Marine Policy 155 (2023) 105761

Contents lists available at ScienceDirect

Marine Policy

journal homepage: www.elsevier.com/locate/marpol

Full length article

Valuing ecosystem services in complex coastal settings: An extended ecosystem accounting framework for improved decision-making

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ARTICLE INFO

Keywords:
System of Environmental Economic Accounting - Ecosystem Accounting (SEEA-EA)
Natural capital
Total economic value
Perspectives of First Nations Peoples
Environmental management
Marine planning

ABSTRACT

What gets measured gets managed is an axiom common to the business world that also applies to the management of environmental assets and processes. But what is the most adequate way to measure ecosystem value to optimise ecosystem management? In this paper, we unpack three valuation frameworks often applied in understanding ecosystem services and their benefits: 1) the Ecosystem Services framework, operationalised by the United Nations System of Environmental Economic Accounting - Ecosystem Accounting (SEEA-EA) framework; 2) value-centric approaches operationalised by the Total Economic Value framework; and 3) First Nations Peoples (FNP) frameworks, which seek to capture values from FNPs' perspective. By assessing the strengths and weaknesses of these value frameworks for managing the World's largest reef ecosystem—the Australian Great Barrier Reef—we construct an extended SEEA-EA valuation framework tailored to complex coastal settings. The significance of our approach is the inclusion of the whole range of benefits from all coastal and marine uses and users and therefore the integration of non-market and FNP values into the more traditional market-based valuation approach. Assessments that jointly consider multiple values originating from these three different frameworks are more likely to produce sustainable management outcomes than more restrictive approaches.

1. Introduction

Coastal populations enjoy a vast spectrum of benefits provided by coastal ecosystems [5,63]. The most obvious one is fishing, with commercial fisheries and aquaculture generating over US$360 billion/year in first sale value [69] and coastal fisheries representing 85% of marine capture fisheries worldwide [34]. Other benefits (provisioning services) include raw materials, filtered water, etc. Regulating services from coastal ecosystems also play essential roles in maintaining human well-being at the local level (e.g. with reefs and coastal wetlands protecting shorelines: [35] as well as at the global level (e.g. through carbon sequestration). Finally, coastal ecosystems also provide many cultural services, including recreation and tourism [9,43], aesthetic and spiritual values, and cultural significance to coastal communities [38,73]. People have been enjoying and caring for coastal resources for thousands of years, with records showing relationships between Australian First

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https://doi.org/10.1016/j.marpol.2023.105761
Received 23 October 2022; Received in revised form 22 June 2023; Accepted 3 July 2023
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Nations Peoples (FNPs) and their traditional lands continuing for more than 60,000 years [14].

Human uses of coastal ecosystems are numerous and diverse, resulting in competing resource allocations. As populations grow and human needs become increasingly diverse and complex, managing natural resources in coastal areas becomes more challenging, particularly in a climate change context [48]. Increased demand for coastal resources is creating a whole range of pressures, and the plurality of users adds further complexity to ensure a fair and sustainable allocation of these resources [96].

Human societies are dynamic and multidimensional, and human activities exhibit intricate feedback loops that cannot be ignored. For example, coastal development, commercial fishing, and maritime transport generate economic value to coastal communities, but the unsustainable management of coastal and marine activities causes widespread disturbance of coastal ecosystems, through increased pollution, oil spills, overfishing, dredging to widen channels, reduced storm surge protection, and habitat destruction that impact on local communities [18,58]. These same communities who derive value from coastal ecosystems also have rights, and are fundamental to mobilising resources for custodianship through management, restoration and stewardship activities [44].

Therefore, coastal resources require judicious management and planning, grounded in a deep understanding of the many uses, benefits and values derived from coastal ecosystems by the full range of human users. Such sustainable coastal resource management implies acknowledging, incorporating and organising the full spectrum of values, including social, ecological, economic and cultural values. Values associated with FNPs may be particularly hard to measure due to their largely intangible and holistic nature, and therefore are less likely to be managed [33,81].

"What gets measured gets managed" is a popular axiom. However, when seeking to manage the natural environment, assessing all uses, users, benefits and values is in practice rarely done for a number of reasons. Firstly, the task of collecting, compiling and using all of the necessary information requires substantial time investment, and the allocated (human and financial) resources are often insufficient for the task. Secondly, timely knowledge exchange between researchers and policy-makers is limited by institutional and cultural differences, inaccessibility of information, limitations in available data, and other barriers resulting in "evidence complacency" [22,67]. Without a sound understanding of the level of use, condition, pressure and users of coastal resources, and changes to these over time, policies and management practices are based on experience, and often on insufficient or outdated information [2,86]. Thirdly, when data are not absent, they are often incomplete, not publicly available, of limited relevance, or not readily available at the right spatial and temporal scale for policy-makers to have a clear picture of the situation and its progression over time. Fourthly, different perspectives and worldviews add further difficulties to measuring the complex relationships between people and the environment, and how information is interpreted and applied differently based on personal knowledge and past experience [74]. These issues can restrict the ability of management to adequately respond to ongoing pressures on natural ecosystems. In addition, the limited amount of available data for coastal and marine areas compared to the amount of data collected in terrestrial ecosystems means that effective management of coastal and marine ecosystems is a greater challenge.

Assuming that these hurdles can be circumvented, and that all necessary data can be collated to construct a sufficiently comprehensive picture of use, a further challenge arises at the valuation stage. Different valuation frameworks can be used to assess and compile all relevant values and identify their beneficiaries in a specific context. Depending on the objective of the assessment, an approach like the Total Economic Value framework [68], which focuses on the different streams of economic values that different users obtain from environmental assets, has often been applied. Another, more recent approach is to conduct the assessment from an ecosystem service perspective. In particular, the ecosystem accounting approach [94] offers several advantages for carrying a detailed assessment of all beneficiaries of ecosystem services within a certain period and at a specific location [56]. These characteristics make ecosystem accounting a suitable approach to set up a continued monitoring program designed to assist environmental management and planning, because they capture the temporal and spatial dimensions of ecosystem services with greater precision. Ecosystem accounting is also specifically designed to provide a consistent system of measurement across time and space that promotes comparability [12].

However, the ecosystem accounting approach also has limitations. First, it was not designed to include the many non-use values derived from environmental assets, nor can it easily integrate values as perceived by marginalised communities, such as FNPs with custodial rights over land and seascapes [65]. Incorporating FNP worldviews within accounts is atypical, and research into how this deficiency could be rectified is still in its infancy. However, initial exploratory studies with land and river based FNP groups are promising [55,57,85]. Second, the approach offers little advice on how to incorporate those items viewed from some cultural perspectives as being immeasurable, either due to having infinite value, or involving culturally taboo values [26]. Third, its reliance on exchange values[8] rather than welfare measures can create further challenges when compiling and aggregating the many values attached to natural resources [83]. There are, however, efforts being made in the literature to bring solutions to these issues [13].

To overcome the shortcomings noted above, we propose a new framework that relies on the principles of ecosystem accounting for identifying all uses, users, benefits and values in a specific context, but borrows elements from other valuation frameworks to circumvent some of the limitations of ecosystem accounting, while also incorporating worldviews from FNPs. Accordingly, this new framework seeks to integrate the insights from different knowledge systems [25,88].

This framework is the result of a thorough review of existing pathways to assess, and value uses, users and benefits obtained from ecosystem services derived from coastal ecosystems. We use the Australian Great Barrier Reef (GBR) as a practical case study. Prompted by Daily and Ruckelshaus [24], this framework aims to take knowledge into action and assist environmental managers and practitioners in monitoring all relevant uses, users and benefits obtained from coastal ecosystems, to make management decisions that are aligned with long-term strategic goals, and with a deeper understanding of the value trade-offs existing across different users groups. The new framework introduced in this paper has been developed in steady consultation and collaboration with local managers from the GBR Marine Park to provide them with information for decision-making that supports coastal management.

Our research objectives are structured as follows:

1. Reviewing and comparing major valuation frameworks of relevance in coastal settings.
2. Identifying the main strengths and weaknesses of each approach.
3. Proposing a new, policy-relevant framework that is fit for ecosystem service valuation and monitoring of uses, users, benefits and values in coastal areas. The framework will jointly account for ecological, economic, social and cultural dimensions, providing a range of complementary information, drawn from different perspectives and

[8] Exchange values are *"the values at which goods, services, labour or assets are in fact exchanged or else could be exchanged for cash"* [92]. That is, the exchange value is the price at which a good or service is exchanged (or would be exchanged if a market existed) multiplied by the quantity exchanged. In contrast, welfare value (or total surplus) is the sum of the consumer and producer surpluses. It is the *"total benefit accruing to consumers and producers from exchanging the quantity of a good at a given price"* (*United Nations* et al.*, 2021*).

worldviews. This information is presented in such a manner that decision-makers can choose the appropriate information they require for any specific purpose, recognising that different purposes require different information.

2. Reviewing relevant value frameworks

Understanding uses and associated benefits of natural resources has typically occurred one of two ways: through an ecosystem services or a value-centric approach. Despite FNPs having a longstanding and deep connection with natural systems, there has been minimal literature attempting to bring FNP values into more conventional valuation studies and even less application of these frameworks. Importantly, this major gap in valuation approaches of not recognising diverse values is gaining increasing recognition [25,70]. In this section we present three major value frameworks from the literature, unpacking their main strengths and weaknesses for application to coastal resource decision-making and showing how weaknesses in one can be “overcome” by strengths of another.

2.1. Ecosystem service frameworks

Multiple frameworks relying on ecosystem services have been proposed in the literature to describe the various channels through which humans benefit from the natural environment. These frameworks conceptualise how humans benefit from goods and services (*flows*) stemming from natural ecosystems (*stocks*). The term “ecosystem service” (ES) was originally coined by Costanza et al. [19]—although associated names and concepts had been around for years [23,27]—and formally defined in the Millennium Ecosystem Assessment [63]. From there on, ES frameworks have evolved as the ES concept itself was being continually refined. This led to the emergence of classifications like The Economics of Ecosystems and Biodiversity (TEEB) [87], the Common International Classification of Ecosystem Services (CICES) [46] and Nature’s Contributions to People (NCP) [32] meant to be, each time, more accurate and comprehensive. The NCP represents one of the more recent evolutions, including diverse and context-specific elements such as social, cultural and spiritual dimensions as experienced by various people through their respective perspectives [49].

In parallel, the growing need for overall assessments of natural capital at national levels led to the development of the field of ecosystem accounting with the System of Environmental-Economic Accounting-Ecosystem Accounting (SEEA-EA) [91] providing an internationally accepted standard framework. Standardising procedures for assessing and valuing ecosystem extent, condition and services, such as that provided by SEEA-EA can support the adoption of ecosystem accounting, and the uptake of use of ecosystem accounting information for policy and decision-making [70].

Ecosystem accounts prepared under SEEA-EA are based around five interconnected stock and flow accounts (Fig. 1). The first two of these represent the stock (extent and condition) of ecosystem assets at a particular point in time (the end of the accounting period), measured in biophysical units. The next two account for the flow of ES that have been provided by that stock during the accounting period; firstly, providing information measured in biophysical units on the services supplied by the different ecosystems to the users (typically households, industry, government), and secondly providing information on the value of benefits those users derive from the services they have used, with these benefits measured in monetary units. The final account provides information on the monetary value of the stock of ecosystem assets at the end of the accounting period, representing the net present value of the associated expected future flows of ES emanating from that asset. Accordingly, the SEEA-EA framework differentiates environmental stocks (actual ecosystem assets) from environmental flows (ES provided), explicitly providing spatial and temporal information on the stocks and flows, and on the suppliers and users of the various flows.

The structure and rigour of this approach, including the specific requirements to measure and account for both the stocks of ecosystem assets and the flows of ES, in biophysical and monetary units, underpins many of the strengths identified from the adoption of the SEEA-EA framework for monitoring and evaluating the uses and benefits by which the environment contributes to human well-being. However,

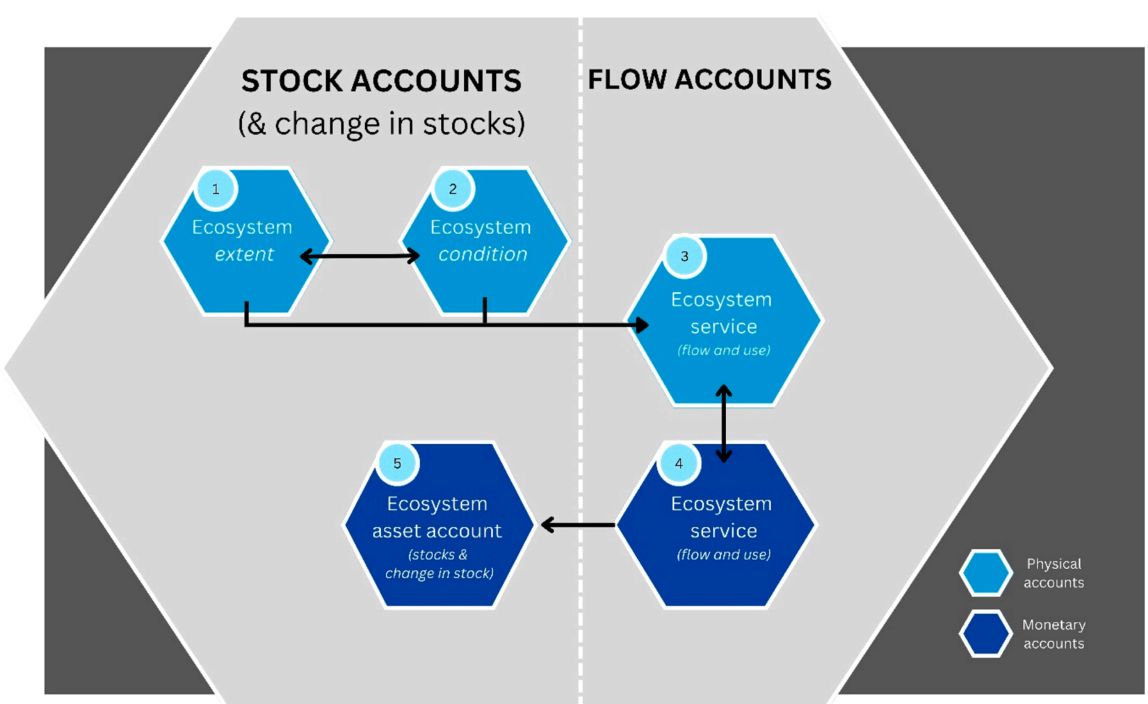


Fig. 1. The SEEA-EA framework to understand uses, users and benefits.
Adapted from UNITED NATIONS et al. (2021) [94].

challenges have also been identified. These are primarily associated with the requirements of the approach itself, such as the use of exchange rather than welfare values, and issues that frequently arise in practice when implementing the approach (e.g. data availability). For instance, the exchange value of commercial fishing in an area can be obtained from total catch volume times fish market prices, facilitating comparison with monetary values recorded in national accounts [94]. However, the well-being (consumer surplus) obtained by recreational fishers from fishing in the area would typically not be accounted for, resulting in part of the well-being generated by ecosystems being overlooked.

2.2. Total Economic Value (TEV) framework

The goods and services obtained from environmental assets have traditionally been assessed in the environmental economics literature through the Total Economic Value (TEV) framework [4,72]. The TEV of a natural resource can be assessed by identifying the various value components that benefit humans. By aggregating the economic values from these different components, one can then estimate the TEV of a natural resource. TEV components are generally divided into categories of use and non-use values. Use values relate to benefits that accrue to individuals using the resource directly or indirectly, through extractive or non-extractive processes [47]. Non-use values can arise through potential future use of the resource (option/quasi-option values), the knowledge that an ecosystem exists (existence value), the benefits that future generations could attain from its existence (bequest value) and the uses and benefits that other individuals or communities may derive from it (altruistic value). Fig. 2 illustrates how TEV components can be classified for a coastal ecosystem like the GBR.

A key strength is its ability to derive a welfare-based monetary value for benefits generated from interactions with environmental assets that do not necessarily result in market-based exchanges [71]. Because of this, the TEV approach can be applied to valuing both stocks and flows of values. In addition, the generation of a monetary value results in a comparable and transferable measure that policy-makers can easily use to make decisions and that enables non-use values to be weighted and considered alongside use values [68]. Finally, due to the TEV methodology, the many components that generate value are made explicit, which is useful in decision-making.

Despite its various strengths, the TEV framework has weaknesses that create limitations for using that approach for the purpose of assessing and monitoring all uses, users, benefits and values and reporting values in a spatially and temporally defined manner. These weaknesses especially relate to the incorporation of FNP values in the TEV, raising questions around how to conceptualise western value systems into the deeply spiritual, and reciprocal cultural connections to land and seascapes, and whether it is even appropriate to monetise such values. Other weaknesses include the usually individual-specific and static nature of values derived in TEV terms, which led scientists to call for more adequate methods to value complex social goods [84].

2.3. First Nations Peoples (FNP) frameworks

FNP worldviews have developed over thousands of years, built upon the evolving relationship between specific groups of peoples and their natural environment. Fundamental differences are frequently found when viewing the human-nature system from the holistic, spiritual, cultural, and nature-centric perspectives of FNPs, compared with that based upon the western science-based worldview [70]. The precise details of the values that define the human-nature relationship will vary according to context (i.e. underpinned by local cultures and knowledge systems). However, many similarities in worldviews between different groups of FNPs are also found. Beyond the benefits provided by the environment to people (often encapsulated by the term ecosystem services but also alternately described, such as in Nature's Contributions to People within the IPBES framework [32]), such worldviews recognise the reciprocal benefits provided by people to the natural environment, through actions of stewardship, ethics, conservation and management (i.e. "peoples' contribution to nature") [16,62]. Such holistic perspectives include viewing peoples and nature as kin, part of an extended family [70,77].

Whilst it can be complex to meld different value-belief systems [36], it is important to recognise FNP values and perspectives within, or at least alongside, frameworks for valuing, monitoring and accounting for the human-nature system. This will limit the risk that these important, but hard to estimate, values are marginalised or excluded altogether

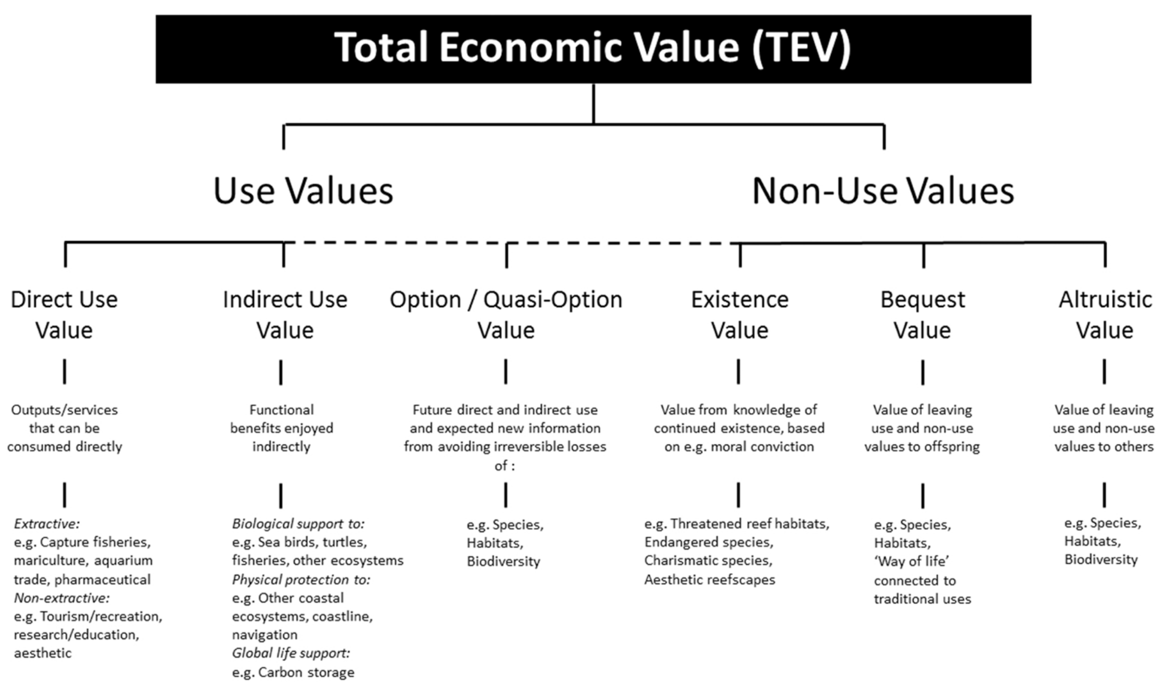


Fig. 2. Total Economic Value framework applied to the Great Barrier Reef [29].

[84]. Recognising such perspectives is also vital to both strengthen the frameworks (and subsequent policy and management decisions) and ensure that a voice is given to those frequently disempowered peoples [59,66].

In Australia, for example, one Indigenous group, the Ewamian People of northern Queensland, represented by the Ewamian Aboriginal Corporation, described how people are seen as an integral part of complex, interconnected ecosystems and consider stewardship of the environment, or "caring for Country", as a reciprocating relationship [85]. Within this holistic, virtuous cycle, Country cares for people, and hence delivers ES, because, and inseparably, people care for Country, with this reciprocal relationship contributing directly and indirectly to the well-being of the people [85].

Recent work with a number of Australian FNPs has explored how their perspectives can be included within ES valuation or ecosystem accounts, including within Western Australia [64,65], Northern Territory [20,55,57], and Queensland [85]. To date, this work within Australia has focused on exploring the perspectives of FNPs within the context of groups whose Country includes land and water in the form of rivers and the connection to Country. Little work has focused on the relationships between groups and sea Country. One notable exception is the work with Traditional Owners of the land and sea Country within the GBR region, where First Nations led work has developed the *Strong peoples – Strong Country* framework to form the basis for monitoring the benefits that contribute to human well-being from the Reef [54].

Taking the work of Stoeckl et al. [85] as an example of FNP framework, the Ewamian Aboriginal framework (Fig. 3) reflects far longer timelines than typically adopted within other frameworks, and illustrates the holistic nature of their connections to Country. The ES benefits (shown in black text within Fig. 3) received from Country were described in terms of the activities that could be enjoyed on Country, the feelings gained from being on and connected to Country, and the cultural connections (similar to spiritual cultural services) to Country. These benefits were considered to be interlinked with, and inseparable from, the activities that they participated in as part of their role as Traditional Custodians of their Country, where stewardship practices were characterised by the terms "caring", "sharing" and "respect", and involved "caring for", "sharing with", and "respecting", both the environment and the people (shown in white text within Fig. 3). These two dimensions of Country caring for people (ES) and people caring for Country (stewardship) were viewed through an important temporal lens: in the past people lived on Country, facilitating both benefit flows (ES and stewardship). However, post-colonisation impacts resulted in many people being forcibly removed from Country and relocated elsewhere, providing barriers to benefit flows. Today, the Ewamian Aboriginal Corporation Board members seek to build a "bridge over troubled waters" to move towards a future where people can again freely access and care for Country, and benefit themselves from the renewed ES flow [85].

It is important to note that while frameworks developed with different FNPs are likely to share some similarities, they are also likely to have important differences as each one is context-specific. For example, the degree of impact of colonisation and post-colonisation history will vary significantly from group to group, as will the importance of different biophysical features such as totem species and significant places.

A (non-exhaustive) summary of the most significant strengths and weaknesses of using the SEEA-EA, TEV and FNP frameworks for the valuation and monitoring of ecosystems, and the uses and benefits of the services they provide, is provided in Supplementary Material Table 1.

3. Extended SEEA-EA framework

3.1. Introducing the framework

While there are many sound frameworks for understanding uses and users of natural resources and their associated benefits, none of these existing frameworks are adequate at presenting all values for all users so as to facilitate an understanding of trade-offs. In this section, we present an extended SEEA-EA framework which seeks to overcome the shortcomings of any one individual framework by combining the three different perspectives on the value of coastal ecosystems to human societies, conveyed through the SEEA-EA, TEV and FNP frameworks (Fig. 4). SEEA-EA does allow and recommend extensions so that alternative measures can be included alongside the main accounts [94], Section E).

We propose a generic series of steps that can be followed to navigate each of these three frameworks and take advantage of their respective strengths. The six steps do not necessarily need to be followed in the same order as discussed here. However, these steps do correspond to six different questions (Where, What, Who, When, How much, and How important) that an analyst should answer. In the next section we introduce a case study to illustrate the application of the extended SEEA-EA framework.

3.2. Case study: the Great Barrier Reef

Located across two thirds of the Queensland coast (Australia), the GBR is one of the world's most unique environmental assets. Covering 344,400 km^2 in area, it is also the largest reef ecosystem in the world (making up approximately 10% of all the world's coral reefs) [41] and a designated UNESCO World Heritage Area (WHA).

The GBR offers the perfect location to test the extended SEEA-EA framework for the valuation of ES and identification of their users in complex coastal settings, as, in addition to its rich biodiversity, the GBR also has substantial economic importance through tourism and recreation [31,75]. The GBR is also of significant social and cultural importance to local communities, including Indigenous, Aboriginal Australian and Torres Strait Islander peoples. There are over 70 FNPs that value the region as their land and sea Country [11,40,50,59,85]. In 2019, the GBR Marine Park Authority and the FNPs established the Traditional Use of Marine Resource Agreements (TUMRAs), a number of community-based plans that respect the traditional uses of the sea country and define specific zones for traditional activities to be undertaken [42].

Managing the different types of uses respectfully and efficiently so that every user, business and activity can thrive and coexist is challenging, especially when it comes to protecting Indigenous and cultural heritage from the increasing pressures from all other activities taking place in modern society. Furthermore, these pressures come in different ways that are not yet fully understood. For instance, the GBR is under certain threats of global magnitude, such as climate change induced ocean warming, ocean acidification and increased occurrence of extreme weather events [39]. Locally occurring activities within the waters of the GBR lagoon and on the adjacent land within the GBR catchment region contribute to cumulative environment impacts. For instance, water quality degradation from agricultural pollution, combined with coral-eating crown-of-thorns starfish outbreaks, cyclones and other stressors can result in coral reefs facing escalating pressure over prolonged periods [1,95]. The dynamic nature of these threats creates another layer of complexity.

3.3. Applying the framework to the GBR case studies

3.3.1. Where is the area of focus?

The *"Where?"* question defines the spatial extent of the ecosystems under investigation (Fig. 1, step 1). We followed SEEA-EA as our central framework because it provides data in spatial format but note that the TEV and FNP frameworks also require a clear definition of the spatial location of a study. This step is fundamental across all three frameworks because it sets the scope and biophysical limits of the assessment, which will invariably determine the areas covered by each type of ecosystem and the ES quantities that can be obtained. Each site is uniquely defined

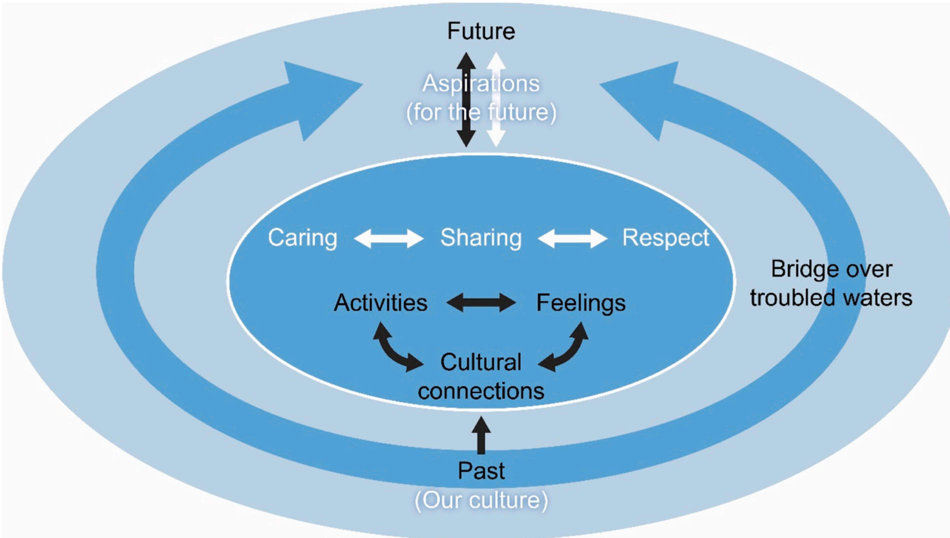


Fig. 3. Aboriginal conceptualisation of the human-nature system based upon the key themes of (a) "connections to Country" – black text; and (b) "what people do for Country" – white text; arrows represent directions of connections between the themes. Six themes in the oval are all closely connected, and placed in a temporal dimension from past, over present, to future where the "bridge over troubled waters" seeks to repair the impact of post-colonisation history and rebuild the flows of benefits between people and Country [85].

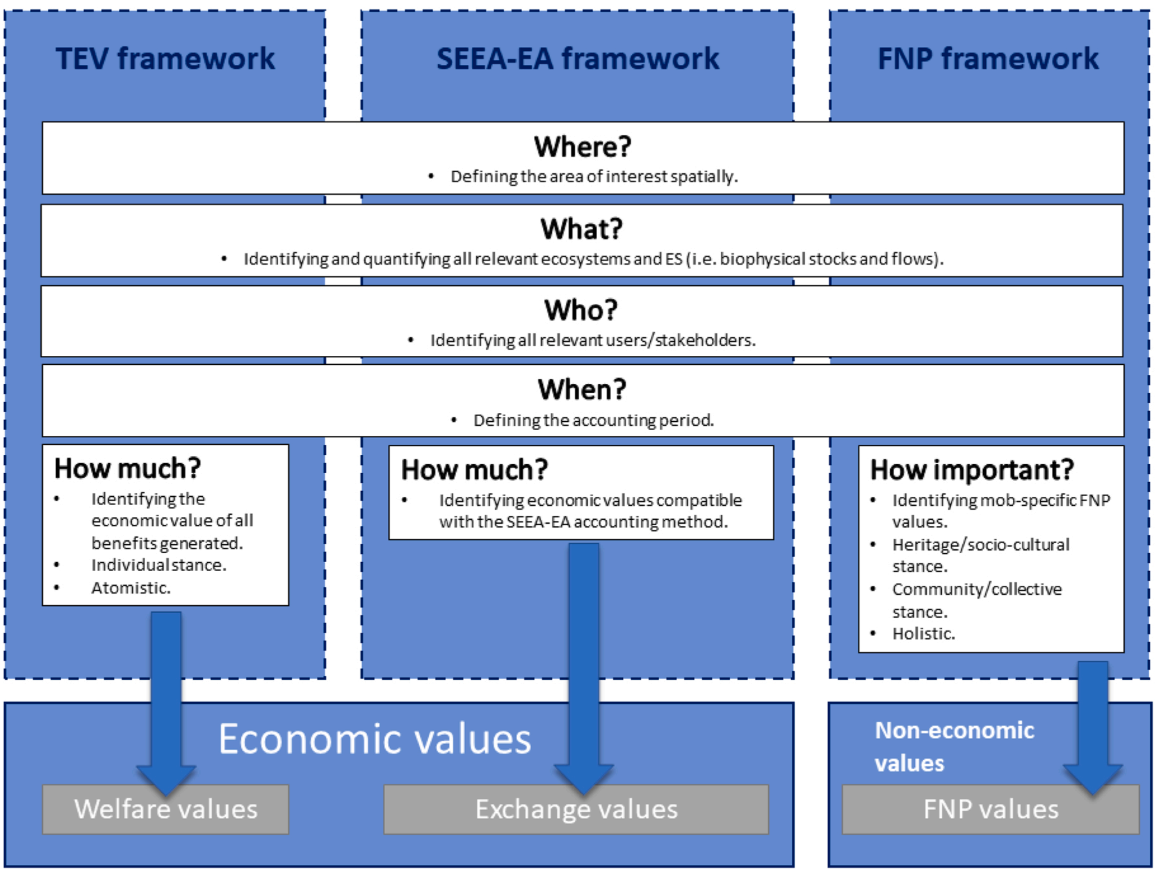


Fig. 4. Stepwise ecosystem accounting process following the extended SEEA-EA methodology.

by its geography, which also determines the likely directions of ES flows [3]. We focus on the GBR (Fig. 5) but more specifically on two particular areas within the GBR Marine Park: the Cairns Area Plan of Management (POM) (yellow area in northern section of Fig. 5) and the Keppels Capricorn Bunkers section of the GBR (yellow area in the southern section of Fig. 5). These areas were selected in discussion with the GBR management authority and because of the significance of the ecosystems and ES generated in these areas, the potential for conflicting uses and the resulting need for more informed management.

3.3.2. *What is being measured?*

Understanding what is being measured is also a consistent reference across all three frameworks consulted to develop the extended SEEA-EA approach. Three key pieces of information to answer the *"What?"* question are: 1) what are the key ecosystems that exist in the area of focus; 2) how far do they extend; and 3) what is their current condition. Once again, whilst it can be argued that the TEV and FNP approaches also require defining what is being measured, the SEEA-EA framework is chosen as the central framework here. The main reason for this is that

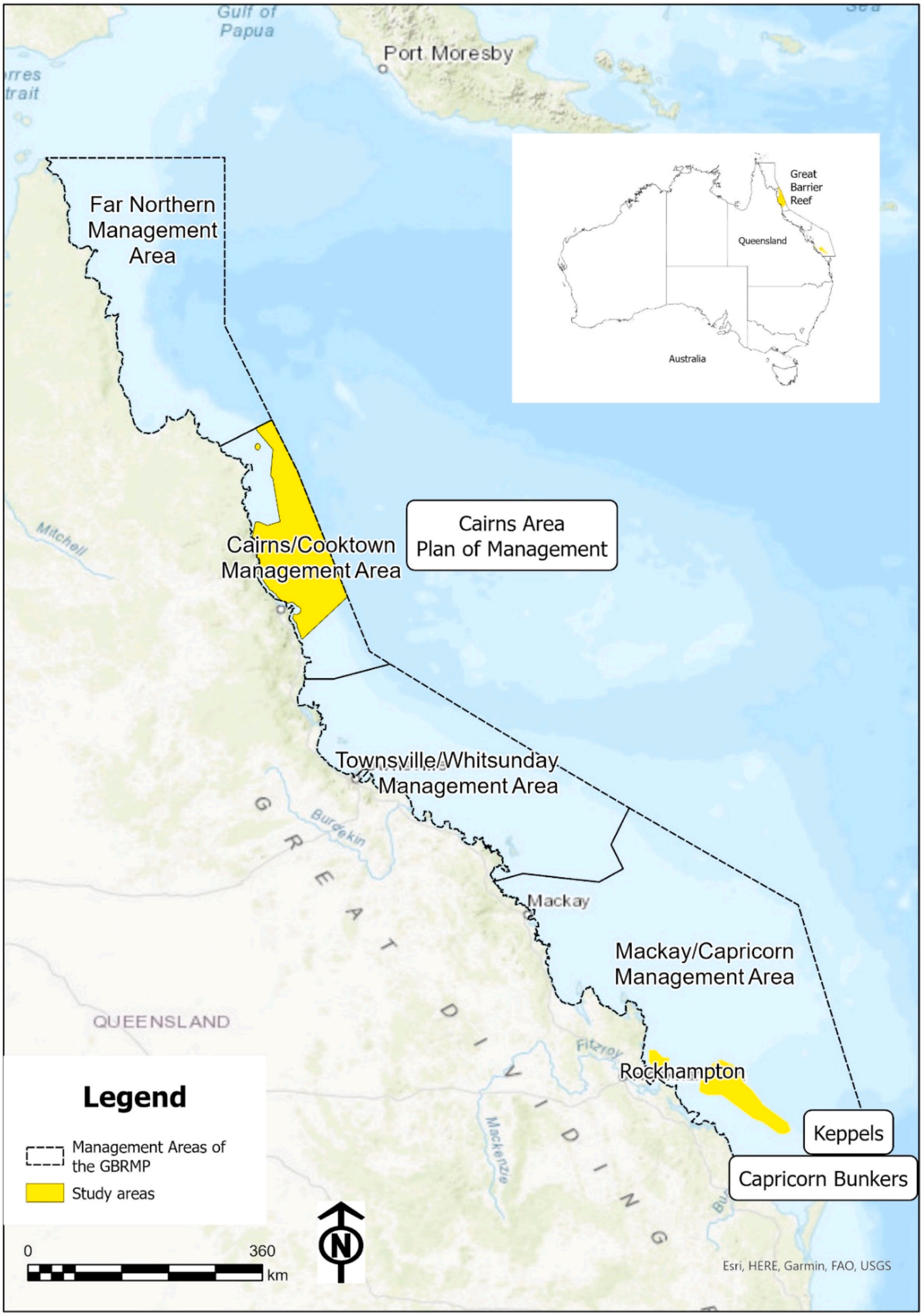


Fig. 5. Map of the two study areas, Cairns Area Plan of Management and the Keppels Capricorn Bunkers, both located in the Great Barrier Reef Marine Park (GBRMP).

the SEEA-EA framework explores the extent of an ecosystem and its condition at the point in time of analysis and through time (see Fig. 1, step 2).

The summary figure in Graphical Abstract illustrates questions one and two for the two GBR case studies. It shows the ecosystems present in the two areas, along with the ES that flow from these ecosystems categorised as provisioning, regulating and cultural services. The selection of the ecosystems for the two case study areas was based on continued consultation with GBR managers and the 2019 Outlook Report produced by the Great Barrier Reef Marine Park Authority [39]. This report classifies the GBR Marine Park into 14 main ecosystems, ten of which are present in the two study areas. These are i. coral reefs, ii. shoals, iii. mangroves, iv. lagoon floors, v. water column, vi. islands, vii. seagrass, viii. coastlines, ix. *Halimeda* (calcareous green macroalgae) banks and x. continental slope. Priority services flowing from these ecosystems were refined for the study areas through consultation with GBRMPA and with reference to the most up-to-date CICES classification [46].

In addition to understanding what ecosystems are present, to complete the stock account component of the SEEA-EA framework (Fig. 1, steps 1–2), an understanding of the condition of these ecosystems is also required. Ecosystem condition can be measured in an intrinsic way using biotic and abiotic compositional (seagrass meadow species), structural (leaf length), physical (light) and chemical (acidity) indicators [51]. The IDEEA Group [51] suggest this approach as it relates to ecosystem function and integrity, independent of what the ecosystem can provide to humanity. In the GBR Marine Park, there are many (but not centralised) sources of information to assist in answering the question of extent and condition[9]. A proper application of the SEEA-EA framework would also require the measuring and reporting of extent and condition of ecosystems on a semi-regular (say, annual) basis to monitor change over time.

3.3.3. Who are the users of the ES flow?

As ES benefit different groups of individuals through society, the next essential question is *"Who?"* i.e. identifying the users and/or beneficiaries of ES, which are also referred to as "economic units" in SEEA-EA [94]. Turkelboom et al. [90] argue that identifying which stakeholders (i.e. any group of individuals effectively or potentially affected by ES) are involved in ES trade-offs is an essential part of environmental decision-making. They identify three groups of stakeholders:

i. *"influential users"*—stakeholders with some influence over decisions made about ES trade-offs and directly facing associate impacts (e.g. farmers, fishers)
ii. *"non-influential users"*—they face the impacts of ES trade-offs but often have little to no influence on decision-making (e.g. tourists, recreationists)
iii. *"context-setters"*—the decision-makers who usually do not directly face the impacts of ES trade-offs (e.g. spatial planners, Governments, International bodies)

The authors observe that influential users and context-setters are generally at the core of the trade-off decision-making, but most impacts tend to be felt by non-influential users. We note that the TEV and SEEA-EA frameworks typically recognise three main categories of ES beneficiaries: enterprises (industry), households (this tends to be a focus for TEV approaches), and Government [93], p.53), that align with the three stakeholder groups above. However, by bringing in FNP approaches to understand values in the GBR case, the *"Who?"* question in our extended SEEA-EA approach for the GBR expands to include households, industry, governments (state and federal) and FNPs. Hence, the selection of relevant users here is made in reference to conceptual elements borrowed from all three frameworks but structured in a way that fits SEEA-EA (see Fig. 4).

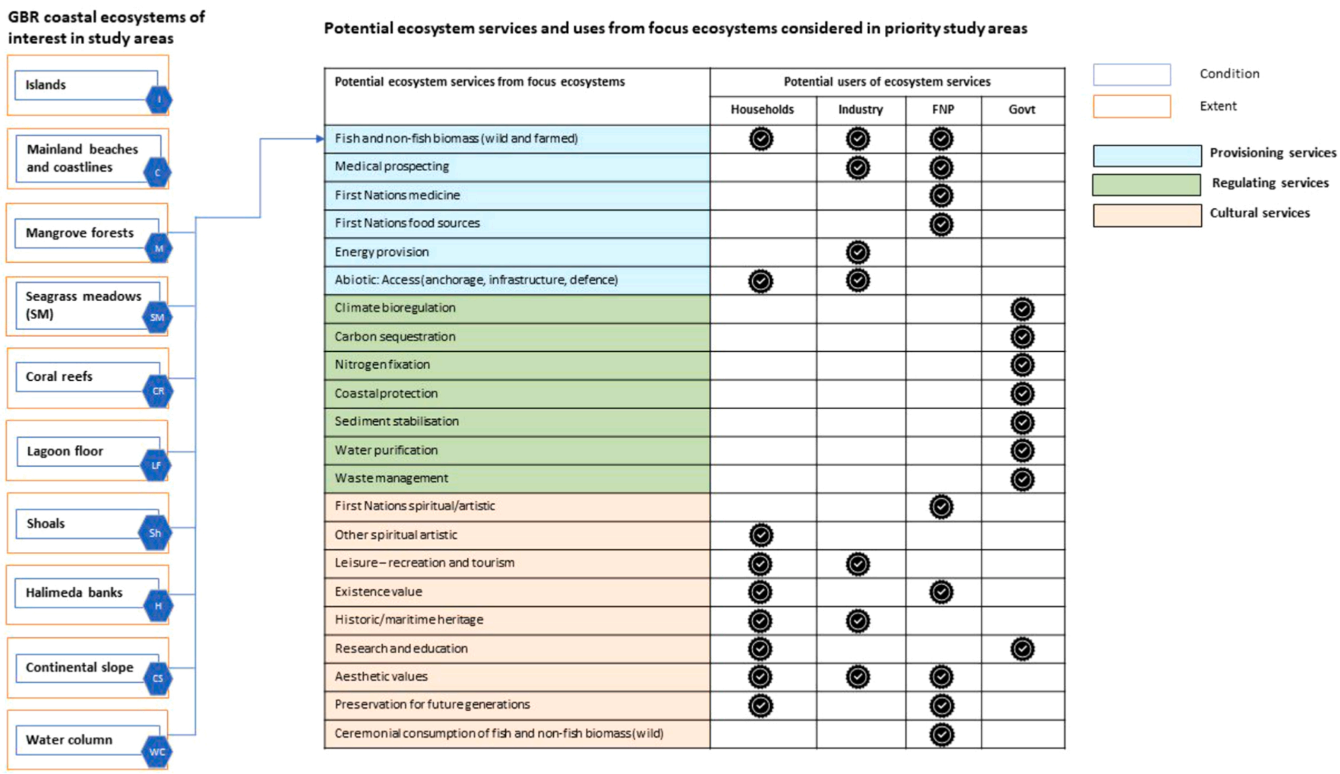
Fig. 6 is a depiction of how the benefits from ES might flow to different users. Fig. 6 highlights that there are often multiple users for a single benefit flow. For example, provisioning services from the Reef flow to households as fish caught during recreation fishing, to FNPs in terms of food and to industry such as commercial fishing. Cultural services provide another example whereby the Reef can provide cultural benefits to multiple users: to households through recreational fishing, on-country cultural benefits to FNPs, and industry benefit due to commercial operation of leisure and recreation activities. Regulating services are most likely to benefit government in the first instance due to the service they provide to biophysical maintenance of the environment. The benefit for government tends to be in the form of cost avoidance (e.g. clean-up cost if coastal stabilisation services are reduced), and also incorporates non-rival and non-exclusive benefits that flow to society as a whole, such as carbon sequestration.

3.3.4. When should measures be taken?

Another essential question is *"When?"*, i.e. specifying the length of the accounting period [93]. Biophysical processes involved in the functioning of ecosystems can occur at very different speeds, ranging from minutes (e.g. metabolism, predation) to years (e.g. seasons), centuries (e.g. hydrological cycles) and sometimes millennia and beyond (e.g. geomorphology). Therefore, it is important to define the timescale of analysis, ensuring that it is meaningful for the final purpose of the assessment. However, whenever dealing with processes impacting human beings, discount rates can increase rapidly, as most would prefer to enjoy ES benefits immediately rather than at a time in the future (limited concern for intergenerational equity). As such, the choice of the right accounting period is often primarily determined by its importance for human decision-making. The calendar year is a common reference period, but the fiscal year may also be chosen depending on the expected format of the final outcomes. For some purposes, where the costs of accounting preparation may be high and the annual values are likely to change fairly slowly, a multi-year approach may be appropriate, perhaps reporting every 5 years (similar to the Australian Government's 5 yearly State of the Environment reports, the 5 yearly Scientific Consensus Statement Reef Water Quality report, or GBRMPA's 5 yearly Outlook report). Figs. 7 and 8.

For longer-term problem mitigation (e.g. UN Climate Action Plan 2020–2030, Reef 2050 Long-Term Sustainability Plan), these annual or multi-year accounting periods can be embedded into decade- or mid-century timeframes. Repeating the process of assessing ES extent, condition and benefit flows over an established time period enables changes to be observed and management actions implemented and assessed for effectiveness. For the GBR, major events such as coral bleaching, changes in governance structures and economic disruptions (Covid-19 pandemic) were considered when selecting accounting timeframes such that data are collected over a time period which would smooth out major disruptions to uses and values across all users. The SEEA-EA framework enables an assessment for a specific point in time and that can be repeated over time to inform multi-year accounting processes. This has great potential for long-term monitoring purposes as it can highlight changes (for better or worse) over time, compared with more time-static valuation approaches such as TEV which may be more useful in the context of cost-benefit analyses for decision-making. Time-bounding valuation is more challenging with FNP approaches. This is because FNP perspectives often account for values over multigenerational time scales requiring ancestors and future generations to be considered within the analysis, suggesting that any applied discount rates should be very low, and approaching zero. Once again, we use SEEA-EA as our central framework (Fig. 4) but recognise the different time scales that values from other approaches, especially from FNP approaches, may bring to a valuation exercise.

[9] See the most recent State of the Environment Report: https://soe.dcceew.gov.au/ (accessed on 27/04/23).



Potential ecosystem services from focus ecosystems	Potential users of ecosystem services			
	Households	Industry	FNP	Govt
Fish and non-fish biomass (wild and farmed)	✓	✓	✓	
Medical prospecting		✓	✓	
First Nations medicine			✓	
First Nations food sources			✓	
Energy provision		✓		
Abiotic: Access (anchorage, infrastructure, defence)	✓	✓		
Climate bioregulation				✓
Carbon sequestration				✓
Nitrogen fixation				✓
Coastal protection				✓
Sediment stabilisation				✓
Water purification				✓
Waste management				✓
First Nations spiritual/artistic			✓	
Other spiritual artistic	✓			
Leisure – recreation and tourism	✓	✓		
Existence value	✓		✓	
Historic/maritime heritage	✓	✓		
Research and education	✓			✓
Aesthetic values	✓	✓	✓	
Preservation for future generations	✓		✓	
Ceremonial consumption of fish and non-fish biomass (wild)			✓	

Fig. 6. GBR ecosystems (based on the [39] classification), priority ecosystem services (ES) in study areas as resolved with GBRMPA decision-makers, and an illustration of how ecosystems generate ES flowing to potential users (FNP=First Nations Peoples, Govt = Government). Hexagon markings (I, C, M, etc.) represent the abbreviated ecosystems and correspond to the representation of ecosystems applied in Figs. 7 and 8. The 22 ES depicted here align with the CICES classification of ES and are those considered by GBRMPA to be the highest management priority in the two study areas. Arrows indicate that multiple ecosystems will generate a flow of ES (here, fish and non-fish biomass (wild and farmed)). The matching between ES and potential users is illustrative only and included to show that more than one user may benefit from an ES flow. User types are consistent with other SEEA-EA applications (e.g. IDEEA Group [51]).

3.3.5. *How much?*

As a fifth step, the analyst may want to answer the *"How much?"* question, which can be expressed in biophysical units (e.g. kgs of fish) and/or as an actual valuation question seeking to monetise the benefits. Converting biophysical amounts of stocks and flows (Fig. 1, step 3) into monetary terms (Fig. 1, steps 4 and 5) remains a necessary step to communicate about the economic value of ES from coastal systems. Fig. 4 depicts how the "how much" question is answered beginning with insight from the SEEA-EA framework and then extending this by drawing on the TEV framework. The SEEA-EA only partially addresses the question of "how much" because it focusses on the market exchange value of products associated with the service (e.g. fish exchanged in the marketplace). By extending the SEEA-EA framework to the TEV, we seek to understand "how much" value exists in the area beyond that realised in exchange, broadening our approach to include welfare values. For example, bringing in quantification of consumer surplus through TEV-compliant methods like the travel cost method, helps understand what users of an ecosystem benefit flow (say fish) would have been willing to pay for that flow above the actual exchange price (indicating value beyond exchange price). Integrating TEV with SEEA-EA also enables the inclusion of non-use values such as option, existence, bequest and altruistic values [10,89,97]. There are a number of studies that demonstrate the value of GBR use (beyond exchange value) and non-use [75,76].

An example of the implementation of the extended SEEA-EA framework for the identification and measurement of ES values related to fish and non-fish biomass in our case studies is provided in Fig. 7. The ES in question is divided in its composing elements, which are in this case wild-caught fish/non-fish biomass and farmed fish/non-fish biomass. Each hexagon represents an ecosystem present in the study area which contributes to the ES. In the next step, we identify and estimate the benefits associated with each ES element. This involves finding relevant indicators (e.g. total volume of fish caught in a calendar year in the area), searching for adequate and reliable data to measure the ES element quantitatively (e.g. productivity of net fisheries in the area), and including an economic multiplier (e.g. commercial fish value). The estimated benefit can then be converted into a TEV-based welfare economic value estimate (e.g. total producer surplus from commercial fisheries in the area), applying an average profit rate for that industry [7]. That final value estimate can then be linked to the group of users benefitting from it (see Fig. 6). The process can be repeated for all selected ES in a study area.

3.3.6. *How important?*

The proposed extended SEEA-EA framework extends the question of *"How much?"* to also answer the question of *"How important?"*. This is done by bringing in the socio-cultural and spiritual values that are associated with a flow of ES and which are particularly important to FNPs. One could argue that steps one to five already provide all the necessary elements for a full assessment, but this would omit that not all contributions to human well-being can, or should, be expressed in monetary terms. Prior studies have shown that numerous natural areas have collective heritage and socio-cultural values that do not involve any form of transaction [60]. Whilst economic measures can be useful to indicate importance, other approaches such as using subjective, deliberative and information market approaches [45,85] can be used to determine the relative importance of different services or activities; such approaches can be particularly useful when exploring FNP values. For this reason, we propose the integration of values as perceived by FNPs, such as expressed through the *Strong peoples – Strong Country* framework

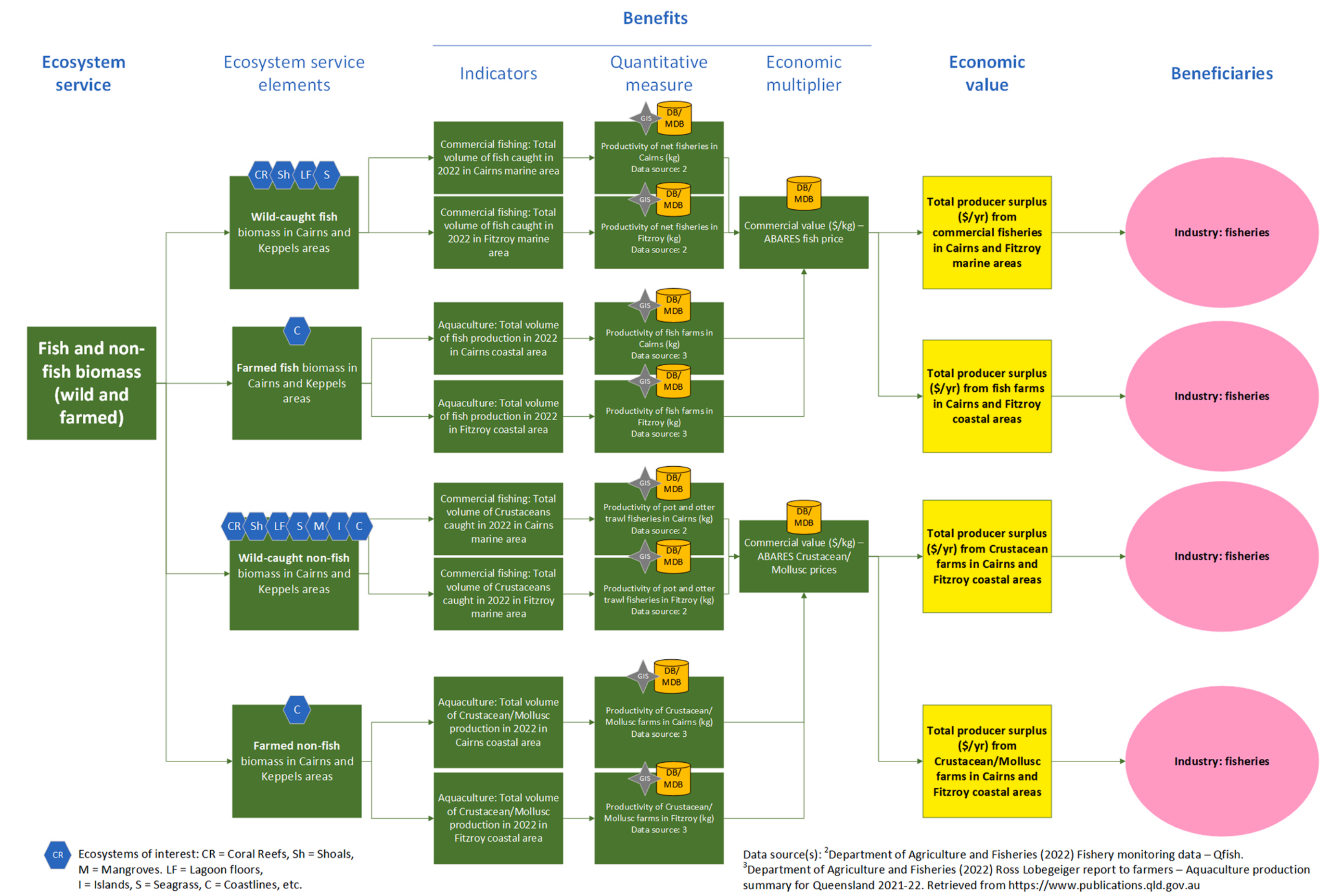


Fig. 7. Example of practical application of the extended SEEA-EA framework to assess the "fish and non-fish biomass" ES and the benefits and values that it generates for the "Industry" user group in the two study areas. ES are converted into indicators so that quantitative measures can be identified and listed in a spatially-explicit (GIS) format. Economic multipliers are also identified and listed in the database to produce the final economic value estimates. This process is repeated for all non-FNP-related ES present in the two study areas.

in the GBR case [54]. That perspective on natural assets largely differs from other members of society in that it tends to be holistic and often (if not exclusively) gives priority to collective values over individual ones. Therefore, we believe that adding FNP value elements is the final piece to provide a comprehensive assessment of uses, users, benefits and values of ecosystem goods and services in a complex coastal environment. For illustration purposes, a practical example of the implementation of the extended SEEA-EA framework for the identification and measurement of an FNP-related ES in our case studies is provided in Fig. 8.

To identify non-monetary benefits, we propose to gather quantitative and/or qualitative information on the importance of these ES (either individually or in combination, recognising the holistic nature of the FNP worldview) to the FNP community and individuals, relative to the other benefit flows from the ecosystem (which only a subset might be assigned an economic value). To determine the "importance", the literature suggests a range of methods to elicit non-monetary values. We apply this approach in Fig. 8, where we consider the cultural (spiritual and artistic) ES and the benefits that flow from these to FNPs. Non-monetary values can be determined by using various deliberative approaches, including: (1) prioritisation or ranking methods; (2) a community's social willingness to commit (actions and resources) to protect or conserve flows of benefits; and (3) cognitive mapping processes to information. Non-monetary values cannot be summed with the monetary values estimated for other benefits, but these non-monetary valuation methods can be used cautiously to compare the relative importance of those benefits that cannot be monetised against those that can. That is, while we cannot and do not try to estimate a monetary value for certain benefits, we may be able to say that this benefit is more "important" than some other economic benefits (e.g. having a job) for FNPs and thus ensure that policy-makers seek to manage what really matters, not just what is easy to measure.

4. Discussion

In this paper, we reviewed three major valuation frameworks of relevance in complex coastal settings: the SEEA-EA, TEV and FNP frameworks. We identified some of their main strengths and weaknesses (see Supplementary Material Table 1) and, following that evaluation, constructed an extended SEEA-EA framework intended to assist decision-makers seeking to identify and monitor the many users and values associated with coastal and marine resources. This extended SEEA-EA framework attempts to combine the three frameworks presented earlier so that we take advantage of their major strengths, while minimising their weaknesses. It proposes a comprehensive, multi-purpose valuation approach, recommended multiple times in the literature [52,53,61] but so far rarely applied in practice, especially in Australia [6,80].

This new framework primarily draws on all three valuation frameworks, but using SEEA-EA as the central framework, to help with the definition of the spatial ("*Where?*") and temporal ("*When?*") boundaries of the case study. The SEEA-EA framework brings added value in the identification and systematic compilation of all relevant ecosystem stocks and flows ("*What?*") by providing a methodology to understand

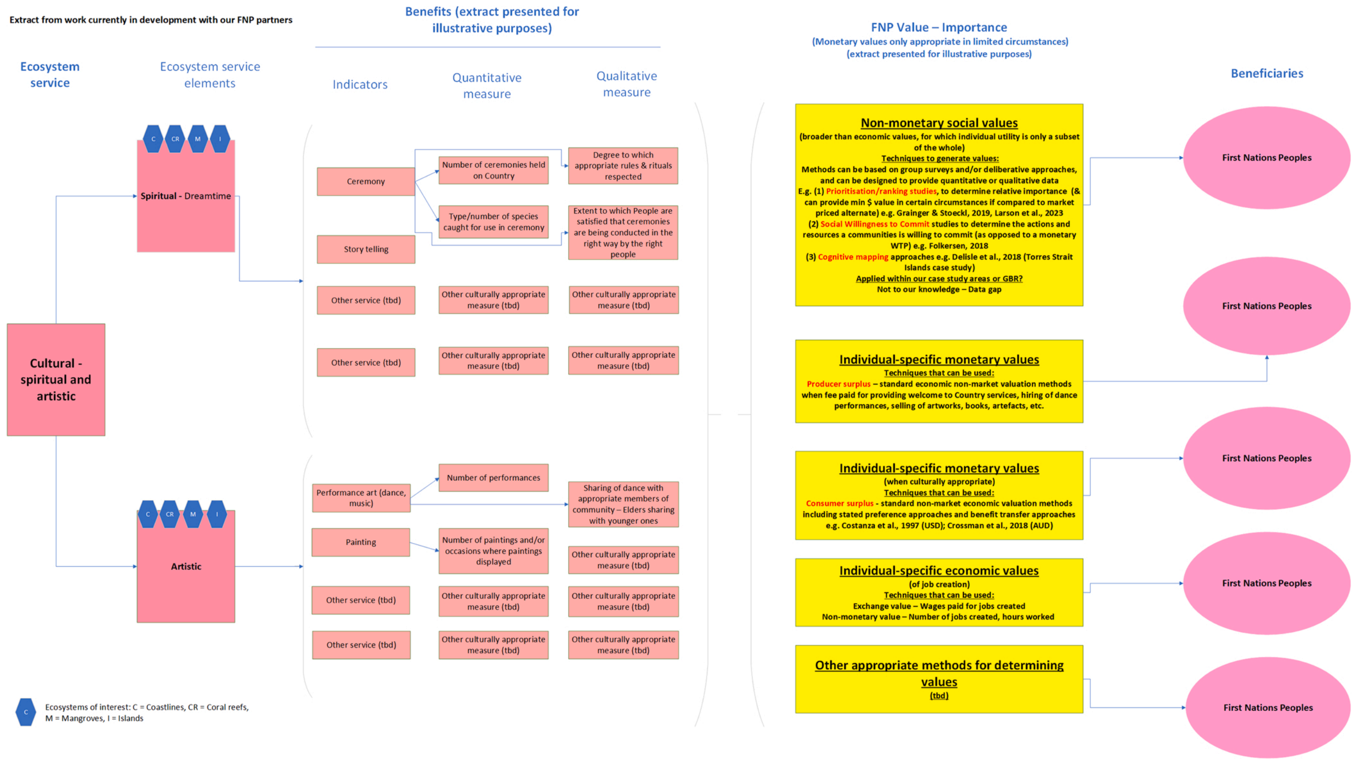


Fig. 8. Example of practical application of the extended SEEA-EA framework for the assessment of the "cultural – spiritual/artistic" ES and the benefits and values that it generates specifically for the "First Nations Peoples" user group in the two study areas. Here, quantitative and qualitative measures are identified and listed in a database. Final value estimates are expressed in non-monetary terms. A similar process is repeated for all FNP-related ES present in the two study areas [21,30,37].

both the extent and the condition of ecosystems, transiting from environmental assets to beneficiaries (*"Who?"*), including FNPs. The TEV framework brings the set of methods to identify and estimate the economic value of use beyond exchange value and non-use value components (*"How much?"*). Finally, the FNP framework adds the FNP perspectives, shedding light on how heritage and socio-cultural aspects are important to different beneficiaries (*"How important?"*). FNP values are treated in parallel to all other values due to their intrinsically different and holistic nature, and because they are guided by the views of FNPs in a specific location (see FNP example in Fig. 8).

When applying the extended SEEA-EA framework to the two GBR case studies, we selected the ten major coastal and marine ecosystems present in these areas. Through deliberation and consultation with local decision-makers, we agreed on selecting the most relevant ES through an adaptive process (Fig. 7). In practice, our rationalisation was based on balancing time and resources needed to retrieve data corresponding to all ES and ecosystems, and their perceived importance in terms of users and value. Engaging with as many groups of local stakeholders as possible will provide clarity on important ES in the study area. Application of this framework in other contexts will require rationalisation based on similar but different factors.

4.1. Limitations

Some limitations of this framework should be acknowledged. First, the integration of FNP values is not yet seamless. Because of their holistic perspectives, viewing people as part of the ecosystem rather than distinct from it [66], it was decided to consider these values aside from all other values. Reconciling FNP values with other values is a complex challenge acknowledged in the literature [79] and further research is required to recognise the benefits that can be generated from the weaving together of different knowledge systems [49,88]. Second, the assumptions made to select the most relevant ES are context-specific and driven by practical reasons, such as data availability and local management priorities. Ideally, a more generic approach should be designed to provide a robust selection methodology. Third, welfare-based marginal values obtained through TEV-reliant methods remain difficult to align with exchange values required by the SEEA-EA methodology [94], but reconciling these values goes beyond the scope of the work presented here. Instead, the extended SEEA-EA aims to create a repository for multiple types of values so that decision-makers have different tools at their disposal to address a multitude of policy questions. Finally, seeking to combine existing data collected for various reasons by different people (likely adopting a range of methods for data collection and value estimates) provides further challenges which must be overcome to ensure the information outputs are reliable and based upon consistent, comparable data and avoiding issues of duplicated or overlapping data and values [83].

4.2. Policy recommendations

A key finding from developing this new framework in consultation with decision-makers is the need to move from individual to collective values as perceived by different groups of users. For example, controlling for heterogeneity among stakeholders while aggregating values [70] is important to get a better understanding of power asymmetries among stakeholders [90], and improve existing policies for managing coastal resources. This observation supports Stoeckl et al. [84] who advocated for using valuation methods that are more adapted to complex social goods (i.e. those that generate benefits accruing to society as a whole) rather than those focussing on simple individual goods. An adequate framework must identify and consider all relevant stakeholders based on their respective levels of influence and sensitivity to coastal resource management policies. First Nations Peoples need to be given particular attention in that respect so that their reciprocal values are considered alongside other values [25,60].

4.3. Future research needs

This framework can help decision-makers identify competing values and interests for coastal resource management, especially in the context of a dynamic, changing climate [15,58]. However, further research is needed that explores how best to combine and integrate values obtained for different users. Changing conditions are likely to gradually alter the dynamics between the different beneficiaries of coastal resources and might tilt the balance of users and related benefits towards a new state that could be sub-optimal (Pareto-wise) for everyone [17]. It is the decision-makers' responsibility to anticipate such power asymmetries, however tools like our extended SEEA-EA framework can inform these decisions by helping resolve potential conflicts between different users of coastal resources in complex settings.

Further work is needed to map all user types against the categories used to make decisions. For example, permits to use the GBR are not granted on a household basis, but rather to specific activities, from individual recreational fishing to large-scale research. Some conversion of categories based on ES is required to support planning and management. Once all necessary data about uses, users, benefits and values are compiled, it is a natural further step to assemble all of these into a comprehensive marine zoning plan that ideally gives equitable weight to the preferences of all affected stakeholders and rights holders [28,78].

5. Conclusions

Some of the most essential ecosystems to human populations worldwide are located within or adjacent to coastal areas and are among the most likely to be impacted by the deleterious effects of climate change, including sea level rise and increased occurrence of extreme weather events. Therefore, it is paramount to better understand the many uses, users, benefits and values associated with these ecosystems. If "what gets measured gets managed", then the collection of spatially and temporally-defined data about ecosystem stocks and flows to human communities is indeed crucial to ensure coastal resources are managed correctly, with a concern for intra- and intergenerational equity [8,82]. In particular, it is important to develop methods that identify and assess the intrinsic (e.g. existence) and relational (e.g. sense of place) values associated with marginalised stakeholders' use of environmental resources so that they can be weighed against more tangible, instrumental values (e.g. fish stocks).

As advocated by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES), there is a crucial need to bridge "knowledge-to-action gaps" to create transformative changes that have a real chance of reversing the current biodiversity crisis and contributing to sustainable development goals. These gaps can be addressed through identifying and compiling context-specific, inclusive, and legitimate values that reflect the diversity of opinions, interests and worldviews of all stakeholders impacted by policies. In complex environmental settings like the GBR, we find that none of the three frameworks we reviewed is completely adequate to understand and measure the diversity of users and values. However, when combined, they offer an effective solution. The extended SEEA-EA framework presented here, together with its application to the GBR case studies, can provide useful guidance for decision-makers managing complex coastal socio-ecological settings.

Declaration of Competing Interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

No data was used for the research described in the article.

Acknowledgements

This study is part of the SEABORNE (Sustainable usE And Benefits fOR mariNE) research project, co-designed by the CSIRO, CQUniversity, and James Cook University, with support from the Great Barrier Reef Marine Park Authority (GBRMPA) and funded by a partnership between the Australian Government's Reef Trust and the Great Barrier Reef Foundation. We are grateful to Gabriela Scheufele (CSIRO), Cindy Huchery (GBRMPA) and Michelle Dyer (GBRMPA) for their help throughout this research and for reviewing earlier versions of this paper. We also want to thank two anonymous referees for their insightful comments. Our thanks also go to Lana Baskerville for her help with producing the beautiful graphical abstract. Finally, we want to express our respect and gratitude to the Traditional Owners of the land on which we have worked and learned through this research, and pay our respects to their Elders, past, present and future.

Appendix A. Supporting information

Supplementary data associated with this article can be found in the online version at doi:10.1016/j.marpol.2023.105761.

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