Ecological Indicators 174 (2025) 113496

Contents lists available at ScienceDirect

Ecological Indicators

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

Valuing the reciprocating services that humans can provide to ecosystems

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ARTICLE INFO

Keywords:
Ecosystem services
Non-market valuation
Nature positive plan
Carbon markets
Biodiversity markets
Environmental economic accounting
Expected value of restoration

ABSTRACT

Long-term sustainability requires that humans consider not only what ecosystems can do for them, but also how humans can 'give back' or reciprocate. Indigenous Australians call this 'caring for country'. Industrial societies have routinely undervalued both the ecosystem services (ES) that nature provides to humans and the reciprocating services (RS) that humans provide to ecosystems. The policy challenge is to find ways of encouraging more RS in industrial societies. The practice of monetarily valuing ES helps highlight their importance and has brought the environment to the forefront of many international policy discussions. We argue that sustainability could be further enhanced by better valuing RS. First, the simple acknowledgement and celebration of RS (without monetary valuation*)* could change institutions, social norms, and behaviours. Second, numerous institutions now provide financial incentives for people to undertake nature-positive projects (a type of RS), but nature-positive investments are hampered by information failures. Comprehensive assessments of the expected value of proposed projects, could fill information gaps and guide investments towards projects that are likely to generate the most benefit. But these are difficult to do well. We discuss some of the particular difficulties of generating meaningful value estimates for RS that generate diverse benefits at large scale, or that create change in highly connected systems. We note the need for more transdisciplinary research to further improve methods; arguing that if we only do what we are currently good at (valuing discrete benefits at small scale and using crude approaches to scale upwards) then we will continue to overlook, undervalue and under resource many of the critically important RS that support us all.

1. Introduction

It has long been recognised that the environment benefits humans in numerous, interrelated ways. However, it was, arguably, the seminal works of Costanza et al. (1997) and Daily (1997), leading to the Millennium Ecosystem Assessment (2005) (MEA), which brought that issue to the forefront of policy. The MEA gathered scientists and policy makers across the globe, formally recognising the importance of the environment to human wellbeing, and institutionalised the term *Ecosystem services (*including provisioning, regulating and maintenance, and cultural services – Haines-Young and Potschin (2012)). The MEA also helped focus global efforts on related environmental issues. Costanza et al.'s 1997 paper, which is in the top ten (global) research papers that policy documents cite most (Chawla, 2024), not only highlighted the global value (and importance) of ecosystem services (ES) but also helped mainstream the practice of monetarily *valuing* ES – see, for example, (Pascual et al., 2010) – which has elevated their importance in policy arenas across the world.

A core hypothesis underpinning this paper is that sustainability requires that humans consider not only what ecosystems can do for them but also what humans can do to 'give back' or reciprocate. It follows that sustainability could be further enhanced by not only regularly valuing ES, but by also regularly valuing *the reciprocating* services (RS) that people provide to ecosystems. This could improve sustainability in two ways. First, by formally recognising the social value of reciprocating services (not necessarily in monetary terms), we raise their social status and may thus encourage more people to engage with and support them. Second, by generating robust estimates of the expected value of different types of RS (of which there are many), we may be able to encourage and help direct resources towards the most effective types of RS, specifically, those that are most likely to repair nature for the benefit of all. We note that substantial bodies of literature highlight the critical importance of

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https://doi.org/10.1016/j.ecolind.2025.113496
Received 9 February 2025; Received in revised form 31 March 2025; Accepted 15 April 2025
Available online 22 April 2025
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actions that help restore and repair nature (see, for example, journals such as *Conservation and Restoration Ecology, Ecological Management and Restoration, Ecological Restoration, Restoration Ecology*), but most of that literature has sought to understand and describe the physical interventions required for effective conservation and restoration in different contexts. This paper focuses on the related, but different, issue of valuation.

Relatively recent globally important legislative changes, such as European Nature Restoration Law (Regulation 2024/1991) and the rapid growth of institutions seeking to raise money to support various activities intended to repair and replenish ecosystems, like the *Nature Positive Plan,* demonstrates a growing global commitment to sustainability. Despite the fact that markets suffer from large transaction costs and may not be the best institution for managing the commons (Costanza et al., 2021) many associated markets – hereafter, *nature-focused markets* – have emerged as a funding mechanism. They are, however, far from perfect. Carbon markets are nowadays common (Denton et al., 2020; Guix et al., 2022; Zhang et al., 2019) but significant problems have been identified in some markets (Pearse and Böhm, 2014) and several major certification schemes have failed to generate (carbon) credits that are deemed 'of sufficient quality' to satisfy requirements detailed in the Paris agreement (Kreibich and Hermwille, 2021). Biodiversity markets are growing in popularity, but are likewise far from perfect (Bull et al., 2015; Devictor, 2015; Griffiths et al., 2019; Lukey et al., 2017; Niner et al., 2017; Peterson et al., 2018; Tarabon et al., 2021; Tupala et al., 2022) and legitimate concerns have been raised about the strong vested interest that players in nature-focused markets have in making profits (Martin-Ortega et al., 2024).

Adam Smith's *invisible hand* (Smith, 1776) highlights that the profit focused motivations of private business can, by *accident,* also serve the interests of society more broadly. However, this only works if stringent conditions hold and few of those conditions hold in modern nature-focused markets. This is particularly so for the condition that calls for *perfect* (or at least, good quality) information about the products offered for sale. In a seminal paper on *the market for lemons,* Akerlof (1970) clearly showed that markets will fail when some people have less information than others. In Akerlof's paper this referred to the fact that people who want to buy a used car have much less information about the car than those who are selling it. His example is also relevant to nature-positive markets: those who have money to support nature positive projects generally know much less about any specific projects than those who have designed them and are trying to obtain funding. We argue that at least some of the failures observed in nature-focused markets are the result of information failure. The policy implication of this is that information-related failures might be at least partially redressed through appropriate, high-quality, valuation. Specifically, our viewpoint article argues that by *valuing* nature-focused projects, it may be possible to improve information flows and the operation of associated investments, helping funders identify and prioritise the most beneficial projects (Amato and Petit, 2023; Kragt et al., 2017; Romsdahl et al., 2015). This will not only have the effect of ensuring that scarce resources are directed towards the most promising nature-focused projects, but it may help promote the long-term sustainability of the connected system which humans and the rest of nature share.

Valuation is, nowadays, relatively common although it has been strongly critiqued for the role it plays in the *commodification of* nature (Gómez-Baggethun and Ruiz-Pérez, 2011). At the risk of over-simplifying core messages from this and related research, critics argue that valuation has spurred the establishment of many global initiatives that raise finance to support the development of markets which pay people to provide nature-focused services (see, for example, Deutz et al. (2020)). This includes both carbon and biodiversity markets. Valuation critics highlight the risk of unintended side-effects from valuation and related market based instruments, arguing that financial (extrinsic) incentives can crowd-out other incentives – a particularly pertinent problem for environmental goods (Agrawal et al., 2015; Gneezy et al., 2011). If a substantial amount of crowding out occurs, nature-focused markets may have the perverse effect of reducing overall incentives to protect the environment (see Martin-Ortega et al. (2023), for a more comprehensive discussion).

Some objections to valuation arise from the fact that early conceptualisations of ecosystem services and associated *valuations* were misperceived as focusing only on the one-way flow of benefits that humans receive from nature rather than the interdependence of humans and the rest of nature that the concept was based on (Costanza, 2024). Díaz et al. (2018) suggested that it might help to instead refer to *nature's contributions to people (NCP)* and numerous scholars have called for more focus on what they refer to as *relational values* (see, for example, (Chan et al., 2018)). These perspectives have enriched discussion of values and valuation (Stålhammar and Thorén, 2019), but simply changing terminology may not be sufficient to significantly alter global trajectories. If aiming to create truly sustainable systems, one must consider the two-way flow of benefits from ecosystems to people and back, and the costs and benefits in both directions. Specifically, one needs to consider both the services that natural ecosystems provide to people (ecosystem services) and the reciprocating services that people provide to the rest of nature (Comberti et al., 2015). These include, but are not limited to, nature-focused projects that involve biophysical interventions (Table 1).

To focus only on the one-way flow of services that ecosystems provide to people (ES) is to risk reducing both environmental and social values over time. People are not just passive recipients of gifts from the rest of nature, they interact with and are interdependent with the rest of nature. Although some interactions are negative and some communities reject reciprocity as a social principle (Hoyte and Mangombe, 2024), there are numerous examples of interactions that are mutually beneficial (reciprocating), especially in Indigenous and local communities (Comberti et al., 2015; Ojeda et al., 2022). A term used by some Australian Aboriginal and Torres Strait Islanders (herein referred to as Indigenous peoples) is that of *Caring for Country*, which involves a broad range of interrelated activities such as: looking after places, resources, stories and cultural obligations; spiritual renewal; provisioning; maintaining kin relations, and maintaining responsibility for country under customary law and practice for the benefit both nature and people, (Altman et al., 2007; Hill et al., 2013; Stoeckl et al., 2021b; Weir et al., 2011). Amazonian examples of practices that generate mutual benefits for people and nature are identified by Comberti et al. (2015); Bhutanese examples of an "ecological care ethic" are provided in Duivenvoorden (2023), Allison (2023) and Rinzin et al. (2009), whilst Ojeda et al. (2022) document other mutually beneficial practices, stressing the importance of reciprocity for both 'ecological legacy' and 'biocultural

Table 1
Examples of the services that nature provides to people (Ecosystem Services) and the services that people provide to nature (Reciprocating Services).

Examples of services that nature provides to people (Ecosystem services) – derived from Haines-Young and Potschin (2012)	Examples of services that people provide to nature (Reciprocating services) – derived from Ojeda et al. (2022)
Provisioning services such as food, fibre, textiles. Regulating and maintenance services such as climate regulation, air and water purification, regulation of water flows – with reduced regulation and reduced flood damage. Cultural services such as recreation, tourism, aesthetics, cultural identity, and feelings of contentment/wellbeing from simply knowing that the environment exists.	Institutional and socio-political arrangements that benefit nature, such as granting legal rights to nature, developing socio-ecological agreements and/or nature-laws, environmental justice movements. Biophysical, *nature focused* projects including programs for recycling, restoration, changing agricultural practices to reduce water or fertiliser use, translocation of species, or habitat enhancement. Symbolic-linguistic or cultural activities that benefit nature, such as the creation of cultural keystone places and species, taboos, ceremonies, rituals and practices.

continuity'. These holistic world views align with a broad literature on integrated social-ecological systems (Berkes, Folke, and Colding 2000; McGinnis and Ostrom 2014; Ostrom 2007), which emphasises that people and nature are inherently inseparable (Kenter, 2018; Pascua et al., 2017), that much environmental degradation has occurred because of the actions of humans (Díaz et al., 2019; Hossain et al., 2020; Jansen et al., 2009; Magnan et al., 2021; Prăvălie, 2021) and that most environmental solutions will involve or require people who have a critical role to play in conserving nature, and in protecting, supporting or otherwise maintaining ecosystems (Costanza et al., 2017; De Groot et al., 2010; Díaz et al., 2015; Pascual et al., 2017).

Long-term sustainability of the interconnected system inevitably requires that both ecosystems and people are consistently replenished and revitalised (Fig. 1). Sustainability can thus be better supported if a reciprocal ethos is mainstreamed into everyday life – formally highlighting humans as an essential, proactive component of the social-ecological framework, and reconstituting institutions to facilitate and support reciprocating services or contributions (Comberti et al., 2015; Ojeda et al., 2022). In addition to recognising the importance (*value*) of ecosystem services, society must also recognise the importance (*value*) of the reciprocating services that people provide to nature, nurturing and encouraging associated reciprocal norms for nature (Cooper et al., 2016; Delevaux et al., 2018; Díaz et al., 2018; Morishige et al., 2018).

Much is known about the valuation of ecosystem services, so in this paper, we focus on the relatively under-researched issue of valuing RS. We do not suggest that it is necessary to generate monetary estimates of *value;* raising the social status of reciprocating services and changing social norms and expectations without attaching a monetary value could do much to change behaviour (Bicchieri, 2016) and alter trajectories for a more sustainable future. A substantial body of literature leverages insights from behavioural science for environmental change, with evidence of success in numerous contexts – see Brown et al. (2010) for an example that involved tourists not only reducing their own litter but also picking up litter left by others. Additionally, there is much that can be done to change the behaviour of groups of people and/or institutions – see Ojeda et al. (2022) for an excellent overview of various formal and informal institutional changes that have, or could, encourage reciprocating behaviours at different social scales. We call for these critically important avenues of research and action to continue, whilst focusing the rest of our discussion on the additional role that valuation can play in further promoting sustainability: namely, providing information to guide resources towards actions that generate the most benefit for both nature and for people for long term sustainability.

There is, however, an important caveat to our assertion that the valuation of reciprocating services can help improve decisions about nature-based investments and the long-term sustainability of the system. Valuation exercises must be able to appropriately assess the extremely diverse array of outcomes associated with nature-focused projects since, by definition, reciprocity requires that there are mutual benefits (i.e., for both ecosystems and people). If valuation only focuses on a subset of outcomes (e.g., only agricultural benefits, or only the preservation of a single species), investments may be directed towards projects that generate a narrow range of easily measured benefits, rather than towards projects that generate the most benefits. This is entirely consistent with insights from the biophysical sciences which flag the need to extend historical focuses on, for example, protected areas, and individual species and to instead consider "conservation and restoration actions that focus on multifunctional connected "scapes"" Pörtner et al. (2023), p 3 – see, also Razak et al. (2022) who identified more than 530 records of coral reef restoration projects undertaken in Indonesia between 2010 and 2020, noting the imperative to develop objectives that focus on holistic reef recovery (rather than on narrow metrics such as the number of corals grown). Narrow, or biased, valuation may also treat certain groups in human society or species in nature differently – possibly ignoring some while favouring others. Comprehensive valuations are thus critical if wanting to promote reciprocating services and if wanting to ensure that investments in nature genuinely support the long-term sustainability of the connected system in which we live.

It is to some of the challenges associated with the valuation of comprehensive, large-scale RS that the discussion now turns.

2. Options for valuing reciprocating services

From about the late 1800 s onwards, economists developed a substantial, technical, and varied toolkit of methods for generating monetary estimates of the value of various environmental goods and services (Bennett, 2011; Freeman III et al., 2014; Getzner et al., 2004; Pascual et al., 2010). Much of this work was, no doubt, spurred on by the institutionalisation of Cost-Benefit Analysis in the United States and elsewhere which generated significant demand for monetised estimates of value (Hanley and Spash, 1993; Stoeckl et al., 2018). While the terminology used by economists when undertaking valuation exercises often differs from the terminology used within the Millenium Ecosystem Assessment,[1] there is absolute agreement, across multiple disciplines, that the benefits people receive from ecosystems are diverse, as are the benefits generated from the reciprocating services provided by people to ecosystems.

Different types of reciprocating services generate different benefits (outcomes) within and across both the biophysical and the human subsystems. When focused on identifying institutional changes that could be enacted to better support reciprocating services, Ojeda et al. (2022) first undertook a systemmatic review of literature to gather examples of reciprocating services, and then categorised those examples in two dimensions – one focusing on the nature of the reciprocating service (symbolic-linguistic-cultural, biophysical, institutional-social-political) and the other focusing on the social/institutional scale at which the activity is implemented. Our focus is on 'value' so we suggest a different, complementary categorisation system, similar to those used by Stoeckl et al. (2018) when classifying the benefits/values of various ecosystem services. The first dimension describes the number and complexity of outcomes generated by a particular service – essentially, the scope of impact; the second dimension describes scale (geographic and social) at which outcomes accrue. Fig. 2 provides specific examples. Understanding these dimensions helps one to identify methods most appropriate to the task of valuing different types of reciprocating services: one size will not fit all.

Different methodological approaches are best suited to valuing different types of goods and services (see, for example, Gregersen (1987); Koetse et al. (2015); Liu et al. (2010)). Market-based methods, for example, can only estimate values associated with goods and services that are exchanged in the market (some provisioning and regulating/maintenance services) and whilst the travel cost method can generate estimates of recreation use values (a type of cultural service), it is unable to estimate non-use/existence values (a different type of cultural service). Similarly, different methodological approaches are best suited to valuing reciprocating services that generate benefits at different scales and scope – see Fig. 2.

Most non-market valuation methods, derive from the bodies of literature associated with welfare economics, cost-benefit analysis and environmental economics – sub-fields of micro-economics. These valuation methods are thus *partial equilibrium* and adept at assessing the value of nature-focused projects that generate a small number of easily defined outcomes at relatively small scale – those in the bottom left corner. Some existing non-market valuation methods – particularly choice experiments, but also contingent valuation, and the life satisfaction approach – are also able to generate reliable estimates of the values that individuals hold for nature-focused services that generate a diverse range of outcomes – the bottom right corner – although, for

[1] For example, economists often refer to use values, indirect use values and non-use values rather than to ecosystem services.

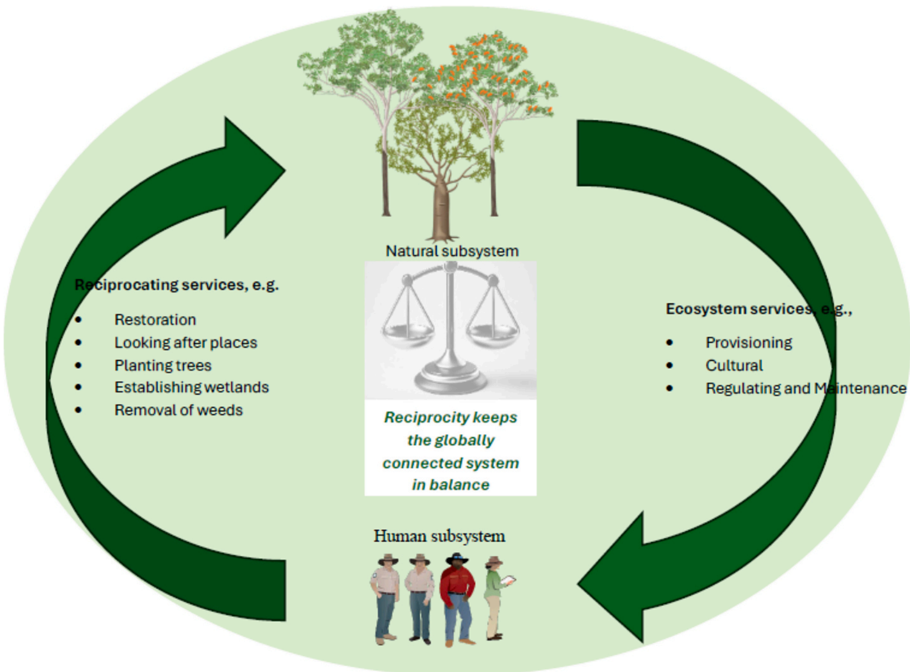

Fig. 1. Natural ecosystems and humans are part of an interconnected system, sustainable only if the (reciprocating) services that are provided by people to the rest of nature, balance the (ecosystem) services that are provided by nature to people. We need to better 'value' reciprocity to encourage sustainability.

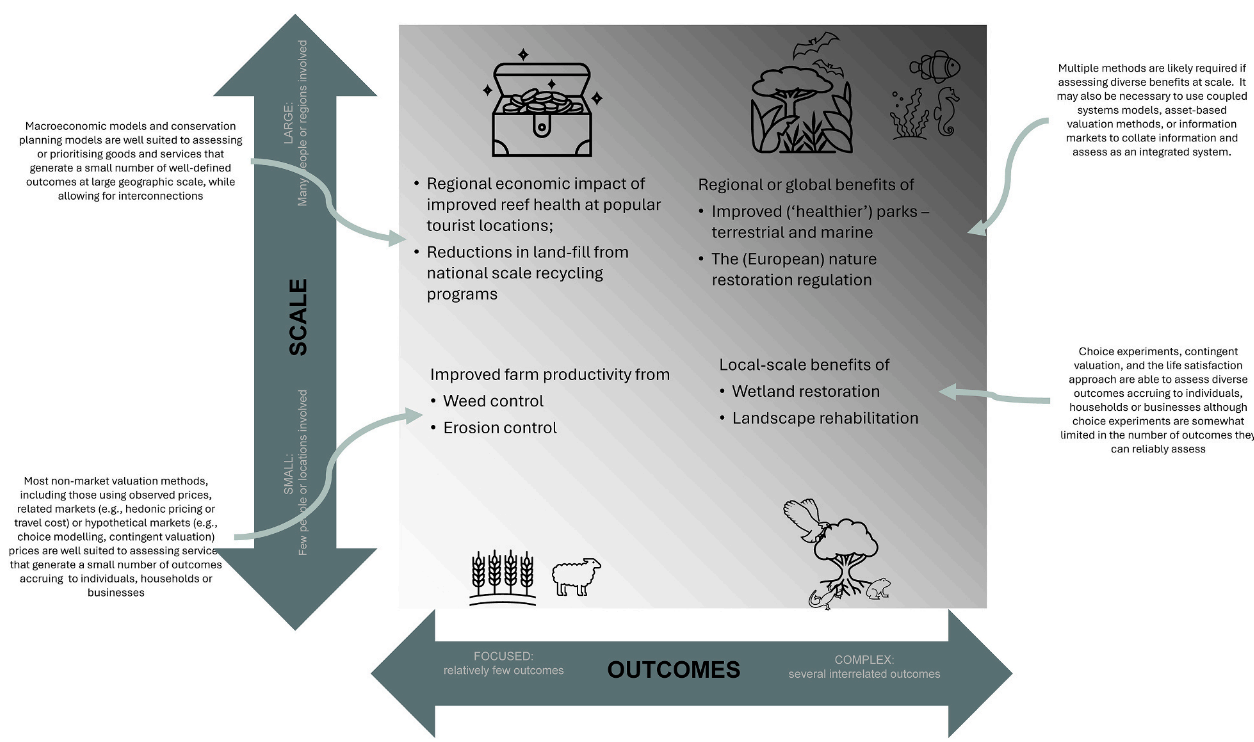

Fig. 2. Different methods are suited to assessing the value of reciprocating services that generate simple or complex benefits at small or large scale. Nature-focused projects and their associated outcomes may be visualised in two dimensions, depending on the scale (vertical axis) and scope (horizontal axis) of impact. The shading highlights that projects that generate a complex array of interrelated outcomes at large social or geographic scale are arguably, the most difficult to 'value'. Bottom left – activities that control weeds and erosion on farms, create a small number of relatively simple ('focused') outcomes (e.g., improved productivity and incomes), the benefits of which have relatively small scale, localised impacts, namely benefits for farmers. Most Top left – improving reef health at popular tourist location and recycling programs can generate national benefits, but the scope of impact may be relatively narrow (e.g., with benefit financial benefits accruing to those who are associated with the tourism industry, or with most ecological benefits focused on a single outcome such as landfill). Bottom right – activities involving wetland or landscape rehabilitation generate a relatively diverse array ecological and socioeconomic outcomes linked to habitat and biodiversity, although the impacts are localised. Top right – improved (healthier) parks and continental scale efforts to restore nature generate a very diverse array of ecological and socioeconomic benefits at large geographic and social scale.

choice modelling in particular, the number of outcomes that can be reliably assessed is somewhat restricted (to about four, possibly as many as six). Although not normally included in lists of non-market valuation methods, both macroeconomic models and conservation planning models are well suited to assessing (or prioritising, if not formally valuing) projects that generate a small suite of very well-defined outcomes at large geographic scale, while allowing for interconnections within the economic system (macroeconomic models) or the ecological system (conservation planning models). However, as both the scope and the scale of impact increases, the valuation process becomes more challenging. It is arguably, the reciprocating services that generate a diverse range of outcomes/benefits over large geographic and social scale (top right corner), which are the most difficult to *value* since proper assessment requires one to consider numerous interacting and confounding factors at multiple scales. It is also, arguably, these types of RS that are the most critically important ones to value well, given the need to encourage actions that promote and support multifunctional connected "scapes" (Pörtner et al., 2023).

Assessing either ecosystem service or reciprocating service values at large scale is a non-trivial exercise for two, interrelated reasons. First, it is more important to be comprehensive than precise when valuing entire ecosystems (Boithias et al., 2016), so valuers who work at large-scale must frequently utilize a collection of different methods, including benefit-transfer. Second, it is important to recognise connectivity because both ecosystem and reciprocating service values are jointly determined by characteristics of the natural and human system and interactions between systems (Binder et al., 2013; Colding and Barthel, 2019; Karrasch et al., 2014; Ringold et al., 2013; Václavík et al., 2016). Large-scale valuation is thus generally a data-intensive exercise, requiring information about both natural and human systems and about interactions between the systems.[2]

At the risk of oversimplifying the valuation process, those aiming to generate empirical estimates of a diverse range of ecosystem service values at large geographic scale need to first, identify and characterise relevant ecosystems (the natural systems), to second, identify and characterise the services provided by those ecosystems; to third, identify and characterise the 'beneficiaries' of those services – the people relevant to the social/human system; and finally, to estimate the value of those services (Panel A, Fig. 3). The ecosystem services that are 'produced' at any particular location can benefit people anywhere in the world (see, for example the map showing global beneficiaries of the ES provided by Antarctica and the Southern Ocean, Stoeckl et al. (2024)), so the geographic boundaries which delineate the natural systems relevant to a valuation exercise (those which provide the ecosystem services) will not always coincide with the geographic boundaries that delineate relevant human systems (where beneficiaries reside).

Related, but subtly different information is required to generate empirical estimates of the value of reciprocating services (Panel B, Fig. 3) which requires consideration of both sides of a connected system. In contrast to valuation exercises that focus only on ES, a distinguishing feature here is the need to also have *causal* information about the way in which the physical activities undertaken by people (the reciprocating services) generate biophysical changes, such as improvements in ecosystem health, which subsequently generate changes in social or economic values.

Valuations that inclusively account for all relevant regions, ecosystems, services, actors and contexts are thus extremely data-demanding (see, for example, Fig. 4 which provides a non-definite overview of different types of data likely to be required). Recent advances in IT and a growth in the number of integrated datasets relevant to connected natural-human systems makes contextual data more accessible, although publicly collated data has invariably been collected for a wide variety of purposes and is not always well suited to valuation – a task which requires specific types of data/information. Aspirations to generate *gold standard* and inclusive empirical value estimates are thus, always and everywhere, curtailed by pervasive knowledge gaps. The paucity of data describing the costs and benefits of reciprocating services such as nature restoration projects and the technical difficulty of quantifying the impacts means that their value is much under-appreciated (Matzek, 2018), and estimates are often imprecise. Stewart-Sinclair et al. (2021), for example, blended data available in De Groot et al. (2012)'s global database of ecosystem services with global estimates of restoration costs to investigate the approximate return on projects designed to restore marine ecosystems. They made particular note of the uncertainty of estimates – noting that data were only available for 12 of the possible 22 relevant ecosystem services.

3. Valuation of projects that generate diverse outcomes at large scale in highly connected systems

Detailed models that describe human systems have been fully integrated with biophysical models that describe natural systems, to develop what are sometimes termed *coupled systems models*[3]*;* these are, arguably, a gold standard method for estimating RS values. The models typically comprise a collection of submodules – one or more for the natural system, one or more for the social system – that can be defined at any scale. The submodules are run in parallel and connections between the submodules include dynamic feedbacks which effectively allow for interactions between and within the natural and social systems, with emergent outcomes (Liu et al., 2007). Changes in the human (ecological) system which occur at time t, can be explicitly incorporated into the ecological (human) system at time t + 1, mimicking a connected and interacting system. Coupled systems models are thus capable of generating information about the value of nature-focused projects that generate diverse outcomes at large scale. They have been successfully used to simulate diverse outcomes into the future and to assess the potential impact of nature-focused projects/policies in both marine (Fulton et al., 2011) and terrestrial environments (Guan et al., 2011).

High quality coupled systems models that provide detail about a large number of outcomes at multiple geographic scales are, however, extremely time and resource intensive to develop (Yue et al., 2024). As a result, it is likely infeasible to develop bespoke coupled-systems models to assess the value of a large number of diverse reciprocating projects that could potentially be put forward for consideration in *nature positive* markets. The following sub-sections thus briefly describe two different – less resource intensive – approaches to assessing the 'value' of reciprocating services. The first is able to consider a very broad range of benefits at very large geographic scale but is not particularly adept at considering connectivity between human and ecological systems. The second is able to consider connectivity, although at much smaller scale. This highlights a need for future research to find ways to deal with scale, scope and connectivity, that are less resource-intensive than coupled systems models – a challenge further elaborated on in the conclusion.

[2] This is true for all valuation methods, including benefit transfer since it is desirable to contextualize estimates for differences in the biophysical or socioeconomic characteristics of relevant regions to increase the validity of transferred estimates. See: Baker, R., Ruting, B., 2014. Environmental Policy Analysis: A guide to non-market valuation, Productivity Commission Staff Working Paper. Productivity Commission, Canberra, Fitzpatrick, L., Parmeter, C.F., Agar, J., 2017. Threshold Effects in Meta-Analyses With Application to Benefit Transfer for Coral Reef Valuation. Ecological Economics 133, 74–85, Johnston, R.J., Besedin, E.Y., Stapler, R., 2017. Enhanced geospatial validity for *meta*-analysis and environmental benefit transfer: an application to water quality improvements. Environmental and Resource Economics 68, 343–375, Johnston, R.J., Rolfe, J., Rosenberger, R.S., Brouwer, R., 2015. Benefit transfer of environmental and resource values. The economics of non-market goods and resources 14.

[3] and sometimes termed *dynamic systems models.*

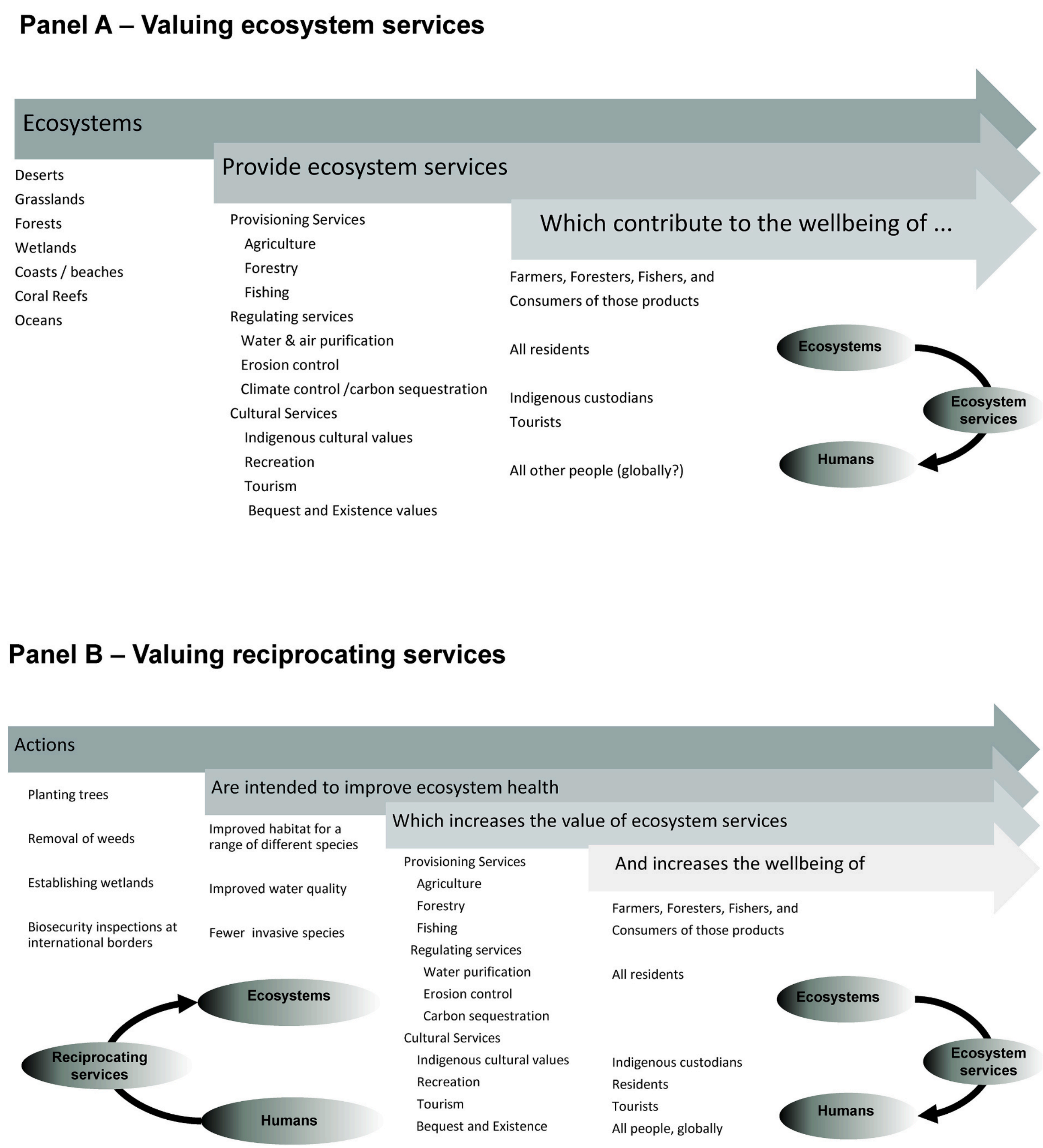

Fig. 3. Generic types of information required when valuing either ecosystem services (panel A) or the nature-focused (reciprocating) services (panel B).

3.1. Allowing for diverse benefits at large scale

Although not providing a rich detailed overview of the connected system, asset-based approaches present a somewhat simple alternative to fully integrated coupled systems models. They effectively allow for the creation of two separate models (one focused on the natural system, one on the human system), with the biophysical model first predicting changes in the natural system, and the human model predicting changes in that system, contingent on the state of the biophysical world. There are no dynamic links that show how changes in the human model might feed-back to impact the biophysical world so these models cannot predict emergent outcomes. Asset-based approaches do, however, create a simulation *test tube* which enables analysts to ignore a large majority of confounding factors and estimate the value of nature-focused projects that generate diverse outcomes at large social and geographic scale – see Appendix A for a graphical and mathematical overview. They have been used to estimate a variety of different activities including a diverse array of benefits from undertaking biosecurity inspections for goods imported into Australia (Dodd et al., 2020; Stoeckl et al., 2023), diverse benefits from controlling crown-of-thorns starfish outbreaks and of mitigating the impacts of climate change in the Great Barrier Reef (Stoeckl et al., 2021a), the (non-market) value of controlling sea-level rise in Australia's north west (Kompas et al., 2024), and the value of expanded reserves for the Giant Panda (Wei et al., 2018).

Asset based valuation methods have several core strengths/advantages:

1) Research teams are able to work in parallel, thus expediting the estimation process and potentially making it possible for the 'valuers' to consider a broader range of benefits than might otherwise be

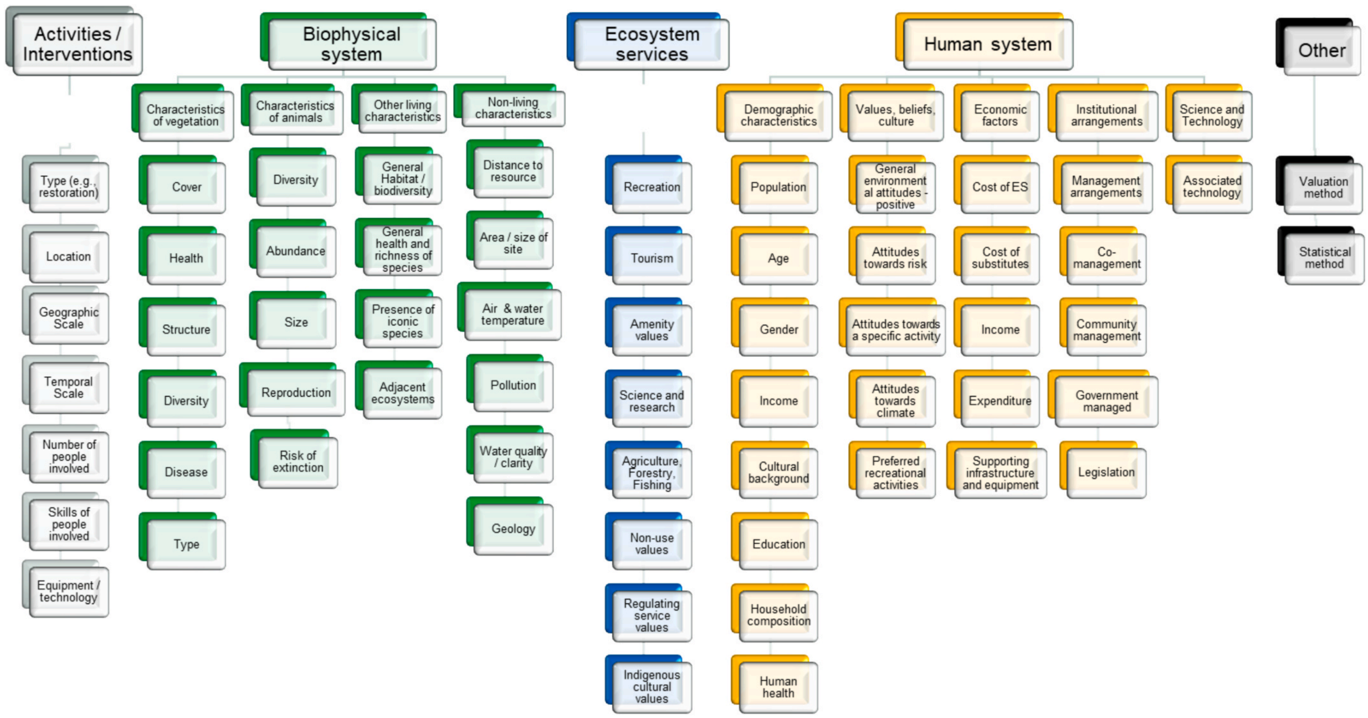

Fig. 4. Stylised representation of the breadth of data required if aiming to generate bespoke estimates of ecosystem or reciprocating service values – a non-definitive list.

the case. Biophysical scientists, for example, can focus on developing simulation models that link projects/activities to measurable environmental changes while socioeconomic scientists can focus on the tasks of (a) estimating current values and (b) determining how those values are likely to change in response to the (predicted) environmental changes identified by the biophysical scientists – a non-trivial task given the paucity of information about the way in which ecosystem service values change in response to changes in ecosystem health (Hernández-Blanco et al., 2022). It is, nonetheless, critically important for both groups to collaborate on design: if the biophysical group generates estimates of the way in which a particular restoration project improves vegetation cover and the socioeconomic group generates estimates of the way in which changes in the survival rates of endangered species affects socioeconomic values, then the two bodies of work cannot be quantitatively combined to generate monetary estimates of the value of the project's restoration activities.

2) Asset-based approaches generate two types of information about the outcomes of reciprocating services: the biophysical changes and estimates of the monetary value of consequent changes in the ecosystem services provided. Dual reporting allows stakeholders to appreciate the full spectrum of the benefits of reciprocating services that sustain both nature and human well-being.
3) Asset-based approaches make it possible for analysts to re-use information about current values to assess the impact of different reciprocating projects. For example, the dataset that was used to assess the impact of crown of thorns starfish control in the Great Barrier Reef (GBR) has also been used to assess the value of other nature-based projects that impact the GBR (specifically, modelling reef values in different climate scenarios – Adaptus et al. (2024)). Likewise, the dataset that was used to assess the value of biosecurity inspections was also used to assess the cost of sea-level rise in the Melbourne area (Kompas et al., 2022) and in North Western Australia (Kompas et al., 2024). Each specific investigation requires researchers to develop biophysical/ecological models to consider the extent to which actions impact the biophysical world, and to make a corresponding assessment of the extent to which those biophysical changes will impact asset values, but the underlying 'current values' layer has multiple uses – and can conceivably be tied to national / international initiatives such as the United Nations System of Environmental Economic Accounting (SEEA) which, effectively, aims to collect data on 'current values' at regular intervals.

Asset based approaches are, nonetheless, reductionist in that they represent the both natural system and the social system systems as collections of independent (separable) values, presumed additive across space and over time. Their use is justifiable in the absence of strong connections or interdependencies between parts of the system or when the changes that are associated with nature-based (reciprocating) projects are relatively small.[4] However, if working in a highly integrated and connected system, changes that occur in one part of the system will affect other parts of the system (particularly if changes are substantial); the value of the whole cannot therefore be assumed to equal the sum of its parts.

3.2. Allowing for connectivity

Noted above, connections can, in theory, be accounted for by developing complex coupled systems models, but those models are expensive and other potentially useful methods exist – notably information markets and deliberative valuation processes which explicitly encourage the exchange of information (Chan et al., 2018; Hansjürgens et al., 2017; Himes and Muraca, 2018; Kenter et al., 2015; Sagoff, 1998). Discussed in the introduction, information asymmetries (where some people have more information than others) can lead to market failure (Akerlof, 1970). As such, it should come as little surprise to find that information markets and deliberative valuation processes that allow for the exchange of information have core advantages if aiming to value RS

[4] Since any indirect (or knock-on) effects are also likely to be minimal, so other parts of the system can be validly ignored for the valuation exercise.

in highly connected systems where information is fragmented and/or altruism is present.

1) If people care about each other, the preferences (values) they express when asked to consider only themselves, are likely to differ from the preferences expressed when asked to consider benefits for a broader group of people (family, friends, community), and this can be effectively done using deliberative process.[5]
2) Reciprocating services often generate a complex array of interrelated outcomes at multiple geographic and social scales (Fig. 2), with changes in one part of the system causing potentially unanticipated changes in other parts. Different people have different information and different understandings about potential outcomes, so the sharing of information greatly improves collective knowledge thus improving the assessment of inclusive social values (Braat et al., 2014; Kenter et al., 2016; Kenter et al., 2015) and helping to redress the information asymmetries that impede markets (Akerlof, 1970).

Deliberative approaches have historically involved workshops and meetings (mostly face-to-face) and are thus well suited to small groups. Advances in technology have, nonetheless, made it possible to connect people across the world, expanding the 'reach' of conversations and making it possible to use these approaches for assessments that are undertaken at larger scale. Deliberative approaches that incorporate innovations from information markets have been trialled in highly connected systems – specifically, in Australian Aboriginal settings. This research has demonstrated that processes which do not allow for deliberation may undervalue reciprocating projects/services that generate diverse, large-scale benefits relative to projects that generate simple benefits (Grainger and Stoeckl, 2019; Stoeckl et al., 2021b). In addition, these deliberative processes revealed connections that analysts would not themselves have thought of, but which are nonetheless important if aiming to assess and compare the benefits (value) of different types of reciprocating services. They have, for example, highlighted the importance of not only considering what needs to be done (e.g., rehabilitating landscapes or establishing nesting sites for endangered species), but also considering how things should be done and by whom, because *the how* strongly influences final values (benefits) – see, for example Finau et al. (2023) and Larson et al. (2023).

4. Conclusion

In addition to recognising the importance (*value*) of the services that ecosystems provide to people (ES), society must also recognise the importance (*value*) of the reciprocating services (RS) that people provide to ecosystems. Raising the status of RS could help change institutions, social norms and behaviours – altering the way in which people view their relationship with the rest of nature from one that is largely exploitative to one that embraces an interdependent and positively reinforcing system for long-term sustainability.

Institutions around the world are working to gather resources intended to help support *nature positive* activities. Comprehensive assessments of these and other types of reciprocating services, may help ensure that subsequent investments in nature are genuinely *for* nature and for people whose wellbeing is inextricably connected to nature. When prioritising the use of funds, it is critically important to ensure that assessments of proposed activities are holistic and comprehensive – irrespective of whether those assessment use money or some other metric. Narrow assessments risk funds being allocated towards projects/activities that generate the most easy-to-quantify benefits, rather than to projects that generate the most benefits per se.

In an ideal world, gold-standard coupled systems models could be used to generate estimates of the likely benefit of different projects; prioritising those that show most promise, but we do not live in an ideal world. Although advances in IT will lower the cost of analytics, making it easier to run large-scale coupled systems models, good quality models require extensive amounts of data and information about parts of the system and interactions between parts and such information is rarely available. This leaves one with a choice of either doing nothing until better information is available (which risks people assigning 'zero' to the missing value), or using models that may not be ideal, but are at least, likely to better than nothing since there are circumstances (most notably, for large projects, with high uncertainty around non-market values, and close-to zero estimates of market values) when "even an inaccurate estimate of [a non-market] value can be more valuable to decision-makers than no number" (Pannell et al., 2025).

Different valuation approaches are likely to be required when assessing different types of RS in different contexts. Asset-based valuation approaches, that allow analysts to consider a broad range of values at large geographic scale are a pragmatic alternative to fully coupled systems models – primarily because they do not focus thought on just one small issue or benefit. They are thus able to provide comprehensive overview of the potential benefits of RS and can be linked to other comprehensive frameworks that consider both social and environmental values such as the UN's SEEA. That said, asset-based approaches do not explicitly account for connectivity between human and ecological systems, inherently assuming that nature, people and services can be neatly divided into separable parcels, individually *valued* and then added to generate estimates of total value. In highly connected systems where it is important to allow for connectivity, deliberative approaches and/ approaches that leverage insights from information markets, are another imperfect albeit pragmatic alternative to the gold-standard coupled systems models.

Ultimately, it will be important to further progress ways of thinking about, promoting, encouraging and valuing reciprocity – perhaps finding ways of blending insights from both information markets and asset-based approaches, or finding entirely new ways of better highlighting the importance of RS and of prioritising the types of RS that generate greatest value for humans and the rest of nature. Thinking only about what nature does for humans, without also thinking about what humans can do for the environment, overlooks a critically important opportunity to find ways of 'giving back', creating a more sustainable future for all.

CRediT authorship contribution statement

Natalie Stoeckl: Writing – review & editing, Writing – original draft, Visualization, Methodology, Conceptualization. **Robert Costanza:** Writing – review & editing. **Namgay Dorji:** Writing – review & editing. **Ida Kubiszewski:** Writing – review & editing. **Bassie Limenih:** Writing – review & editing. **Jing Tian:** Writing – review & editing. **Satoshi Yamazaki:** Writing – review & editing.

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.

Acknowledgements

The authors acknowledge the support of the University of Tasmania and the University College London. Some of the research discussed in this paper was partially funding from the Australian Government under the National Environmental Science Program's Resilient Landscapes Hub NESP and some was undertaken for the Reef Restoration and Adaption Program (RRAP), which is funded by the partnership between the Australian Governments Reef Trust and the Great Barrier Reef

[5] Unless they have prior and perfect knowledge and are so able to consider all other people's preferences when making decisions.

Foundation (partners include: The Australian Institute of Marine Science, CSIRO, the Great Barrier Reef Foundation, Southern Cross University, the University of Queensland, Queensland University of Technology and James Cook University). The RRAP partners acknowledge Aboriginal and Torres Strait Island Peoples as the first marine scientists and carers of Country. We acknowledge the Traditional Owners of the places where we and RRAP works, both on land and in sea Country. We pay our respects to elders; past, present and future; and their continuing culture, knowledge, beliefs and spiritual connections to land and sea Country.

We thank two anonymous reviewers for taking the time to provide insightful and useful comments on an earlier version of this manuscript.

Appendix A. – Asset based approaches

Fig. 5 provides a visual overview of these asset-based approaches. Operationally, various non-market valuation methods are used to generate simple estimates of a diverse range of current ES values; for example, $V_0 \approx P_0 \times Q_0$ [6], where P_0 and Q_0 represent the current price and quantity of the service provided. Estimates such as these are contingent upon existing/current social and environmental conditions so non-market valuation methods are also used to make predictions about the way in which biophysical changes might impact ecosystem service values – e.g., estimating $\frac{\partial V}{\partial Environment}$. In a separate, but related activity, biophysical simulation models are used to make predictions about the condition of the environment annually, both with and without, an intervening nature-focused project. This provides estimates of both:

Δ *Environment with the project*$_t$ (formally the difference in condition between time = t and time = t + 1) and

Δ *Environment without the project*$_t$ (formally the difference in condition between time = t and time = t + 1).

These pieces of information are then combined, to make predictions about the way in which (predicted) biophysical changes will impact ecosystem service values and thus natural capital (the asset). Formally, the values at time t + 1:

$$V_{t+1} = V_t - \textit{damages during the year}$$

and where:

$$\textit{damages during the year, with the project} = \frac{\partial V}{\partial Environment} \times \Delta\ \textit{Environment with the project}_t$$

and

$$\textit{damages during the year, without the project} = \frac{\partial V}{\partial Environment} \times \Delta\ \textit{Environment without the project}_t$$

The simulation *test-tube* thus allows analysts to assume all-else-constant, so the difference between asset value-estimates with and without the project tells analysts about the expected *value* of the project – formally, the damages it can be expected to avoid (Fig. 5).

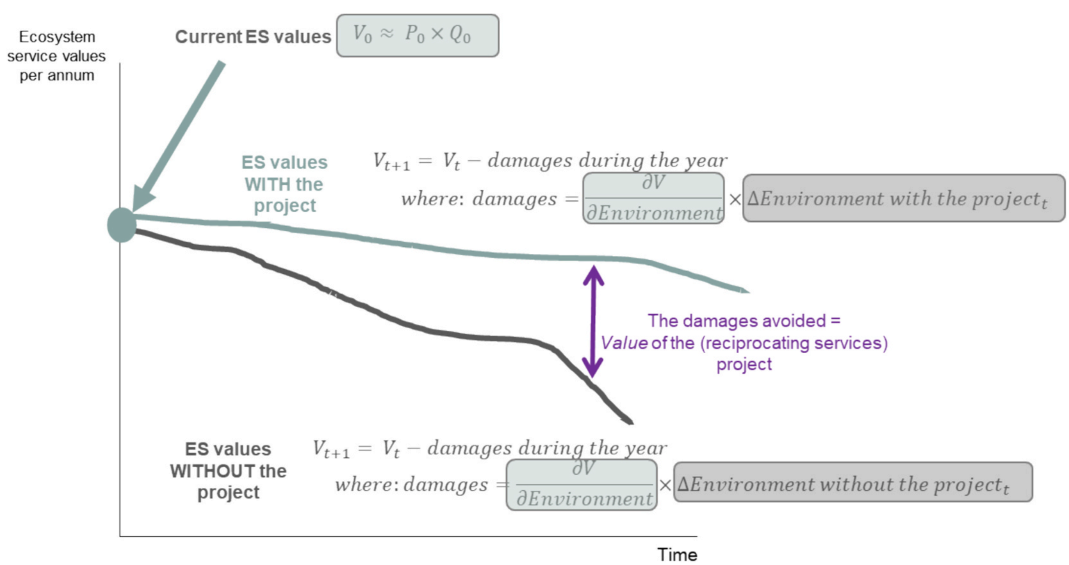

Fig. 5. Stylised representation of the asset-based approach to valuing nature-focused projects (reciprocating services).

[6] These are what economists call total (rather than marginal) values. Current values should reflect surpluses (formally, net economic benefits) if aiming to use final estimates within a cost-benefit analysis. If aiming to align estimates with frameworks such as the United Nation's system of environmental economic accounting United Nations Committee of Experts on Environmental-Economic Accounting (UNCEEA), 2021. System of Environmental-Economic Accounting—Ecosystem Accounting (SEEA EA). White cover publication, pre-edited text subject to official editing, Available at: https://seea.un.org/ecosystem-accounting., current values need to represent *exchange* values, so should be estimated by simply multiplying (current) price and quantity.

Data availability

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

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