a composite attribute dataset** that should include the following:
    - the attribute description, level, and category
    - the spatial data source, scale, date, and spatial accuracy
    - the attribute data source (if this differs from the spatial dataset) and date
    - qualifiers – naturalness, period and trend, cover and biomass and information about the qualifiers
    - a text field to record field information from the source dataset, and to describe how the polygon data was verified
    - a unique code to identify data sources, and how they were captured, for example a code representing a derived or interpreted dataset (e.g. the HAT interpreted with orthophoto and LiDAR as above).
2) **maintain and store source datasets in a manner** that allows them to be easily located, identified and their lineage understood. For example:
    - include a unique code that separates the original source data from any processed by-products that are reprocessed or crosswalked to an attribute
    - document if the dataset or its derivatives contribute to multiple attributes and categories
    - store the original downloaded data/link, metadata, references, and derived working spatial datasets in separate folders.
3) **develop and document any sub-method for the attribute mapping -** for each attribute, a sub-method will be required, which documents how different datasets have been combined to develop a consolidated mapped attribute dataset. The sub-method should document the crosswalk schema between the scheme and the source dataset and justify reasons for doing so. Sub-methods may be referenced in metadata documents or published online to accompany the overall mapping method
4) **plan for the transfer of information** from the attribute classification stage to the typology stage. Include the set of mapped attributes associated with an attribute classification in the typology dataset so that they can be queried side-by-site in a single unioned dataset. This should be done to ensure they can be linked back to the composite attribute datasets and that it is possible to trace back from a type to its attributes, including those that do not participate in the typology rule-sets. Consider a relational database structure, where key fields link each dataset to the other. Section 5 Figure 15 provides an example, where information flows from the attributes dataset to the typology dataset through a chain of linking polygon identifier codes (IDs)**.**

3.3 Crosswalking

Crosswalking involves matching field values of the source dataset(s) to attributes and categories of the scheme (see Figure 8 demonstrating crosswalking of two datasets to the ‘consolidated’ category of the attribute ‘Consolidation’). The available categories of the scheme may provide a range of different ecological resolutions, depending on the purpose of the classification, the taxonomic resolution of the field data, or the spatial resolution of the surrogate metric (‘tiers’, see section 3.1 and Module 1 page 22 section 3.4, DEHP, 2017a). For example, a seagrass scientist may choose to crosswalk all seagrass datasets to leaf form, and crosswalk other structural macrobiota to broader or finer categories. In another example, in the Central Queensland project (DEHP, 2017b), REs matching the scheme’s seascape-scale categories were crosswalked to the structural macrobiota attribute. For this project broad scale categories such as ‘grass/herb/sedge’ were only available/ distinguishable for some areas, but in other areas it is possible to distinguish and potentially split into finer categories (e.g. grass or herb, succulent, sedge, bare).



LITH_SUMMA	Consolidation
	-
Basaltic to andesitic (rarely dacitic and rhyolitic) volcaniclastic sandstone an	Consolidated
Basaltic to andesitic lavas, thin pyroclastic deposits, volcaniclastic sandstone	Consolidated
Chert, jasper, mudstone, siltstone, lithic sandstone, limestone and altered	Consolidated
Clay, silt, sand, gravel and soil; colluvial and residual deposits	Unconsolidated
Clay, silt, sand, gravel and soil; colluvial and residual deposits (generally on	Unconsolidated
Clay, silt, sand, gravel: highest terraces of Fitzroy River flood plain alluvium	Unconsolidated
Clay, silt, sand, gravel: intermediate terraces of Boyne and Fitzroy River floo	Unconsolidated
Clay, silt, sand, gravel; flood-plain alluvium	Unconsolidated
Clay, silt, sand, gravel; flood-plain alluvium on high terraces	Unconsolidated
Clayey chert gravel; colluvium and slopewash	Unconsolidated
Clayey chert gravel; colluvium and slopewash; deeply weathered	Unconsolidated
Clayey sublabile to quartzose sandstone, sandy claystone, laminated siltsto	Consolidated
Coastal grassland, uncnsolidated fine to medium-grained feldspathic sand,	Unconsolidated
Coastal tidal flats, mangrove flats, supratidal flats, saltpans and grasslands -	Unconsolidated
Coherent and autoclastic rhyolite; domes and cryptodomes	Consolidated

Figure 8: A Crosswalking example. In this example, two disparate dataset sources are translated into the common attribute of consolidation by crosswalking to the scheme. The GBR Features is a dataset interpreted from Landsat imagery (GBRMPA, 2004). To populate ‘consolidation’, GBR Features’ ‘Cay’, ‘Reef’ and ‘Rock’ were crosswalked to the ‘Consolidated’ category, while ‘Sand’ and ‘Island’ were crosswalked to ‘Unconsolidated’. Geology 1:100,000 (DNRME, 2014) the lithology summary field were sorted into hard geologies and crosswalked to the ‘Consolidated’ category, while softer sediments, were crosswalked to ‘Unconsolidated’ (see bottom centre crosswalk table).

3.4 Mapping the qualifiers: naturalness, period and trend, cover, biotic height, biomass

Changes in ecosystems may represent natural variations or may constitute a shift in the state or type for an ecosystem (Done, 1999). Variations in biophysical attributes are captured during the mapping of attributes through the use of qualifiers which add supplementary or additional information to attribute datasets to describe patterns of change (see Box 7).

> *Box 7*
>
> ***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 (see Module 1 section 3.4.2, DEHP, 2017a).*
> ***Naturalness** considers the integrity of a component and the degree of anthropogenic influence (see Module 1 section 3.4.2, DEHP, 2017a).*

Where an attribute is modified by anthropogenic influence, it is recorded in the naturalness qualifier field of each attribute, which flows through to the type.

The following examples explain the application of modified naturalness qualifiers to an attribute, and the resulting ecosystem type:

- a jetty or a wharf is built on an unconsolidated (subtidal) substrate:
    - the consolidation attribute changes from ‘unconsolidated’ to ‘consolidated’ and the naturalness qualifier is ‘modified’ for the consolidated attribute
    - the inundation attribute changes from ‘subtidal’ to both ‘intertidal’ and ‘subtidal’ (as it is above and below the waterline) and its naturalness qualifier is ‘modified’
    - both the dominant type of ‘intertidal consolidated’ and co-type of ‘subtidal consolidated’ –have a ‘modified’ naturalness qualifier due to modified attributes of consolidation, and inundation.
- a boulder rock wall is built along a river channel on sandy muddy sediment and a gently sloping bank and the rock wall extends into the subtidal area:
    - substrate grain size (or sediment texture, i.e. the mix of grain sizes) has changed from ‘sandy mud’ to ‘boulder’ and its naturalness qualifier is ‘modified’
    - terrain morphology has changed from ‘plane’ (gently sloping) to ‘ridge’ and its naturalness qualifier is ‘modified’
    - inundation has changed from ‘subtidal’ to ‘intertidal’ where ‘boulders’ now extend out into the river channel and its naturalness qualifier is ‘modified’
    - the ecosystem type is allocated to ‘intertidal boulders’, with ‘subtidal boulders’ allocated to the section of the boulder rock wall footing extends into the subtidal area – the naturalness qualifier is ‘modified’ for the type based on ‘modified’ substrate grain size, terrain morphology and inundation.
- a channel is excavated across a tidal flat with mud, sand and seagrass to a boat ramp and excavated marina:
    - inundation has changed from ‘intertidal’ to ‘subtidal’ in the marina and the channel and its naturalness qualifier is ‘modified’
    - terrain morphology is ‘modified’, that is from ‘plane’ to ‘channel’ (the access channel from the boat ramp) and ‘depression’ (the marina), and the boat ramp is a ‘plane’ (sloping)

- consolidation is ‘modified’, that is from ‘unconsolidated’ to ‘consolidated’ (boat ramp)
- substrate grain size (sediment texture) has changed from ‘muddy sand’ to ‘mud’ in the channel and the depression
- structural macrobiota has changed from ‘seagrass’ to ‘none’ in the channel and depression
- ecosystem types have changed from ‘intertidal’ to ‘subtidal’ (marina, channel) – the naturalness qualifier is ‘modified’ for the type.

A note field provides a description of how the attribute has changed, and what has caused the change. An example of changes in inundation is shown in Figure 9 below.

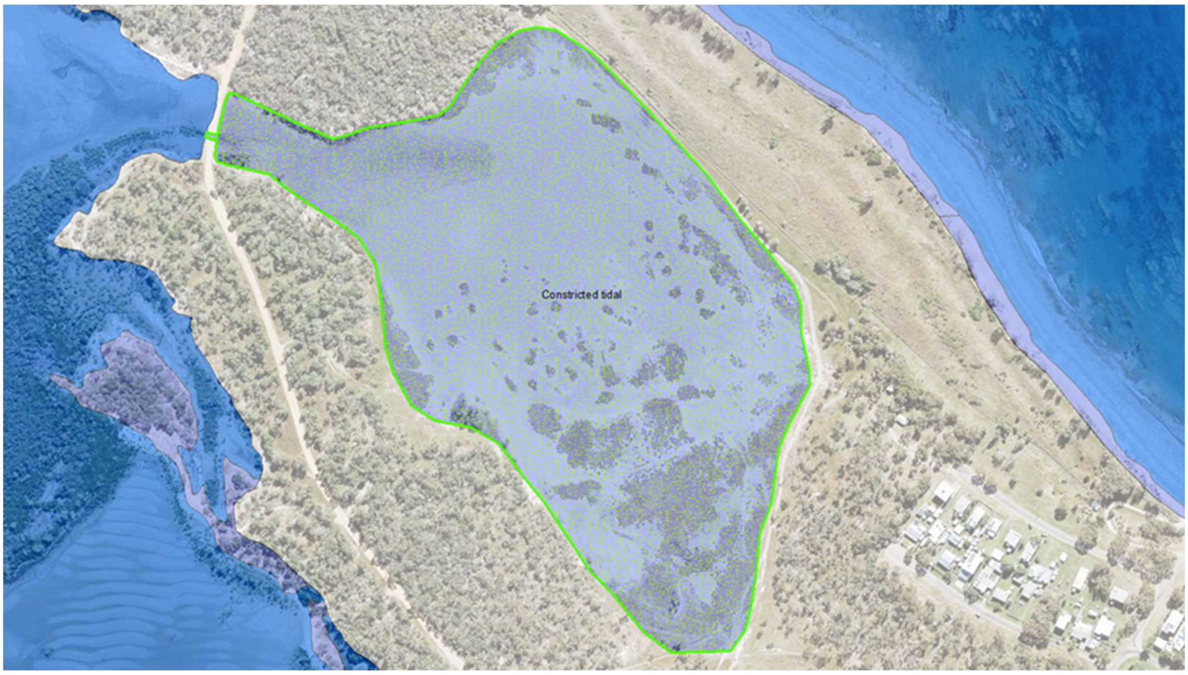


Figure 9: Example of Modified Inundation. The inundation attribute dataset above shows the intertidal and subtidal area as transparent blue over an orthophoto. A modified tidal area is outlined in green, i.e. a causeway/culvert constricting tidal flows (example from the Central Queensland Project, DEHP, 2017b).

A mapped typology also needs to include naturalness qualifiers (refer to section 5 mapping a typology classification). The transfer of qualifier information from the attributes layers to the types dataset needs a relational data model that links the types and the attribute datasets using common identifier codes in both. Linked tables enable selections in one table to flow across to the next table (via a relational data model, see Figure 10 and Figure 15). Selecting a modified record in the attribute dataset highlights the information to transfer to update the naturalness qualifier field in the types dataset (see Figure 10).

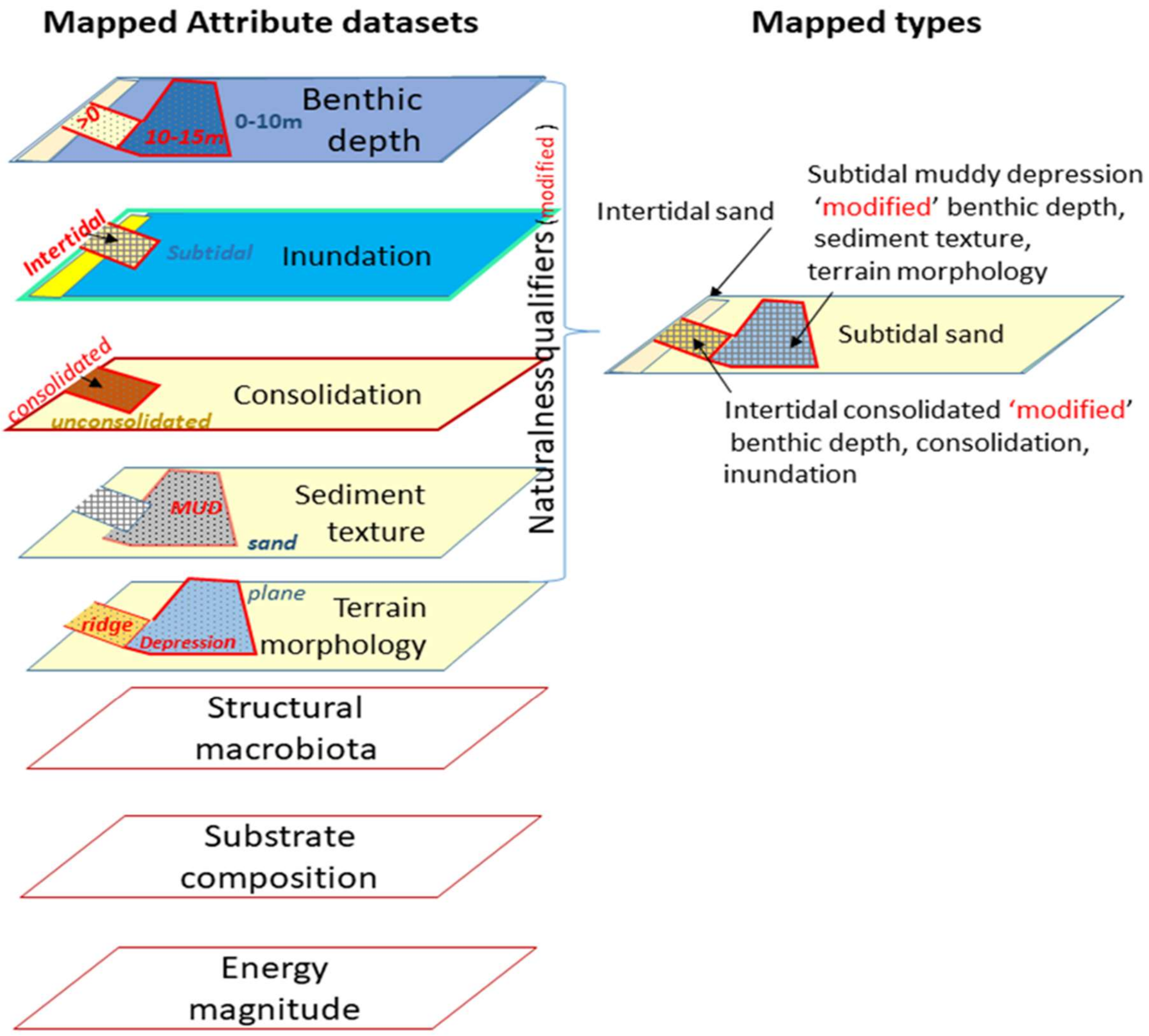


Figure 10: Capturing Naturalness Qualifiers. Naturalness qualifiers are captured in each attribute composite dataset associated with an attribute classification (red outline), then transferred to the mapped typology (hatched) via a relational database model as shown above, listing the attributes that have been modified to identify 'modified' types that are a result of anthropogenic influence.

To apply the other qualifiers, information is captured in the relevant attribute dataset (see Module 1 Appendix 6.4), which then feeds through to update the types dataset. The remaining qualifiers are most relevant to the structural macrobiota attribute, for example:

- **period and trend** (temporal qualifiers) are relevant to time-series datasets or ephemeral attributes, such as a composite seagrass dataset for a given area, composed of overlaid seagrass inventory datasets, surveyed at different times. Seagrass scientists characterise these meadows as either persistent, intermittent etc. and each pattern need to be broken into period (e.g. seasonal), and trend (e.g. either constant, fluctuating, or cyclic)
- **cover** helps determine the type and co-type in a mixed polygon with concatenated categories, or where different structural macrobiota datasets overlap. For example, if the category is 'Mangrove/Saltmarsh' and the cover is '70/30' in the structural macrobiota attribute, then the type should be 'Mangrove' and co-type 'Saltmarsh'
- **biomass** - a seagrass meadow of mixed ovoid and narrow strap seagrasses has biomass either allocated based on their combined mass, or separately using concatenation, as above

- **biotic height** is the height of the structural macrobiotic category e.g. height of the seagrass meadow or of a mangrove forest (similar to 'ecologically dominant layer' of RE mapping in Neldner *et al.,* 2019).

3.5 Attribute compilation: overlaying source datasets – based on confidence

A compiled attribute spatial dataset is a data-rich synthesis product with multiple fields. This versatile product has many uses beyond ecosystem typology classification (e.g. predictive habitat models, storm tide modelling, blue carbon, understanding knowledge gaps etc.). In addition to the considerations in section 3.1 to 3.4 above, the following steps are necessary to produce an integrated composite spatial attribute dataset:

- **organising source datasets according to confidence -** an attribute compilation process that incorporates confidence will inform quality assurance stages of the mapping (see section 7.1.1). When all source datasets are crosswalked to the categories of an attribute dataset, they need to be superimposed in the geographic information system (GIS) software to visualise how they will combine to form a draft mapped attribute composite layer. The datasets need to be re-ordered, shifting the most accurate datasets to the top of the list and the least accurate (e.g. broad scale, low confidence) datasets to the bottom of the list (see Figure 11)
- **tracking the dataset source for geometry and category identity, and sorting the data by accuracy -** source datasets used for decision-making are tracked in two fields, one for the **feature source** (i.e. the polygon geometry source) and another for the **attribute source** (i.e. the source confirming the identity of the attribute category) (see Figure 12). Information about the spatial accuracy, attribute accuracy, surrogate dataset source etc. is assembled in a separate spreadsheet linked to these source codes (check source dataset metadata- if unavailable or scant, seek data lineage from companion publications or reports). Broad scale, low accuracy datasets are progressively replaced by higher resolution datasets and overlaid in a composite layer. After overlaying all data sources, expert interpretation of their extent against high-resolution imagery can be used to validate or improve their spatial resolution and attribute identity.

Compile into integrated composite attribute spatial datasets:

- to create an **integrated composite attribute dataset** that optimises accuracy of surrogate datasets, a 'cookie-cutting' process takes place where the more accurate layers are sequentially clipped from the less accurate ones. Once this cookie-cutting is done, all datasets can then be joined into an integrated composite attribute dataset where polygons do not overlap (i.e. are 'flat', see Figure 13)
- it is possible to retain overlapping polygons in a composite attribute dataset, such as in the structural macrobiota example below, however an extra 'flattening' step may be necessary
- **'flatten' attribute datasets with overlapping category polygons** (as required) either before the typology is run or following the typology process. This removes any overlaps in the attribute layer and converts the data into a concatenated format. This 'flattening' process differs from the creation of an integrated composite attribute, taking each combination of overlapping polygons, cutting them into separate polygons, and concatenating the categories within in each overlap area. The flattened attribute dataset needs to maintain a link back to the original overlapping one, so as to resolve any later issues regarding dominance of each category. To enable this, a common identifier code field is needed to link the 'flattened' dataset back to its overlapping counterpart (see Figure 15).

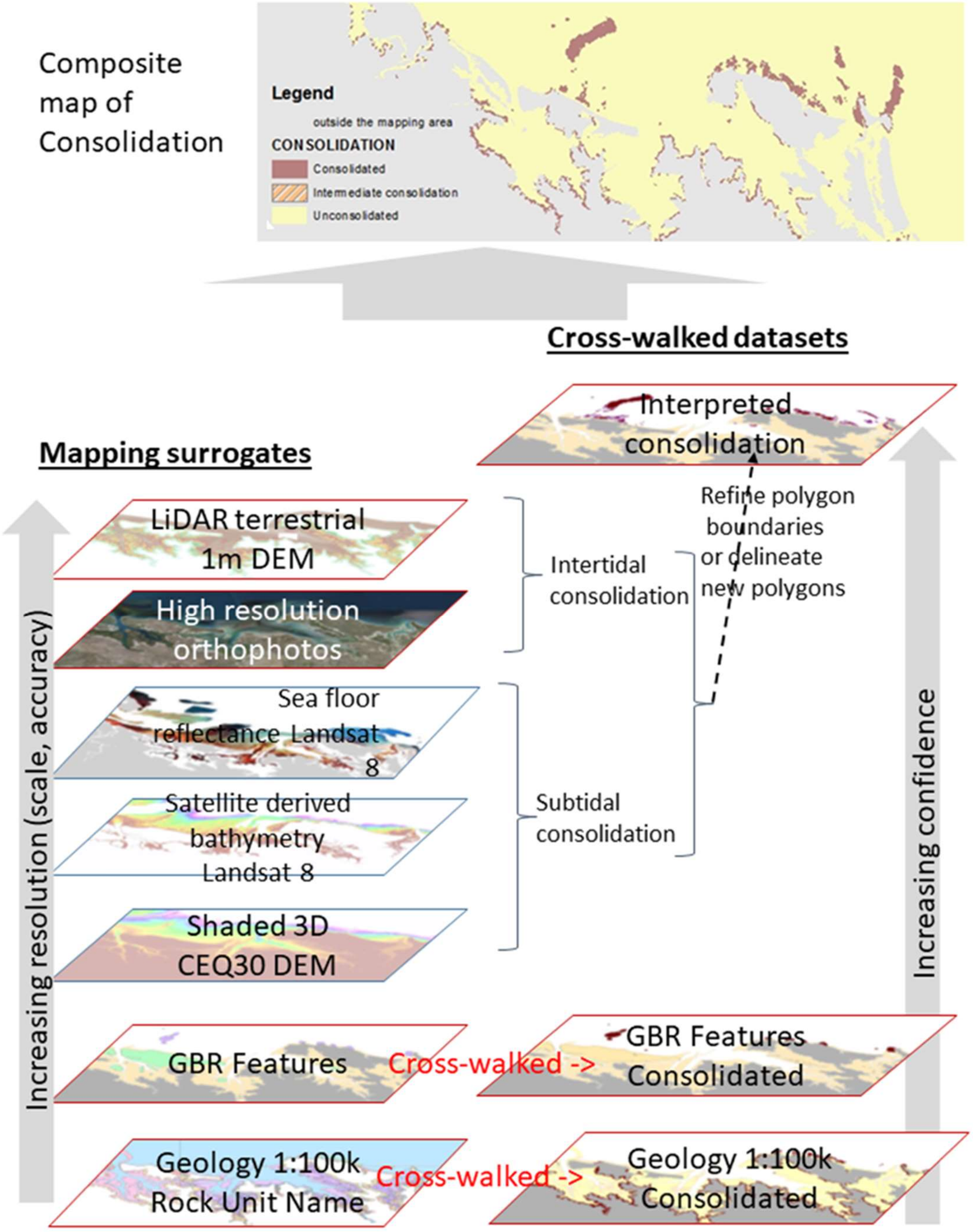


Figure 11: Assembly of Surrogate Spatial Datasets in Order of Confidence. This example from the Central Queensland Project (DEHP, 2017b) shows the sorting process prior to assembling and integrating composite attribute datasets (see Figure 7 example c). Broad scale, coarse level attributes at the bottom are replaced by superimposed, increasingly finer scale, and higher spatial and ecological resolution, mapping surrogate datasets. The composite spatial dataset retains the polygons from geology and GBR features, except where interpreted from high resolution data. Acronyms: Light Detection And Ranging (LiDAR), 30 metre raster Digital Elevation Model (DEM) of Central Queensland subtidal sea floor (CEQ30) DEM (DES, 2019a).

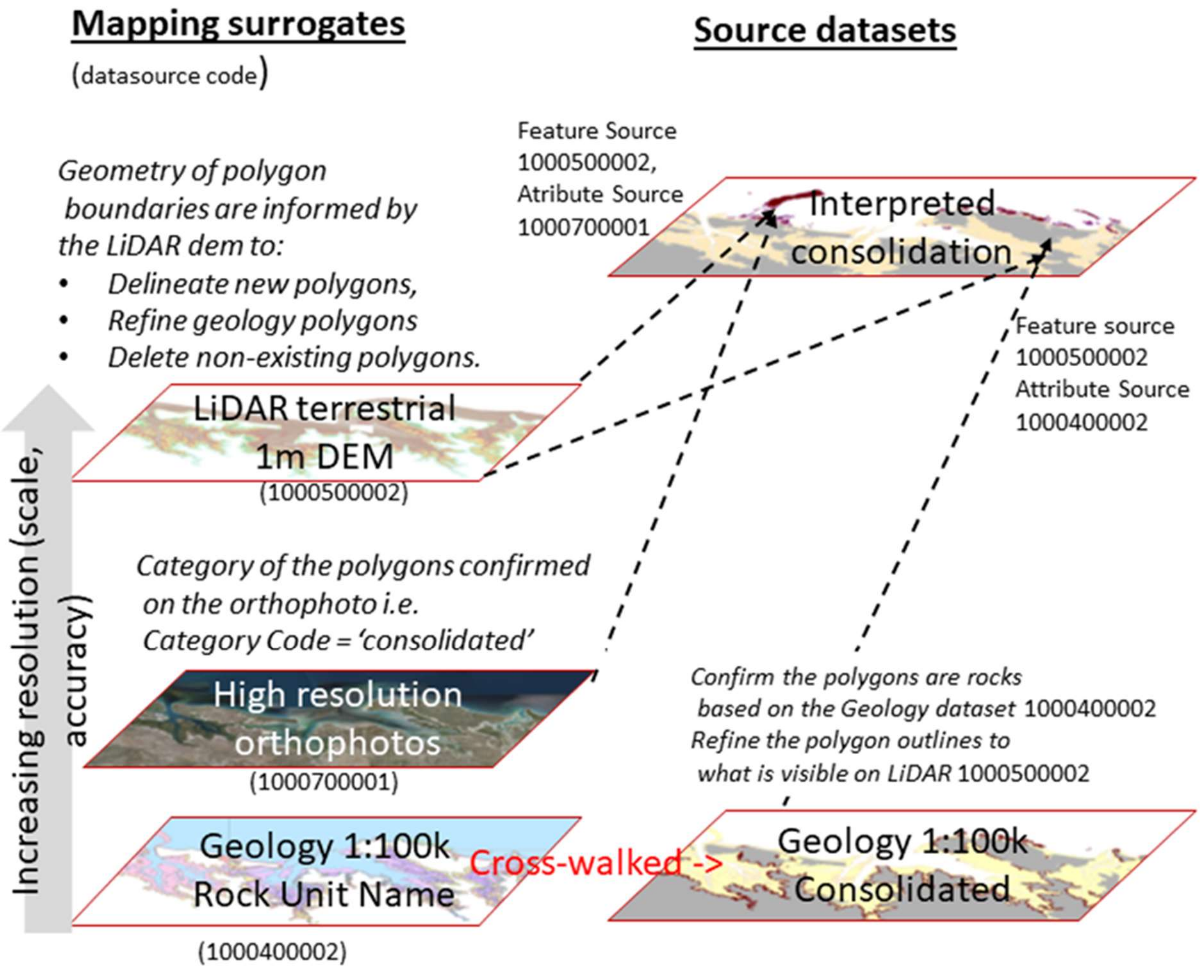


Figure 12: Using Code Fields to Document Source Geometry and Category Data Sources. An attribute dataset may contain source data from a number of datasets, i.e. its geometry from one source and the category code from another source. In this example, the interpreted consolidation source dataset is derived from multiple mapping surrogates, based on the best available mapping surrogate. One polygon has its geometry derived from LiDAR (feature source is 1000500002) and its category code is confirmed by high resolution orthophotos (attribute source 1000700001). Another polygon has its geometry sourced from LiDAR (feature source is 1000500002) and its category was confirmed by the geology dataset, whose geometry is at a coarser scale (attribute source 1000400002). The fields of feature source and attribute source together with the category code and the polygon geometry are captured in the interpreted source dataset, to be incorporated ultimately into the composite attribute dataset. A notes field may explain how each feature was interpreted.

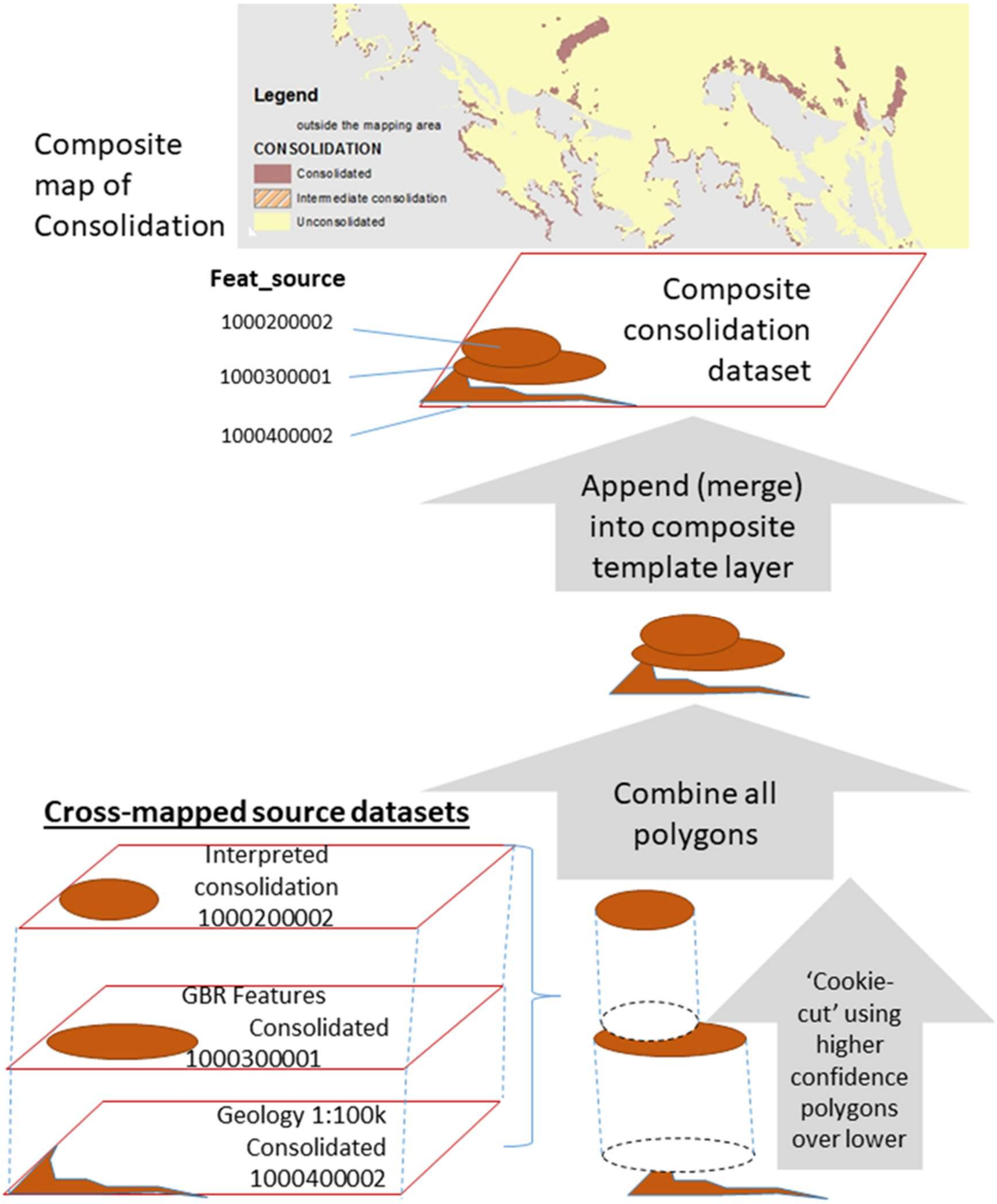


Figure 13: Creating an Integrated Composite Attribute Dataset. To create an integrated composite attribute dataset, source datasets that have been crosswalked and assembled in order of confidence (Figure 11) are then progressively reassembled in order of confidence and appended to the composite attribute dataset. The data source codes and the category code (e.g. 'consolidated') are transferred across to appropriate fields in the composite attribute dataset (Figure 12). In this Consolidation attribute example, polygon boundaries do not overlap – this is not always the case, e.g. structural macrobiota may overlap.

4. Capturing panel information

As previously outlined, expert panel technical guidance is essential in implementing a set of mapped attributes associated with an attribute classification and a mapped typology. Thorough and logical capture of panel information is needed to run the typology and continued engagement with the technical experts is required after the workshops.

4.1 Agenda preparation for a facilitated workshop

The scope and nature of technical input required and products that will be made available to the technical advisory panel to guide them in their decision-making needs to be considered prior to the workshop. Tasks include:

- identification of technical experts who have relevant knowledge
- preparing the workshop terms of reference, including clarity on roles
- drafting an agenda and agreed outcomes for the workshop(s)
- preparing presentations on classification stages and project workflow
- highlighting the key spatial decisions, the panel will make
- selecting potential candidate attributes for the panel to visualise (e.g. Figure 14).

Spatial information about attributes needs to be assembled and collated prior to workshop to enable the panel to visualise how the attributes could potentially interact.

4.2 Capturing technical panel information

The technical panel facilitated workshop provides an opportunity for all participants to contribute their knowledge to the process. To ensure this happens, panel members need to understand expectations, and have multiple opportunities to contribute knowledge that take into account their different communication styles. It is essential that the spatial analysts assisting with the panel capture the typology rule-sets in an appropriate format, see section 5.1. Technical information presented needs to be visual, e.g. maps, workflow examples.

Specific decisions with mapping implications that need to be recorded include:

- the biophysical attributes and categories selected for attribute classification and the typology (e.g. Figure 14 lists the six attributes chosen for the Central Queensland Project, DEHP, 2017b)
- the thresholds that are relevant to the purpose of the classification and categories of the attribute
- the purpose and scale (level) of the typology classification, approximate number of types, mapping scale and desired output unit size
- how the attributes will be combined to determine a type and the hierarchy of the attributes used to determine how types and co-types will overlay
- the identification of available spatial information relating to biophysical attributes and instructions for their use, (usually by individual consultation out-of-session) i.e. interpretation of source datasets, metadata, accuracy and mapping methods; how to crosswalk or translate datasets into the attributes and categories of the scheme.

B_DEPTH	benthic depth (depth to the sea floor)
CONSOL	consolidation (rockiness for potential attachment of biota)
INUNDTN	inundation (tidal)
NRG_MAG	energy magnitude (wave)
SED_TEX	sediment texture (mixtures of mud, sand & gravel)
SMB_CMP	structural macrobiota (animals & plants with living structure)
SUB_CMP	substrate composition (origin e.g. terrestrial / carbonate)
T_MORPH	terrain morphology (ups and downs of the terrain)

Figure 14: Eight Attributes Selected by the Central Queensland Technical Panel. This example lists attributes chosen from the scheme by the technical advisory panel for attribute classification, typology and mapping in the Central Queensland Project (DEHP, 2017b). When mapped, these comprised the set of mapped attributes associated with the attribute classification. For each attribute, a separate spatial attribute dataset was compiled and independently mapped based on the category field of that attribute. The set of eight draft spatial datasets were mapped by category in a single digital mapping window to demonstrate potential overlays for the designation of types. Abbreviations represent dataset names.

Accurately documenting actions and decisions of the technical panel is critical, especially in the case of mapping applications. Discussions among panel members provide essential background logic behind decisions. In addition to the questions suggested in section 2.3 and section 2.4, the facilitator and the mapping team should capture mapping-related information, including:

- any data sharing agreements or confidentiality issues necessary to secure access to the dataset or limitations to its release/use
- identify ways to reduce the combinations of attributes and categories to only those required for the purpose (e.g. 'collapsing down', reclassification)
- consider ways to maintain dominance of types or attributes
- adjusting/re-ordering typology mapping rule-sets, identifying which options are flexible versus non-negotiable
- thresholds for qualifiers, e.g. cover, biomass (where mixed categories are present).

After a draft typology is mapped, the output needs to be checked (see section 3.4.2). A second workshop of the expert panel may be necessary to examine the result and adjust the typology rules, picking up typology errors and source data errors and sourcing additional data to fill knowledge gaps (see Module 1, section 5.3.4 page 49, DEHP, 2017a). Experts should:

- provide feedback on a draft typology and which classes should be amalgamated (reclassification)
- provide feedback on draft mapping of types and their attributes.

5. Mapping typology

The set of mapped and classified attributes associated with an attribute classification (and spatial databases supporting this) provide the basis for typology mapping. If necessary, the order of the typology mapping rule-sets is adjusted, types merged or split, etc. iteratively mapping the typology until a final output is obtained. Recording the typology rule-sets in a transparent way that can be understood by technical experts and translated into mapping queries is an essential first step of mapping a typology.

The desired **outputs** affect data assembly and mapping. For example, a **mapped typology** should consider the **number of types** necessary to address the purpose. The number of attributes and categories selected, 'collapsed down' and how many types are ultimately mapped, have a flow-on to mapping and resources. Different end users will need different outputs, such as mapping and other products. A robust data schema should be able to support a number of different end uses. For example:

- a manager may need a more generalised cartographic product with an aggregated list of types
- general public users may require an online mapping tool that allows exploration and explanation (e.g. type and attribute descriptions)
- spatial professionals may require a technical database with a relational database model.

Applying a typology from several different attributes identified during attribute classification requires decisions to be made in a particular order or hierarchy (see section 5.2.3, determine attribute hierarchy) that will determine the order in which the typology rule-sets are applied to different combinations of attributes and categories. For example, in Figure 4, the 'Type: Mangroves' is determined by the attributes structural macrobiota and benthic depth for which typology rule-sets are 'structural macrobiota = 'Mangrove' and above it, the rule 'Depth = Shallow/Deep/Unknown'. Rule-sets for a typology such as those in Figure 4 can be used for a variety of purposes, such as describing types, identifying them in the field, or mapping them as a **mapped typology.**

5.1 Developing and recording typology rules-sets for mapping

Typology rule-sets are a product in themselves, providing a framework for ecosystem type descriptions. Type descriptions may be simply a list of attributes and categories that are diagnostic for that type, or link to mapping and information on the biophysical attributes.

Having a well-documented typology rule-set is essential to ensure a smooth typology mapping process. Recording of the rules associated with a typology should have occurred when capturing technical panel information as part of section 4.2. Having a prepared template that the panel can interact with is a useful way to display their decisions for future reference, minimise errors in translating the typology rule-sets to spatial queries, and allow for iterative adjustment on inspection of typology mapping products (see section 9.6 Appendix A3 for an example from the Central Queensland Project, DEHP, 2017b).

Recording typology rule-sets - typology rule-sets need to be easily translatable into mapping queries applied to the union of attributes dataset. Typology rules may include 'collapsed categories', that is, several categories are grouped together for the purposes of the typology and allocated a group name-e.g. 'intertidal' (i.e. every category that is not subtidal). A template spreadsheet lists attributes, categories, and collapsed categories in a structured way to clearly associate types with their typology rule-sets (see section 9.5 Appendix A2). Two versions exist, one named for panel feedback and further refinement, and another coded for implementation in typology software.

Colour coding attributes and categories enables visualisation of the relationship between the attributes in columns and the types as rows (as in section 9.6 Appendix A3).

Indexing the typology mapping rule-sets - each mapping rule is assigned a unique number, which is independent from the sort order in which the decision rule is applied, such that a typology mapping rule-set maintains the same ID or index number but a sort order may change with adjustments of the typology mapping rule-sets. This enables these rule-sets to be easily re-ordered to adjust the final mapping.

Order typology mapping rule-sets - it is difficult when originally designing typology rule-sets to envisage how they will operate. The order in which the typology rule-sets are run reflects the hierarchy of attributes and can be adjusted depending on feedback or the outputs of the typology mapping.

5.2 Running typology rules, checking mapped outputs, and allocating qualifiers

Constructing a unified dataset of all attributes - for typology, independence is no longer maintained and fundamental information must be transferred to a unified (‘unioned’ in GIS terminology) layer of attributes for allocation of types according to typology rule-sets. It is important to maintain a relational database schema as described below, to easily trace mapping outputs (section 5.3) and enable full transparency and quality assurance (see section 7). Attribute datasets are checked for their integrity and a field is created for each attribute’s category value and ID, to link back to its original attribute dataset. This chain of linkages enables tracing from the type via the attributes to the data source (see Figure 10 and Figure 15). The final product is a single dataset consisting of every attribute and category, with IDs to link to full attributes. The category codes and polygon IDs of each of the attribute datasets are preserved during the unioning operation. The end product may be a very large dataset with many slivers due to different scales and accuracies in datasets, as the unioning process preserves the linework of every polygon of every dataset, generating a new polygon ID. This product may not be suitable for all applications and users and may require simplification (see section 5.4).

Running typology rules - typology rule-sets are run against the unioned attributes layers in a succession of queries that test the combination of attributes and categories. Typology rule-sets are allocated for all types (there can be many different types in the one polygon). The order of these rule-set determines which of the many types is allocated as the dominant one. All others become co-types, in the same order as the sort-order. The unioned attributes layer has now become a mapped typology (see Figures 15 and 16). Usually many different type combinations match attributes and categories of a mapping unit. To resolve this, the hierarchy of attributes in the typology determines which should be the dominant type, with the remainder being designated as **co-types.** For example, three different types are allocated to a polygon, ‘mangroves’, ‘saltmarsh’ and ‘muddy sand’. The hierarchy of attributes in the typology may have a rule where biota types are allocated before non-biota types, hence the type would either be ‘mangroves’ or ‘saltmarsh’ and the co-type ‘muddy sand’.

Where source datasets overlap within an attribute dataset, they may require different treatments, depending on the purpose for the typology, i.e. ‘flattening’ and concatenation prior to running the typology, or resolving overlapping types after the typology.

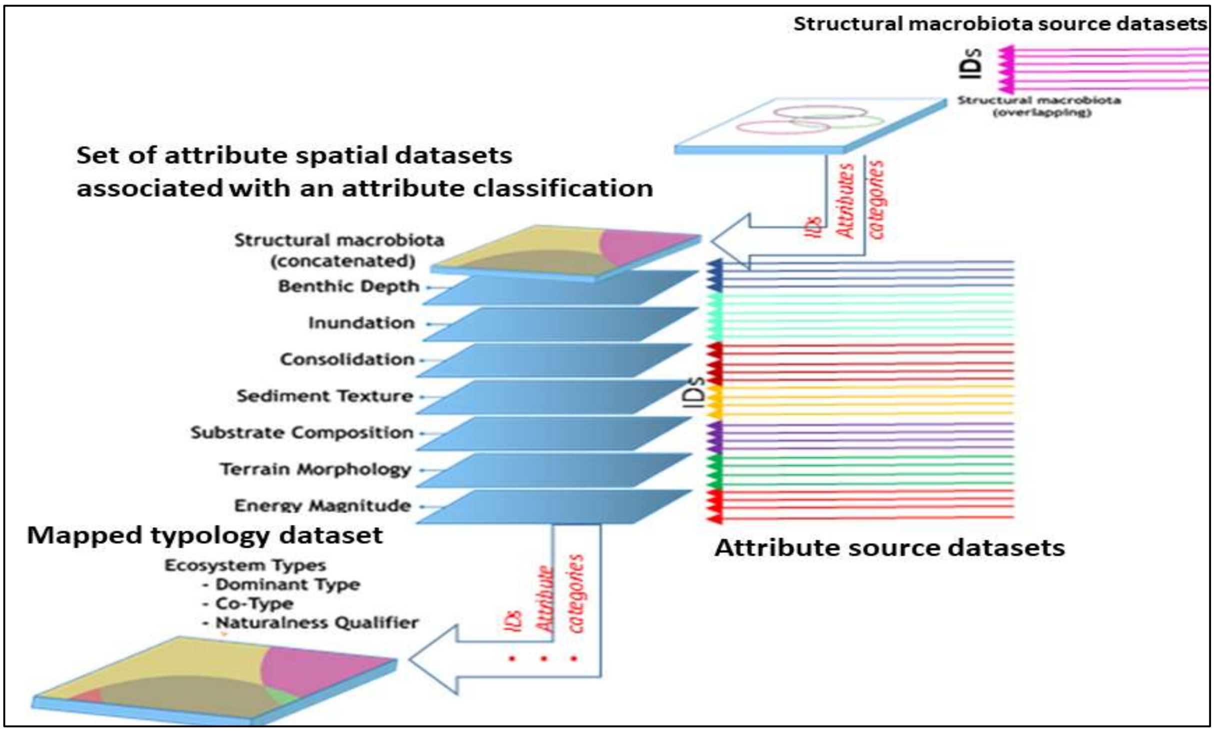


Figure 15: Linking the Typology, Attributes Datasets and Source Datasets. Maintaining a chain of data linkages between the typology, attributes and source datasets provides transparency. The IDs and attribute categories from source datasets flow to compiled attribute datasets, and to the unioned attributes dataset. In this example, concatenation precedes typology.

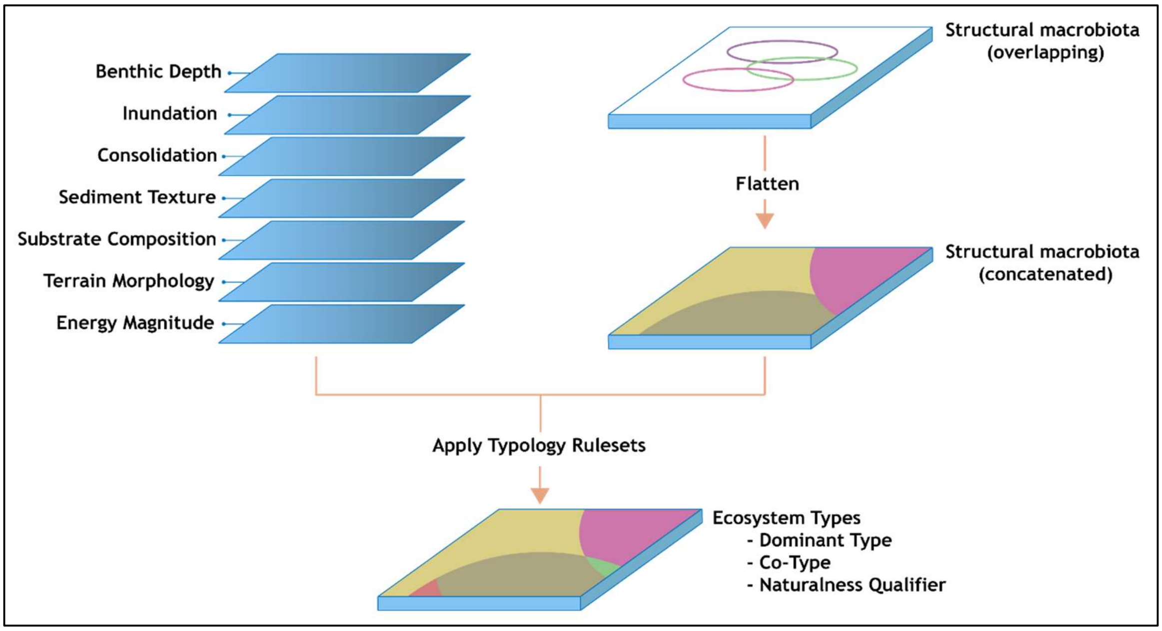


Figure 16: Example GIS Workflow for Unioning Attribute Spatial Datasets for Typology. In this example, 'flattening' precedes typology. In preparation for typology, all attribute spatial datasets are unioned. The unioned attributes layer becomes the mapped typology layer when all types and co-types are allocated. For each attribute the naturalness qualifier is allocated (see section 3.4). If necessary, other qualifiers may be applied during 'flattening' or during unioning.

5.3 Reviewing output, refining typology rule-sets, and re-running the mapped typology

The mapped typology dataset is reviewed for logical allocation of typology rules and any polygon inconsistencies. Reviewing typology output is an iterative process, i.e., adjusting typology rule-sets and re-running the typology until a satisfactory product is achieved. Dominant types are checked against the hierarchy, types are inspected against high resolution visualisation tools (e.g. imagery, elevation data). Any anomalies are addressed by re-adjusting the order of the typology rule-sets and attributes associated with each rule-set after re-mapping the types. To enforce the correct order for allocation of types, it may be necessary to add other categories and attributes to the type query (while not diagnostic of the type, they may be necessary to enforce the type order for mapping). Changes to the typology rule-sets are copied to an updated version of the typology rule-sets in a new spreadsheet. The updated spreadsheet is fed back to the typology software, to allocate an updated version of types.

A mixture of categories may be present at all scales or be a limitation of the scale of the surrogate dataset. This is represented in the attribute dataset by concatenation (i.e. with a separator '|' or '/'). For example, if the structural macrobiota category is 'mangroves/saltmarsh' and the cover qualifier is '60/40', the type allocation will be 'Mangrove/Saltmarsh' (see section 3.4 Module 1, p.23, DEHP, 2017a).

When reviewing the outputs of the classification, there may be **'non-types', 'incompatible types' or 'catch-all' types** that are an artefact of scale or gaps in inventory. Typology rule-sets need to take into account discrepancies that are artefacts of the mapping process, scale of inventory data, and/or absence of data. *Seek specialist advice from an experienced spatial analyst with expertise in typology, who will create specific typology mapping rule-sets to enforce the original order and intent of the technical experts*. Being ecologists whose expertise is usually in a single field, technical advisors are often unable to envisage types created during the overlay and joining of different attribute datasets from disciplines in which they are unfamiliar. The following are examples:

- 'non-types' or 'incompatible types' are artefacts of mapping rules that logically do not exist, or are an artefact of mismatches in mapping scale e.g. 'subtidal saltmarsh' captured by inexact subtidal boundaries
- 'catch-all' types identify gaps in inventory, knowledge, or outside project boundaries.

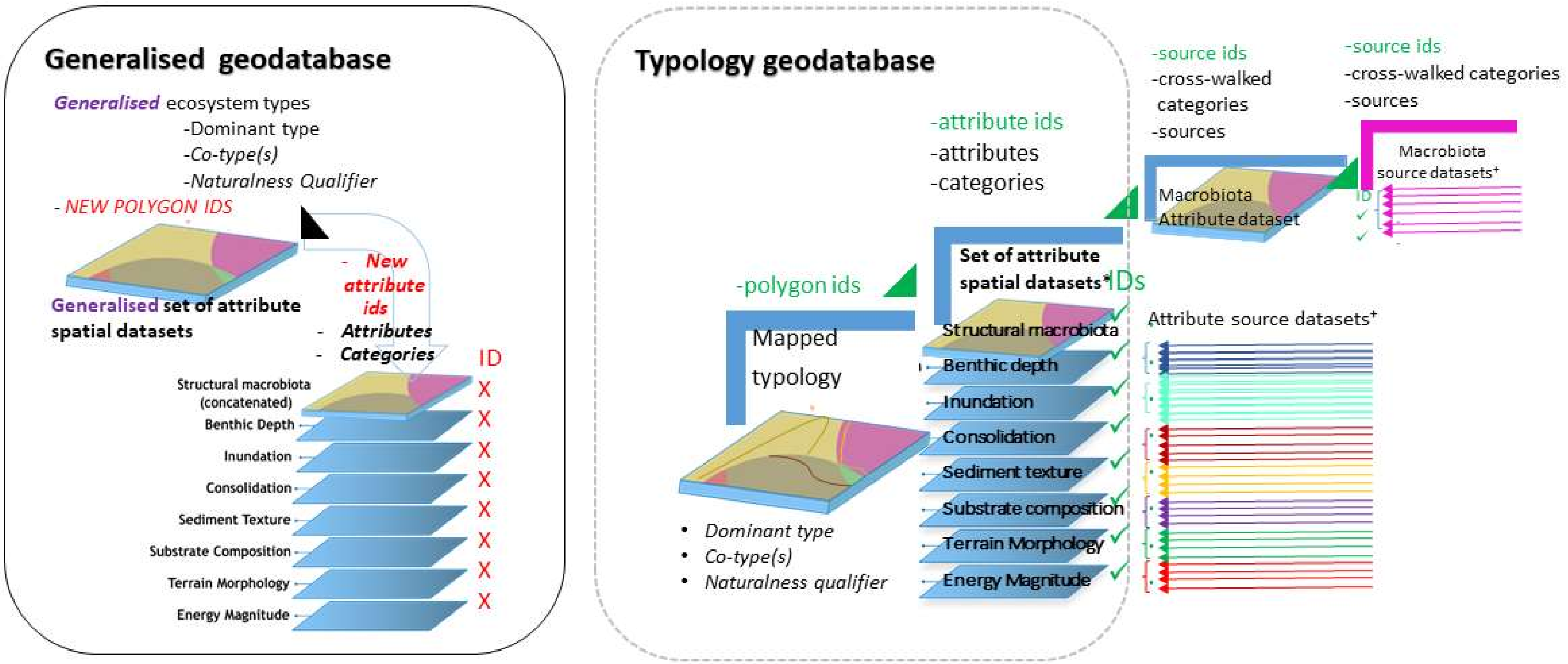
Once the typology reflects the desired intent, a draft of the typology mapping is released for expert review. Draft type names are allocated, initially incorporating all of their attributes, with regard to technical advice, and with a view to their final release (e.g. intertidal ovoid seagrass on muddy sand and sand).

5.4 Simplifying mapping products

A mapped typology that incorporates and links to the attribute classification is a very large dataset that is unsuitable for online delivery. As the attribute datasets result from a range of different scales and accuracies, the union of such datasets usually create many sliver polygons which need to be generalised in some way for presentation.

Generalised mapping products are derived from the original, detailed ecosystem types by grouping sliver ecosystem type polygons based on a desired minimum mapping area (see Module 1 section 3.2 table 3, (DEHP, 2017a)). Important types or qualifiers that fall below the mapping scale need to be masked from generalisation. There are many different ways to generalise, e.g. dissolving based on a threshold area and polygon perimeter, smoothing or snapping boundaries, simplifying complex linework. This work is a mix of automated and manual inspection. Generalisation should always be approached with caution for the following reasons:

- types that are typically small in area and width may disappear, being incorporated into larger types (e.g. small consolidated reefs, narrow boulder walls, fine tidal boundaries etc.). Solutions to consider to maintain quality assurance include:
    - retaining generalised polygons that disappear as a point or line layer, flagging their presence in a field e.g. ‘contains’
    - excluding small or narrow types from the generalisation process but retaining them in the generalised product. The generalised typology layer will have a minimum upper spatial scale, but contain features of a finer spatial scale e.g. a seascape scale map has some habitat level (e.g. a narrow coffee rock ledge) and community level features (e.g. a coral bommie)
    - overlaying the generalised typology dataset against the mapped attribute dataset, correcting any misaligned polygon boundaries.
- generalisation reduces the transparency of a final mapped type by breaking the links to the base set of mapped attributes associated with an attribute classification when polygons are merged into a different, larger type. Maintain quality assurance (for example, in the typology for the Central Queensland Project (DEHP, 2017b):
    - listing the attributes and categories in fields in the typology layer
    - providing the original attribute classification datasets as a backdrop to the generalised typology
    - retaining the original typology dataset, noting any changes that were implemented during the online quality assurance process.
- generalised typology maps lack the links to the original attributes and data sources (see Figure 17), however they provide an accessible product to visualise the different attributes that are associated with an ecosystem type, and provide a link to other online products such as ecosystem type descriptions. Prior to release, ecosystem type names need to be simplified to enable the user to identify easily with what is in the field. The number of attributes in the title is reduced (e.g. intertidal ovoid seagrass). For display purposes, related ecosystem types may need to be displayed with similar symbologies (e.g. all intertidal seagrass ecosystems with the same shading, all subtidal seagrass ecosystems a lighter shading).



X New IDs of the Generalised mapped attributes cannot correspond to those of the original set of attribute spatial datasets associated with an attribute classification* as generalised polygons no longer match

X Inability to link back to the Attribute source datasets+

✓ IDs maintain links between the types,

✓ The set of attribute spatial datasets associated with an attribute classification*, and the

✓ The Attribute source datasets+

Figure 17: Comparing a Generalised Geodatabase with the Detailed Typology Geodatabase. Right: Relationships between the mapped typology geodatabase, the set of attribute spatial datasets associated with an attribute classification, and source datasets are preserved using a chain of IDs (right). Left: A generalised ecosystem types map and geodatabase retains the attributes behind the types, but due to different polygon linework the attribute IDs no longer match back to the original set of mapped attributes associated with an attribute classification.

6. Product release

After the review and refinement process, product testing is conducted with a range of stakeholders. Product testing forms part of the quality assurance process, testing the content of the typology mapping and the functionality of the delivery system. These processes are consistent with the product release process for the Queensland Groundwater Dependent Ecosystem Mapping Method (DSITI, 2015).

6.1 Conduct online quality assurance product testing

Mapping and typology products should be made available to a target technical audience through a restricted version of an online interface tool (i.e. a web mapping application). Technical experts include natural resource managers at national and state levels as well as target users. The target technical experts also include members of the original technical panel who devised the classification.

A request for review should be provided to reviewers, stating the focus of product testing, requesting the identification of errors in mapping products, and feedback on the useability of the delivery system. A guideline to the interface and linkages to other products (e.g. ecosystem type descriptions) should be provided. One-on-one guided assessments of the mapping and the interface with a subset of reviewers is an effective but time consuming process that provides very valuable insights into final product delivery and ensures that the reviewer has a deep understanding of the product. Experts may also identify options for the future and to address knowledge gaps.

6.2 Finalisation and product release

The final stage needs to balance the detail and importance of feedback received during the wider quality assurance process with the resources required to implement these suggestions. Mapped ecosystem type and attribute datasets are approximations based on current ecological understanding, and on datasets available at the time of mapping. Errors identified in step 6.1 should be corrected, but conceptual and ecological feedback needs to be addressed in future updates of ecosystem types mapping.

Released finalised ecosystem type mapping must be integrated with the ecosystem type descriptions, information about the biophysical attributes of the attribute classification, and the underlying classification scheme principles (DEHP, 2017a).

Targeted information sessions should be provided to managers, at conferences and to other forums. User guides and online education tools are required to provide guidance on the background and interpretation of online products. Wider awareness of the product should be encouraged, demonstrating the usefulness of the scheme as a standard approach to encourage new inventory datasets to be collected and collated in mutually compatible formats suitable for data synthesis and compatible with existing mapping products.

7. Quality assurance and method limitations

For any map products to be useful, the process used to develop them needs to be **transparent**, with its **confidence** explicitly defined and documented, and quality assurance steps incorporated into each classification stage to increase user confidence in the product (see Module 1, DEHP, 2017a). **Quality assurance** is strengthened by providing opportunities for continuous improvement.

> *Box 8*
>
> ***Confidence*** *is the 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*
> - *an expert's confidence in a model (from Module 1 glossary, DEHP, 2017a).*

Transparency is critical to the development of any classification scheme, as the open demonstration of the procedure used to derive classification, typologies, and mapping increases acceptance of the final product. Transparency is maintained through thorough documentation and in the storage and linking of data (see Module 1 section 3.9 p. 32, DEHP, 2017a).

Document classification and mapping stages and decisions that result in simplification, for example:

- retain **technical panel information** and feedback as a reference (section 3.3.2)
- use the **typology template** (see Appendix 10.7) to document decisions including attribute selection, the simplification that occurs when categories are ‘collapsed’, and the application of typology rule-sets to define ecosystems (section 3.3.3)
- **allocate versioning** to mapped typologies for a specific purpose, and generalisations of the mapped typology
- maintain relational database and spatial **connections** between the source data, attributes, and classified types. These transparent linkages enable review of decisions and the original basis for mapping. Generalised products break these linkages, requiring a need to refer to the original detailed database
- assess **crosswalking confidence**, i.e. document the degree to which the source dataset matches the attributes and categories of the scheme
- provide information on the accuracy and confidence associated with source data.

Any simplification or generalisation process incurs limitations, which need to be documented.

7.1 Confidence in classification stages

Applying a classification scheme always reduces the complexity of the environment. Module 1 of the scheme discusses the concepts of simplification, dimension reduction and generalisation, and lists several classification stages that result in dimension reduction (see Module 1 section 3.6, page 30, DEHP, 2017a).

Confidence in classification products requires consideration of the accuracy of the source data and its surrogate datasets, and the limitations of the set of mapped attributes associated with an attribute classification and mapped typology stages (see sections 3.3, 3.4 and 3.5), noting the relationships between the scale and method of source mapping and base data (Figure 18).

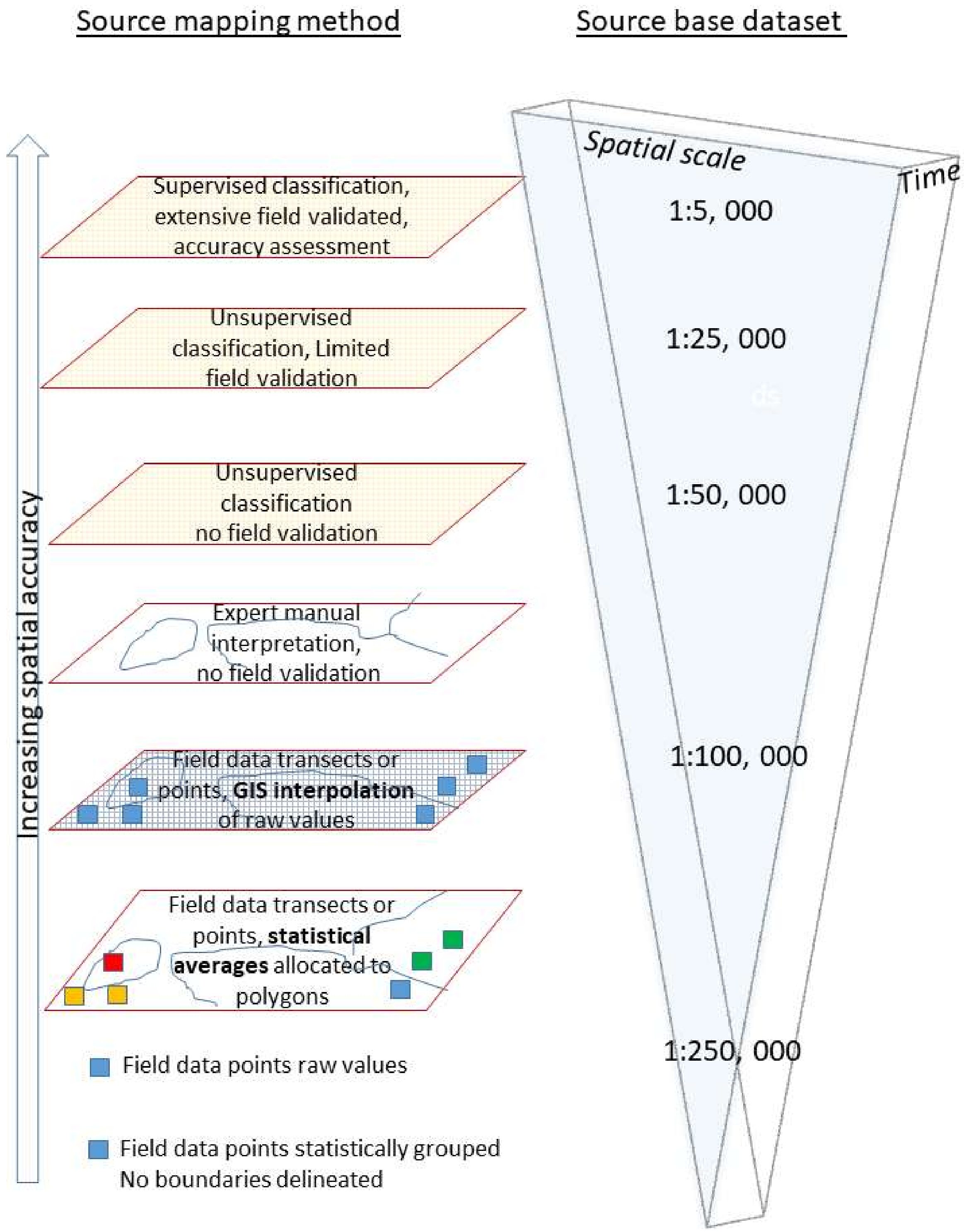


Figure 18: Source Mapping Methods, Base Data Scale and Accuracy. Accuracy of source datasets can be assessed on two independent sliding scales, however the spatial resolution and accuracy of the method (left) is affected by the scale of base data (right).

Limitations in classifying and mapping types originate from gaps in the mapping, methods, and data density of the source datasets. When mapping an attribute classification, the crosswalking process also presents challenges. Multiple attribute datasets provide multiple lines of evidence that reduce limitations, increasing confidence in a mapped and classified product. Limitations associated with a mapped typology include the degree of simplification and generalisation needed for online presentation.

7.2 Confidence in a set of mapped attributes associated with an attribute classification

The source dataset's spatial and attribute resolution and structure all affect the way the crosswalking process incorporates a set of mapped attributes associated with an attribute classification.

Multiple lines of evidence - the ability to cross-check or validate source datasets, refining one dataset using another, adds to the confidence that an attribute will be accurately mapped. A mapping method that collates multiple attribute datasets benefits by combining multiple lines of evidence including by-products of remote sensing, GIS and field validated thematic data mapping (DSITI, 2015). Advantages and disadvantages of multiple lines of evidence include:

- **an increase in precision in mapping** (e.g. Figure 11)
- **boundary non-alignment.**

Discrepancies in boundaries between datasets derived by different methods and scales may highlight incompatibility between datasets and reflect data gaps. It may be necessary to disregard the boundary of a broad, inaccurate dataset, replacing it with a refined spatial layer which in turn improves confidence in the attribute classification. The broad dataset may still apply to the attribute source.

Crosswalking confidence - the degree to which a classified dataset is accurately crosswalked to the scheme is assessed during the crosswalking process, i.e. the degree to which a source dataset's classes, metrics or thresholds of the source dataset match the scheme's categories (Module 1, DEHP, 2017a). The following best practice confidence principals are drawn from the CMECS scheme (see Appendix H, FGDC, 2012):

- exactly match (=). Confidence is 'High' (certain). For example, RE mapping of intertidal polygons in Bioregions 8 and 11 are an exact match, and confidence is high
- less than equivalent (<). The dataset is one-to-many, or many-to-one in comparison with the scheme category. Its confidence is 'Moderate' (somewhat certain). For example, the mapping dataset has a finer degree of mapping and categorisation than the scheme, and needs to be grouped up to approximate scheme categories; or a broader dataset that needs ancillary data to split
- uncertain (~). There is some connection between the attributes and categories of the Scheme, but the relationship is not clear. The connection is based on the best educated guess by the mapping team.

Challenges in crosswalking mapping scenarios and solutions include (see CMECS, 2012 for a full list of typical crosswalking issues), for example, when the source dataset:

- is **a mixture of two categories that** requires concatenation, or
- includes **more detailed polygons/categories than the scheme** (see '<' confidence above).

The solution is to group up the mapping polygons into the broader categories of the scheme but provide the ability to split out finer categories by adding the original legend in a text field. If the dataset scale is broader and can be split, look for ancillary data to enable the split. For example, Regional Ecosystems mapping groups grass, herb, and sedge in the southern half of Central Queensland Project area (DEHP, 2017b). An ancillary dataset Bruinsma and Danaher (2002) splits some polygons with grass mapping which is also visible on LiDAR and orthophotography. These ancillary layers are used to split the dataset.

7.3 Confidence of mapped typology

A critical difference between the mapped attributes dataset and the mapped typology dataset is, while **independence** of the mapped attributes is acceptable across different sources and scales, in a mapped typology their alignment is necessary due to the **hierarchy** of attributes. This means when applying types, overlapping boundaries will need to be resolved in some way, balancing limitations of simplification with increased complexity and reduced mapping clarity. For certain typology mapping applications, it may be preferable to retain an attribute classification as a source of reference and checking point to verify and retain the point-of-truth back to source data.

Boundary non-alignment - discrepancies between boundaries of multiple, overlapping source datasets lead to significant complexities when multiple attribute datasets are unioned, resulting in many slivers of attributes and types. Possible solutions will have implications for confidence, including:

- **the 'flattening' of attributes datasets,** either prior to running the typology (section 3.5) or afterwards (5.2) where concatenation reduces mixed or overlapping datasets to a single grouped polygon
- **the generalisation of** the final types dataset as described in section 5.3
- **the allocation of 'non-types', 'incompatible types' or 'catch-all types'** as described in section 5.3
- field inventory and field validation of source data, data density and scale (see Figure 18 and section 7.1). Often the scarcity of datasets and lack of replication in surveys in the intertidal and subtidal environment means it is not possible to employ rigorous statistical approaches when assigning confidence levels (e.g. as recommended by Congalton 1991). Assembly of attributes and designation of types can identify knowledge gaps, which can then allow for the collection of new inventory data.

Accuracy assessment - the ultimate way to assess the accuracy of a map is by undertaking an assessment of the certainty (or confidence) of encountering a particular habitat type within the given region of the mapping project (e.g. Congalton, 1991). This can be done through a systematic field validation process, though a comparison of known habitat types that have been accurately mapped in the field during past surveys, with the resultant predictive map (e.g. Roelfsema *et al.* 2013, 2018). Alternatively, the type layer is compared with a validation field layer in a 'confusion matrix' where user's and producer's accuracies are compared (see Congalton, 1991).

Compiling the mapping intensity of all field observations for a given attribute highlights inventory focus areas but also knowledge gaps and approaches to fill these gaps in the future, for example:

- **by drawing together inventory, attribute classification** highlights gaps in fundamental datasets, locations that are either challenging to inventory, or remote from transport pathways e.g. areas outside navigation channels and ports, above and below the low water mark in shallow waters, turbid nearshore areas and estuary entrances
- **routinely adding field inventory for a number of different attributes** rather than targeted exclusively to project data would help to address gaps in highly accessible areas to supplement existing field data and to inform remote sensing projects
- **the georeferencing and sharing of monitoring and transect data** enables better characterisation of polygon datasets through crosswalking. Georeferenced monitoring point data can be used to enrich or interpret other mapping surrogates to better predictively

model extent, e.g. classification or validation of remotely sensed spectra or object-based analyses.

7.4 Inform standards

As outlined in this document, field sourced data for attribute classification and typology mapping is highly variable, and many datasets have specific designs and purposes that render them unsuitable for use (e.g. monitoring or statistically analysed ecological datasets grouped up to a single point coordinate, lack of accurate or reliable metadata etc.). Adherence to appropriate metadata standards (e.g. ISO metadata standard) will enhance the usefulness of field sourced data. Attributes and categories of the scheme can provide field standards for the design of inventory, i.e. data schema and Standard Operating Procedures (SOPs) to enable standard data collection methods for seamless integration of data into future classification and mapping.

Beneficial additional information/principles to incorporate into SOPs include:

- maximising end-uses of field data when designing a field inventory project to consider a range of biophysical attributes
- a checklist of minimum standards to enable field data collected to be compatible with the scheme. Appendices 6.2 and 6.3 of Module 1 (DEHP, 2017a) provides a list of attributes and categories for seascape and habitat levels of the scheme. Attributes and categories are also listed on the intertidal and subtidal attributes pages in the ecology tab of Wetland*Info* (DES, 2019d)
- a list of potential additional attributes can easily be collated in a targeted SOP
- a standardised process to accurately georeference site data (e.g. georeferencing of each photo, georeferencing the beginning and end of transects, videos, tows etc)
- base georeferenced site data always accompanies statistically analysed pattern outputs.

8. Attribute and Typology Mapping as a Rich Data Synthesis Tool Informing EBM

This method applies the Queensland Intertidal and Subtidal Ecosystem Classification Scheme to benthic ecosystem mapping and is designed to cover all ecosystems within Queensland state waters (DEHP, 2017a*).* Application of the scheme to mapping addresses the principles of EBM, by documenting the location of ecosystem components and their attributes (characteristics) within a recognised classification framework that complements land-based mapping. It serves a wide range of applications, guiding classification, data synthesis, mapping, and monitoring.

Applying a classification standard to existing source data provides an information resource for natural resource management and planning, to guide investment, research, survey and targeted inventory, communication, and education, and to inform decision-making. The document is designed for scientists and managers who are thinking of applying the method, for project design, inventory and/or baseline mapping, or data compilation projects, for discussion with their spatial ecologist, analyst and/or data wrangler colleagues.

Stages and steps of attribute classification, typology and mapping and their spatial implications are outlined. Workflow is designated between the technical advisory panel guiding attribute classification and typology, and the team mapping their decisions. Classification scope, scale, attributes selected, the number and order of types designated have mapping implications, such as how technical panel information is captured, the spatial database supporting the mapping of attributes and types designed, and end products released.

A rich data synthesis is created when source spatial datasets are assembled and organised around biophysical attributes of the scheme, into a set of mapped attributes accompanying an attribute classification. Existing source datasets can be crosswalked (translated) to the attributes and categories of the scheme, enabling many disparate datasets to be assembled into a composite attribute spatial dataset.

The attribute spatial data assembly process orders and re-assembles source datasets according to accuracy/reliability, accounting for varying scales, source data methods, metrics, and surrogate datasets. The attribute compilation process involves source data selection and data schema design to enable source data to be incorporated, its identity maintained, and accuracy and spatial origin tracked. Examples demonstrate the crosswalking process and mapping of change using qualifiers (e.g. naturalness, period, and trend). Finally, source datasets are compiled into a single composite attribute dataset to support a mapped attribute based on the category field of the dataset.

The typology mapping process is guided by the accurate capture and elicitation of typology rule-sets through the technical panel process. The mapping team apply typology rule-sets via queries to a unified dataset of attributes and categories that link to each composite attribute dataset and its source datasets. Typology rules are hierarchical, determined by the order in which decisions are made about each attribute and category. Through an iterative process a type map can be produced by running rule-sets, examining the mapping product, and re-running until a satisfactory end product is achieved that makes ecological sense to the technical panel, and to potential users who test this product. Online products may require generalisation, which has implications for the ability to trace back to data sources as the linework no longer reflects these original source data or identifiers.

Online mapping is delivered as a suite of interactive products with linkages to ecosystem type descriptions and biophysical attributes.

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Appendix A1: Definitions and abbreviations

Definitions in Appendix A1 are scientific, ecological definitions. Spatial analysts should also refer to definitions in Appendix A1.1. for software-specific terminology. For definitions below, refer to Wetland*Info* (DES, 2020b).

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

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 (Aquatic Ecosystems Task Group, 2012).

Attribute classification: defines and categorises components of the environment into attributes and categories and is not hierarchical within a level (DES, 2020b).

Attribute themes: are broad groups used to describe attributes e.g. terrain, substrate, energy, hydrology (physical/chemical) and biota (DES, 2020b).

Co-types: Multiple types coexisting in the same place at the same time.

DEM: Digital elevation model.

LiDAR: Light detection and ranging**.**

MBES: Multi-beam echosounder.

Source dataset: a data file that contains spatial ecological knowledge. (See section 2.1).

Type: a kind, class, or group as distinguished by a particular characteristic.

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 purpose (Aquatic Ecosystems Task Group, 2013).

A1.1 GIS terminology: Technical software-specific definitions

Database: One or more structured sets of persistent data, managed and stored as a unit and generally associated with software to update and query the data (ESRI, n.d.).

Data file: A file that holds text, graphics, or numbers. *N.B. see above 'source dataset', i.e. a data file that is contains ecological source data* (ESRI, n.d.).

Field: A column in a table that stores values (ESRI, n.d.). *N.B. Modified after ESRI 'attribute values'. In this document the 'attribute' is used in its ecological sense – see above definition.*

Field mapping (geoprocessing): Defining the field structure and content for an output dataset. *N.B. It is possible to crosswalk a source dataset to the scheme through a field mapping exercise, where the source field is mapped to corresponding attributes and categories of the scheme.*

GIS: Geographic Information System.

Geodatabase data model: The schema for the various geographic datasets and tables in an instance of a geodatabase. The schema defines the GIS objects, rules, and relationships used to add GIS behaviour and integrity to the datasets in a collection (ESRI, n.d.). *N.B. Geodatabase is ESRI software, a relational database that links geographic datasets with tables. Other spatial software may use different terminology.*

Schema: The structure or design of a database or database object, such as a table, view, index, stored procedure, or trigger. In a relational database, the schema defines the tables, the fields in each table, the relationships between fields and tables, and the grouping of objects within the database (ESRI, n.d.). *N.B. Not to be confused with scheme i.e. the Queensland Intertidal and Subtidal Ecosystem Classification Scheme, see above definition.*

Spatial: Related to or existing within space.

Spatial database: A structured collection of spatial data and its related data, organized for efficient storage and retrieval (ESRI, n.d.). *N.B. ESRI terminology uses the term 'attribute data', however the term 'attribute' is reserved in its ecological sense in this document.*

Appendix A2: Example of attribute and category 'collapsing'

The table below shows a sub-set of attributes and categories from a typology workshop. The two attribute datasets shown are Inundation and Structural macrobiota. Attributes are colour-coded and listed in the top row.

The categories for each attribute are those listed in the seascape scale classification, from Module 1 Appendix 6.2 (DEHP, 2017a).

The central row lists the 'collapsed categories', i.e. the categories that the technical advisory panel chose to group together for the purpose of the project, i.e. for general management purposes. For example, for the Inundation attribute categories were collapsed into either: 'Subtidal', 'Intertidal', 'Intertidal indeterminate' or 'unknown'. Selected structural macrobiota categories that were collapsed included: turf and filamentous algae (collapsed into 'other algae'), hard corals of bushy, massive, submassive, vase/foliose, plate/table, encrusting and mixed growth forms were collapsed into 'non-branching'.

Attribute	Collapsed Categories (seascape, other)	TYPE_ID TYPES
Inundation	Subtidal	Subtidal
	Intertidal	LI
	Intertidal	Mid-Low (MLWS to MLWN)
	Intertidal	Upper Low (MLWN to MSL)
	Intertidal	Low - undifferentiated
	Intertidal	Lower Medium (MSL to MHWN)
	Intertidal	Upper-Medium (MHWN to MHWS)
	Intertidal	Medium - undifferentiated
	Intertidal	High (MHWS to HAT)
	Intertidal	Intertidal - undifferentiated
	Intertidal	High - undifferentiated
	Intertidal indeterminate	Indeterminate
	Unknown	Unknown
Structural macrobenthos	GHS	Grass-herb-sedge
	Grass	Grass
	Succulent	Succulent
	Sedge	Sedge
	Mangrove and other trees	Mangrove and other trees
	Mangrove (ceriops)	Mangrove (ceriops)
	Mangrove (rhizophora)	Mangrove (rhizophora)
	Mangrove (avicennia)	Mangrove (avicennia)
	Mangrove (mixed)	Mangrove (mixed)
	Other trees and shrubs	Other trees and shrubs
	Seagrass - ovoid	Ovoid
	Strap (width unspecified)	Strap (width unspecified)
	Strap (wide)	Strap (wide)
	Strap (narrow)	Strap (narrow)
	Other seagrass	Fern-like
	Other seagrass	Cylindrical
	Other seagrass	Other
	Other algae	Erect calcareous
	Other algae	Erect macrophytic (mac.algae)
	Algae (microphytobenthos)	Encrusting (inc. CCA)
	Other algae	Turf mat
	Other algae	Filamentous
	Other algae	Other
	Other biota	Other flora
	Molluscs	Molluscs (other)
	Molluscs	Molluscs (oysters)
	Molluscs	Molluscs (scallops)
	Coral - Hard	Hard coral - undifferentiated
	Branching	Hard coral - branching
	non- branching	Hard coral - bushy
	non- branching	Hard coral - massive
	non- branching	Hard coral - submassive
	non- branching	Hard coral - vase/foliose
	non- branching	Hard coral - plate/table
	non- branching	Hard coral - encrusting
	non- branching	Hard coral - mixed structures
	Corals	Hard/soft corals undifferentiated
	Octocorallians	Soft coral (octocorallians)
	Other fauna	Sponges
	Other fauna	Ascidians
	Other fauna	Crinoids
	Other fauna	Tubeworms
	Other fauna	Bryozoans
	Other fauna	Barnacles
	Other fauna	Other fauna
	Other biota	Other biota
	None	None
	Unknown	Unknown

Appendix A3: Extract of a typology rule-set template

The same attributes and categories shown in Appendix A4 are shown in the table below.
The sort order of the ecosystem types is in the first column on the left hand side.
The index number of the ecosystem types ('TYPE_ID') is in the second column from the left hand side.
Ecosystem type names are in the second column from the left.
Combinations of attributes and categories that constitute typology rule-sets are shaded by blue cells.
For example, the diagnostic attributes for the intertidal coral ecosystem type 21 includes:

- **Inundation** 'Intertidal' i.e. any of the categories in the third row that correspond to 'intertidal' in the second row, and
- **Structural macrobiota** 'Coral' i.e. any of the coral structural macrobiota categories.

Intertidal coral is allocated as the twelfth ecosystem type in the sort order or hierarchy.

	Attribute	Inundation													Structural macrobenthos																																															
	Collapsed Categories (seascape, other)	Subtidal	Intertidal	Intertidal	Intertidal	Intertidal	Intertidal	Intertidal	Intertidal	Intertidal	Intertidal	Intertidal	Intertidal indeterminate	Unknown	GHS	Grass	Succulent	Sedge	Mangrove and other trees	Mangrove (ceriops)	Mangrove (rhizophora)	Mangrove (avicennia)	Mangrove (mixed)	Other trees and shrubs	Seagrass - ovoid	Strap (width unspecified)	Strap (wide)	Strap (narrow)	Other seagrass	Other seagrass	Other seagrass	Other algae	Other algae	Algae (microphytobenthos)	Other algae	Other algae	Other algae	Other biota	Molluscs	Molluscs	Molluscs	Coral - Hard	Branching	non-branching	non-branching	non-branching	non-branching	non-branching	non-branching	non-branching	Corals	Octocorallians	Other fauna	Other fauna	Other fauna	Other fauna	Other fauna	Other fauna	Other fauna	Other biota	None	Unknown
TYPE_ID	TYPES	Subtidal	LI	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	High - undifferentiated	Indeterminate	Unknown	Grass-herb-sedge	Grass	Succulent	Sedge	Mangrove and other trees	Mangrove (ceriops)	Mangrove (rhizophora)	Mangrove (avicennia)	Mangrove (mixed)	Other trees and shrubs	Ovoid	Strap (width unspecified)	Strap (wide)	Strap (narrow)	Fern-like	Cylindrical	Other	Erect calcareous	Erect macrophytic (mac.algae)	Encrusting (inc. CCA)	Turf mat	Filamentous	Other	Other flora	Molluscs (other)	Molluscs (oysters)	Molluscs (scallops)	Hard coral - undifferentiated	Hard coral - branching	Hard coral - bushy	Hard coral - massive	Hard coral - submassive	Hard coral - vase/foliose	Hard coral - plate/table	Hard coral - encrusting	Hard coral - mixed structures	Hard/soft corals undifferentiated	Soft coral (octocorallians)	Sponges	Ascidians	Crinoids	Tubeworms	Bryozoans	Barnacles	Other fauna	Other biota	None	Unknown
	INTERTIDAL																																																												
3	Succulent with herb		x	x	x	x	x	x	x	x	x	x					x																																												
4	Sedge		x	x	x	x	x	x	x	x	x	x						x																																											
2	Grass		x	x	x	x	x	x	x	x	x	x				x																																													
17	Bare areas above MSL (i.e. Saltpan with or without microphytobenthos)								x	x	x	x																																																	x	
1	Grass-herb-sedge (undifferentiated)		x	x	x	x	x	x	x	x	x	x			x																																														
6	Ceriops		x	x	x	x	x	x	x	x	x	x								x																																									
7	Rhizophora		x	x	x	x	x	x	x	x	x	x									x																																								
8	Avicennia		x	x	x	x	x	x	x	x	x	x										x																																							
9	Mixed mangroves		x	x	x	x	x	x	x	x	x	x											x																																						
5	Mangroves and other trees (undifferentiated)		x	x	x	x	x	x	x	x	x	x							x																																										
10	Other trees and shrubs		x	x	x	x	x	x	x	x	x	x												x																																					
21	Intertidal coral		x	x	x	x	x	x	x	x	x	x																														x	x	x	x	x	x	x	x	x	x	x										
