Comparing biodiversity valuation approaches for the sustainable management of the Great Barrier Reef, Australia

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Abstract

The Great Barrier Reef (GBR) is a World-known, iconic environmental asset whose complex functioning is largely ascribed to its outstanding biodiversity, ranging from genes to plants, animals and entire ecosystems. Biodiversity has been key to its resilience over the past millennia. However, the combined effects of climate change, water quality degradation and coastal development are threatening the GBR's resilience. There is a crucial need to better understand the value of biodiversity in that region to encourage sustainable policy-making.

Different approaches have been suggested in the literature to value biodiversity. First, we review the use of a Total Economic Value framework to look into all dimensions of biodiversity values. Second, we describe an approach relying on ecosystem services. The suitability of these two approaches to value biodiversity in the GBR is assessed. Next, we review 23 finance mechanisms and discuss the possibility to use them to alleviate pressures on ecosystems and biodiversity in the GBR. We conclude by stressing the importance of biodiversity valuation in the GBR, highlight some of the remaining challenges and provide recommendations for future research avenues.

Keywords

Environmental; Non-market valuation; Ecosystem services; Resilience; Natural capital; Biodiversity finance

JEL classification

Q20, Q56, Q57

1 Introduction

Australia is experiencing one of the sharpest biodiversity declines in the world, second only to Indonesia (Waldron et al., 2017). Australian biodiversity faces multiple threats, including for instance: mining (Kujala et al., 2015), agriculture (George et al., 2012), land use change (Seddon et al., 2011), uncontrolled wildfires (Hayward et al., 2016) and, deforestation and habitat fragmentation (Evans, 2016). To minimise risks of future losses, there have been a range of reserve, regulatory, planning and program measures introduced at the national, state and local government levels. However the introduction of further protection measures typically requires justification that measures will be effective, that there is broad public support for increased protection, and that the costs of the new measures do not exceed the benefits generated.

The Great Barrier Reef (GBR) is a major focus of current conservation efforts in Australia, where there are concerns around declining health of reef ecosystems, coral bleaching and water quality degradation (De'ath and Fabricius, 2010). The 2017 Scientific Consensus Statement (Waterhouse et al., 2017) recommended urgent action to maintain and improve the resilience of the coastal and marine ecosystems of the GBR through implementing more intensive management of catchment water quality, active biodiversity and ecosystem protection approaches, and more effective mitigation measures against climate change. There is potential for the pressures on reef health to affect genotypic diversity and gene flows among coral species (Ayre and Hughes, 2004). The current status of biodiversity in the GBR is, however, debatable. Coral cover has diminished in the past few years but biodiversity loss has remained limited, probably because of the systemic resilience of this complex ecosystem (Darling et al., 2017; Hock et al., 2017).

Valuation of conservation benefits is often required to justify additional public regulation and expenditure programs. As early as 2001, Nunes and van den Bergh stated that the monetary valuation of biodiversity was sensible to estimate its impacts on human welfare. However, they also warned that the whole range of benefits to human society generated by biodiversity was still poorly understood and, as such, valuation estimates could only provide an incomplete picture. The Economics of Ecosystems and Biodiversity initiative has provided a global platform to harmonise efforts made to recognise, demonstrate and capture the economic value of ecosystems (TEEB, 2010). A vast amount of studies have applied market-based and non-market based approaches to valuing natural resources and ecosystems (see Laurila-Pant, 2015 for a review). Studies have also advocated for the inclusion of the non-economic values of biodiversity, which could complicate even more its assessment (Bartkowski et al., 2015; Meinard and Grill, 2011).

Few studies have attempted to value biodiversity or ecosystem services (ER) in the GBR (see the review made by De Valck and Rolfe, 2018), although there have been a number of studies which have valued improved protection more generally (e.g. Rolfe and Windle 2011a,b, 2012a,b). Deloitte Access Economics (2017) estimated the GBR to have an asset value of $56 billion, contributing $6.4 billion/yr in value added and over 64,000 jobs to the Australian economy (mostly from tourism, recreation, fishing and scientific industries). Except perhaps for Stoeckl et al. (2011, 2014) who looked into the value of ES for the GBR, no study so far has attempted to value biodiversity specifically in the GBR. Valuing biodiversity is, however, important to ensure the sustainable management of this natural asset. Valuation helps decision-makers develop more informed policies that consider preferences from a large diversity of stakeholders. Valuation is essential to organise governance for an adequate management of the environment at the local, State and national levels. Finally, valuation is also crucial to design finance mechanisms for preserving natural assets in situations where social costs and benefits are not equally distributed.

In this paper, we aim to review some of the main approaches followed in the literature to value biodiversity and identify which ones seem more appropriate in the context of the Great Barrier Reef. Non-market valuation techniques are reviewed and their capacity to accommodate biodiversity into the Total Economic Value (TEV) framework is explored. Based on the results of our study, recommendations are made on what biodiversity finance mechanisms can be applied to address the issue of biodiversity loss in the GBR.

The paper is structured as follows. Section 2 defines biodiversity and reviews the use of non-market and ES valuation techniques for valuing biodiversity. Section 3 combines these different elements to draw a full picture of the value of biodiversity in the GBR and recommends biodiversity finance mechanisms that could fit that context. Section 4 discusses future research avenues and concludes the paper.

2 Different approaches to biodiversity valuation

2.1 Defining Biodiversity

Biodiversity is defined as “the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part” (MEA, 2005). TEEB (2010) complete this definition by adding that “biodiversity reflects the hierarchy of increasing levels of organization and complexity in ecological systems; namely at the level of genes, individuals, populations, species, communities, ecosystems and biomes”. Biodiversity[1] implies communities of living organisms (biocoenoses) interacting with the abiotic environment (biotope). Biodiversity is therefore one of the major driving forces behind functioning ecosystems (Figure 1).

[1] As reminded by Bartkowski et al. (2015), it is important to differentiate this technical definition of biodiversity from the use of this term as a synonym for “nature” – like it is often done in the media.

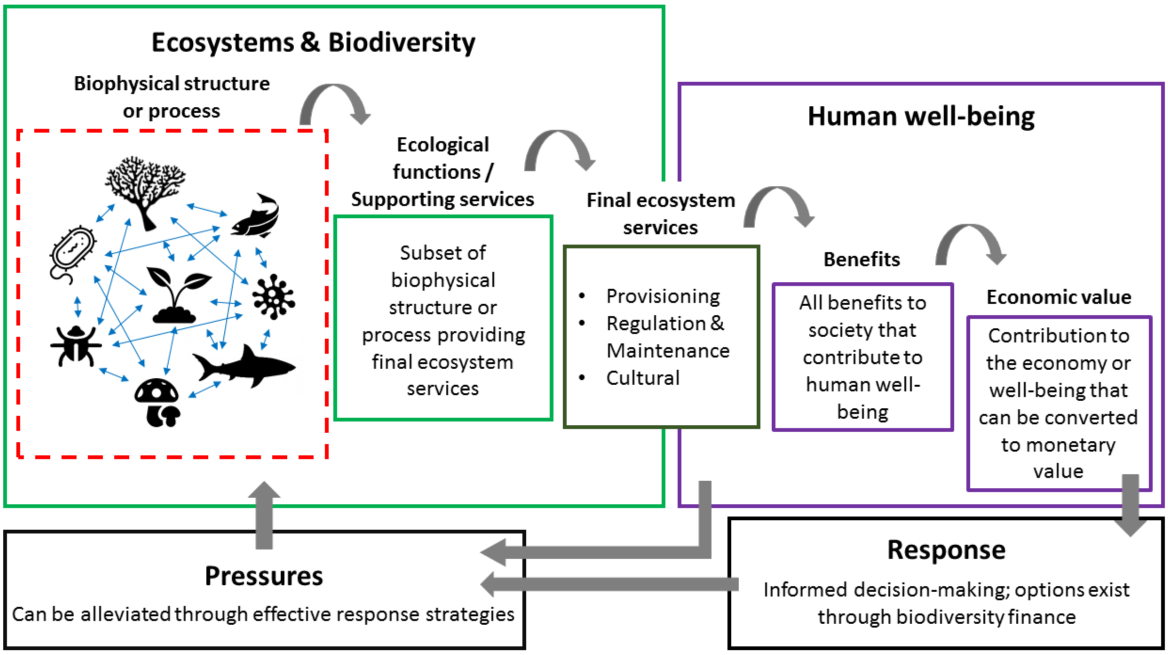

Figure 1. Framework linking biodiversity, ecosystem services and human well-being (Sources: de Groot et al., 2010; Haines-Young and Potschin, 2009, 2018). Note: The depiction of biodiversity is purely theoretical and not intending to provide an accurate representation of the entire biophysical structure or process.

Because of its multidimensionality (e.g. hierarchical levels, evolutionary diversity, species-specific traits), biodiversity is difficult to measure (Farnsworth et al., 2015). So, proxies have been used in the literature to approach it from various angles (Bartkowski et al., 2015; Magurran, 1996; Santini et al., 2017). Since the establishment of the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) in 2012, efforts to produce essential biodiversity variables (EBVs) have been instigated – mostly via the Group on Earth Observations Biodiversity Observation Network (GEO BON) (Scholes et al., 2012). EBVs were developed to form the consensual basis of biodiversity monitoring programs worldwide and help capture the most dominant dimensions of biodiversity change (Turak et al., 2017). Six categories of EBVs are reported by GEO BON (Pereira et al., 2013): i. Genetic composition (e.g. allelic diversity), ii. Species populations (e.g. abundance), iii. Species traits (e.g. phenology), iv. Community composition (e.g. taxonomic diversity), v. Ecosystem function (e.g. net primary productivity) and vi. Ecosystem structure (e.g. habitat structure).

The links between biodiversity and ES have long been debated over the past two decades (Balvanera et al., 2006; Harrison et al., 2014; Ricketts et al., 2016; Schwartz et al., 2000). The MEA (2005, p.25) drew some of these links. First, biodiversity affects key ecosystem processes such as biomass production, nutrient and water cycling, and soil formation, related to the provision of supporting services (Figure 1). Second, biodiversity also impacts final ecosystem services. For instance, biodiversity can enhance the resistance of natural ecosystems to invasive species and is an essential biological control factor against pest, disease, and pollution (regulation and maintenance services). It contributes to maintaining pollinator diversity, which is crucial for the provision of plant-derived ES. It affects carbon sequestration and therefore helps mitigate climate change. Biodiversity also supports –often indirectly– provisioning and cultural services that contribute to human well-being.

Humans impact biodiversity, mostly through population growth and increasing per capita consumption. Pimm et al. (2014) estimated extinction rates for birds, amphibians and mammals about three times higher for the period 1900 to present than prior to 1900. If not addressed, this accelerating rate of biodiversity loss is expected to drastically affect human well-being (Cardinale et al., 2012). Waldron et al. (2017) showed that conservation spending could curb biodiversity loss provided that an increasing amount of money would be allocated to biodiversity conservation, due to the continuing intensification of human development pressures. One challenge of particular importance is to identify how protection and conservation programs can be financed, and how public funds can be augmented with private funds to deliver higher levels of protection. This is particularly relevant to the GBR, where despite evidence that the natural asset generates large commercial values (Deloitte Access Economics, 2017) and ES (De Valck and Rolfe, 2018), most funding to protect the reef is sourced from public expenditure (DEHP, 2016).

2.2 Total Economic Value and non-market valuation

2.2.1 The Total Economic Value framework

The Total Economic Value (TEV) framework is the general standard for approaching the value of environmental goods and services (OECD, 2006; Pearce & Özdemiroglu, 2002). This atomistic approach looks into all value components separately then combines them to obtain the total economic value of the good or service in question. The TEV framework provided in Figure 2 shows an application to coral reefs (Cesar, 2000), where values are firstly categorised into use and non-use values, and then distinguished further into Direct Use, Indirect Use and different components of non-use values. Under this approach, the TEV for the GBR would be the sum of direct extractive uses (e.g. fishing, tourism), direct non-extractive uses (e.g. recreation), indirect uses (e.g. ecosystem services), and non-use values (e.g. existence values).

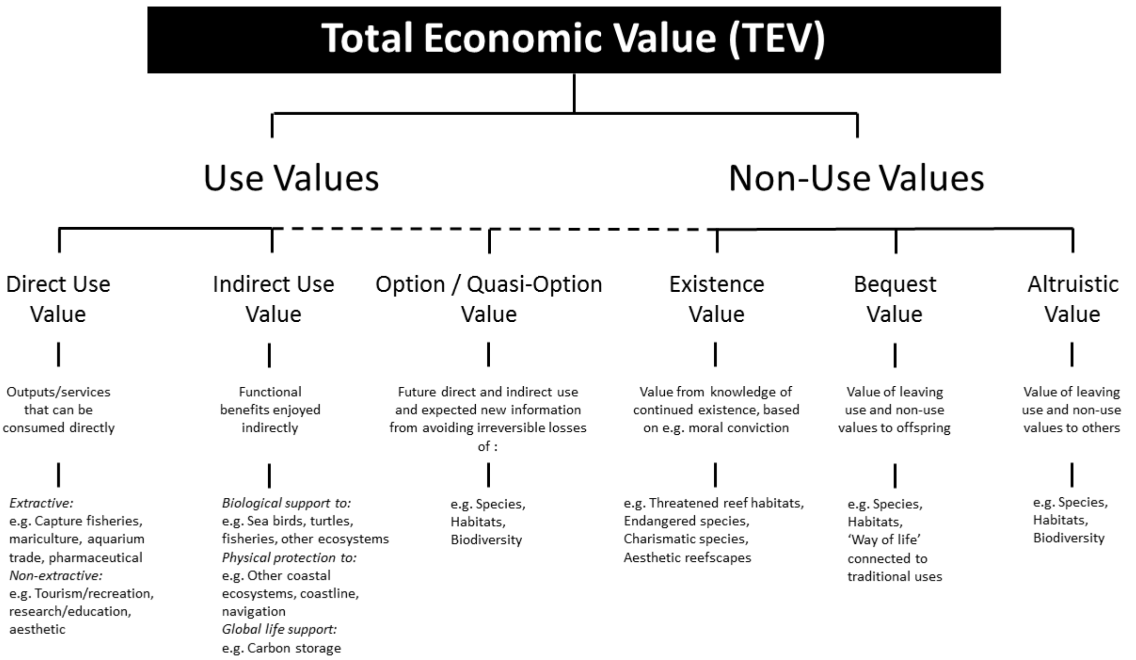

Figure 2. Total Economic Value (TEV) framework relevant to the GBR (Adapted from Cesar, 2000).

Few studies have, however, applied the TEV to value the GBR, although there has been a number of studies that valued specific components, such as fishing (e.g. Prayaga et al., 2010), recreation (Rolfe and Gregg, 2012) and non-use values (Rolfe and Windle, 2012a,b). There have been two applications of this framework to the GBR of particular note. Oxford Economics (2009) summed values for use and non-use components of the GBR, estimating the annual TEV of the GBR to be c. $1.5 billion/yr, while Deloitte Access Economics (2017) used a similar approach to estimate an overall TEV of c. $56B, with significant components being tourism ($29B), existence values ($24B) and recreation ($3B).

2.2.2 Total Economic Value of Biodiversity

However, the TEV framework has been argued by some to be impractical for the study of biodiversity values. Fromm (2000) argued that it needed to be extended to encompass other values related to biodiversity and stemming from ecosystem structures and functions. Aside from production values and individual values, biodiversity ensures the protection of natural capital and consequently human capital and man-made capital, which should also be valued. Admiraal et al. (2013) stressed the inadequacy of a utility-centred TEV framework for the sustainable use of natural capital. Bartkowski (2017) upgraded the TEV framework to accommodate extra dimensions of value that allow a better approximation of the value of biodiversity (Figure 3). He included the spatial (local vs. external values) and temporal (certain vs. uncertain world values) dimensions of value. Bartkowski (2017) emphasised that biodiversity was essentially contributing to the TEV through uncertain-world values, which involve option and insurance values, and through inter-ecosystem value spill-overs.

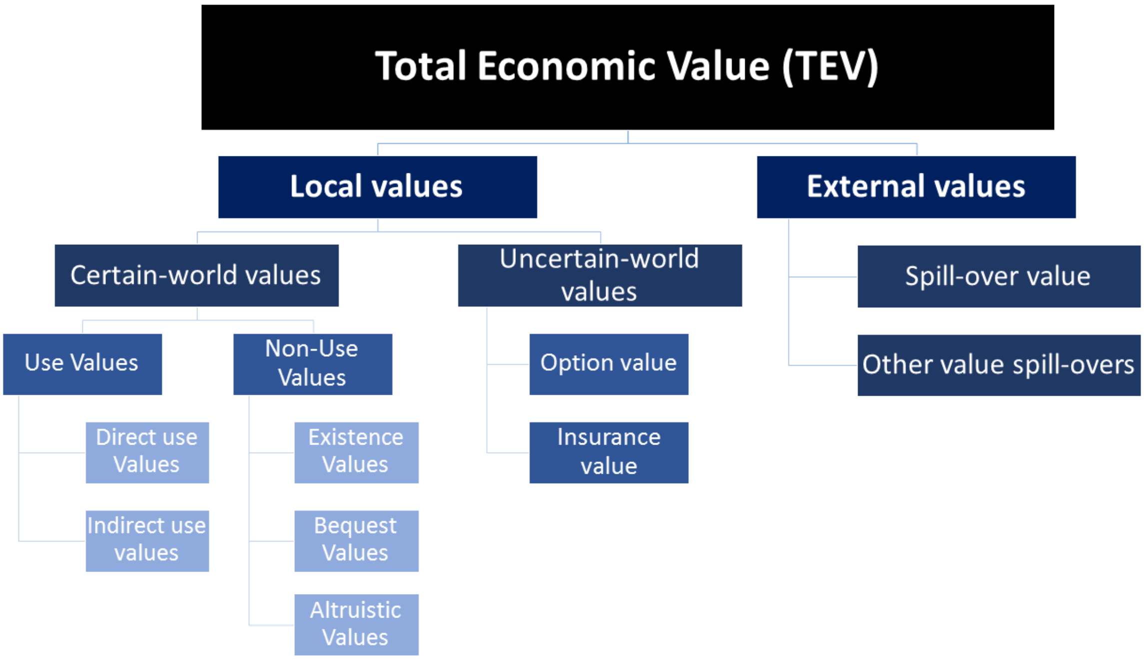

Figure 3. Upgraded Total Economic Value framework, including spatial and temporal dimensions that are needed to approach the value of biodiversity (Bartkowski, 2017).

In Bartkowski's vision (2017), biodiversity holds option and insurance values by acting as a guarantee to meet future needs in an uncertain world (Figure 3). In opposition, biodiversity also holds use and non-use values relating to the present, called "certain-world values". Biodiversity holds insurance value thanks to its contribution to the resilience of ecosystems to exogenous shocks, which increases the chances of a steady supply of ES. In turn, biodiversity also contributes to intergenerational equity, by maintaining ecosystems in a functional state for future generations (i.e. bequest values). The option value of biodiversity relates to its capacity to meet future demand for ES. Option value is inherently subjective as it depends on future preferences for which one can only make predictions.

Next to the temporal dimensions of biodiversity, spatial dimensions should be considered. They relate to the consideration that an ecosystem can contribute to the value of another. Local values refer to the "bundle" of values of a primary ecosystem (here, the GBR), and external values refer to its contribution to the value of secondary ecosystems. External values take the form of spill-over values related or not to biodiversity (Figure 3). Spill-over values differ from existence and altruistic values as they correspond to values physically based elsewhere, rather than preferences from individuals located elsewhere.

2.2.3 Non-market valuation techniques suitable for biodiversity

Three main families of valuation techniques can be applied to approach the TEV of environmental goods and services: i. direct market valuation, ii. revealed preferences, and iii. stated preferences . It is beyond the scope of this paper to review all existing valuation techniques, therefore we refer to Pearce and Özdemiroglu (2002) for a review. Also, not all techniques are adequate to value biodiversity (Nijkamp et al., 2008). Bartkowski (2017) found out that a suitable method should be able to value non-marketed goods and services, handle people's subjectivity, account for uncertainty (option and insurance values) and multidimensionality, and not rely on pre-defined preferences (as biodiversity is not necessarily to be "consumed").

Based on these criteria, Bartkowski concluded that stated preference techniques like the discrete choice experiment (DCE) and deliberative monetary valuation seemed most appropriate to value biodiversity. DCEs can control for the multi-dimensionality of biodiversity and the presence of uncertainty at different levels thanks to their reliance on attributes that can represent each of these elements in various qualitative and quantitative proportions (Barkmann et al., 2008; Eggert and Olsson, 2009; Hoyos, 2010; Johnston et al., 2011). This argument also makes DCEs more adapted to biodiversity valuation than other stated preference methods like contingent valuation.

Deliberative monetary valuation (DMV) combines economic (stated preference valuation) and political (deliberative polling) processes to value environmental resources (Lo and Spash, 2013; Spash, 2007). A small group of individuals representing the pluralism of stakeholders in the target population is gathered to discuss a hypothetical environmental change. Stated willingness-to-pay (WTP) for the proposed environmental change is expressed after discussion, so that each stakeholder can form an informed understanding of the issue at stake. WTP is consequently the result of a collective agreement rather than the expression of individual preferences. DMV is increasingly embraced to value the environment, especially its intangible aspects like cultural services and biodiversity (Bartkowski and Lienhoop, 2018; Lienhoop et al., 2015; Orchard-Webb et al., 2016).

A different approach to valuation is to infer the value of biodiversity or an ecosystem by linking changes in those systems to changes in economic or human systems, rather than explicitly valuing particular services or components. In one example of this approach, Stoeckl et al. (2014) estimated the TEV of the GBR combining different approaches (e.g. life satisfaction framework), generating benefits around $15-20 billion/yr. That TEV estimation relied on community-defined benefits rated on their importance to overall quality of life and compared to market benchmarks. Community-defined benefits rated more important than the benchmark were assumed to hold at least the same value. Therefore such approach can only produce relative values, resulting in rough estimations. Still, it offers a possible alternative to approach the value of biodiversity.

2.3 Ecosystem services

Biodiversity can also be approached using an ES perspective (MEA, 2005; TEEB, 2010). Instead of focussing on the different types of values, the idea is to focus on the different types of ecosystems composing the GBR and estimate the flows of ES stemming from it. The methodology described below is essentially similar to the Experimental Ecosystem Accounting one, developed as part of the System of Environmental Economic Accounting (United Nations, 2014).

A first step is to acquire information about the study area (here the GBR) and each composing ecosystem. The GBR is made of 14 ecosystems (Table 1), covering areas of different sizes and contributing to various extents to its overall biodiversity value. Geospatial Information on land use types (from GIS and remote sensing) is a necessary starting point. It will allow estimating the relative quantity of each type of ecosystem (i.e. stock) at a given point in time for the study area.

Table 1. Fourteen ecosystems composing the Great Barrier Reef (Source: GBRMPA, 2012)

Coastal Ecosystems	Pre-European settlement Total Area (km^2)	Current Total Area (km^2)	Percentage remaining and condition
Coral reefs	Unknown but more extensive than today	2600	Extent of loss of coastal fringing reefs unknown. Around 50% decline in coral cover over the central reefs in the past two decades.
Lagoon floor	20,456	20,456	100% remaining. Affected by poor water quality and fishing (trawling) in some areas.
Islands	Unknown vegetation. Mapping only completed for larger islands	Not calculated, but around 1050 islands of three types	More than 30% national parks. Around 5% of islands extensively modified by developments.
Open water	7200 km^3	7200 km^3	Around 60% of inshore waters regularly exceed Great Barrier Reef Marine Park water quality guidelines
Seagrasses	Unknown but believed to be more extensive than today	5668	Around 1% cleared for port development. Water quality is affecting coastal seagrass communities south of Cooktown, although the extent of loss is unknown.

Coastline	7752 km	7752 km	Around 1% of coastline is directly impacted by reclamations, groynes, jetties etc.
Estuaries (Mangroves and tidal saltmarshes)	4339	3969	91% although some 30% of tidal saltmarshes are affected by bunding.
Freshwater wetlands	1431	1238	87%, with the health and condition varying between individual wetlands.
Forested floodplain	24,597	12,655	51% with grazing occurring within some areas
Heath and shrublands	5351	5026	94% condition unknown
Grass and sedgelands	12,364	5989	48% condition unknown
Forests	239,608	145,380	61% condition unknown
Woodlands	105,123	64,592	61% with grazing occurring within some woodlands
Rainforests	26,886	16,744	62%

A second step is about assessing the level of biodiversity for each composing ecosystem through the construction of a biodiversity richness or intactness indicator (Scholes and Biggs, 2005). This can be a complex endeavour in practice. Biodiversity is in essence multidimensional so a composite indicator must be developed, based on different metrics assessing different aspects of biodiversity. Prior studies have, however, managed to demonstrate substantial differences in biodiversity richness between ecosystems and biomes, using for instance species richness of vegetation types (Behera et al., 2005) or productivity levels of forest ecosystems (Liang et al., 2016).

A third step will imply converting the different levels of biodiversity richness to economic values (in monetary terms) per ecosystem type. Studies like Costanza et al. (1997, 2014) relied on benefit transfer, assuming a constant unit value per hectare of ecosystem type and multiplying that value by the total area of each type to obtain aggregate figures. When values are aggregated (here, at the GBR level), some double-counting may occur and is potentially hard to avoid, because of the feedback loops existing in ecosystems (Fu et al., 2011), which is why careful attention should be paid during the calculation of biodiversity values.

A fourth step will consist of a sensitivity analysis to build a confidence interval around the values produced through this ES-based approach. Different scenarios can be developed that involve various assumptions about the levels of biodiversity richness of each ecosystem. Once values are calculated for each scenario, they can be put together to produce a realistic distribution of values. The development of scenarios should represent possible evolutions of ecosystems based on a range of pressures. Different ecosystems will show various levels of resilience to stress.

3 Biodiversity in the GBR: From valuation to finance

3.1 Biodiversity valuation in the GBR: In practice

Based on the review in Section 2, it appears that different options exist to value biodiversity in the GBR, each of which has validity depending on the purposes and underlying constructs of the assessment. The TEV approach offers an advantage of comprehensiveness to identify and list all dimensions contributing to the overall value of the GBR. By contrast ES valuation approaches offer the means to focus on the most essential drivers underpinning systems, which is essential to generate quantitative measures of ES provision. Other methods, such as the life satisfaction approach (Stoeckl et al., 2014), may be more inclusive and generate larger value estimates, but lack the direct linkages between asset and value or service and value that the TEV and the ES approaches respectively provide.

For situations when the link between ES and biodiversity is hard to establish, biodiversity proxies may be applied. Cultural and regulating services are typical examples where biodiversity proxies may become handy. For instance, indicators such as the presence of apex predators (Atwood and Hammill, 2018) or indicators of ecosystem resilience can be used to draw the link with regulating services (e.g. biological control). Similarly, charismatic megafauna (Hausmann et al., 2017; Huveneers et al., 2017), endangered species (Richardson and Loomis, 2009) and habitats (Hatton MacDonald and Morrison, 2010) can be used to approximate cultural services (e.g. tourism). No proxy is perfect surrogate for biodiversity though, but they may become useful depending on the context (Scholes and Biggs, 2005).

To date, the main issue in the GBR seems to remain the lack of data necessary to undertake a comprehensive assessment of biodiversity values. Also, a lot of biodiversity values are still poorly understood and require further investigation (Figure 3). This lack of understanding of the different dimensions of value may lead to sub-optimal conservation efforts as places needed to achieve one particular aspect of biodiversity conservation may be of little impact to achieve others (Klein et al., 2009). As funding sources are limited, such pragmatic aspects of biodiversity conservation should not be overlooked. This realisation led to the development of conservation planning tools like Marxan (Ball et al., 2009), that can help prioritise biodiversity conservation efforts so that they are spatially-optimised.

Convenience for spatial planning and decision-making of selected biodiversity assessment and valuation approaches should always be a priority. Marxan was developed to meet such purposes and demonstrated positive outcomes for the definition of Marine Protected Areas (Evans et al., 2015; Malcolm et al., 2012). Environmental valuation has been applied to develop innovative finance mechanisms (see Section 3.2) capable of supporting the development of such Marine Protected Areas and therefore represents a crucial part of the biodiversity conservation process (Barr and Mourato, 2009; Castaño-Isaza et al., 2015).

3.2 Finance mechanisms

The Australian and Queensland Governments have developed a number of plans to improve protection of the GBR, together with significant public investment over multiple programs to help achieve targets (DEHP, 2016). As more evidence becomes available about what benefits can be achieved in different programs it has become possible to identify the extent to which existing investments have been cost-effective (Rolfe et al., 2018), and what should be the priorities for further investment (Star et al., 2018). Allied with this has been growing interest in innovative forms of financing, partly to help augment commitments of public funds with private capital[2].

We reviewed the 23 biodiversity finance mechanisms listed by the United Nations Development Program (UNDP, 2017). These mechanisms spanned six categories: i. Grants, ii. Debt and Equity, iii. Risk Management, iv. Fiscal, v. Regulatory, and vi. Market mechanisms. A summary of the relevance of the different mechanisms to the GBR is provided in Table 2 below, followed by a discussion of the most relevant approaches. As the discussion shows, many financing mechanisms are not relevant to the GBR, either because of the specific problem being addressed or the nature of Australia as a developed country.

Table 2. Financing standards for sustainable development (Adapted from UNDP, 2017).

Mechanism	**Description**	**Application to GBR**
Biodiversity Offsets	Measurable conservation outcomes resulting from actions that compensate for significant residual adverse biodiversity impacts arising from development projects	Some offset mechanisms are in place for impacts of major developments[3]
Bio-prospecting	Systematic search for biochemical and genetic information in nature in order to develop commercially-valuable products and applications.	None at present
Carbon Markets	Carbon markets aim to reduce greenhouse gas emissions cost-effectively by setting limits on emissions and enabling the trading of emission units.	Beyond the scope of the GBR
Climate Credit Mechanisms	Market mechanisms that enable entities, for which the cost of reducing emissions is high, to pay low-cost emitters for carbon credits that they can use towards meeting their emission-reduction obligations. An example is the Clean Development Mechanism.	Beyond the scope of the GBR
Crowd-funding	Approach for projects, organizations, entrepreneurs, and startups to raise money for their causes from multiple individual donors or investors.	Beyond the scope of the GBR
Debt for Nature Swaps	Agreement that reduces a developing country's debt stock or service in exchange for a commitment to protect nature.	Not relevant as Australia is a developed country
Disaster Risk Insurance	Disaster risk insurance schemes cover—against a premium—the costs incurred by the insured entity from extreme weather and natural disasters.	Not particularly relevant for biodiversity losses
Ecological Fiscal Transfers	Integrating ecological services means making conservation indices (e.g. size/quality of protected areas) part of the fiscal allocation formula to reward investments in conservation.	Not applied at present

[2] For example the Reef Trust program of the Australian Government explicitly canvasses the potential to access private funds through mechanisms such as green bonds (http://www.environment.gov.au/marine/gbr/reef-trust - Accessed 12/10/2018).
[3] See http://www.environment.gov.au/marine/gbr/reef-trust/offsets

Enterprise Challenge Funds	Funding instrument that distributes grants (or concessional finance) to profit-seeking projects on a competitive basis.	Some application of competitive tenders to improve water quality[4]
Entrance and Activity Fees	Tourists pay entrance and activity fees for access to a protected area. Related-revenues can contribute to biodiversity conservation through retention by specific sites or protected area systems, revenue sharing agreements with communities, and earmarked transfers from the central government or agencies.	An environmental management charge is collected from tourists by the Great Barrier Reef Marine Park Authority[5]
Environmental Trust Funds	Legal entity and investment vehicle to help mobilizing, blending, and overseeing the collection and allocation of financial resources for environmental purposes.	Some NGO's such as Greening Australia are involved in the GBR
Green Bonds	Bonds where proceeds are invested exclusively in projects that generate climate or other environmental benefits.	Not applied at present
Impact Investment	Investments made with the intention to generate a measurable social and environmental impact alongside a financial return.	Not applied at present
Lotteries	Governments and civil society groups use lotteries as a means of raising funds for benevolent purposes such as education, health, preservation of historic sites and nature conservation.	Beyond the scope of the GBR
Payments for Ecosystem Services	Payments for ecosystem services (PES) occur when a beneficiary or user of an ecosystem service makes a direct or indirect payment to the provider of that service.	Not applied at present – most current programs are once-off grant mechanisms
Public Guarantees	Guarantees can mobilise and leverage commercial financing by mitigating and/or protecting risks, notably commercial default or political risks.	Not applied at present
Remittances (Diaspora Financing)	Private unrequited transfers sent from abroad to families and communities in a worker's country of origin.	Not relevant as Australia is a developed country
Social Development Impact Bonds	A public-private partnership that allows private (impact) investors to upfront capital for public projects that deliver social and environmental outcomes in exchange for a financial interest.	Not applied at present
Taxes on Fuel	Fuel taxes can reduce the consumption of fossil fuels and greenhouse gas emissions while generating public revenues.	Not directly relevant to the GBR
Taxes on Pesticides and Chemical Fertilisers	Taxes on certain pesticides and chemical fertilisers can mobilise fiscal revenues while mitigating the negative effects associated with pesticide/fertilisers application and promoting sustainable agriculture practices.	Not applied at present

[4] See http://www.environment.gov.au/marine/gbr/reef-trust/repeated-reverse-auctions
[5] See http://www.gbrmpa.gov.au/zoning-permits-and-plans/environmental-management-charge

Taxes on Renewable Natural Capital	Any fee, charge or tax charged on the extraction and/or use of renewable natural capital (e.g. timber or water).	Not particularly relevant to the GBR
Taxes on Tobacco	Excise taxes on tobacco products can raise fiscal revenues, improve health and well-being, and address market failures.	Not relevant
Voluntary Standards (finance)	Standards applicable to the financial sector that capture good practices and encourage the achievement and monitoring of social and environmental impacts	Not applied at present

Currently most efforts to protect the GBR are provided by government through: (a) regulatory mechanisms, such as zoning the GBR into different use areas, including green zones, (b) governance arrangements, including the establishment of the Great Barrier Reef Marine Park Authority and Natural Resource Management groups in key catchments draining into the GBR, and (c) funds, largely through grant programs to encourage primary producers to reduce pollutants leaving farms and properties. Beher et al. (2016) and Rolfe et al. (2018) have identified that these grant programs are not very efficient, recommending that better ways to prioritise and allocate funding be identified. The use of water quality tenders and other auction mechanisms to allocate public funds are one approach to improving cost effectiveness (Rolfe and Windle, 2011b), as are efforts to prioritise where public funds are best invested (Star et al., 2018).

Some pollution issues affect water quality in the GBR, either from diffuse sources (e.g. agriculture) or point sources (e.g. sewerage treatment plants), while other issues stem from over-use (e.g. tourism in some areas), over-access (e.g. fishing) or threats from climate change. Pollution issues from agriculture have been addressed through a mix of encouragement, extension and grant programs to encourage changes in farming systems. Payments for ecosystem services are a major alternative to grants programs (Engel et al. 2008), but are less appropriate for pollution issues, as that would imply that farmers would have to be paid annually to reduce pollution.

There has been limited use of user pays principles, with tourists to the GBR being charged a daily access fee (Deloitte Access Economics, 2017). However there are no charges on other direct uses such as recreational fishing, or resource rents on commercial fishing. Pollution taxes, such as taxes on chemical fertilisers and pesticides, have not been applied. Other mechanisms, such as offsets and green bonds, are more focussed on attracting private finance. While an offset program is now in place for the GBR, it is still voluntary to some degree, and only appropriate for offsetting losses from further development. A type of green bond scheme termed Reef Credits is being developed, where farmers can be awarded credits for activities that improve water quality, and then sell those credits to government or private industry[6].

[6] See https://greencollar.com.au/reef-credits/

4 Discussion and Conclusions

In this paper, we have demonstrated that biodiversity valuation could be approached from ecosystem services and Total Economic Value perspectives. Due to the complex nature of biodiversity, a number of proxies have been proposed in the literature to approach it. We presented five categories of proxies, looking at biodiversity from various angles. Each of them can become useful depending on the context, even though the literature tends to suggest that a multi-attribute approach is probably more appropriate. This is particularly true for valuation base on discrete choice experiments, where using multiple attributes to represent biodiversity may help reduce respondents' cognitive biases.

Valuation information can help to evaluate options for financing mechanisms. User pay mechanisms rely on identifying groups who are enjoying direct uses of an asset, or who are benefitting from ES. Studies such as Stoeckl et al. (2011), Deloitte Access Economics (2017) and De Valck and Rolfe (2018) help to identify that tourists and recreation users are key groups generating value from the GBR, while Waterhouse et al. (2017) confirm that agriculture is the sector that is having the major impact on water quality entering the GBR. Yet the size of the non-use values for protecting the GBR, as identified by Rolfe and Windle (2012a,b) and Deloitte Access Economics (2017), confirm that protection of the GBR is largely a public good. Given that Australia is a developed country, public funding can only be expected to be allocated from within the country, where the ongoing challenges are to improve the efficiency in the way that it is prioritised and allocated (Star et al. 2018).

Practicality is another important element of biodiversity conservation that should not be overlooked. The bottom line is to influence decision-makers so that biodiversity conservation enters the decision process and is weighted along other potential outcomes of any project. One cannot value what they do not know; and cannot make informed prioritisation decisions if they do not have suitable metrics to gauge the benefits associated with biodiversity conservation scenarios, nor the price to pay to enjoy ES. Biodiversity valuation is therefore the fundamental and necessary step towards developing suitable finance mechanisms and, in turn, effective decision-making.

Remaining challenges come from the fact that the links between biodiversity and ES is still not fully understood. Data is often missing to evaluate those links. Also, the assessment of certain types of ES like for instance cultural services is particularly challenging. Biodiversity itself consists of a range of dimensions that may be difficult to value (Figure 1). To our knowledge, no comprehensive biodiversity valuation that embraces all these dimensions of value has been done so far and there is even doubt on whether this is achievable in practice due to the intangible nature of certain value dimensions. The bequest, existence, option and uncertainty values of biodiversity seem particularly difficult to assess in that regard (Bartkowski, 2017).

Another issue relates to the difficulty to combine all types of value. The TEV framework was designed to draw attention to the fact that humans benefit from the environment in a multitude of ways, not all of them requiring use of the environment. As such, the total economic value of an area is not equal to the simple sum of all types of values. Value overlaps exist and some values may be hard to translate to monetary terms. Therefore, a more appropriate use of the TEV framework is to guide researchers in the selection of appropriate valuation methods for a specific policy context.

ES valuation faces similar issues. For instance, including both supporting and other types of ES in valuation exercises likely leads to double-counting (Fisher and Turner, 2008; Fu et al., 2011). In addition, ES usually come as “joint products” (Costanza et al., 1997), making it difficult to disentangle them to estimate their respective values. While it is not impossible to apply different valuation methods alongside each other, de Groot et al. (2002) recommend to identify the most to least suitable ones to estimate a specific ES. The difficulty to calculate the total economic value through the additive sum of ES values can explain why most valuation studies have only concentrated on a restricted number of ES.

Nevertheless, due to the increasing threats on biodiversity, reality is urging us to promptly develop pragmatic solutions. This realisation has for consequence that there is still room for using biodiversity proxies to simplify the complex nature of biodiversity, even if they may carry the risk of underestimating the value of biodiversity (Bartkowski et al., 2015). The essential biodiversity variables developed by GEO BON may provide guidance to construct such proxies (Pereira et al., 2013). In the GBR, a number of initiatives are being set up to raise awareness about the value of biodiversity (GBRMPA, 2014). ES assessments are also being carried out to raise awareness about their value to society. Surprisingly though, few valuation studies have been done so far to assess the value of the GBR (De Valck and Rolfe, 2018; Deloitte Access Economics, 2017; Stoeckl et al., 2011, 2014).

Further work is needed to identify the components of biodiversity in that region and assess how they benefit local communities through ES provision. Such work may be particularly missing for the terrestrial and coastal ecosystems that are also part of the Great Barrier Reef Marine Park (Table 1). In addition, uncertainty about future levels of human pressure on natural ecosystems and their implication for biodiversity in Australia require us to keep a conservative approach that favours the chances for biodiversity to prosper in the future by taking effective actions to conserve it today (Pepper et al., 2017). Therefore, future studies that look into the different values of biodiversity in the GBR are required because they are the fundamental blocks needed to build finance mechanisms that can ultimately change the fate of the GBR for the better.

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