



Valuation of disaster risk reduction ecosystem services of Australia's coastal wetlands: review and recommendations

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ABBREVIATIONS

ACES	A Community on Ecosystem Services
ANAE	Australia National Aquatic Ecosystem classification
BRI	Benefit Relevant Indicators
CBA	Cost benefit analysis
CICES	Common International Classification System for Ecosystem Services
CS	Classification system
DAWE	Department of Agriculture, Water and Environment
DRFA	Disaster Recovery Funding Arrangements
DRR	Disaster risk reduction
EDF	Expected damage function
EEA	European Environment Agency
ES-CS	Ecosystem services classification system
FECS-CS	Final Ecosystem Services Classification System
FES	Final ecosystem services
GET	Global Ecosystem Typology
GDP	Gross Domestic Product
IPBES	International Platform on Biodiversity and Ecosystem Services
INT\$	International dollar
MS	Microsoft
NESCS Plus	National Ecosystem Services Classification System Plus
SEEA	System of Environmental-Economic Accounting
TEEB	The Economic of Ecosystems and Biodiversity
UNSD	United Nations Statistics Department
US EPA	United States Environmental Protection Agency

1 EXECUTIVE SUMMARY

Coastal wetlands enable a wide range of benefits through the provision of ecosystem services. These include cultural and intrinsic benefits related to the existence of biodiversity and wetlands themselves. Wetlands provide food (fish and seafood) and mitigate climate change by sequestering and storing carbon. In addition, coastal wetlands contribute to improved health by providing recreational opportunities and filtering pollutants from water. They can also protect human property from coastal storms, floods, sea level rise and subsidence.

The valuation of disaster risk reduction ecosystem services that protect human property has been identified as a useful approach to improve coastal planning. However, valuations have often failed to be adequately considered by decision makers.

To help understand and address this gap, a literature review, expert consultation and analysis was undertaken. The review captured valuation studies—primarily from the past decade—that were identified through online searches using over 20 terms related to coastal wetlands and disaster risk reduction (IDEEA Group 2020a). The studies included values of the disaster risk reduction ecosystem services provided by 148 coastal wetlands globally. In addition, fifteen experts were interviewed using both structured and open ended questions. Finally, the results of the literature review and consultations were analysed.

In these studies, disaster risk reduction ecosystem services provided by coastal wetlands are described with a variety of terms from wave attenuation to natural hazard mitigation. But they can all be understood as the role coastal wetlands play in the “protection of human property.” This description is consistent with Ramsar and major ecosystem services classification categories and systems, such as the Millennium Ecosystem Assessment.

The major factors influencing the value of a coastal wetland disaster risk reduction ecosystem services are frequency and severity of hazards, property values, wetland extent, wetland condition and wetland ecosystem type. The greater the property values and wetland extent and better the condition, the more valuable the wetland. In addition, some ecosystem types have biophysical properties that better protect human property than others. For example, a saltmarsh will protect property better than a coral reef of comparable size, quality and location.

In Australia, twenty-eight wetlands, or wetland groups, were valued. Because of the grouping of wetlands into large geographic areas (e.g. salt marshes of temperate Australia), these studies cover the full extent of Australia’s coastal wetlands. However, in these cases, the large geographic scales or the valuation techniques used yielded values which were often broad ranges. For example, one study noted the value of a hectare of wetlands ranging from INT\$¹(2019) 2.57 to 11,477 (Gaylard et al. 2020). Studies such as these can raise awareness but do not guide coastal planning decisions.

¹ INT\$ is the international dollar, a hypothetical currency unit based on purchasing power parity that the U.S. dollar has at a given point in time.

Valuations that had the most influence on coastal planning used explicit local valuation approaches. One example is the ongoing valuation of Port Phillip Bay & Bellarine Peninsula. Its initial reports valued the salt marshes of the region at AUD\$(2019) 29,888,000 (Carnell, P.E, Reeves, S.E, Nicholson, E. et al. 2019) in terms of the disaster risk reduction services they provide. This study was conducted at small spatial resolution, providing coastal planners with clear options about the disaster risk reduction implications of decisions relating to every section of the coast's coastal marshes. This is critical because most coastal planning decisions are made with reference to specific locations. These approaches also rely on quality data and modelling of the biophysical and economic benefits that coastal wetlands provide.

There is extensive modelling expertise in Australia and around the globe. However, modelling specialists (e.g. wave, wind, ecosystem functions, structural integrity) could collaborate more effectively in building interoperable models, that is, models that integrate storm, wind, wave and other components of hazards, such that decision makers are provided integrated rather than discrete pieces of information. Moreover, modellers are encumbered by the poor adoption of standards for ecosystem types, ecosystem services and general biophysical and economic data. Finally, most valuation processes fail to effectively engage decision makers to help ensure acceptance of results.

The following steps are recommended to address these gaps:

1. *Promote explicit local valuation approaches* over those focused on raising awareness or determining the opinions of stakeholders
2. *Encourage the use of standards for identifying ecosystem types and ecosystem services and collecting data* so that researchers can more efficiently define, discover and utilize data about the relationships among key attributes of different ecosystem types
3. *Advance the use of best practices in stakeholder engagement* so that valuations are fully embedded in coastal planning decision making processes
4. *Build partnerships among environmental, engineering and insurance modelers* to advance the accuracy of models and valuations
5. *Explore opportunities for hedonic pricing studies* (which isolate the impact of specific variables on property pricing) as the coastal real estate market appears to have started incorporating the risks from coastal hazards
6. *Support Pacific island nations' use of explicit local valuation approaches* so they may improve their coastal planning in the face of significant hazards

The recent increase in studies applying explicit local valuation approaches in Australia is encouraging. The ongoing Mapping Ocean Wealth valuation studies in Port Phillip Bay and Western Port is an example of good practice. This project will not only demonstrate the efficacy of the approach but is also likely to spur other coastal planners to take similar steps. In turn, the costs and quality of the next round of valuations will be influenced by adoption of best practices in classification and decision maker engagement.

Resource constraints suggest the need for a prioritization of candidate wetlands to be valued. Such an exercise could be conducted at the national or state level and include factors such as the threat of

conversion of the wetland, the risk of natural hazards, the existence of an ongoing coastal planning efforts and the value of human property protected by the wetlands. Consideration should also be given to building data standards and datasets for later use by coastal planners, the insurance industry and other stakeholders in modelling and valuation. The same prioritization criteria could be used for a data prioritization effort.

2 THE ROLE OF COASTAL WETLANDS

Australia's coastal wetlands provide vital services including coastal protection, fisheries production, blue carbon capture and pollutant removal. Marine fauna utilise coastal habitats as nursery areas as well as for shelter and feeding. Despite these benefits, pressures from agri- and aquaculture, industry and urban expansion (Seto et al. 2011) have been driving loss of extent and condition of coastal wetlands and the services they provide. Wetland and other coastal habitats are increasingly at risk from losses of biological and physical resources (e.g. fish, water, energy, space) and the consequences of a warming climate and sea level rise (Elliott et al. 2016, Creighton et al. 2016). As a result, management of these coastal resources has come into prominence (Waltham et al. 2019).

Ecosystem protection and restoration has been recognised as key to coastal wetland resilience in Australia (Clark & Johnston 2017, Waltham et al. 2019, Creighton et al. 2015, Taylor & Creighton 2018). Efforts to restore these wetlands and hence recapture their natural values and ecosystem services has expanded. It has also been recognised that this will require a coordinated approach, involving elements such as prioritisation, monitoring and evaluation, and the engagement of governments, communities and industries.

A total of 28 coastal or estuarine wetlands as well as 6 islands/reefs are listed under the Ramsar Convention as wetlands of international importance in Australia. An integral objective in the management of these wetlands is protection of the various environmental, biodiversity, economic and cultural services they provide. Recently, there has been interest in protecting and restoring coastal wetlands for the disaster risk reduction services they provide to human property from natural hazards such as storms (e.g. cyclones, storm surge), including long term hazards (e.g. sea level rise subsidence) (Folan et al. 2019, Taylor & Creighton 2018) .

Managing and restoring coastal wetlands is primarily done at the local level through zoning, management and related regulatory steps, with state and federal coordination. One approach that can support this local scale management is economic valuation. Accurate valuation of the ecosystem services coastal wetland provide can help decision makers manage the trade-offs among development options. For example, converting a coastal wetland into real estate development may increase economic opportunities for the construction and retail sectors, but harm the fishing industry through loss of nursery services and affect home values by making the area more vulnerable to coastal storms. Valuation of impacts of competing development or retention/restoration options should deepen the understanding of the economic advantages and disadvantages of each option.

A review of the effectiveness of disaster risk reduction valuation approaches in influencing decision making is warranted.

3 SCOPE OF THE REPORT

3.1 Process

The Australian Ramsar Administrative Authority (the Authority) within the Department of Agriculture, Water and Environment (DAWE) commissioned this report to explore the techniques, approaches, results and utility of valuation of disaster risk reduction services ecosystem services provide by coastal wetlands. The Authority coordinates implementation of the Ramsar Convention on Wetlands in Australia and supports Ramsar Oceania Region members from Pacific island nations.

The report provides guidance to DAWE in advancing valuation and related data management so that the full value of Australia's coastal wetlands in providing disaster risk reduction services can be realised in decision making. The report was developed in four phases. They were:

- In phase 1, global best practices on coastal wetlands ecosystem services identification, measurement and valuation were captured, as well as the needs of institutions that make decisions regarding this natural capital.
- In phase 2, Australia's experience with valuation of disaster risk reduction services for coastal wetlands was captured. Valuation methods used were reviewed for their quality and their ability to influence decision making.
- In phase 3, the relevant knowledge gaps for Australia were identified along with the needs for data and improved valuation methods. This included a review of possible solutions to filling these gaps, including the potential links to supporting standards and best practices. Recommendations were made based on this gap analysis.
- In phase 4, the totality of this research and analysis was captured in this report, two MS Excel workbooks and a bibliography of valuation studies.

3.2 Scope

This report focuses on the valuation of disaster risk reduction (DRR) ecosystem services provided by coastal wetlands. Disasters risks include those caused by natural hazards from storms (e.g. cyclone, tsunami) and long term hazards whose impacts generally occur or build over several years or decades (e.g. sea level rise, subsidence) (

Figure 1). The physical characteristics, structures and ecosystem functions (e.g. wave attenuation) allow wetlands to assist in the protection of human property. Because of these disaster risk reduction ecosystem services, the impacts of hazards such as building damage can be mitigated.

Beyond the scope of this report are other ecosystem functions and services that coastal wetlands provide. These range from nursery habitats for fish to recreational opportunities and being a source of building materials. The provision of these services by coastal wetlands is also impacted by natural hazards. For example, a cyclone may kill hatchlings and eliminate a mangrove's poles and thatching. This will impact fishers and those that use wood materials from mangroves. This report focuses only

on the impacts to human property. The long-term socioeconomic impacts of natural disasters are greater than the economic damage attenuated by disaster risk reduction ecosystem services.

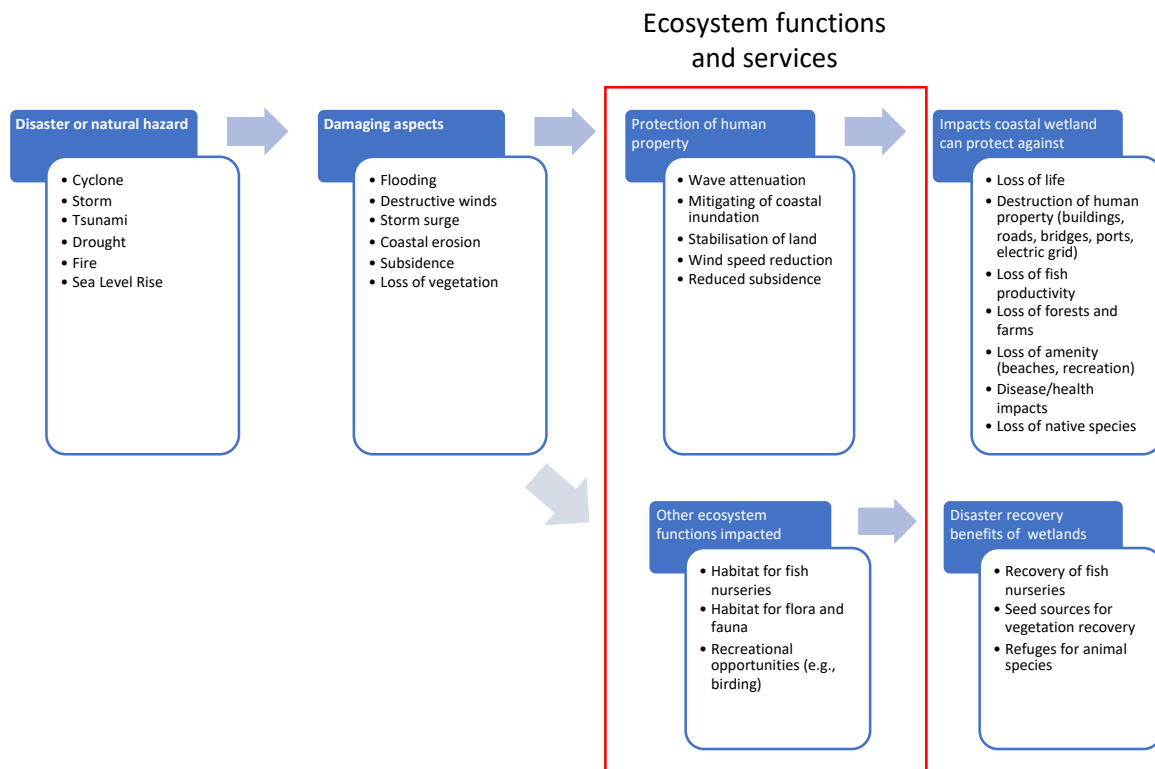


Figure 1 Disasters, damages, protection and impacts of coastal wetlands

The description of the relationships among hazards, ecosystems and impacts in Figure 1 provides a general narrative. However, recent advances in the application of valuation techniques demand greater precision in the distinctions among functions, ecosystem services and benefits. The research detailed in Appendix 4 Natural capital accounting data structure

The System of Environmental-Economic Accounting (SEEA) (United Nations et al. 2014b) is the global standard for natural capital accounting. One component of SEEA, is that provides uniform classification of data for improved speed and accuracy in defining and discovering data. **Error! Reference source not found.** demonstrated how SEEA organized different social and economic data.

Table 11 SEEA data classification structure

Generic SEEA data classification structure (adopted from United Nations Statistics Division 2018)		
Subcomponent	Definition	Example
Physical extent	Area in terms of coverage and arrangement	Topography, geography
Institutional extent	Zoning such as regulatory and planning areas	State and Council Zones, Ramsar boundaries
Ecosystem extent	Extent and composition of the ecosystem types	Seagrass, rocky reef, mangrove and salt marshes
Context	Contextual information that makes up the broader socio-ecological system	Cities, agricultural land, river connections
Coastal use	Terrestrial areas designated for use relating to the marine environment	Homes, ports, piers
Use	Uses of the wetland environment	Disaster risk reduction, tourism, fishing
Physical characteristics	Physical attributes system quality	Soil types, waves, tides, winds, salinity, heat content, mean sea surface, mean dynamic topography, turbidity (reflectance), mixed layer thickness, water pressure, water density
Chemical characteristics	Chemicals and nutrients system quality	Phosphate, nitrate, silicate, alkalinity, pH, CO ₂ , oxygen/hypoxia, tritium, oil-spill trajectory
Biological characteristics	Biological attributes	algal bloom, water quality, pests (starfish, sea urchins), bleaching

Generic SEEA data classification structure (adopted from United Nations Statistics Division 2018)

Subcomponent	Definition	Example
Ecological characteristics	Ecological characteristics of system	Cover, density, diversity of species
Biotic assets	Living natural assets	Aquatic plants, seaweeds, fish, birds, shrubs, trees,
Abiotic assets	Nonliving natural assets	Beach, seafloor sediments and rocks
Biotic physical services	Services that living components of the system provide	Protection of human property (wave attenuation, wind speed reduction), habitat services, carbon sequestration and storage, cultural services, tourism
Biotic monetary services	Valuation of physical services	As above, but valuation perspective
Abiotic physical services	Non-living components the system provides	Wind and wave energy reduction,
Abiotic monetary services	Valuation of abiotic physical services	Wave attenuation of rocky reef

Appendix 5 History of ecosystem services classifications shows that a lack of precision leads to poor selection of metrics and therefore less precise valuations. This may not be important to building general awareness of the DRR ecosystem services, but for coastal planning, this becomes critical in quantitative and monetary analysis. Moreover, when integrating DRR values with those related to fisheries and wood products, these distinctions are essential to avoid double counting (Appendix 4 Natural capital accounting data structure

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Appendix 5 History of ecosystem services classification

A more robust ecosystem service measurement and valuation framework for understanding DRR ecosystem services is needed than the one described in Figure 1.

3.3 Measurement and valuation framework

3.3.1 Classification of ecosystem services and related elements

This report uses a measurement and valuation framework based on ecosystem services classification systems.

Publication of the Millennium Ecosystem Assessment defined four groups of ecosystem services (i.e. provisioning, regulating, cultural, supporting) (Millennium Ecosystem Assessment 2003). Since then, there has been progress on how the identification, or naming, of ecosystem services connects to their measurement and valuation². The core finding is that by consistently applying classification standards to the identification of ecosystem services, they will be named more accurately and therefore the process of selecting metrics and valuation techniques should improve (Finisdore et al. n.d.). Moreover, the broader the adoption of these classification standards at the local, state and national scales, the greater the ease at which research can be integrated among studies. Even within a single study, values of different ecosystem services can be more easily combined if they are identified with the same classification system.

² For details see Appendix 4 Natural capital accounting data structure

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Appendix 5 History of ecosystem services classification.

Only the National Ecosystem Services Classification System Plus (NESCS Plus) (United States Environmental Protection Agency (US EPA) 2020) and the Common International Classification System for Ecosystem Services (CICES) (Haines-Young & Potschin 2018) meet the standards of being a classification system. They are the only groups or classifications of ecosystem services that embody the principles of classification science (Finisdore et al. n.d., Appendix 5). As shown in Table 1, both classification systems describe the disaster risk reduction (DRR) ecosystem service for coastal wetlands in effectively the same way. Likewise, the Millennium Ecosystem Assessment (Millennium Ecosystem Assessment 2003) and The Economic of Ecosystems and Biodiversity (TEEB) (Bishop 2013) wording describes the same environmental-economic relationship³.

Table 1 Descriptions of DRR ecosystem services

Classification system or grouping	Description of the DRR ecosystem service
MA	Natural hazard mitigation
TEEB	Moderation of extreme events
CICES	Regulation of baseline flows and extreme events for: <ul style="list-style-type: none"> • Buffering and attenuation of mass movements • Hydrological cycle and water flow regulation (Including flood control, and coastal protection) • Fire protection (the bullets represent a sub-classification of the first line)
NESCS Plus	Presence of ecosystems' composite end products (e.g. coastal wetlands) for the protection of human property of users (e.g. industry, household, government)

This report uses the terms “disaster risk reduction (DRR)” and “protection of human property.” They are used synonymously with the TEEB, CICES and MA definitions as well as the terms used in the literature. A comparison of the term in the literature and those in Table 1 is in section Literature review and stakeholder interviews.

3.3.2 Connecting measurement and valuation concepts

Consistent with the best practices in ecosystem services classification, this report uses the framework in Figure 2. The coastal wetland ecosystem has various characteristics and processes (e.g. nursery habitat, wave attenuation, mitigation of coastal inundation, carbon sequestration). These enable the delivery of ecosystem services, one of which is the “protection of human property” that provides

³ This similarity contrasts with the CICES ecosystem services of “food” that is absent from NESCS Plus. NESCS Plus focuses on the ecosystem services that soil, rainfall and local temperatures provide to farmers.

benefits to people such as storm damage reduction. Hazards impact coastal wetlands' environmental functions and their provision of ecosystem services, such as their ability to protect property.

The ecosystem service represents the point where specific ecosystem functions deliver benefit to people. All other ecosystem characteristics and processes that are delivering benefits to people are excluded. This is called a "final" ecosystem service and requires both a biophysical and socioeconomic component (Boyd & Banzhaf 2007a). Appendix 5 has a detailed description of the final ecosystem services concept, its origin and utility.

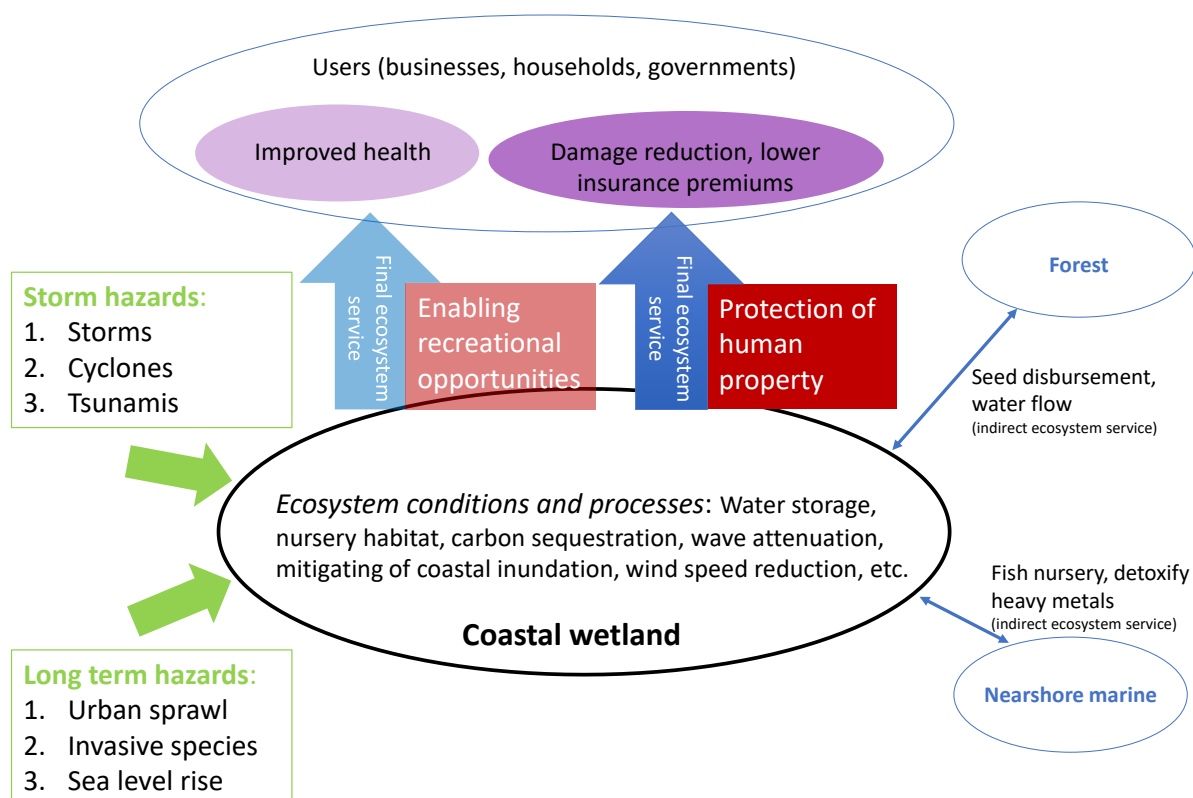


Figure 2 Study framework (adapted from United Nations Statistics Division 2018)

Coastal wetlands can provide other ecosystem services, such as "enabling activities promoting health, recuperation or enjoyment..." that wetlands have been demonstrated to provide (Carter 2015). In addition, coastal wetlands enable the provision of intermediate ecosystem services⁴ that are provided to other ecosystems (e.g. seed disbursement by fauna to nearby forests, nurseries for fisheries). Some of these intermediate ecosystem services indirectly impact human health. For example, coastal wetlands can detoxify heavy metals in water that could be consumed by fish, and affect human health (McComb et al. 2015). Wetlands also have cultural values, serving as sacred places for communities to hold special ceremonies. There are also intrinsic values from the existence of these places and their

⁴ Intermediate ecosystem services are ecosystem functions and processes that are delivered between or among ecosystems. (United Nations 2017)

biodiversity. One demonstration of this value is voluntary donations to organizations such as Greening Australia (<https://www.greeningaustralia.org.au/>) by people who never visit these sites.

Failing to use a final ecosystem services framework complicates the integration of these ecosystem services values. This includes integration within a site, among sites in a landscape and from among studies conducted at different times (Finisdore et al. n.d.).

3.3.3 Coastal wetland types

To provide a clear reference point, this report focuses on coastal ecosystem types that are included in Ramsar's wetland type classifications. They are:

- A — Permanent shallow marine waters in most cases less than six metres deep at low tide; includes sea bays and straits
- B — Marine subtidal aquatic beds includes kelp beds, sea-grass beds, tropical marine meadow.
- C — Coral reefs
- D — Rocky marine shores; includes rocky offshore islands, sea cliffs
- E — Sand, shingle or pebble shores; includes sand bars, spits and sandy islets; includes dune systems and humid dune slacks
- F — Estuarine waters; permanent water of estuaries and estuarine systems of deltas.
- G — Intertidal mud, sand or salt flats
- H — Intertidal marshes; includes salt marshes, salt meadows, saltings, raised salt marshes; includes tidal brackish and freshwater marshes
- I — Intertidal forested wetlands; includes mangrove swamps, nipah swamps and tidal freshwater swamp forests
- J — Coastal brackish/saline lagoons; brackish to saline lagoons with at least one relatively narrow connection to the sea
- K — Coastal freshwater lagoons; includes freshwater delta lagoons (Larmour 1994)

There are other classifications of ecosystem types. They include the Australian National Aquatic Ecosystem (ANAE) classification (Aquatic Ecosystem Task Group 2012) and the IUCN Global Ecosystem Typology (GET) (Keith et al. 2020). These typologies are discussed later in this report with recommendations on their utility for measurement and valuation.

Upon development of a joint Commonwealth, state and territory wetlands inventory, the extent and condition of Australia's wetland types will be clearer. Research for this report used the Australian Wetlands Database, including the 2005 Directory of Important Wetlands (Environment 2005) to help identify and name specific wetlands. Every effort has been made to identify the specific wetlands in each Australian valuation study. The MS Excel file that accompanies this report lists all the wetlands and studies that were captured and integrated into this report along with related meta data.

3.3.4 Other considerations

It is important to note that DRR ecosystem services are not produced by coastal wetlands in isolation of other ecosystem types and ecosystem features. Rather, a combination of geology, geomorphology, sediments, soils and hydrogeology across coastal ecosystems affects the carriage of these ecosystem services (Fox et al. 2020). For example, cliffs, beaches and coastal streams can contribute to DRR. Valuation studies need to consider the interactions of all these features in their analysis.

The study framework (Figure 2) builds on previous Australian (Whiteoak & Binney 2012) and Ramsar (Barbier et al. 1997) commissioned studies. There are no new valuation techniques in conceptual terms. However, the concepts and techniques have been progressively refined since those reports were written, including through the development of international guidance on accounting for ecosystems (United Nations 2017, United Nations et al. 2014a, United Nations et al. 2014b). These advances are reflected in Figure 2's use of the final ecosystem services concept and are explained throughout this report.

To manage the breadth of the research, the literature review of DRR valuation research was limited to studies from the past decade. A few studies were captured from earlier dates because of they either demonstrated unique perspectives on valuations techniques or because of their prominence in the literature. The total number of studies captured, 59, was similar to other surveys of the valuation literature. Two such studies identified 34 and 25 respectively (Brander et al. 2006, Organisation for Economic Co-Operation and Development 2018).

This report focused on disaster risk reduction ecosystem services of coastal wetlands. Unless otherwise specified, reference to any part of this scope (i.e. DRR, ecosystem services, coastal wetlands, wetlands) should be considered as reflecting the entire scope. For example, mention of "ES valuation techniques" refers to only to ecosystem services valuation techniques from coastal wetlands related to DRR.

4 GLOBAL BEST PRACTICES

The global best practice in valuation of DRR ecosystem services from coastal wetlands is the use of “explicit local valuation approaches.” Described below, these approaches are generally based on the expected damage function valuation technique, but are also combined with elements from production function and replacement costs techniques. Because explicit local valuation approaches use smaller scale data (e.g. three metre, twenty metre resolution), the results are better able to inform local decision making, the scale at which most coastal management decision are made.

4.1 Summary of valuation techniques

Valuing DRR ecosystem services can be understood as measuring how the coastal wetland affects the natural hazard and the impacts of these hazard on property. For example, a tropical storm’s ability to create flooding and strong winds represents the natural hazard. The process of determining the direction, strength and related factors of where wind and waves will go is referred to as biophysical modelling. These biophysical factors can damage property through water damage or damage to physical structures. This economic modelling can be expressed in quantitative (e.g. 100 homes flooded 2 feet) or economic terms (e.g. AUD\$1,000,000 of damage).

The DRR value of the coastal wetland is expressed by how this biophysical-economic model changes with and without the wetland. Using the example above, the model may show that without the wetland the storm damage is AUD\$1,500,000. Therefore, the wetland provides AUD\$500,000 of DRR ecosystem services from this kind of storm. Because hazards vary in location, intensity and the impacts they cause, average damage or a range of likely damages are often used in valuations.

The major factors influencing the value of a coastal wetland are frequency and severity of hazards, property values, wetland extent, wetland condition and wetland ecosystem type. The greater the property values and wetland extent and better the condition, the more valuable the wetland. In addition, some ecosystem types have biophysical properties that better protect human property than others. For example, a saltmarsh will protect property better than a coral reef of comparable size, quality and location (Neumeier & Ciavola 2004).

There are six DRR ecosystem service valuation techniques used for coastal wetlands valuation. In general, the more accurately the technique models, the greater the data and expertise needed. The key techniques include production function and cost-based techniques, stated preference techniques and benefit transfers. Each is described below and summarised in Table 2. Although not applied in any of the studies captured, the hedonic pricing technique can be effective and is also described below.

Details on these valuation techniques are available in studies commissioned by the Australian government and the Ramsar Secretariat (Whiteoak & Binney 2012, Kirkpatrick 2011, Barbier et al. 1997), as well as general environmental economic literature (Bishop 2013).

4.1.1 Production function techniques

Production function or production change valuation techniques are biophysical and economic models of how changes in ecosystem services impact economic activities. For example, the harm caused by deteriorating wetland conditions on fish catch can be described mathematically. These techniques require extensive ecological and economic data, usually at the site level, and that the economic and environmental relationships are well understood. They are generally considered more robust than techniques that statistically tease out these relationships without site level data.

4.1.2 Cost based techniques

Cost based techniques rely on measuring changes in market values resulting from changes in ecosystem services. Two key groups are notable.

Expected damage function (avoided cost)

Expected damage function (EDF) techniques estimate the value of the protective function of a wetland in reducing economic damage. EDF has been used in risk assessment of airline safety performance, disease rates and expected flood damage (Whiteoak & Binney 2012). The biophysical modelling component of EDF is akin to production change techniques and two terms are interchangeable. Likewise, the economic modelling of EDF often uses replacement cost techniques that are described below.

These valuation techniques can all be considered as components of EDF techniques. This report categorizes them independently, but the distinctions are imprecise and therefore interpreted differently across valuation literature.

Replacement costs

Replacement cost techniques assume that the value of an ecosystem service is equal to the cost of replacing that service (Whiteoak & Binney 2012). For example, the flood protection services provided to nearby houses from a wetland may be valued based on the cost of constructing a revetment wall that provides the same level of protection as the wetland.

The total value of the all ecosystem services provided by the wetland may differ from the cost of a suitable replacement for the DRR ecosystem services. For example, the wetland may also contribute fisheries and enable recreation that are not included in the replacement cost for DRR ecosystem services. This said, because replacement cost techniques reflect actual market values, it is generally welcomed for use in financial analysis.

4.1.3 Stated preference techniques

Stated preference techniques measure individuals' preferences about the value associated with the change in the provision of an ecosystem services or the ecosystem itself. Two common stated preference techniques are contingent valuation and choice modelling.

Contingent valuation

The contingent valuation, or contingent behaviour techniques, describe hypothetical changes in an ecosystem services, or an ecosystem itself, and asks respondents to state how their behaviour would change (Whiteoak & Binney 2012). The approach is often used to measure marginal benefits and costs to communities due to incremental changes in the quality of wetlands. The effectiveness of contingent valuation depends on respondents' understanding the ecosystem services discussed. Contingent valuation can be prone to "warm glow bias", whereby respondents state they would provide significant monetary contributions to the protection of natural assets in a hypothetical scenario, however, would not contribute the same amount in reality. Respondents have also been known to offer "protest bids" of zero willingness to pay for wetland conservation, skewing results.

Choice Modelling

Choice modelling presents respondents with different ecosystem services delivery scenarios, often with different prices for each. Respondents are asked to identify their preference, revealing their willingness to pay for these changes (Whiteoak & Binney 2012). It can also be subject to a number of survey biases that can bring results into question. Nevertheless, it can provide insights into a community's values for ecosystem services.

4.1.4 Benefit transfer techniques

Single and marginal point transfers, function and meta value analysis transfers

Benefit transfer techniques apply the values from reference sites—estimated using direct valuation techniques such as those described above—to the study sites. Single point transfers take a single value, typically the total value of an ecosystem service, and apply it to the study site. Marginal point transfers also use a single value, but adjust it to a condition at the study site. For example, the value of views of an estuary can be adjusted for the difference in average property values (Whiteoak & Binney 2012).

Because a study site's characteristics often differ from the reference site's (e.g. size, quality of wetland, populations), benefit transfer functions can be used to incorporate several characteristics into a function that is applied to the study site. Finally, with meta value transfers, the values and characteristics from several reference sites are used to create a transfer function. These more sophisticated benefit transfer techniques can reduce error rates in the highest quality studies from 50 to 20 percent, although this level of uncertainty may remain unsuitable in some decision making contexts (Boyle & Parmeter 2017).

4.1.5 Hedonic pricing techniques

Hedonic pricing techniques isolate the impact of specific variables on property prices to determine the effect of changes to ecosystem services on those property prices (Whiteoak & Binney 2012). For example, coastal properties more prone to coastal erosion could have lower prices if the market is responding to coastal erosion risk (Anning 2012). The technique is robust, data intensive (e.g. property

sales data) and requires specialised statistical skills. No hedonic pricing examples were captured in this literature review. This may reflect the unique data required for hedonic analysis⁵ or the Australian real estate market not yet incorporating DRR ecosystem services from coastal wetlands (Mallon in IDEEA Group 2020a).

Table 2 Summary of DRR valuation techniques (Organisation for Economic Co-Operation and Development 2018, Johnston et al. 2017, Whiteoak & Binney 2012, Brander et al. 2006)

Group	Technique	Description	Advantage	Disadvantage
Production function	Productivity change	Detailed ecological and econometric modelling	<ul style="list-style-type: none"> Robust analysis Data integration opportunities 	<ul style="list-style-type: none"> High data, time and technical requirements Study quality varies Does not produce monetary values if used in isolation of other techniques
Cost based	Expected damage function (Avoided damage cost)	Valuation of damage avoided because of the wetland	<ul style="list-style-type: none"> Robust Incorporates elements of production function modelling Used in adaptation planning 	<ul style="list-style-type: none"> High to mid level data, time and technical requirements Generally requires strong production function knowledge/modelling
	Replacement costs	Cost of replacing wetland's DRR services with built infrastructure	<ul style="list-style-type: none"> Has utility for adaptation planning Based on market prices 	<ul style="list-style-type: none"> High to mid level data, time and technical requirements Requires an understanding that protection of human property is one of several values provided by ecosystems
Stated preference	Contingent valuation and choice modelling	Analysis of willingness to pay survey for changes to a wetland (e.g. expansion of wetland)	<ul style="list-style-type: none"> Can measure non-monetary services such as aesthetic and spiritual services as well as DRR 	<ul style="list-style-type: none"> Mid level data, time and technical requirements Tends to produce higher values than other techniques
Benefit transfer	Single and marginal point transfers	Reference site value transferred, sometimes adjusted for marginal value	<ul style="list-style-type: none"> Low level data, time and technical requirements 	<ul style="list-style-type: none"> 20-50% error rate is best practice
	Function and meta value analysis transfers	Reference site (s) with characteristics (e.g. extent, species diversity) are used to develop a value function		

4.2 Literature review and stakeholder interviews

The literature review captured 59 DRR ecosystem services valuations studies of coastal wetlands (Appendix 1 List of valuation studies). They document valuations of DRR for 148 coastal wetlands

⁵ Proximity parameters use in hedonic pricing reflect short distances (e.g. 0-500m for urban green space) that may be less appropriate for wetlands. They may reflect a hedonic values close to zero for property that is "in proximity" of coastal wetlands when in fact significant value exists. (Plant in IDEEA Group 2020a)

worldwide

(see

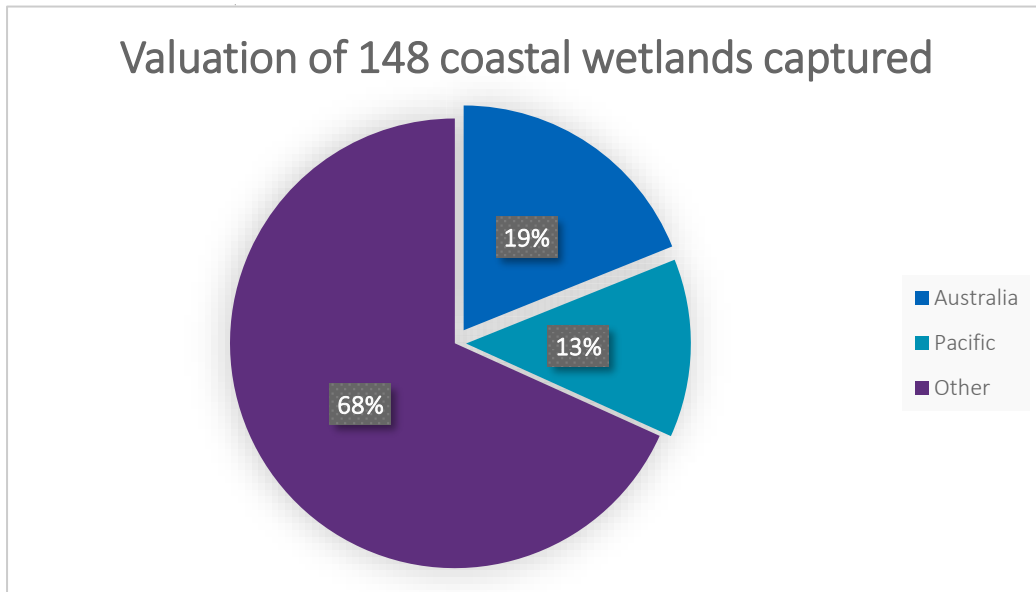


Figure 3), some of which are wetland groups (e.g. all the coastal wetlands of a state). As a result, there is some overlap among them. Twenty-eight of these wetlands or wetland groups, 19 percent of the total, were in Australia. Nineteen valuations were from the Pacific i.e. ten Vanuatu, six Fiji, one Samoa, one Solomon Islands, one Kiribati) and 101 were from other locations. Of the Pacific examples, those in Samoa and Kiribati are within the Ramsar Convention’s Oceania Region, to which Australia belongs. In addition, 15 Australian and international experts were interviewed.

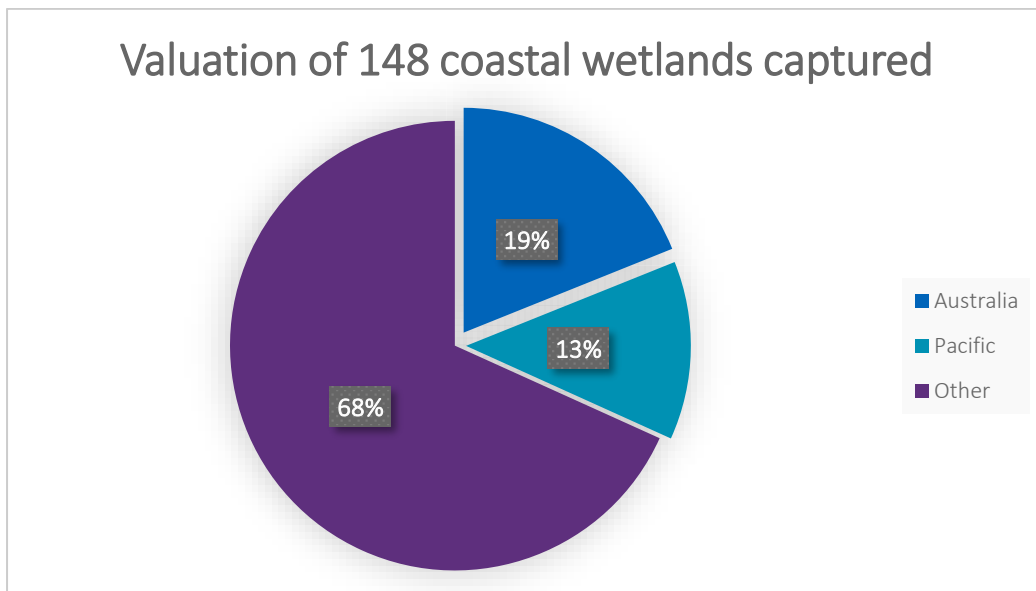


Figure 3 Number of wetlands valuations captured

The literature review identified 27 unique descriptions of valuation techniques (Table 3). While they are named in slightly different ways, the techniques are similar to the list of standard techniques in

Table 2. Table 3 highlights that while some studies described the techniques uniquely, they are not substantively different from those described above.

Table 3 Classification of techniques from literature to Table 2

Technique identified in the literature	Corresponding technique from Table 2
Predicted casualties avoided using spatial based modelling	Expected damage function (Avoided damage cost)
Values inferred by literature aggregation	Benefit transfers
Biophysical model and damage costs avoided	Expected damage function (Avoided damage cost)
Risk based damage costs avoided	Expected damage function (Avoided damage cost)
Substitute cost method	Replacement costs
Regression based damage cost avoided	Expected damage function (Avoided damage cost)
Replacement cost and damage cost avoided	Expected damage function (Avoided damage cost)
Expected damage function based damage cost avoided	Expected damage function (Avoided damage cost)
Damage cost avoided	Expected damage function (Avoided damage cost)
Replacement cost	Replacement costs
Insurance industry-based flood risk model and damage cost avoided	Expected damage function (Avoided damage cost)
Simulated local sea-level change for marshland using InVEST model to determine reduction in protective levee height necessary due to marshland	Expected damage function (Avoided damage cost)
Estimated number of properties and residents protected (damage avoided) by coastal habitats estimated using differences in scenarios from InVEST model.	Expected damage function (Avoided damage cost)
Biophysical modelling (using the physics of flood, surges, waves) and deriving a NPV of damages (avoided property damage using depth damage functions, avoided business interruption, and avoided levee costs)	Expected damage function (Avoided damage cost)
Coastal protection index and avoided damage costs	Expected damage function (Avoided damage cost)
Expected damage function	Expected damage function (Avoided damage cost)
Storm-related deaths avoided	Expected damage function (Avoided damage cost)
Coastal protection index	Expected damage function (Avoided damage cost)
Biophysical model	Productivity change
Damage cost avoided	Expected damage function (Avoided damage cost)
Biophysical modelling and expected damage function	Expected damage function (Avoided damage cost)
Questionnaire	Contingent valuation and choice experiments
Discrete choice experiment	Contingent valuation and choice experiments
Contingent Valuation	Contingent valuation and choice experiments
Biophysical modelling and replacement/substitute cost	Expected damage function (Avoided damage cost)
Health damage avoided	Expected damage function (Avoided damage cost)
Benefit transfers	Benefit transfers

Using the list of standard classifications from Table 3 reveals that the expected damage function (EDF) technique was the most widely applied, representing 98 of the 148 wetlands valued (66 percent) (Figure 4).

Twenty valuations (13 percent) used replacement costs techniques to value wetlands, for example, based on the construction costs of a bulkhead that would provide the similar DRR functions. The productivity change technique was used once (1 percent) to measure wave quantitative impact information as part of a coastal engineering project. There are more biophysical studies of this nature that were not captured by this report’s literature review. As EDF, replacement and productivity change techniques are often used collectively, it is worth noting that these three techniques represent 119 valuations (80 percent).

Sixteen valuations (11 percent) used benefit transfer techniques. Contingent valuation was used on 13 wetland and wetland group valuations (9 percent). These contingent studies were a part of coastal planning efforts to determine stakeholder understanding of the DRR benefits provided by wetlands and the choices they prefer.

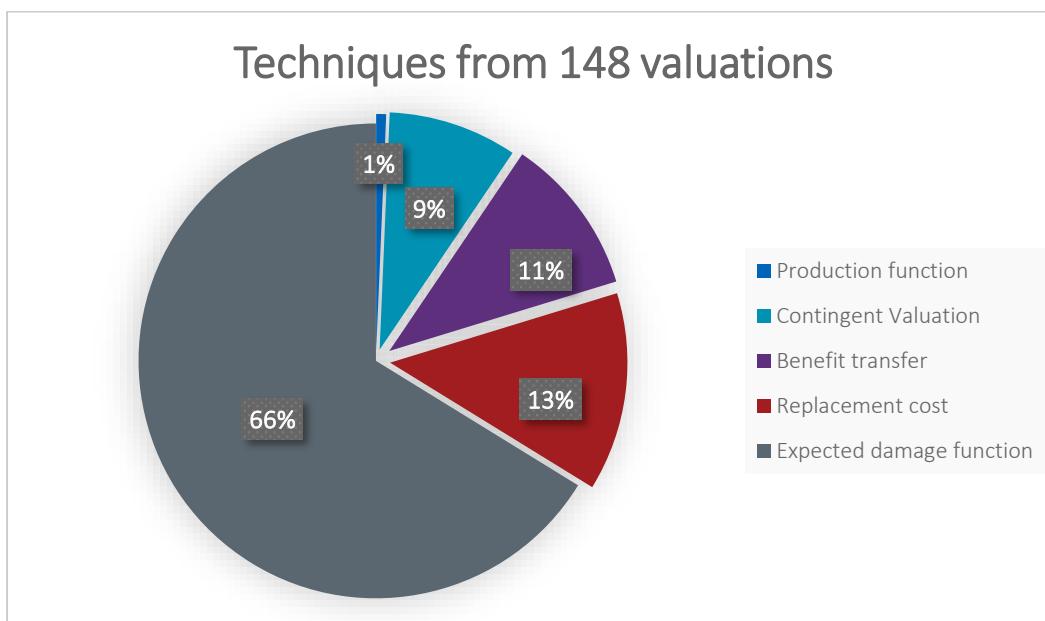


Figure 4 Valuation technique frequency of use

In terms of purpose, in the 98 studies using EDF techniques, all were connected in some way to coastal planning. They were used for cost benefit analysis (CBA) of coastal development options, to help determine the impacts of coastal development, etc. Only eighteen of the 148 studies appear to have been driven by academic interests (e.g., Gaylard et al. 2020) but these focused on influencing coastal planning decisions, though they were not integrated with a planning effort.

4.3 Approaches to using valuation techniques

Each valuation technique has advantages and disadvantages. In many cases the choice of a valuation technique for a study is driven by the decision being made and resource constraints (e.g. budget, deadlines). These constraints can also drive the use of components of two or more techniques in a single study. For example, if the data exists, a researcher may build a production function into an EDF based analysis.

Moreover, research shows that the quality or accuracy of a valuation is generally less important than its acceptance by stakeholders. This acceptance comes from researchers' engagement of decision makers throughout the valuation process. The engagement builds acceptance in the techniques and underlying valuation concepts (Posner et al. 2016, see Box A).

Therefore, turning to the needs of decision makers is warranted. They have three reasons to use DRR valuation, which can be understood as valuation approaches. They are:

- A) *Awareness raising valuations* that use large geographic scales that are generally void of site specific data. They are less costly and complex, but deliver valuations that are less useful for coastal planning and cost benefit analysis (CBA) compared to other approaches. For example, one study valued the DRR services from any hectare of Australia's temperate mangroves from INT\$⁶(2019) 44 to 11,477 per year (Gaylard et al. 2020). All of the benefit transfer valuations captured (Gaylard et al. 2020 [see Box B], Russi et al. 2013) fit into this category, as does one expected damage function valuation that analysed expected cyclone damage (Ouyang et al. 2018) using change in GDP to estimate damage impacts. The value ranges and geographic scales of these approaches raise awareness but are not suitable for coastal planning.
- B) *Stakeholder engagement valuations* that reveal how communities feel about change to DRR ecosystem services provided by coastal wetlands (Akber et al. 2018, Kim & Petrolia 2013, Gray et al. 2017, Vázquez-González et al. 2019). These contingent valuation studies directly measure communities' preferences for coastal planning purposes, but do not provide monetary valuations.
- C) *Explicit local valuations* that typically use Expected Damage Functions (EDF) and have robust data. They are typically used to influence zoning, management and conservation efforts. There is variability in the robustness among EDF techniques, which these examples demonstrate.
 - a. *Index valuations*, where a range (e.g. 1-5) of biophysical change or economic impacts are estimated and often a coefficient is used as a proxy for detailed analysis. For example, several environmental characteristics can be scored for their contribution to DRR based on the literature, and integrated into single score (Table 4). Index valuations are defensible and can have utility to decision makers. They provide approximate contributions of the coastal wetland to DRR. But they cannot be used for engineering or insurance purposes.

⁶ INT\$ is the international dollar, a hypothetical currency unit based on purchasing power parity that the U.S. dollar has at a given point in time.

Table 4 Calculation of the coastal protection index based on characteristics of the coastline (Pascal et al. 2015)

Factor	Score				
	Very strong 5	Strong 4	Medium 3	Low 2	Null 1
	Rocky shore	Mix of rocks/ sediments/ mangroves	Mangroves	Sediments	Beaches
Coastal exposure	Protected bay	Semi-protected bays	Artificial reefs	Low protected bay or coast	No protection
Reef morphology, area and distance to coastal physical structure	Continuous barrier (> 80%) close to the coast (< 1 km)	Continuous barrier (> 50%), patch reef, close to the reef	Fringing reef (width > 100 m)	Coral formation discontinuous	No reef
Inner crest slope, crest width	Very favourable conditions (gentle slope, large crest width)	Favourable conditions (slope, large crest width)	Favourable conditions (at least one condition: slope, crest width)	Reduced favourable conditions (strong slope, reduced crest width)	None
Platform slope	6–10%	2.5–6%	1.1–2.5%	0.4–1.1%	< 0.4%
Mean depth (< 1 km from the shoreline)	< 2 m	< 5 m	> 5 m	< 10 m	< 30 m
Other ecosystems	Mangroves and seagrasses > 75% coastline	Mangroves and seagrasses > 50% coastline	Mangroves and seagrasses > 25% coastline	Mangroves and seagrasses < 25% coastline	None

- b. *Generic models*, such as InVEST (The Natural Capital Project 2019) that are designed for operation by non modelling experts. While these models can be customized they rarely are. Six additional generic models are described in Appendix 3 along with the data required for their use.
- c. *Customized valuation models*, usually bespoke exercises that rely on extensive data inputs and customization. Customization is often done by starting with generic models and building new components (see Das & Crépin 2013 for an example). For the development of built infrastructure or insurance products, customized valuation models are preferred.

A final note on valuation techniques is that advances in Earth observation, modelling and computing are making this modelling easier. The valuation techniques and approaches can also be improved with easy access to reliable, properly classified data. The insurance industry representatives interviewed for this report noted their interest in such data and that it would improve their coastal insurance

products and reduce the risks to homeowners, businesses, lenders and insurers (Mallon and LaPlastrier IDEEA Group 2020a).

Box A: Belize valuation: best in class

Belize's ecosystem valuation, rather than being an external exercise, was a part of its Integrated Coastal Zone Management Plan. The Plan was developed through an iterative process that engaged a full range of stakeholders including government officials, environmentalists, fishers, hoteliers, tour operators, among others, all of whom had direct interest in the management of the shoreline. As a result, the explicit local valuation approaches based on InVEST (The Natural Capital Project 2019), influenced the zoning decisions of the Plan.

The Plan was developed by iteratively exploring development scenarios. The first iteration had three scenarios:

- *Conservation*, representing the view of environmentalists
- *Development*, based on rapid natural resource utilization and urban expansion
- *Informed management*, that balanced conservation and development perspectives

After initial data gathering, local stakeholder groups were formed to explore the scenarios. Training, expert interviews, field trips, public comments among other measures were used to ensure acceptance of the process and science. Numerous mapping and InVEST modelling exercises were run (including DRR, fishing, tourism) until the *informed management* scenario was chosen. Then, four unique versions of the *informed management* scenario were modelled until a final selection was made.

As a result, not only was the DRR value informative, but so were ecosystem service valuations. Moreover, the Plan had broad acceptance and has served as a basis for sustainable development in Belize. (Rosenthal et al. 2014)

4.4 Pacific island nations

Under the Ramsar Convention on Wetlands, Australia is part of the Oceania Region, and has an interest in promoting coastal wetland management in that Region, including in Pacific island Contracting Parties. Members of the Group include Australia, Fiji, Kiribati, Marshall Islands, New Zealand, Palau, Papua New Guinea and Samoa. The value of coastal wetlands in the Pacific island nations has been challenged by development pressures. In competing for global tourism revenue, coastal wetlands have been replaced by resorts, golf courses, cruise ship terminals and retail centres. As a result, areas where wetlands have been removed or degraded are facing increasing risk from sea level rise and storms. Valuation exercises have been undertaken to inform these types of decisions.

A total of 10 DRR valuations studies from Fiji, Kiribati, Samoa, Solomon Island, Tonga and the Vanuatu have been captured. They value 22 unique coastal wetlands and wetland groups (e.g. North Coast of Viti Levu) (Table 5). Of these, 18 were focused on coral reefs, 2 on intertidal marshes and 2 intertidal forested wetlands. A total of 20 valuations used EDF techniques. One used replacement cost techniques—the costs of a seawall in Samoa. Another the production function—the index from Kiribati. All of these studies were conducted as part of coastal planning efforts.

Table 5 Valuation studies from the Pacific

Country	Wetland	Ecosystem type	Valuation technique	Value (annually)	Reference
Fiji	South coast of Viti Levu	C — Coral reefs	Expected damage function	US\$ (2014) 2,796,764-5,813,205	Gonzalez, et al., 2015
Fiji	North coast of Viti Levu	C — Coral reefs	Expected damage function	US\$(2014) 2,139,373-3,565,6235	Gonzalez, et al., 2015
Fiji	South coast of Vanua Levu	C — Coral reefs	Expected damage function	US\$(2014) 529,362-882,270	Gonzalez, et al., 2015
Fiji	North coast of Vanua Levu	C — Coral reefs	Expected damage function	US\$(2014) 283,852-473,086	Gonzalez, et al., 2015
Fiji	All coral reefs	C — Coral reefs	Expected damage function	US\$(2014) 6,368,785-10,614,642	Gonzalez, et al., 2015
Fiji	Viti Levu and Vanua Levu	I — Intertidal forested marshes	Expected damage function	US\$(2015) 88,000-610,000 USD	Atkinson, et al., 2016
Kiribati	All of Kiribati	C — Coral reefs	Production function	Index of 2, 2, 2, and 3 (out of 5) for North Tarawa, South Tarawa, Abaiang and Kiritimati respectively	Rouatu, et al. 2017
Samoa	Sataoa and Sa'anapu	I — Intertidal forested marshes	Replacement costs	WST\$(2001) 6,425,000	Mohd-Shahwahid and McNally, 2001
Solomon Islands	Guadalcanal	C — Coral reefs	Expected damage function	US\$(2013) 3,348,522-5,580,869	Arena, et al., 2015
Tonga	Tongatapu	C — Coral reefs	Expected damage function	USD\$(2013) 6,525,251-10,875,418	Salcone, et al., 2015
Vanuatu	Crab bay	H — Intertidal marshes	Expected damage function	INT\$US(2001) 93 per hectare	Bulu, et al., 2014
Vanuatu	Eratap	H — Intertidal marshes	Expected damage function	INT\$US(2001) 3,426 per hectare	Bulu, et al., 2014
Vanuatu	Emua	C — Coral reefs	Expected damage function	EU€(2009) 136	Pascal, et al., 2011
Vanuatu	Piliura	C — Coral reefs	Expected damage function	EU€(2009) 816	Pascal, et al., 2011
Vanuatu	Unakap	C — Coral reefs	Expected damage function	EU€(2009) 816	Pascal, et al., 2011
Vanuatu	Laonamoa	C — Coral reefs	Expected damage function	EU€(2009) 1,088	Pascal, et al., 2011

Country	Wetland	Ecosystem type	Valuation technique	Value (annually)	Reference
Vanuatu	Worasifiu	C — Coral reefs	Expected damage function	EU€(2009) 272	Pascal, et al., 2011
Vanuatu	West coast of Efate	C — Coral reefs	Expected damage function	US\$(2013) 8,398,740-13,997,901	Pascal, et al., 2015
Vanuatu	East coast of Efate	C — Coral reefs	Expected damage function	USD\$(2013) 764,701-1,274,502	Pascal, et al., 2015
Vanuatu	Malekula	C — Coral reefs	Expected damage function	USD\$(2013) 783,695-1,306,159	Pascal, et al., 2015
Vanuatu	Espiritu Santo	C — Coral reefs	Expected damage function	USD\$(2013) 2,899,934-4,833,224	Pascal, et al., 2015
Vanuatu	Efate, Malekula and Espiritu Santo	C — Coral reefs	Expected damage function	USD\$(2013) 13,776,056-22,960,093	Pascal, et al., 2015

5 VALUATION OF AUSTRALIA'S COASTAL WETLANDS

Valuation of DRR ecosystem services provided by Australia's coastal wetlands appears to be moving from the category of awareness raising approaches to those based on explicit local valuation approaches. While benefit transfer valuations are still being conducted, there has been an increased use of the expected damage function (EDF) and replacement cost techniques, especially for adaptation planning.

Over the past decade, most mainland Australia's coastal wetlands DRR ecosystem services have been valued through six studies of 28 wetlands or wetland groups⁷ (**Error! Reference source not found.**). Fifteen were conducted as awareness raising approaches—benefit transfer techniques (Gaylard et al. 2020, see Box B) and expected damage function techniques (Ouyang et al. 2018). While these valuations cover the full extent of coastal wetlands, they were geographically broad geographic scales and for only the natural hazards of (1) flood damage from cyclones throughout Australia and (2) coastal erosion from storms in temperate Australia. While not useful for coastal planning, they can be used to raise awareness of the economic benefits of maintaining coastal wetlands.

Twelve valuations used explicit local valuation approaches, combining elements of expected damage function, production function and replacement cost techniques. While this report did not explore the intent of these valuations in detail, all 28 were likely undertaken to deepen understanding or advance the knowledge for coastal planning efforts.

The final valuation study (Department of Environment and Heritage Protection 2012) used production function techniques and did not produce an economic value. This study demonstrates the biophysical modelling central to explicit local valuation techniques. With an understanding of how wave energy is dissipated by mangroves, the reduced economic damage to human property can be determined.

The most current study, is the ongoing Mapping Ocean Wealth project (Carnell, P.E, Reeves, S.E, Nicholson, E. et al. 2019). While the full analysis is under review, the project was integrated with adaptation planning efforts in Port Phillip Bay and Western Port in Victoria. The planning is exploring how the impacts of climate change are likely to cause coastal wetland locations to migrate, how this might impact the delivery of ecosystem services and what restoration efforts could be implemented (Ferns in IDEEA Group 2020a).

Mapping Ocean Wealth used the InVEST generic model (The Natural Capital Project 2019). This avoided the costs of building a new model, but still enabled explicit local valuation to be conducted. There was also extensive data collection and classification, including the use of SEEA natural capital accounting standard, and the valuation was integrated with coastal planning processes. Local decision makers were engaged, increasing the study's likelihood of influencing decision making. This is contrasted with the awareness raising valuation approaches, such as those based on benefit transfer techniques (Gaylard et al. 2020 see Box B), that are unlikely to influence coastal planning.

⁷ There is overlap among the wetland groups. For example, the valuations in Victoria's Western Port are also included in valuations of the Southeast Australian group.

Box B: Australia benefit transfer study

To demonstrate the wealth of values from ecosystem services enabled by Australia's temperate marine ecosystems, the DRR ecosystem services from salt marshes and mangroves were valued. The results were a per year, per hectare values of between INT\$(2019) 2.57 and 11,506 (Gaylard et al. 2020). These ranges, common for benefit transfer techniques, do not adequately inform coastal management, as a wetland being considered for conversion could have a value anywhere in this range.

Table 6 Australian valuation studies

	Study (6)	Wetland/wetland group	Ecosystem type	Description	Commissioned by	Valuation technique	Valuation approach	Value	Use of results
1.	DEHP, 2012	Cocoa Creek, Townsville, QLD	I — Intertidal forested wetlands	Government report on the flood and cyclone protection provided by natural assets	None	Production function	Explicit local valuation	Townsville: 50 per cent of wave energy transmitted through 230m of mangroves, less than 20 percent of energy transmitted through 310m	Contributed to coastal management efforts
2.	Oxford Economics, 2009	Great Barrier Reef	C—Coral reef	Report on the effects of bleaching on the Great Barrier Reef	Commissioned by the Great Barrier Reef Foundation	Replacement cost	Awareness raising valuation	AUD\$10 billion over 25 years (AUD\$1 billion for Cairns)	Contributed to Great Barrier Reef management
3.	Whiteoak, et al., 2012	Moreton Bay	Coastal wetlands	Literature review on the economic value of ecosystem services provided by wetlands	Commissioned by the Department of Sustainability, Environment, Water, Population and Communities	Expected damage function (Avoided damage cost)	Awareness raising valuation	AUD\$16,200/dwelling affected	Contributed to valuation policy discussion
4.	Carnell, et al., 2019	Port Phillip Bay & Bellarine Peninsula	B — Marine subtidal aquatic beds	Report on the values provided by coastal wetlands in Australia	Funded and supported by The Nature Conservancy, Deakin University, The Thomas Foundation, HSBC Australia, The Ian Potter Foundation, Victorian Government, NSW Government and	Expected damage function and replacement cost	Explicit local valuation	AUD\$(2019) 89,010,000	Analysis is ongoing and is intended to inform coastal adaptation planning and restoration.
5.	Carnell, et al., 2019	Port Phillip Bay & Bellarine Peninsula	I — Intertidal forested wetlands					AUD\$(2019) 20,200,000	
6.	Carnell, et al., 2019	Port Phillip Bay & Bellarine Peninsula	H — Intertidal marshes					AUD\$(2019) 29,888,0000	
7.	Carnell, et al., 2019	Western Port	B — Marine subtidal aquatic beds					AUD\$(2019) 470,000	
8.	Carnell, et al., 2019	Western Port	I — Intertidal forested wetlands					AUD\$(2019) 2,910,000	
9.	Carnell, et al., 2019	Western Port	H — Intertidal marshes					AUD\$(2019) 1,170,000	
10.	Carnell, et al., 2019	Southeast Australia	Coastal wetlands					AUD\$3.6 billion by 2090	
11.	Carnell, et al., 2019	Southeast Australia	Salt marshes					AUD\$(2019) 720 million by 2090	

	Study (6)	Wetland/wetland group	Ecosystem type	Description	Commissioned by	Valuation technique	Valuation approach	Value	Use of results
12.	Carnell, et al., 2019	Southeast Australia	Mangroves		the Australian Research Council			AUD\$(2019) 1.86 billion by 2090	
13.	Carnell, et al., 2019	Southeast Australia	Seagrass					AUD\$(2019) 82.7 million by 2090	
14.	Ouyang et al., 2018	Total NT	Coastal wetlands	Valuation of cyclone mitigation provided by coastal wetlands in Australia versus seawalls in China.	Academic paper with no funding from the “public, commercial, or not-for-profit sectors.”	Expected damage function (Avoided damage cost)	Awareness raising valuation	USD\$(2011) avg. 49,240/year/hectare	Contributed to overall discussion on the importance of wetland valuation and conservation and additional valuations in China. (Ouyang 2020)
15.	Ouyang et al., 2018	Total QLD						USD\$(2011) avg. 39,067/year/hectare	
16.	Ouyang et al., 2018	Total WA						USD\$(2011) avg. 44,502/year/hectare	
17.	Gaylard et al., 2020	Total WA Temperate	H — Intertidal marshes	A benefit transfer study of the DRR and other values from temperate coastal wetlands	Academic, funded by an Australian Government Research Training Program Scholarship	Benefit transfer	Awareness raising valuation	INT\$(2019) 2.57-11,505/year/hectare	None (academic study)
18.	Gaylard et al., 2020	Total SA							
19.	Gaylard et al., 2020	Total TAS							
20.	Gaylard et al., 2020	Total VIC							
21.	Gaylard et al., 2020	Total NSW							
22.	Gaylard et al., 2020	Total QLD Temperate	I — Intertidal forested wetlands					INT\$(2018) 44-11,477/year/hectare	
23.	Gaylard et al., 2020	Total WA Temperate							
24.	Gaylard et al., 2020	Total SA							
25.	Gaylard et al., 2020	Total TAS							
26.	Gaylard et al., 2020	Total VIC							
27.	Gaylard et al., 2020	Total NWS							
28.	Gaylard et al., 2020	Total QLD Temperate							

With regards to Australia's 66 Ramsar sites, 24 of them (39 percent) have been valued for their DRR ecosystem services. (Table 7). This is one half of all 25 coastal Ramsar sites. However, because these studies use different datasets and criteria for determining the extent of a wetland (e.g. habitat type, ecosystem type), it is difficult to integrate these with the list of wetlands in

Table 6. Only the Port Phillip Bay and Bellarine Peninsula studies use local explicit valuation approaches and are therefore likely to inform coastal planning.

Table 7 Valuation studies at Ramsar wetlands

Ramsar number	Name	State	Study
1	Cobourg Peninsula	NT	Ouyang et al., 2018
2	Kakadu National Park	NT	Ouyang et al., 2018
13	Corner Inlet	VIC	Carnell, et al., 2019
18	Port Phillip Bay & Bellarine Peninsula	VIC	Carnell, et al., 2019
19	Western Port	VIC	Carnell, et al., 2019
21	Gippsland Lakes	VIC	Carnell, et al., 2019
23	Towra Point Nature Reserve	NSW	Carnell, et al., 2019
24	Hunter Estuary Wetlands	NSW	Carnell, et al., 2019
31	Ord River Floodplain	WA	Ouyang et al., 2018
33	Roebuck Bay	WA	Ouyang et al., 2018
34	Eighty-mile Beach	WA	Ouyang et al., 2018
35	Forrestdale and Thomsons Lakes	WA	Ouyang et al., 2018
36	Peel-Yalgorup System	WA	Ouyang et al., 2018
38	Vasse-Wonnerup System	WA	Ouyang et al., 2018
39	Lake Warden System	WA	Ouyang et al., 2018
41	Moreton Bay	QLD	Ouyang et al., 2018
42	Bowling Green Bay	QLD	Ouyang et al., 2018
44	Shoalwater and Corio Bays Area	QLD	Ouyang et al., 2018
51	Great Sandy Strait	QLD	Ouyang et al., 2018
52	Myall Lakes	NSW	Carnell, et al., 2019
54	Becher Point Wetlands	WA	Ouyang et al., 2018
55	Lake Gore	WA	Ouyang et al., 2018
57	Edithvale-Seafood Wetlands	VIC	Carnell, et al., 2019
67	Glenelg Estuary and Discovery Bay Wetlands	VIC	Carnell, et al., 2019

Consistent with previous studies on Australia’s development planning and management, (Keenan et al. 2019, Pittock et al. 2012, Marre et al. 2016, Clark & Johnston 2017, Marre et al. 2015) this reports’ engagement with state and local decision makers noted their general awareness of monetary valuation of coastal DRR ecosystem services (IDEA Group 2020b). The stakeholders felt the available valuations could not be used for local decision making (IDEA Group 2020b). The one exception to this is the work of the Mapping Ocean Wealth (Carnell, P.E, Reeves, S.E, Nicholson, E. et al. 2019) project that worked collaboratively with local decision makers. However, given an appropriate state or national policy context, such studies would have more efficacy.

6 DECISION MAKING CONTEXTS

The majority of coastal management decisions in Australia are made by local council, state and territory level governments through coastal spatial planning, ecosystem-based coastal planning or

similar approaches (Clark & Johnston 2017). Federal policies also exist that support local coastal planning, such as disaster funding arrangements. They can be informed by awareness raising valuation approaches. In addition, there are integrated coastal zone management frameworks that could shift planning to state, national or interjurisdictional governmental bodies. But even with such a shift, local governments are likely to continue playing an influential role.

As a result, to influence local coastal planning, information and analysis needs to be conducted at the appropriate geographic scale and readily accepted by local decision makers.

There are two key pathways where valuation can influence local decisions: (i) informing regulatory actions and (ii) supporting cost benefit analysis.

6.1 Regulatory actions

Some coastal wetlands are regulated under the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act) if they are listed as a Ramsar wetland, contain nationally threatened species, ecological communities, or migratory species. The EPBC Act has an important role in maintaining the ecosystem services provided by wetlands.

However, these regulations do not effectively address the broader landscapes and seascapes. For example, Bowling Green Bay in northern Queensland is a Ramsar listed wetland. The catchment in which it resides has been modified for agricultural production, delivering high nutrient, sediments and herbicides to the wetland. These land use impacts to wetlands (which are not related to a specific action or decision) are beyond the reach of the EPBC Act, resulting in coastal wetland degradation and loss. State and territory environmental assessment legislation generally operates in a similar way, focused on a single species or protected areas and not the broader landscape.

Coastal planning and strategic environmental assessments provide an opportunities address some of these issues.

6.1.1 Disaster Recovery Funding Arrangements

Disaster Recovery Funding Arrangements and programs can fund up to 75 percent of the restoration of coastal wetlands in the event of disasters (Department of Home Affairs 2010). Ecosystems that protect property with the greatest value, especially if the property enables essential services such as a hospital, are likely to determine the prioritisation of restoration efforts. For example, a coastal wetland protecting a fire station and large apartment complex will be restored before a coastal wetland protecting a retail establishment and urban park. DRR valuations can inform this prioritisation but, in order to do so effectively, must use locally explicit valuation approaches.

6.1.2 Strategic environmental assessments

State sponsored strategic environmental assessments have been identified as a means to collect data, model and value how ecosystem change effects the delivery of benefits to society (Geneletti 2019).

Such base analysis could provide public and private sectors with the means to more easily incorporate disaster risk reduction ecosystem services into coastal planning.

6.2 Cost benefit analysis

Most coastal planning decisions require balancing interests among stakeholders (Clark & Johnston 2017). Cost benefit analysis (CBA) is a key part of this balancing because it can provide a single unit of comparison for several scenarios or options (e.g. protecting the wetland, protecting half of the wetland). Privately commissioned CBAs demonstrate a net benefit to the company, while state managed CBA for large developments or policies show the net benefit to society. CBA analyses typically analyse the net impacts to different stakeholder groups.

The inclusion of ecosystem services in CBA through valuations has been identified by many stakeholders as a useful approach to improving management of Australia's coasts (Marre et al. 2015, Clark & Johnston 2017). There are examples of Australian frameworks for incorporating ecosystem services values into CBA (Plant & Prior 2014, Plant et al. 2012). CBA's efficacy lies in ensuring that decision makers understand and trust the valuation that is conducted (Posner et al. 2016). This requires careful engagement and leadership internal to the planning processes. This integration can also improve the incorporation of local knowledge from non-experts, strengthening analysis. But this does not discount the need to have effective valuation techniques that are defensible. Indeed, well executed valuations have influenced the creation of marine parks, introduction of visitor fees to parks and limiting of extractive activities around the world (Markandya 2016).

Beyond thorough stakeholder engagement (e.g. clear policy question/choice, effective communications and access to decision makers, clear presentation of techniques and assumptions), (Waite et al. 2014) effective valuations for CBA should:

- Be locally explicit in their scale so that it matches the needs of decision makers (Keenan et al. 2019)
- Be spatially explicit in the biophysical and economic modelling (Sheaves et al. 2020)
- Minimise double counting (Markandya 2016, Pittock et al. 2012)
- Allow multiple ecosystem services to be integrated through use of final ecosystem services concepts (Rhodes et al. 2018)
- Consider alternative development scenarios (Rosenthal et al. 2014)

There are state and national guidelines for incorporating ecosystem services values into CBA (Office of Best Practice Regulation 2016, Department of the Prime Minister and Cabinet 2014). However, the implementation of this guidance varies across Australian governmental jurisdictions in relation to CBA (Keenan et al. 2019, Pittock et al. 2012). Budget constraints in CBAs typically inhibit the collection of data and therefore benefit transfer studies that rely on existing data are used. In Australia, and around the globe, the general trend has been towards favouring market-based techniques that rely on actual prices such as replacement costs or expected damage function (damage mitigation cost). There is less

interest in the CBA community for using non-market valuation, revealed preference (hedonic pricing) or stated preference techniques. (NSW Treasury 2017).

Finally, DRR is only one ecosystem services that coastal wetlands can provide. CBA analysis should consider the full range of values from recreational and fisheries related services, to potentially increased presence of mosquitoes. This reinforces the needs for identifying and measuring ecosystem services using classification systems (see Appendix 5 History of ecosystem services classification a full discussion).

6.2.1 Adaptation planning

DRR valuation in cost benefit analysis may have the most utility as a component of adaptation planning. Australian guidance for incorporating CBA into coastal adaptation is well documented (Wise & Capon 2016). Moreover, there are successful uses of DRR valuation in cost benefit analysis. One was based on analysis of competing conservation and development scenarios (Rosenthal et al. 2014 see Box A). Australia's Mapping Ocean Wealth project may be equally influential because it followed a similar process and is aligned with the CBA guidance.

This said, often adaptation actions can be implemented through disaster planning processes. By applying the same valuation approaches, conservation or restoration of coastal wetland may be more likely to be implemented by gaining new advocates (Cunningham and Jacobs in IDEEA Group 2020a).

6.2.2 Coastal insurance, real estate and construction industry

At present, the Australian real estate market does not sufficiently incorporate natural hazard risks into prices. In general, properties with higher risk from hazards are no more expensive than similar properties with lower risk profiles. In addition, there are no requirements for homeowners to purchase coastal disaster insurance and there is likely only one retail provider of this insurance (Mallon in IDEEA Group 2020a).

The insurance industry has been developing numerous biophysical models for coastal risk analysis in Australia (Bruyère et al. 2019). Such analysis can improve existing products and develop innovative insurance products based on maintaining the health of coastal wetlands (Swiss RE 2019). However, Australia's analysis does not include the DRR ecosystem services provided by coastal wetlands. The data for this explicit local biophysical modeling is rarely available in Australia. When local government can provide the data, it is often incomplete or classified inconsistently (Mallon and LePlastrier in IDEEA Group 2020a).

The insurance industry experts interviewed for this report stressed the importance of this data. First, there may be liability issues for local governments that have the data but do not make it available. Second, it is beyond the scope of the industry to collect this data. Moreover, the classification demands of the data in order to make it consistent nationally, call for a federally led effort (Mallon and LePlastrier in IDEEA Group 2020a). This point has also been stressed to the Royal Commission into

Natural Disaster Arrangements (The Royal Commission into Natural Disaster Arrangements 2020) by representatives for the insurers. The Commission should be releasing its finding in late 2020 (LePlastrier in IDEEA Group 2020a).

Because insurance is so critical to the real estate sector, this improved insurance market should generate market efficiencies by spreading coastal disaster risk throughout the insurance sector. This would bring efficiencies to the real estate market, and influence the degree to which coastal disaster risk is embedded in market prices. Finally, the improved data and biophysical modeling is likely to be used by the construction sector, reducing their costs and improving resiliency.

6.3 Non-monetary alternatives

There are alternatives to monetary based CBA. Multiple indicator assessments, multi-criteria analysis, cost effectiveness analysis, expert panels and similar techniques allow qualitative and quantitative social and environmental factors to be considered, sometimes in combination with monetary values. However, the effectiveness of these alternatives largely rests on strong biophysical modeling or knowledge. Therefore, regardless of the decision or type of decision-tool being used, modeling and related data are warranted (Hatfield-Dodds 2005).

7 GAP ANALYSIS

While other approaches and techniques have utility, DRR valuation is most effective at influencing coastal planning decision making when it is based on explicit local valuation approaches. Applying these approaches in turn, is dependent on strong biophysical and economic modelling, as well as the availability of related data (Boutwell & Westra 2015). Moreover, the data and modelling needed for these approaches also has value to the non-monetary alternatives described above as well as the insurance and other industries.

The apparent shift towards explicit local valuation approaches is evidence of this impact to date. But there are pragmatic steps that can be taken to maintain this movement. They include: forming research partnerships, advancing the use of new ecosystem typologies, adopting ecosystem service classification systems and improving collection and classification of data.

7.1 Research partnerships

The iterative improvement of biophysical and economic modelling is driven by investments in education, technology and the basic science upon which this modelling rests (e.g. ecology of wetlands). Moreover, because modelers are specialists (e.g. water quality, storm surge), the unique knowledge sets of engineers and insurance professionals are likely to add value to any DRR modelling conducted by environmental professionals alone. (Malmquist 2020, Folan et al. 2019, Wielgus in IDEEA Group 2020a) Therefore, research partnerships among biological, engineering and insurance modelers should prove valuable.

7.2 Advancing the use of ecosystem typologies

The biophysical and economic modelling needed for valuation is built on definitions of ecosystem types. Each ecosystem type has its own biophysical properties. These properties determine the production of ecosystem functions and processes and associated supply of ecosystem services. For example, research shows that the wetland types most effective at attenuating wave energy and turbulence are partially submerged and emergent wetlands such as salt marsh, intertidal bottomland forest and oyster reefs (Neumeier & Ciavola 2004).

This becomes especially important when benefit transfer techniques are used. These techniques depend on transfers of characteristics from reference to study sites (e.g. ecosystem type, wetland extent, distance from human property). Without a clear description of the ecosystem type, transferred values can have error rates of several orders of magnitude.

Beyond benefit transfers, as the ecological science of wetlands and related modelling progresses, ecosystem typologies become more important to speeding analysis, because new learning builds on existing knowledge of an ecosystem type and how it functions. There are also advances in spatial data management that require clear delineation among ecosystem types for proper data integration. Ecosystem typologies can allow ecosystem types to be consistently identified and digitally integrated, supporting improved environmental management.

Although the Ramsar typology provide a strong starting point, Australia's National Aquatic Ecosystem (ANAE) classification improves on this significantly. It better supports the identification of Australia's unique ecosystems (Aquatic Ecosystem Task Group 2012). The ANAE classification is being used extensively in Queensland and gaining support in the other states.

Consideration could also be given to adopting the IUCN's recently released Global Ecosystem Typology (GET) (Keith et al. 2020). It is intended for adoption at the next IUCN World Congress and to underpin ecosystem types in the UN System of Environmental-Economic Accounting (Bogaart et al. 2019). It is likely to be integrated into the programs of multilateral institutions such as the CBD, UNEP and Ramsar. Finally, because GET is compatible with Ramsar and ANAE, a national shift to this typology should be void of complication.

Australia's coastal management community does not identify ecosystem services uniformly. Research shows that ad hoc processes lead to poorly chosen metrics and therefore valuations of ecosystem services (Czucz et al. 2018). It also complicates the integrating studies. This includes valuations of different ecosystem services from the same site, the same ecosystem service in a regional and studies of ecosystem services globally (Finisdore et al. n.d., see Appendix 5 for a full discussion of this issue).

The Millennium Ecosystem Assessment's four groups of ecosystem services (see Appendix 4 Natural capital accounting data structure

The System of Environmental-Economic Accounting (SEEA) (United Nations et al. 2014b) is the global standard for natural capital accounting. One component of SEEA, is that provides uniform

classification of data for improved speed and accuracy in defining and discovering data. **Error! Reference source not found.** demonstrated how SEEA organized different social and economic data.

Table 11 SEEA data classification structure

Generic SEEA data classification structure (adopted from United Nations Statistics Division 2018)		
Subcomponent	Definition	Example
Physical extent	Area in terms of coverage and arrangement	Topography, geography
Institutional extent	Zoning such as regulatory and planning areas	State and Council Zones, Ramsar boundaries
Ecosystem extent	Extent and composition of the ecosystem types	Seagrass, rocky reef, mangrove and salt marshes
Context	Contextual information that makes up the broader socio-ecological system	Cities, agricultural land, river connections
Coastal use	Terrestrial areas designated for use relating to the marine environment	Homes, ports, piers
Use	Uses of the wetland environment	Disaster risk reduction, tourism, fishing
Physical characteristics	Physical attributes system quality	Soil types, waves, tides, winds, salinity, heat content, mean sea surface, mean dynamic topography, turbidity (reflectance), mixed layer thickness, water pressure, water density
Chemical characteristics	Chemicals and nutrients system quality	Phosphate, nitrate, silicate, alkalinity, pH, CO ₂ , oxygen/hypoxia, tritium, oil-spill trajectory
Biological characteristics	Biological attributes	algal bloom, water quality, pests (starfish, sea urchins), bleaching
Ecological characteristics	Ecological characteristics of system	Cover, density, diversity of species
Biotic assets	Living natural assets	Aquatic plants, seaweeds, fish, birds, shrubs, trees,
Abiotic assets	Nonliving natural assets	Beach, seafloor sediments and rocks
Biotic physical services	Services that living components of the system provide	Protection of human property (wave attenuation, wind speed reduction), habitat services, carbon sequestration and storage, cultural services, tourism
Biotic monetary services	Valuation of physical services	As above, but valuation perspective
Abiotic physical services	Non-living components the system provides	Wind and wave energy reduction,
Abiotic monetary services	Valuation of abiotic physical services	Wave attenuation of rocky reef

Appendix 5 History of ecosystem services classification for background on provisioning, regulating, cultural and supporting groups) is likely the default standard in Australia. CICES, however, has been adopted in Queensland (Ronan in IDEEA Group 2020a) and is part of SEEA which has been adopted by the DAWE's Environmental-Economic Accounting area (Interjurisdictional & Environmental-Economic Accounting Steering Committee 2018). Its adoption across Australian institutions will save resources presently being devoted to defining ecosystem services, discovering ecosystem services data and research as well as the creation of classifications and groupings of ecosystem services (Finisdore et al. n.d., Ronan in IDEEA Group 2020a).

7.3 Improving the collection and classification of data

Along with classification and modelling, data is a critical bottleneck to the expanded use of explicit local valuation approaches. Data collection, cleaning and classification—by some estimates—is 60 percent of the time needed for environmental modelling (Bagstad 2020). Moreover, the absence of data often forces researchers to use less desirable valuation approaches, such as benefit transfers (Keenan et al. 2019, Plant in IDEEA Group 2020a).

Primary data collection and data storage is often done without reference to a standard that classifies data (e.g., System of Environmental-Economic Accounting [SEEA]). Hence, data labelling and later discovery or repurposing of data becomes more challenging. This forces researchers to devote more resources to developing protocols and classifications. (Finisdore et al. n.d.)

While Australia lacks a classification standard for coastal wetlands data and natural capital in general, there are ongoing efforts. First, SEEA is being explored as a national accounting standard. More specific to coastal wetlands, Queensland has developed and used AquaBAMM to assess the value of coastal wetlands (Clayton et al. 2006, Ronan in IDEEA Group 2020a). Similarly, the Northern Territory, Western Australia, New South Wales and Victoria also have developed both river and wetland assessment tools (DELWP 2018, Department of Water 2011, Duguid et al. 2005, Claus et al. 2011). Examining these methodologies, both the Queensland and Victorian wetland assessment tools are more detailed, outlining a range of indicators to be measured and used in determining the condition of a wetland. South Australia developed a wetland condition assessment approach, which forms part of state wide assessment of waterfowl abundance (Department of Environment and Water 2014).

Both the Queensland and Victorian approaches standardise the process of data classification, which could be particularly relevant and useful when considering wetlands at a local (named) level, for example within a local government or Natural Resources Management region. While both have been designed to meet state priorities, at the national level there is a need for a nationwide approach to wetland condition assessment.

Having a single approach to wetland condition assessment, containing primary data at the national level, could be used efficiently in nationwide prioritisation modelling. An example is shown below in **Error! Reference source not found.**, which shows the applicability of using AquaBAMM's classification for collecting and organizing data for the InVEST Coastal Vulnerability Model. These classifications are similar to SEEA (see Appendix 4 Natural capital accounting data structure and other coastal wetland DRR models (Appendix 3 DRR lists 6 models and their data needs). Because the data is easily

transferred among these standards, the national adoption of AquaBAMM—or a combination of AquaBAMM and the DEELWP standard—for wetland assessment would also reduce the costs of quality explicit local valuation.

Table 8 Comparison of AquaBAMM criteria, indicators and measures from Burnett River catchment (Clayton et al. 2006) with data needed for InVEST Coastal Vulnerability Model (The Natural Capital Project 2019)

Criteria & Indicators	Measures	Data needed for InVEST (some is optional)
1 Naturalness Aquatic		
1.1 Exotic flora/fauna	1.1.1 Presence of 'alien' fish species within the spatial unit 1.1.2 Presence of exotic plants instream within the spatial unit	
1.2 Aquatic communities/assemblages	1.2.1 SOR1 aquatic vegetation condition 1.2.2 SIGNAL22 score (Max) 1.2.3 AUSRIVAS3 score - Edge (Min band) 1.2.4 AUSRIVAS3 score - Pool (Min band) 1.2.5 EPT4 score (Max)	
1.3 Channel features modification	1.3.1 SOR1 bank stability 1.3.2 SOR1 bed & bar stability 1.3.3 SOR1 aquatic habitat condition 1.3.4 Presence of dams/weirs within the spatial unit 1.3.5 Inundation by dams/weirs (% of waterway length within the spatial unit) 1.3.6 Snag removal within the spatial unit	
1.4 Hydrological modification	1.4.1 APFD5 score - modelled deviation from natural under full development 1.4.2 % natural flows - modelled flows remaining relative to predevelopment 1.4.3 % no flows - modelled low flows relative to predevelopment	
1.5 Water quality	1.5.1 Median Total Phosphorous (ug/L) 1.5.2 Median Total Nitrogen (ug/L) 1.5.3 Median Turbidity (ug/L) 1.5.4 Median Conductivity (ug/L) 1.5.5 Median pH	
2 Naturalness Catchment		
2.1 Exotic flora/fauna	2.1.1 Presence of exotic plants in the riparian zone within the spatial unit	
2.2 Riparian disturbance	2.2.1 % area remnant vegetation across the spatial unit relative to preclear extent within buffered watercourses (i.e. in the riparian zone) 2.2.2 % area of wetland REs in the spatial unit relative to preclear extent 2.2.3 Total number of REs within riparian areas relative to preclear number of REs within buffered watercourses 2.2.4 SOR1 reach environs 2.2.5 SOR1 riparian vegetation condition	
2.3 Catchment disturbance	2.3.1 % 'agricultural' land-use area by spatial unit (i.e. cropping and horticulture) 2.3.2 % 'grazing' land-use area by spatial unit 2.3.3 % 'vegetation' land-use area by spatial unit (i.e. native veg + regrowth) 2.3.4 % 'settlement' land-use area by spatial unit (i.e. towns, cities, etc)	
2.4 Flow modification	2.4.1 Farm storage (overland flow harvesting and gully dams) calculated by surface area within the spatial unit	
3 Diversity and Richness		
3.1 Species	3.1.1 Richness of amphibians 3.1.2 Richness of native fish 3.1.3 Richness of native reptiles 3.1.4 Richness of native waterbirds 3.1.5 Richness of aquatic plants (macrophytes)	Root density (#/m ²), Root height (Mangrove) (m), Root size (Mangrove) (m), stem density (#/m ²), stem height (m)
3.2 Communities/assemblages	3.2.1 Number of macroinvertebrate taxa (Family level taxonomy) 3.2.2 Riparian vegetation richness represented by richness of REs along watercourses within a specified buffer distance from the stream	
3.3 Habitat	3.3.1 SOR channel diversity	
3.4 Geomorphology	3.4.1 Richness of geomorphic features (i.e. features determined according to GAR6 method) within the spatial unit	
4. Threatened Species and Ecosystems		

Criteria & Indicators	Measures	Data needed for InVEST (some is optional)
4.1 Species	4.1.1 Presence of rare or threatened aquatic ecosystem dependent fauna species 4.1.2 Presence of rare or threatened aquatic ecosystem dependent flora species	
4.2 Communities/assemblages	4.2.1 % area of 'of concern' or 'endangered' wetland REs in the spatial unit relative to pre-clear extent	
5 Priority Species and Ecosystems		
5.1 Species	5.1.1 Presence of aquatic ecosystem dependent 'priority' fauna species or other lists such as ASFB9, WWF10, etc) 5.1.2 Presence of aquatic ecosystem dependent 'priority' flora species 5.1.3 Habitat for, or presence of, migratory species 5.1.4 Habitat for significant numbers of waterbirds	
5.2 Ecosystems	5.2.1 Presence of 'priority' aquatic ecosystem as per Expert Panel lists and/or discussions	
6 Special Features		
6.1 Geomorphic features	6.1.1 Presence of distinct, unique or special geomorphic features	
6.2 Ecological processes	6.2.1 Presence of (or requirement for) distinct, unique or special ecological processes	
6.3 Habitat	6.3.1 Presence of distinct, unique or special habitat (including habitat that functions as refugia or other critical purpose)	
6.4 Hydrological	6.4.1 Presence of distinct, unique or special hydrological regimes (e.g. ephemeral stream, wetland)	Vegetation type (red mangrove, seagrass)
7 Connectivity		
7.1 Significant species or populations	7.1.1 The contribution (upstream or downstream) of the spatial unit to the maintenance of significant species or populations, including those features identified through Criterion 5 and/or 6 7.1.2 Possibility for migratory or routine 'passage' of fish and other fully aquatic species (upstream and/or downstream movement)	
7.2 Groundwater dependent ecosystems	7.2.1 The contribution (upstream or downstream) of the spatial unit to the maintenance of groundwater ecosystems with significant biodiversity values, including those features identified through Criterion 5 and/or 6 (e.g. karsts, cave streams, artesian springs)	
7.3 Floodplain and wetland ecosystems	7.3.1 The contribution (upstream or downstream) of the spatial unit to the maintenance of floodplain and wetland ecosystems with significant biodiversity values, including those features identified through Criterion 5 and/or 6	
7.4 Terrestrial ecosystems	7.4.1 The contribution (upstream or downstream) of the spatial unit to the maintenance of terrestrial ecosystems with significant biodiversity values, including those features identified through Criterion 5 and/or 6	
7.5 Estuarine and marine ecosystems	7.5.1 The contribution (upstream or downstream) of the spatial unit to the maintenance of estuarine and marine ecosystems with significant biodiversity values, including those features identified	
8 Representativeness		
Indicators & Measures not developed or implemented for Burnett River catchment ACA		Bathymetry(m), bed shear stress, cross shore distance Depth average undertow (m/sec), depth of still water (m), hurricane high waves (m), long shore current (wind induced), Wave climate, wave height (distant storm swells) (m), wave number, wave period (s), wave power (kW/m), wave surge (m), sea level increase surface wind, offshore maximum sustained wind speed (km/hr),

8 PRIORITISING WETLANDS FOR FUTURE VALUATIONS

Constraints on the availability of resources for coastal management call for a prioritisation of coastal wetlands for valuation studies. A state government or local council focus may be the most effective because of their lead role in coastal planning. The following criteria may be considered as a basis for prioritising among different sites.

- 1) *Conversion threat*—what threats face the wetland. This may be a combination of its protected status (e.g. Ramsar, National Park, Indigenous Protected Area) and development pressures (see Figure 2 Study framework (adapted from United Nations Statistics Division 2018)).
- 2) *Hazard risk*—cyclone, sea level rise, subsidence risk could all be considered (see Figure 2 Study framework (adapted from United Nations Statistics Division 2018)).
- 3) *Existing planning effort*—a disaster, adaptation or coastal development effort may be underway or planned. A valuation may improve the evidence base for decisions and serve as an example for other locations.
- 4) *Value of human property*—on average, coastal wetlands providing DRR ecosystem services to more expensive properties will have higher valuations. Higher valuations are more likely to influence decision making. This may set precedent for the use of valuation in other areas.

Such a prioritisation exercise may be aided by Australia's existing awareness-raising valuations (see Valuation of Australia's coastal wetlands). Additional insight may be gained if the criteria used in prioritisation exercises are given numerical weights and aggregated to provide a composite score.

As shown in

Table 9, Van Coppenolle & Temmerman 2020 assessed and ranked cities around the world for the populations at risk, property at risk and size of coastal ecosystems. Further data is required to make such a prioritisation of Australia's coastal wetlands. Such an exercise should include state and local decision makers. Finally, although this report focuses on prioritisation of DRR ecosystem services, any prioritisation exercise could include a broader range of ecosystem services.

Table 9 Cities, populations, asset risk and coastal ecosystem in flood path (Van Coppenolle & Temmerman 2020)

Rank	City	Country	Population 2005 (000)	Population at risk (000)	Assets at risk (US\$bil)	Coastal ecosystem (km ²)	Coastal Ecosystem (types)
1	Khulna	Bangladesh	1,494	441	4.41	2005.95	Mangrove Forest
2	Conakry	Guinea	1,425	41	0.40	1138.19	Mangrove Forest, Seagrass Meadow
3	Guayaquil	Ecuador	2,387	412	8.86	741.20	Mangrove Forest
4	Kuwait	Kuwait	1,810	14	1.16	621.66	Seagrass Meadow, Coral Reef
5	Manila	Philippines	10,686	113	2.69	522.32	Mangrove Forest, Seagrass Meadow
6	Douala	Cameroon	1,761	11	0.13	482.61	Mangrove Forest
7	Accra	Ghana	1,981	14	0.18	426.61	Mangrove Forest, Seagrass Meadow
8	Shanghai	China	14,503	2,353	72.86	396.55	Salt Marsh
9	Ho Chi Minh City	Vietnam	5,065	1,931	26.86	372.68	Mangrove Forest
10	Hong Kong	Hong Kong SAR	7,041	223	35.94	348.77	Mangrove Forest, Seagrass Meadow
11	Davao	Philippines	1,327	3	0.06	325.23	Mangrove Forest, Seagrass Meadow
12	Guangzhou	China	8,425	2,718	84.17	303.96	Mangrove Forest, Salt Marsh
13	Palembang	Indonesia	1,733	127	2.50	263.01	Mangrove Forest
14	Luanda	Angola	2,766	1	0.02	260.67	Mangrove Forest, Seagrass Meadow
15	New Orleans	USA	1,010	1,124	233.69	241.37	Salt Marsh
16	Miami	USA	5,434	2,003	416.29	236.87	Mangrove Forest, Salt Marsh, Seagrass Meadow, Coral Reef
17	Hangzhou	China	2,831	17	0.53	231.89	Salt Marsh
18	Dakar	Senegal	2,159	18	0.17	213.67	Seagrass Meadow
19	Zhanjiang	China	1,514	230	7.13	208.05	Mangrove Forest, Salt Marsh, Seagrass Meadow
20	Kuala Lumpur	Malaysia	1,405	270	15.06	188.34	Mangrove Forest

A parallel or alternate prioritization of building datasets is also worthy of consideration. Given that data availability is the primary impediment to improved valuations and that generic models such as InVEST can be used by non experts, by simply providing data, the coastal planning community will face lower barriers to conducting quality biophysical modelling and valuation. In addition, the real estate, insurance and construction industries could repurpose this data (Mallon and LePlastrier IDEEA Group 2020a).

9 CONCLUSIONS AND RECOMMENDATIONS

Coastal wetlands enable a wide range of benefits through the provision of ecosystem services. These include cultural and intrinsic benefits related to the existence of biodiversity and wetlands themselves. Wetlands provide food (fish and seafood) and mitigate climate change by sequestering and storing carbon. In addition, coastal wetlands contribute to improved health by providing recreational opportunities and filtering pollutants from water. They can also protect human property from coastal storms, floods, sea level rise and subsidence.

The extent, condition, location and ecosystem type influence coastal wetland's ability to provide this disaster risk reduction ecosystem services. To help coastal managers include them in decision making, monetary valuation has been used.

The degree to which valuation influences coastal planning decisions depends on the use and quality of explicit local valuation approaches. This quality, in turn, is driven by how readily the valuations can be integrated with valuations of other ecosystem services and existing statutory planning processes. The implementation of these two steps is eased with the adoption of classification standards for ecosystem types, ecosystem services and data. Attention is also warranted to improving modelling itself as well as the stakeholder engagement process critical to decision makers' acceptance of valuations. Finally, this data and modelling is helpful to decision making processes that do not use monetary values, as well as to the insurance, real estate and construction sectors.

Most of Australia's coastal wetlands have been valued. These valuations were generally conducted at large geographic scales or with valuation techniques that deliver large value ranges. Both produced broad ranges in approximate values. For example, one study noted the value of a hectare of wetlands ranging from INT\$(2019) 2.57 to 11,477 (Gaylard et al. 2020). Studies such as these can raise awareness but do not guide coastal planning decisions. In contrast, a valuation study that was integrated with coastal adaptation planning efforts, valued the DRR ecosystem services of intertidal marshes of Port Phillip Bay & Bellarine Peninsula, Victoria, at AUD\$(2019) 29,888,000 (Carnell, P.E, Reeves, S.E, Nicholson, E. et al. 2019). This study was conducted at small spatial resolution, providing coastal planners with clear options about that DRR implications of every section of marsh.

Conducting these explicit local valuations requires strong biophysical modelling about where hazards such as flood waters and winds will impact human property. This modelling in turn, depends on access to quality data. This data and modelling is also required for most other coastal planning approaches and techniques, and can be readily used by the insurance, real estate and construction sectors (Table 10). Therefore, the improvement of data is likely to improve coastal planning in ways that are difficult to anticipate.

Table 10 Dependence of techniques and approaches on biophysical modelling

	Approach	Technique	Note
Coastal planning requires biophysical modelling (data dependent)	Explicit local valuation	Production function	Components of these techniques are often combined
		Expected damage function	
		Replacement cost	Used for CBA
	Stakeholder engagement	Stated preference	Requires clear options and stakeholder knowledge
	Non monetary decision approaches	Expert panel, cost effectiveness analysis, multicriteria analysis, empirical social values, unweighted multiple indicator assessment	Quality biophysical modelling is needed
	Repurpose data	Insurance products	Data has been requested by industry
	Repurpose data	Construction, real estate	Industry would likely use data
	Awareness raising		Benefit transfer
Hedonic pricing			Real estate market is not sufficiently incorporating disaster risks

There are valuation techniques that are not dependent on this data and complex modelling (Table 10). Benefit transfer techniques are often used because of data or capacity shortfalls. Benefit transfer techniques can raise awareness and provide decision makers with a point of reference especially at the state or national level. In addition, hedonic pricing techniques can reveal how DRR values are incorporated into property values. Presently, the Australia real estate market has not incorporated these values, impeding the use of hedonic pricing.

In order to expand the use of explicit local valuation approaches, the following steps are recommended:

1. Promote explicit local valuation approaches

Nearly all Australian coastal wetlands have been valued. Recent studies (Keenan et al. 2019) and interviews conducted for this report, indicate most state and local government decision makers in Australia are generally aware that DRR values are provided by coastal wetlands (IDEAA Group 2020b). Therefore, additional benefit transfer valuations are unlikely to create additional knowledge that coastal planners can use for local decision making. This said, awareness raising approaches, such as benefit transfers, may provide value to national or state policy analysis.

Thus, explicit local valuation approaches—that incorporate elements of production function, expected damage function and replacement costs techniques appropriately—should provide the most benefit to local decision making. Stated preference techniques could be useful, though generally, when a decision rests on stakeholder’s preference from two or three clear choices, this depends on quality biophysical modelling. Finally, the data created by explicit local valuation approaches can be repurposed by the insurance, real estate and construction industries.

2. Encourage the use of standards for ecosystem types, ecosystem services and data

As part of efforts to improve its management of natural areas, Australia has begun adopting the SEEA natural capital accounting standard. SEEA classifies data in ways that are interoperable with standard national accounting and its related financial and economic analysis, such as cost benefit analysis⁸. At the same time, parts of the Australian Government have begun using components of the SEEA standard (e.g. CICES) because of its immediate value, and there will be advantages in building linkages between work on the SEEA and other environmental measurement work.

For example, Queensland is using CICES to identify ecosystem services along with AquaBAMM for wetland monitoring. (Ronan in IDEEA Group 2020a) The Australia National Aquatic Ecosystem (ANAE) classification is being used more broadly. It, or the IUCN Global Ecosystem Typology (GET), could be promoted broadly. It is notable, that once captured, this classified data could be easily incorporated into government reporting frameworks.

Working towards improved harmonization and standardization would not only improve valuation, but also accelerate learning and data interoperability across government departments and economic sectors. Success of such standards depends on their flexibility and adaptability to local circumstances. Because they have been extensively tested and refined, SEEA, ANAE, GET, CICES and AquaBAMM are ready for broad adoption.

3. Advance the use of best practices in stakeholder engagement for valuations

In coordination with the promotion of explicit local valuation approaches, stakeholder engagement needs improvement. Researchers are likely unaware of the benefits that a few simple steps can offer. Several options are worth consideration. There may be value in repurposing an existing list of best practices (Waite et al. 2014, Rogers et al. 2015) into a checklist, with examples of how valuation can be conducted in a way that fully engages stakeholders, and widely promoting this checklist. Improving stakeholder engagement, however, may require changes to the process used for government sponsored CBA. Most are contracted to external parties who have minimal engagement with decision makers.

4. Build partnerships among environmental, engineering and insurance modellers

⁸ While for the purposes of monetary valuation SEEA focuses on exchange values and CBA on welfare values which include consumer surplus, the measurement of DRR ecosystem services in physical terms and associated data on ecosystem type and condition will underpin all monetary values provided by coastal wetlands.

The quality of disaster risk reduction modelling will improve more quickly with partnerships among key experts. This shared learning could be advanced through a long term research project, with focus on developing best practices or targeted research such as implementing a best in class⁹ explicit local valuation of a priority wetland.

5. Explore opportunities for hedonic pricing studies

The real estate market has responded to coastal risks only in select Australian communities. (Anning 2012). Should this market failure continue correcting itself, a hedonic pricing study could provide valuable insights on the DRR values of coastal wetlands. It may also directly impact insurance premiums and coastal planning as the study would reflect actual housing prices. Engaging the real estate and insurance sectors would speed the application of results into sector practices.

6. Support Pacific island nations' prioritisation and explicit local valuation of wetlands

Australia is part of the Ramsar Convention's Oceania Region, with an interest in promoting sustainable coastal wetland management in Pacific islands within that Region. Pacific island nations are heavily dependent on coastal wetlands for disaster risk reduction and threats from development are real. An integrated effort to prioritize likely valuable wetlands that are also at risk of being converted could be followed by targeted explicit local valuations. Stakeholder participation would be critical to the success of such an effort.

The recent increase in studies applying explicit local valuation approaches in Australia and around the globe is encouraging. Continuing this progress, however, requires addressing critical bottlenecks related to the quality of modelling and data. This report details the rationale for pragmatic recommendations that build on Australia's existing expertise.

⁹ It is beyond the scope of this report to define fully, but best in class explicit local valuation would depend factors including the scale of data, the number of environmental parameters used, ultimately focused on improving the accuracy and precision of models.

10 APPENDIX 1 LIST OF VALUATION STUDIES

These valuation studies were identified and their results and analysis captured in this report.

No	Study
1.	Akber, et al., 2018; Storm protection service of the Sundarbans mangrove forest, Bangladesh
2.	Arena, et al., 2015; National marine ecosystem service valuation: Solomon Islands
3.	Arkema, et al., 2013; Coastal habitats shield people and property from sea-level rise and storms
4.	Atkinson, et al., 2016; Prioritising mangrove ecosystem services results in spatially variable management priorities
5.	Badola and Hussain, 2005; Valuing ecosystem functions: An empirical study on the storm protection function of Bhitarkanika mangrove ecosystem, India
6.	Badola, Barthwal and Hussian, 2012; Attitudes of local communities towards conservation of mangrove forests: A case study from the east coast of India
7.	Barbier, 2001; Valuing Mangrove Conservation in Southern Thailand
8.	Barbier, 2007; Valuing ecosystem services as productive inputs
9.	Barbier, et al., 2013; The Value of Wetlands in Protecting Southeast Louisiana from Hurricane Storm Surges
10.	Bayas, et al., 2011; Influence of coastal vegetation on the 2004 tsunami wave impact in west Aceh
11.	Beck, et al., 2018; The global flood protection savings provided by coral reefs
12.	Bennet, 2015; Australia's Coastal Wetlands, 2010
13.	Birol, et al., 2009; Optimal management of wetlands: Quantifying trade-offs between flood risks, recreation, and biodiversity conservation
14.	Boutwell and Westra., 2015; The economic value of wetlands as storm buffers
15.	Boyer-Villemare, et al., 2014; Quantifying community's functional awareness of coastal changes and hazards from citizen perception analysis in Canada, UK and Spain
16.	Bulu, et al., 2014; Economic valuation of mangrove ecosystem services in Vanuatu
17.	Burke, et al., 2008; Coastal capital: economic valuation of coral reefs in Tobago and St. Lucia.
18.	Carnell, et al., 2019; Mapping Ocean Wealth Australia: The value of coastal wetlands to people and nature
19.	Costanza, et al., 2008; The Value of Coastal Wetlands for Hurricane Protection
20.	Das and Crépin, 2013; Mangroves can provide protection against wind damage during storms
21.	Das and Vincent, 2009; Mangroves protected villages and reduced death toll during Indian super cyclone
22.	Department of Environment and Heritage Protection, 2012; Natural assets for flood and cyclone resilience: Synthesis of scientific evidence on the role of natural assets to reduce the human impacts of floods and cyclones

No	Study
23.	Emerton, 2005; Values and Rewards: Counting and Capturing Ecosystem Water Services for Sustainable Development
24.	Flight, et al., 2012; Valuing Wetland Ecosystem Services: A Case Study of Delaware
25.	Franco and Luiselli, 2014; Shared ecological knowledge and wetland values: A case study
26.	Gaylard, et al., Review of coast and Marine Ecosystems in Temperate Australia Demonstrates a Wealth of Ecosystem Services. <i>Front. Mar. Sci</i> 7:453.
27.	Gerrad., 2010; Wetlands reduce damages to infrastructure, Lao PDR
28.	Gonzalez, et al., 2015; Fiji National Marine Ecosystem Service Valuation
29.	Grabowski, et al., 2012; Economic Valuation of Ecosystem Services Provided by Oyster Reefs
30.	Gray, O'Neill and Qiu, 2017; Coastal residents' perceptions of the function of and relationship between engineered and natural infrastructure for coastal hazard mitigation
31.	H.O and McNally, 2001; An Economic Valuation of the Terrestrial and Marine Resources of Samoa
32.	Hassan, Olsen and Thorsen, 2019; Urban-rural divides in preferences for wetland conservation in Malaysia
33.	Huxham, et al., 2015; Applying Climate Compatible Development and economic valuation to coastal management: A case study of Kenya's mangrove forests
34.	Kim and Petrolia, 2013; Public perceptions of wetland restoration benefits in Louisiana
35.	Liu, et al., 2019; Rice paddy fields' hidden value for typhoon protection in coastal areas
36.	Liu, et al., 2019; The value of China's coastal wetlands and seawalls for storm protection
37.	Menéndez, 2020., 2020; The Global Flood Protection Benefits of Mangroves
38.	Merriman and Murata., 2016; Guide for Rapid Economic Valuation of Wetland Ecosystem Services
39.	Ming, et al., 2007; Flood mitigation benefit of wetland soil - A case study in Momoge National Nature Reserve in China
40.	Narayan, et al., 2016; Coastal Wetlands and Flood Damage Reduction Using Risk Industry-based Models to Assess Natural Defenses in the Northeastern USA
41.	Ouyang et al., 2018; Spatially-explicit valuation of coastal wetlands for cyclone mitigation in Australia and China
42.	Oxford Economics, 2009; Valuing the effects of Great Barrier Reef bleaching
43.	Parthum, 2017; Benefits of the fire mitigation ecosystem service in The Great Dismal Swamp National Wildlife Refuge, Virginia, USA
44.	Pascal, et al., 2011; Cost-benefit analysis of community-based marine protected areas: 5 case studies in Vanuatu, South Pacific
45.	Pascal, et al., 2015; National marine ecosystem service valuation: Vanuatu
46.	ProAct Network, et al., 2008; The role of environmental management and eco-engineering in disaster risk reduction and climate change adaptation

No	Study
47.	Ragkos, et al., 2006; Using a functional approach to wetland valuation: The case of Zazari-Cheimaditida
48.	Reddy, et al., 2016; Evaluating the role of coastal habitats and sea-level rise in hurricane risk mitigation: An ecological economic assessment method and application to a business decision
49.	Reeves, et al, n.d. Mapping Ocean Wealth, The Nature Conservancy, Melbourne, Australia
50.	Reguero., 2018; Comparing the cost effectiveness of nature-based and coastal adaptation: A case study from the Gulf Coast of the United States
51.	Rezaie, et al., 2020; Valuing natural habitats for enhancing coastal resilience: Wetlands reduce property damage from storm surge and sea level rise
52.	Rouatu, et al. 2017; National Marine Ecosystem Service Valuation: Kiribati
53.	Ruckelshaus, et al., 2016; Evaluating the Benefits of Green Infrastructure for Coastal Areas: Location, Location, Location
54.	Russi, et al., 2013; The Economics of Ecosystems and Biodiversity for Water and Wetlands
55.	Salcone, et al., 2015; National marine ecosystem service valuation: Tonga
56.	Sigren. et al., 2018; The Effects of Coastal Dune Volume and Vegetation on Storm-Induced Property Damage: Analysis from Hurricane Ike
57.	Sun and Carson, 2020; Natural assets for flood and cyclone resilience: Synthesis of scientific evidence on the role of natural assets to reduce the human impacts of floods and cyclones
58.	Vázquez-González, et al., 2019; The value of coastal wetland flood prevention lost to urbanization on the coastal plain of the Gulf of Mexico: An analysis of flood damage by hurricane impacts
59.	Whiteoak, et al., 2012; Literature Review of the Economic Value of Ecosystem Services that Wetlands Provide Final Report

11 APPENDIX 2 LIST OF EXPERTS INTERVIEWED

The following experts were interviewed. The MS Excel file (IDEEA Group 2020a) provided with this report contains notes from the discussions with each expert.

No.	Name	Organization
1.	Dr. Simone Maynard	University of the Sunshine Coast/IUCN
2.	Dr. Jeffrey Wielgus	U.S. National Oceanic and Atmospheric Administration (NOAA)
3.	Mike Ronan	Queensland Wetlands Program, Department of Environment and Science
4.	Sel Sultmann	Coastal Planning, Department of Environment and Science
5.	Dr Mike Coote	WA, Wetlands Section, Department of Biodiversity, Conservation and Attractions
6.	Dr Alaric Fisher	NT, Species Conservation, Department of Environment and Natural Resources
7.	Andrew Crane	TAS, Policy and Conservation Advice Branch, Department of Primary Industries, Parks, Water and Environment
8.	Dr. Michael Bordt	ESCAP
9.	Tamara van Polanen Petel	Port Phillip Bay Coastal Hazard Assessment
10.	Lawrance Ferns	Marine Policy (VIC)
11.	Dr. Karl Mallon	Climate Risk Pty Ltd, XDI Systems, climateevaluation.com
12.	Dr. Rebecca Cunningham	Institute for Sustainable Futures (University of Technology Sydney)
13.	Dr. Brendt Jacobs	Institute for Sustainable Futures (University of Technology Sydney)
14.	Dr. Roel Plant	Institute for Sustainable Futures (University of Technology Sydney)

Candidate questions included

1. "What is the state of knowledge coastal wetlands disaster risk reduction ecosystem services values and valuation data in your sector?"
2. "What barriers exist to using valuation studies?"
3. "How can valuation studies and data be made most effective to your sector?"
4. "What value would standardized data provide?"

12 APPENDIX 3 DRR COASTAL WETLAND MODELS

Six DRR ecosystem services valuation models from the U.S. Environmental Protection Agency’s EcoModels Library (U.S. Environmental Protection Agency 2020).

Model Name	Mangrove wetland development, Tampa Bay, FL, USA	Coastal protection, Europe	ARIES (Artificial Intelligence for Ecosystem Services) Flood Regulation, Puget Sound Region, Washington, USA	CRPI (Coral Reef Protection Index, St. Croix, USVI	Decrease in wave runoff (by reef), St. Croix, USVI	Coastal Protection provided by Coral, Seagrasses and Mangroves in Belize:
Model Short Name	Mangrove development, Tampa Bay, FL, USA	Coastal protection, Europe	ARIES flood regulation, Puget Sound Region, USA	CRPI, St. Croix, USVI	Decrease in wave runoff, St. Croix, USVI	Coastal protection in Belize
Document Author	Osland, M. J., Spivak, A. C., Nestlerode, J. A., Lessmann, J. M., Almario, A. E., Heitmuller, P. T., Russell, M. J., Krauss, K. W., Alvarez, F., Dantin, D. D., Harvey, J. E., From, A. S., Cormier, N. and Stagg, C.L.	Liquete, C., Zulian, G., Delgado, I., Stips, A., and Maes, J.	Bagstad, K.J., Villa, F., Batker, D., Harrison-Cox, J., Voigt, B., and Johnson, G.W.	Yee, S. H., Dittmar, J. A., and L. M. Oliver	Yee, S. H., Dittmar, J. A., and L. M. Oliver	Guannel, G., Arkema, K., Ruggiero, P., and G. Verutes
Document Year	2012	2013	2014	2014	2014	2016
Document Title	Ecosystem development after mangrove wetland creation: plant-soil change across a 20-year chronosequence	Assessment of coastal protection as an ecosystem service in Europe	From theoretical to actual ecosystem services: mapping beneficiaries and spatial flows in ecosystem service assessments	Comparison of methods for quantifying reef ecosystem services: A case study mapping services for St. Croix, USVI	Comparison of methods for quantifying reef ecosystem services: A case study mapping services for St. Croix, USVI	The Power of Three: Coral Reefs, Seagrasses and Mangroves Protect Coastal Regions and Increase Their Resilience
Document ID	97	296	302	335	335	350
Document Status	Peer reviewed and published	Peer reviewed and published	Peer reviewed and published	Peer reviewed and published	Peer reviewed and published	Peer reviewed and published
Comments on Status	Published journal manuscript	Published journal manuscript	Published journal manuscript	Published journal manuscript	Published journal manuscript	Published journal manuscript
EM Source or Collection	US EPA	EU Biodiversity Action 5	ARIES	US EPA	US EPA	InVEST

Driving Variables (and Units)	Time (yr)	Artificial surface cover (%) Coastline geomorphology rank for coastal protection (Not applicable) Emerged habitat rank for coastal protection (Not applicable) Maximum wave significant height (m) Number of UNESCO World Heritage Sites (No.) Population density (hab/km ²) Relative sea level rise (mm/yr) Road density (km km ⁻²) Slope (degrees) Storm surge potential (100 yr return period) (m) Submarine habitat rank for coastal protection (Not applicable) Tidal range (m)	Dam storage (Not applicable) Detention basin storage (Not applicable) Developed land in 100-year floodplain (y/n) (Not applicable) Hydrologic soils group (Not applicable) Impervious cover (Not applicable) Mean annual precipitation (mm) Slope (Not applicable) Successional stage (vegetation) (Not applicable) Tree canopy cover (Not applicable) Vegetation height (Not applicable) Vegetation type (Not applicable)	Reef distance (from shore) (m) Reef distribution (Not applicable) Reef habitat type class (Not applicable)	Beach slope angle (%) Offshore (deep water) wave height (m) Wave height nearshore (m)	Bathymetry (m) Bed shear stress (Not reported) Cross shore distance (Not reported) Depth average undertow (m/sec) Depth of still water (m) Hurricane high waves (m) Long Shore current (wind induced) (Not reported) Offshore maximum sustained wind speed (km/hr) Reduction in wave height (m) Root density (#/m ²) Root height (Mangrove) (m) Root size (Mangrove) (m) Sea level increase (Not applicable) Stem density (#/m ²) Stem height (m) Surface wind (Not reported) Vegetation type (red mangrove, sea grass) (Not applicable) Vegetation wave energy dissipation (Not reported) Wave climate (Not applicable) Wave height (distant storm swells) (m) Wave number (Not reported) Wave period (s) Wave power (kW/m) Wave surge (m)
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Model Name	Mangrove wetland development, Tampa Bay, FL, USA	Coastal protection, Europe	ARIES (Artificial Intelligence for Ecosystem Services) Flood Regulation, Puget Sound Region, Washington, USA	CRPI (Coral Reef Protection Index, St. Croix, USVI	Decrease in wave runup (by reef), St. Croix, USVI	Coastal Protection provided by Coral, Seagrasses and Mangroves in Belize:
Constant or Factor Variables (and Units)		Weight for artificial surface cover (unitless) Weight for coastline geomorphology (unitless) Weight for emerged habitats (unitless) Weight for maximum wave significant height (unitless) Weight for number of UNESCO World Heritage Sites (unitless) Weight for population density (unitless) Weight for relative sea level rise (unitless) Weight for road density (unitless) Weight for slope (unitless) Weight for storm surge potential (unitless) Weight for submarine habitats (unitless) Weight for tidal range (unitless)		Scaled magnitude of coastal protection for each reef habitat type (Not applicable) Scaled magnitude of coastal protection for reef distance (from shore) (Not applicable) Scaled magnitude of coastal protection for reef distribution (Not applicable)		Atmospheric pressure (normal) (mb) Atmospheric pressure constant (Not applicable) Breaker coefficient (Not applicable) Coral class (live/dead) (Not applicable) Coral friction coefficient (Not reported) Coral reef type (barrier or fringe) (Not applicable) Coriolis parameter (Not reported) Deep water significant wave height (m) Drag coefficient (Not reported) Gravity constant (Not reported) Hurricane barometric pressure (mb) Hurricane forward speed (km/hr) Peak period (significant wave height) (s) Radius of maximum winds (km) Stem/trunk diameter (m) Storm surge reduction (Mangrove) (m/km) Water density (Not reported) Water density (Not reported) Wave breaker index (Not applicable) Wave radial frequency (Not reported)

Model Name	Mangrove wetland development, Tampa Bay, FL, USA	Coastal protection, Europe	ARIES (Artificial Intelligence for Ecosystem Services) Flood Regulation, Puget Sound Region, Washington, USA	CRPI (Coral Reef Protection Index, St. Croix, USVI	Decrease in wave runup (by reef), St. Croix, USVI	Coastal Protection provided by Coral, Seagrasses and Mangroves in Belize:
Intermediate Variables (Computed) (and Units)		Human demand for coastline protection (Not applicable) Natural capacity for coastal protection (Not applicable) Natural exposure of coastlines (Not applicable)	Evapotranspiration (Not applicable) Mean days of precipitation per year (Not applicable) Soil infiltration (Not applicable)			Bottom friction wave energy dissipation (energy) (Not reported) Energy source (wind set up) (Not reported) Vegetation wave energy dissipation (Not reported) Wave breaking energy dissipation (Not reported)
Observed Response Variables (and Units)	Mangrove adult tree density (ind./ha) Mangrove adult tree diameter (cm) Mangrove juvenile tree density (ind./m ²) Mangrove juvenile tree height (cm) Percent sand (%) Percent soil moisture (%) Soil bulk density (g/cm ³) Soil carbon (g/kg) Soil carbon storage (g/m ²) Soil nitrogen storage (g/m ²) Soil organic matter (%) Spartina above ground biomass (g/m ²) Spartina stem density (stems/m ²)					

Model Name	Mangrove wetland development, Tampa Bay, FL, USA	Coastal protection, Europe	ARIES (Artificial Intelligence for Ecosystem Services) Flood Regulation, Puget Sound Region, Washington, USA	CRPI (Coral Reef Protection Index, St. Croix, USVI	Decrease in wave runup (by reef), St. Croix, USVI	Coastal Protection provided by Coral, Seagrasses and Mangroves in Belize:
Computed Response Variables (and Units)		Coastal protection ecosystem service benefit (Not applicable) Coastal protection ecosystem service flow (Not applicable)	Actual flood regulation for developed land in 100-year floodplain (mm) Actual flood regulation summed for developed land in 100-year floodplain (billion m ³ water/yr) Gray infrastructure storage (water) (Not reported) Green infrastructure storage (water) (Not reported) Ratio of actual to theoretical flood regulation for developed land in 100-year floodplain (%) Theoretical flood regulation (mm) Theoretical flood regulation summed (billion m ³ water/yr)	Coral reef protection index (unitless)	Decrease in wave runup (%)	Inundation level (m) Mudbed scour (m ³ /m) Sand erosion potential (W/m)

13 APPENDIX 4 NATURAL CAPITAL ACCOUNTING DATA STRUCTURE

The System of Environmental-Economic Accounting (SEEA) (United Nations et al. 2014b) is the global standard for natural capital accounting. One component of SEEA, is that provides uniform classification of data for improved speed and accuracy in defining and discovering data. **Error! Reference source not found.** demonstrated how SEEA organized different social and economic data.

Table 11 SEEA data classification structure

Generic SEEA data classification structure (adopted from United Nations Statistics Division 2018)		
Subcomponent	Definition	Example
Physical extent	Area in terms of coverage and arrangement	Topography, geography
Institutional extent	Zoning such as regulatory and planning areas	State and Council Zones, Ramsar boundaries
Ecosystem extent	Extent and composition of the ecosystem types	Seagrass, rocky reef, mangrove and salt marshes
Context	Contextual information that makes up the broader socio-ecological system	Cities, agricultural land, river connections
Coastal use	Terrestrial areas designated for use relating to the marine environment	Homes, ports, piers
Use	Uses of the wetland environment	Disaster risk reduction, tourism, fishing
Physical characteristics	Physical attributes system quality	Soil types, waves, tides, winds, salinity, heat content, mean sea surface, mean dynamic topography, turbidity (reflectance), mixed layer thickness, water pressure, water density
Chemical characteristics	Chemicals and nutrients system quality	Phosphate, nitrate, silicate, alkalinity, pH, CO ₂ , oxygen/hypoxia, tritium, oil-spill trajectory
Biological characteristics	Biological attributes	algal bloom, water quality, pests (starfish, sea urchins), bleaching
Ecological characteristics	Ecological characteristics of system	Cover, density, diversity of species
Biotic assets	Living natural assets	Aquatic plants, seaweeds, fish, birds, shrubs, trees,
Abiotic assets	Nonliving natural assets	Beach, seafloor sediments and rocks
Biotic physical services	Services that living components of the system provide	Protection of human property (wave attenuation, wind speed reduction), habitat services, carbon sequestration and storage, cultural services, tourism
Biotic monetary services	Valuation of physical services	As above, but valuation perspective
Abiotic physical services	Non-living components the system provides	Wind and wave energy reduction,
Abiotic monetary services	Valuation of abiotic physical services	Wave attenuation of rocky reef

14 APPENDIX 5 HISTORY OF ECOSYSTEM SERVICES CLASSIFICATION

This section is adapted from a Sustainable Flows working paper (Finisdore et al. 2019).

When the concept of ecosystem services (ES) was popularized¹⁰ in 1997's *Nature's Services* (Daily 2013) and *Valuing Ecosystem Services* (Costanza et al. 1997) two lists defined them. One list had thirteen ES, the other seventeen, from which discussion to define, group, measure, and value ecosystem services grew. Today the utility of applying the principles of classification systems (CS) to the field is being discussed (Bordt & Saner 2019).

Classification systems organize information so that data may be easily compared with other data (U.S. Bureau of Labor Statistics n.d., Hancock 2013). CS are used in a wide array of fields; those related to ecosystem services include ecology, hydrology, economics, national accounting, and health. These fields require large amounts of data that are often collected, analysed, and shared among independent practitioners. CS all have a:

1. Hierarchy of classification that nests sub-groups¹¹ in a way that is complete, mutually exclusive, consistent, relevant to the practical needs of users (e.g. balanced among users' needs) and what they are defining and measuring, stable through time, and comparable to other classifications (Fu et al. 2011, Wu 1999, Hoffmann & Chamie 1999, Hancock 2013).
2. Thesaurus that lists all the terms related to the classification system
3. Vocabulary that can be used to search the data
4. Flexible structure that balances stability with the needs of novel research (Hoffmann & Chamie 1999, Overhage & Suico 2001)

Common examples¹² of CS include the Linnaean taxonomy (Bruno & Richmond 2003), PhyloCode (Bruno & Richmond 2003), and the UN Food and Agriculture Organization's Land Cover Classification System (Di Gregorio & Jansen 2000). These were developed because each community needed a common language, an easy way to share data and research findings with heterogeneous metrics, and because there was no natural law or existing process addressing these needs (Overhage & Suico 2001).

Recognizing the need for a common language, the Millennium Ecosystem Assessment (MA) proposed four types of ES:

- Supporting—natural processes that help maintain other ecosystem services (e.g., nutrient cycling, primary production)

¹⁰ Writing on the concept of ecosystem services dates to Plato, at least, and lists of ecosystem services emerged in the 1960s. However, popularization of the concept related to current discussions on ecosystem services started in 1997.

¹¹ Flat CS are effective, but are simple lists of classification such as “gender: male, female” and cannot organize the complexity of ecosystem services because they do not capture hierarchical relationships (See endnote 64, Czúcz 2017).

¹² An extensive list of classification systems and resources can be found at <http://www.taxonomywarehouse.com>.

- Provisioning—the goods or products from ecosystems used by people (e.g., water, timber, food)
- Regulating—the benefits people receive from an ecosystem functioning to regulate natural processes (e.g., erosion control, temperance of flooding)
- Cultural—the nonmaterial human benefits from ecosystems (e.g., recreation, inspiration) (Alcamo et al. 2003)

The MA four types improved over the simple lists of ecosystem services offered in 1997, but the MA itself cautioned against considering it a classification (Alcamo et al. 2003). Regardless, the MA four types quickly gained wide use. They were even adapted for national ecosystem assessments. (UK National Ecosystem Assessment 2011, HaMAARAG 2018) The Economics of Ecosystems and Biodiversity (TEEB) revised¹³ the MA four types along with bifurcating ecosystem services from “benefits,” because benefits to humans routinely involve combining ecosystem services with economically produced inputs (Bishop 2013).

A few years after TEEB was published, and following on the exclusion of “benefits,” the European Environment Agency (EEA) printed a Common International Classification of Ecosystem Services (CICES)—that doubled the number of services in TEEB and offered a hierarchical structure for classifying ecosystem services (Figure A1) (Haines-Young & Potschin 2013). It was the first ecosystem services classification system (ES-CS). CICES is currently in version 5.1.

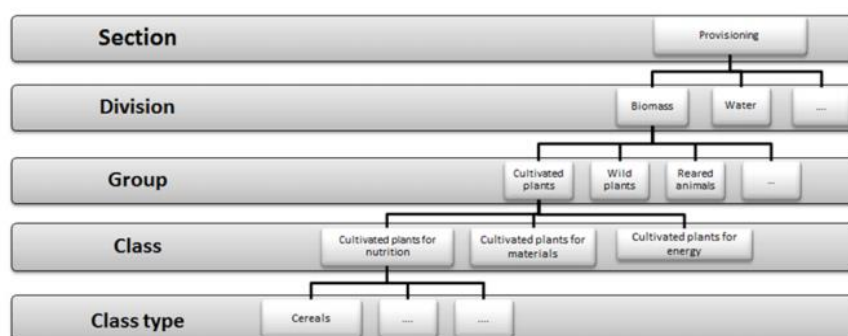


Figure A1 CICES V5.1 hierarchical levels (Haines-Young & Potschin 2018)

The US EPA then released the Final Ecosystem Services Classification System (FEGS-CS), (Landers & Nahlik 2013) and soon after the National Ecosystem Services Classification System (NESCS). (United States Environmental Protection Agency (US EPA) 2015) Both the FEGS-CS and NESCS include beneficiaries (Figures 2 and 3) in their hierarchies. The primary NESCS structure has been adopted for research exploring what natural capital accounts—a measure of the stocks and flows of natural resources—might look like for the US. FEGS-CS is being used to upgrade NESCS into NESCS Plus.

Similar to the MA, the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) explicitly acknowledged the multiple contributions that nature makes to people, but argued that some valuation approaches (e.g., single currency, single indicator, single benefit) often

¹³ For example, TEEB use the term “habitat” rather than “supporting.”

fail to capture this diversity. While the IPBES scientific community acknowledges that decision making relies to a great extent on these “instrumental values,” (Pascual et al. 2017) it supports the integration of multiple assessments of the value of nature to people in decision making. (Gómez-Baggethun et al. 2014). In response, IPBES both defined eighteen categories of Nature’s Contributions to People (NCP) and called for them to be understood through the local, cultural-context as bundles that “follow distinct lived experiences such as fishing, farming or hunting or from places, organisms, or entities of key spiritual experience such as sacred trees, animals or landscapes.” NCP cannot be placed in a hierarchy, but seeks to consider knowledge from western science, indigenous peoples, and the local context equally in decision making (Díaz et al. 2018).

As FEGS-CS, NESCS, CICES, and NCP were advancing, the UK National Ecosystem Assessment produced “the first analysis of the UK’s natural environment in terms of the benefits it provides to society and continuing economic prosperity.” (UK National Ecosystem Assessment 2011) It not only advanced accounting practices but influenced thinking around the globe. (Change 2012). It explicitly included final ecosystem services in its framework (UK National Ecosystem Assessment 2011).

In part to better support ecosystem accounting methodologies aligned with the principles of national accounts by recommending a single ecosystem services classification system, the United Nations Statistical Division group working on the System of Environmental-Economic Accounting (SEEA) facilitated workshops among experts representing the CICES, FEGS-CS, and NESCS and natural capital accounting communities. These workshops include discussions on how components of each ES-CS offer advantages to natural capital accounting. Details on these advantages can be found elsewhere (e.g. UNSD Meeting and Workshops [webpage](#)).¹⁴ SEEA chose these three because they were the only ones with hierarchical structures and that embodied final ecosystem services (FES) thinking.¹⁵

¹⁴ This appendix describes some structures and elements of CICES, FEGS-CS, NESCS, and NESCS Plus where appropriate. These are for descriptive purposes only and are not opinions on the relative merits of any ES-CS.

¹⁵ Recent versions of CICES more fully incorporate the FES concept than earlier versions.

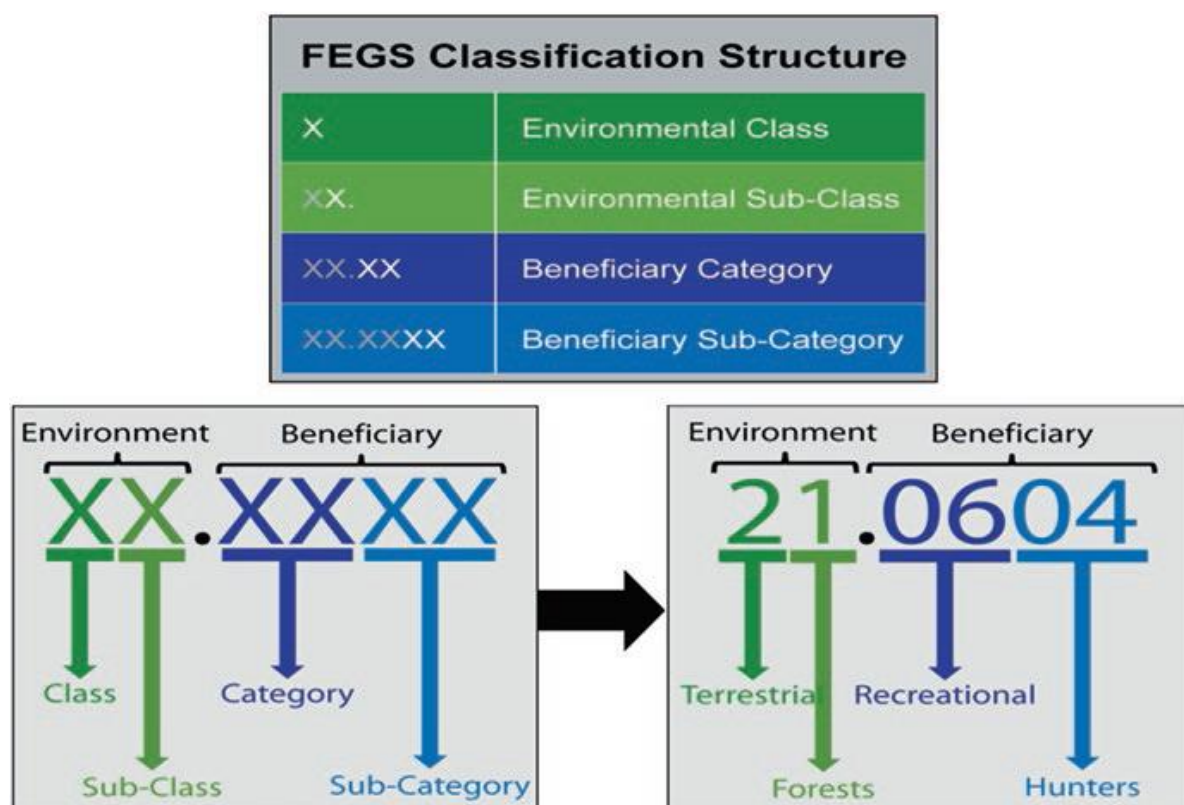


Figure A2 FEGS-CS hierarchal levels and coding (Landers & Nahlik 2013)

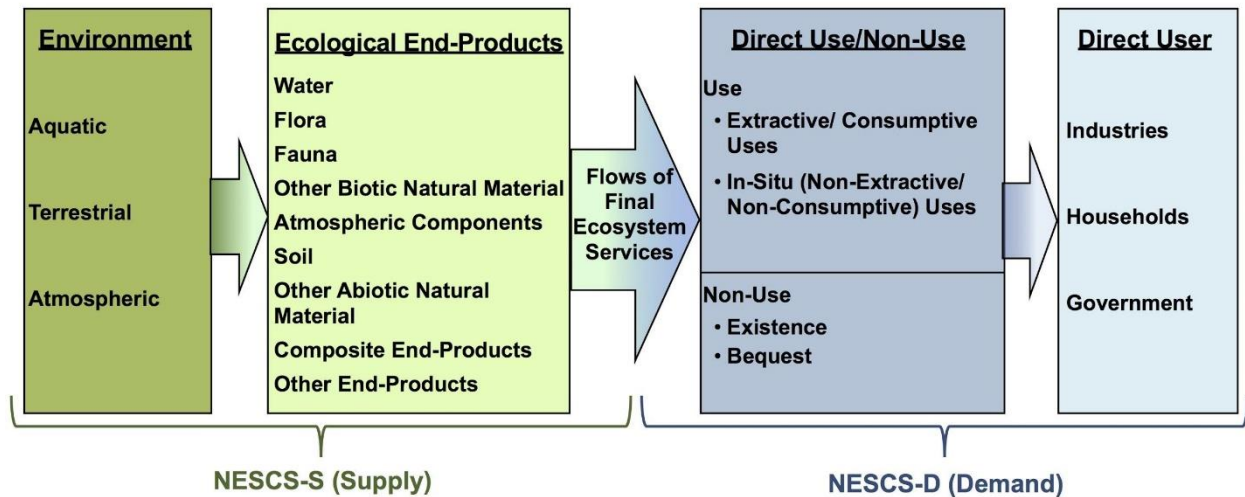
“Final” in FES in the four ES-CS described above (i.e., CICES, FEGS-CS, NESCS, and NESCS Plus), refers to the point where an ecological product transitions from being predominantly ecological to being a predominantly economic input that will often be a) mixed with man-made capital to produce an economic benefit, or b) directly used or appreciated. FES are flows to economic units (e.g., private companies & businesses, households, public agencies & bureaus) (Boyd & Banzhaf 2007b, United Nations 2017). Figure A3 shows how one ES-CS defines this flow of FES.

Consider that for ocean fish to make it to market, a boat, fishing supplies, fuel, and labor are needed. The transition point, or ecological end product—fish in ocean for harvest—occurs when the application of manmade capital makes the fish catchable by the fisher. The transition point is also determined by who is using the ecological end-product.¹⁶ To the fisher, fish directly available for harvest is the FES, whereas to a tourist, fish for recreational viewing is the FES. Turning to agriculture, to a farmer, water up-take by crops from favourable rains is the ecological end-product that enters the agricultural economy. To a tourist, it is the view of the landscape the farm sits in that enters the tourism sector of the economy.

¹⁶ ES-CS define ecological end products differently, but all note its centrality to developing a hierarchy.

Figure A3 National Ecosystem Services Classification System hierarchical levels and elements (Adapted from United States Environmental Protection Agency 2015)

NESCS Four-Part Classification Structure (condensed)



There is an active debate on the relative merits of FES over ecosystem services (see BoxA1) (Finisdore et al. 2016, Fisher et al. 2009, Wong et al. 2015). In addition, there are different interpretations of the boundaries of an FES and how they may be applied in different techniques (e.g., assessments, accounting, stakeholder engagement). (Rhodes, Landers, Petersen, et al. 2016, Bordt et al. n.d.) Regardless, the only known way to construct a hierarchy that follows the formal rules outlined above (e.g., complete, mutually exclusive, exhaustive, consistent) is by using the FES concept. Unless an alternative is developed, FES based hierarchies stand alone.

Box A1: Benefit relevant indicators versus ES-CS

“BRIs are measures that capture the connection between ecological change and social outcome by considering what is valued by people, whether there is a demand for the service, [and] how much is used...” (Olander et al. 2017) BRIs have a structure similar to FES, requiring both ecological [production] and economic [demand] measures based on the causal chains from ecological functions to human use of end-products (Olander et al. 2017).

While comparisons between benefit relevant indicators (BRIs) and FES have been made, (Olander et al. 2017, Olander et al. 2018) no formal, nor extensive comparison has been made between BRIs and ES-CS. A few are offered here.

Principally, the BRIs structure does not provide a hierarchy. As a result, BRIs do not provide the benefits—described below—that ES-CS do. In particular, the ability to help unify the identification and measurement of ecosystem services and improve transfer of ecosystem services knowledge, is largely absent. Because of the similarities between BRIs and FES, practitioners familiar with BRIs should find the use of ES-CS relatively easy.

These four ES-CS also have nested hierarchical levels, elements, codes and name (Table A1). Differences among the ES-CS reflect design choices or biases (Hancock 2013). Regardless of these differences, these ES-CS organize a great deal of information, allow practitioners to traverse the hierarchy, and define an FES by (a) the context in which the ecological end-product is being used—and (b) by identifying elements of the FES within the ES-CS. Each of the elements, in turn, are associated with common names and numeric codes.

Table A1 Generic ES-CS terms used in this paper

Term used in this appendix	Specific ES-CS terms and examples		
	CICES	FEGS-CS <small>(to be retired)</small>	NESCS and NESCS Plus <small>(to be retired) (from FEGS-CS and NESCS)</small>
Hierarchical level* <small>(each has nested sublevels)</small>	Section, Division, Group, Class, Class Type	Environmental Class, Environmental Sub-Class, Beneficiary Class, Beneficiary Sub-Class	Environment, Ecological End-Products, Direct Use/Non-Use, Direct User
Example elements of the FES (element)**	Provisioning, Biomass, Wild Animals, Terrestrial, Nutrition	Terrestrial, Forest, Recreational, Hunting	Forest, Fauna, Hunting for Consumption, Households
Code	1.1.6.2	21.0604	21.3.1106.2
Example of the FES the system names	Food from wild animals	Recreational forest hunting	Animals in forests, hunting for household consumption
*A hierarchical level is a “holon”—each level is a whole for the level below and a part for the level above. This means that each holon level defines the boundaries of the level below. Users of ES-CS can move among higher and lower hierarchical levels confident that each			

level is properly nested and therefore (1) mutually exclusive from the other hierarchical levels and (2) consistent within that level. For example, the CICES's Division "Biomass" will only contain plants and animals, and not soils or habitats.¹⁷

**Practitioners employ the hierarchy of an ES-CS to identify the FES of interest. Traversing the span of the hierarchy as one would go through a checklist helps prompt the practitioner not to overlook potential FES of interest. CICES intends a narrowing from the general to the specific (within Provisioning, Regulating and Maintenance, and Cultural), whereas the FEGS-CS, NESCS and NESCS Plus require the selection of elements that must be matched together to meet their identification criteria for an FES.

UNSD SEEA workshops are ongoing to select or develop an ES-CS useful over the long term for ecosystem accounting purposes. Parallel discussions on the relative merits among ES-CS have been taking place in the literature and at A Community on Ecosystem Services (ACES), (Finisdore et al. 2016, Rhodes, Landers, Haines-Young, et al. 2016) at a High Level Discussion on Ecosystem Accounting, (Partnership Ecosystem Services 2018) at a workshop on natural capital accounting, (Irwin & Schaltegger 2015) the Natural Capital Coalition, (NCC 2016) and at other forums. Finally, as is described in detail later in this paper, practitioners have started drawing from ES-CS principles, specifically using the:

- 1) Structure of ES-CS to label ecosystem services
- 2) Metrics associated with elements in an ES-CS

Applying these principles effectively turns ecosystem services into FES and aligns and creates more explicit and appropriate choice of metrics. These principles are already being used to derive or identify FES and their elements without explicitly using ES-CS (Jiang & Ouyang 2016, Bell et al. 2017, Jiang et al. 2015).

The ad-hoc approach to defining and grouping ES

Despite these efforts to advance the use of ES-CS, many practitioners continue to define ecosystem services differently from study to study. There are examples of practitioners selecting definitions from among groupings and classification systems and even customizing the definitions for individual studies (McDonough et al. 2017). Within this disorder, the MA four types appears to be the most frequently used definition, grouping, or classification of ES (Haines-Young & Potschin 2018).

Hesitance within the field to adopt ES-CS (i.e., CICES, FEGS-CS, NESCS, NESCS Plus) may have a few causes. ecosystem services practitioners may:

1. Anticipate little impact from not adopting an ES-CS on the ability to receive funding, publish research, or engage in policy discussions due to low demand for ES-CS based research.
2. Perceive few benefits to any specific project, as practitioners appear to believe they fully understand FES or have grown accustomed to ambiguous definitions of ecosystem services and their measures (e.g., indicators, indices). As a result, a study's scope can influence the measures selected. (Czúcz et al. 2018) While there is an argument—mirrored in other

¹⁷ Figures 1, 2, and 3, present different ES-CS hierarchical structures. CICES used the MA four types as its starting point for developing the hierarchies. FEGS-CS, NESCS and NESCS Plus used descriptions of FES flows—from the environment to the beneficiary—as the basis of its holons. In NESCS and NESCS Plus, there are four parallel holons. The first holon is Environment and the top level of that hierarchy could be labeled A1, Ecological End-Product may be labelled B1, through to Direct Users, D1. The second hierarchical level within Environment is Classes that could be labelled A2 and after that Forests A3, etc. In the FEGS-CS, using this same rule for parallel and nesting holons, the four listed hierarchical levels might be called A1, A2, B1 and B2. In the CICES, each listed hierarchical level is a nesting for the next, so A1, A2...A5.

fields—that with enough data and computing power, inferences can be made about the data, many view ecosystem services as being more illustrative than empirical. This is especially true with ecosystem services research focused on ecosystem functions. (Czúcz et al. 2018)

3. Read standards and guidance documents (e.g., IFC Performance Standard, Natural Capital Protocol) as not endorsing ES-CS and providing little guidance on the level or rigor, leaving practitioners to use the MA four types and treating an ecosystem services assessment as an insignificant requirement
4. Be unaware how best to integrate and scale ecological, social, and economic data and measure ES, (Preston & Raudsepp-Hearne 2017) both of which are enabled by ES-CS as is described below
5. Have, through staff training, tools and systems development, case studies, and marketing materials passively adopted MA or TEEB groupings
6. Seek to deliver data and analysis that is readily recognized by local stakeholders alone, rather than also aligning these with an ES-CS
7. Find value in understanding ecosystem services as “boundary objects” where flexible definitions of ecosystem services are valuable (Steger et al. 2018)
8. Not understand the advantages of “full spectrum” ecosystem services classification that accommodates all FES
9. Experience fatigue from engaging in similar efforts to standardize terms, systems, and procedures such as satellite data, metrics, and monitoring and evaluation procedures; for which funding is often limited and which are generally more successful in smaller fields with less diversity of disciplines (Villa et al. 2017)
10. Perceive the costs of implementation to be high, including:
 - a. Updating research, tools, and techniques to be consistent with a ES-CS
 - b. Traversing the learning curve, especially if there is no assisted or automated means for application such as an online ES-CS selection tool or pre-tagged data sets
 - c. Learning how to numerically code or tag ecosystem services with the ES-CS and principles (Wilkinson et al. 2016) of data stewardship
 - d. Sorting through any inconsistent application of ES-CS to date by other practitioners and possibly absorbing the costs of transition without clarity on the field’s direction (Hlava 2018)
11. Have concerns—however valid—about ES-CS and how they function in practice

As a result, few are using ES-CS, leaving the field to an “ad-hoc approach” to defining, grouping, or classifying ES. This includes new research, but also meta-analyses and interregional assessments that often seek to unify knowledge among studies. Many tools, databases, publications, and guidance documents mention ES-CS, but have been reticent to endorse them (see the NCC 2016, United States Environmental Protection Agency n.d.). Practitioners define and group ecosystem services differently, sometimes even if they are working for the same institution (Bolt et al. 2016). Other practitioners choose definitions of ecosystem services from different groupings or classifications systems and even change their definitions. (McDonough et al. 2017) Moreover, some research actually measures things other than what the authors purport to study (Czúcz et al. 2018).

This ad-hoc approach has merit. ecosystem services provide multiple values to multiple beneficiaries (Maze et al. 2016) that are integrated into decision making in different ways (Costanza et al. 2017). Depending on the decision making context, consideration of either the qualitative or quantitative

ecosystem services values may be appropriate (Pascual et al. 2017). Over time, the ad-hoc approach could help change social norms and eventually lead to changes in practices (Houdet 2017)—ecosystem functions may become an ever larger factor in decision making,¹⁸ even without ES-CS. There has already been some movement in this direction (Costanza et al. 2017).

This said, there are increasing calls among practitioners for ES-CS. Many have concluded that improved definitions and terms are required for the success of ecosystem services approaches (Guerry et al. 2015, Wong et al. 2015, Neale et al. 2018, Crossman et al. 2013, Seppelt et al. 2012). Indeed, practitioners have been using international standards for years. The ISO 14007 standards provide guidance for “determining environmental costs and benefits”, while 14008 defines acceptable practice for “monetary valuation.”¹⁹ Further, investments by the European Environment Agency, US EPA, Chinese Academy of Sciences, China’s Ministry of Ecology and the Environment (previously known as the Ministry of Environmental Protection²⁰), UNSD SEEA, and leaders in natural capital accounting are generating ES-CS and FES based tools and applications which speaks to the importance practitioners places on ES-CS. These tools and applications include using ES-CS:

- To support implementation of the EU Biodiversity Strategy to 2020 (via the EU MAES and INCA projects) (Maes et al. 2014)
- In structuring the US EPA’s EcoServices Model Library so that it provides analysis of FES not just ecosystem services (United States Environmental Protection Agency n.d.)
- To develop at least 4 customized versions of CICES for specific studies (Czúcz et al. 2018) that help reduce the total number of FES and use locally appropriate terms
- To help define beneficiaries for US EPA’s Superfund program (United States Environmental Protection Agency 2017)
- To guide structural components of the ESMERALDA database (Union n.d.)

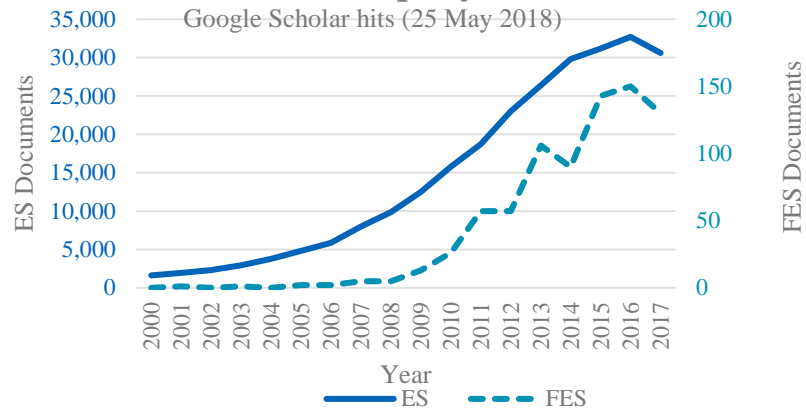
Finally, research is increasingly referencing “final ecosystem services” relative to “ecosystem services” since FES were first described in 2007 (Boyd & Banzhaf 2007b) (Chart A1).

¹⁸ The extent of ecosystem services integration into decision making can be measured by (1) comparing the frequency that monetary values are used in healthcare policy versus environmental policy debates and (2) the degree to which ecosystem services are included in impact assessments, life cycle assessments, corporate valuations, among other environmental approaches, tools, and orthodox techniques of environmental science.

¹⁹ These standards do not focus on ecosystem services frameworks and definitions but seek to align the ecosystem services applications and techniques with other ISO standards.

²⁰ The Chinese government is the world’s largest investor in ecosystem services and is developing a FES based national accounting system, the Gross Ecosystem Product (GEP), as well as other more targeted accounting systems (e.g., for its National Key Ecological Function Zones).

Chart A1: ecosystem services and FES documents per year



Most importantly, detailed below, experience with CS in other fields suggests that adoption of ES-CS will be successful and speed the incorporation of ecosystem services in decision making, making ecological functions a greater part of decision making.

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