Environmental Science and Policy 116 (2021) 20–29

Contents lists available at ScienceDirect

Environmental Science and Policy

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

Linking biodiversity into national economic accounting

Steven King [a,*], Michael Vardon [b], Hedley S. Grantham [c], Mark Eigenraam [d], Simon Ferrier [e], Daniel Juhn [f], Trond Larsen [f], Claire Brown [a], Kerry Turner [g]

[a] United Nations Environment Programme World Conservation Monitoring Centre (UNEP-WCMC), 219 Huntingdon Road, Cambridge, UK
[b] Fenner School of Environment and Society, Australian National University, Canberra, Australia
[c] Wildlife Conservation Society, NY, USA
[d] IDEEA Group, Melbourne, VC, Australia
[e] CSIRO Land and Water, Canberra, Australia
[f] Conservation International, Arlington, USA
[g] CSERGE, University of East Anglia, UK

A R T I C L E I N F O

Keywords:
System of environmental economic accounting
SEEA-EEA
Biodiversity
Ecosystem services
Sustainable development

A B S T R A C T

Biodiversity underpins the supply of ecosystem services essential for well-being and economic development, yet biodiversity loss continues at a substantial rate. Linking biodiversity indicators with national economic accounts provides a means of mainstreaming biodiversity into economic planning and monitoring processes. Here we examine the various strategies for biodiversity indicators to be linked into national economic accounts, specifically the System of Environmental-Economic Accounts Experimental Ecosystem Accounting (SEEA EEA) framework. We present what has been achieved in practice, using various case studies from across the world. These case studies demonstrate the potential of economic accounting as an integrating, mainstreaming framework that explicitly considers biodiversity. With the right indicators for the different components of biodiversity and scales of biological organisation, this can directly support more holistic economic planning approaches. This will be a significant step forward from relying on the traditional indicators of national economic accounts to guide national planning. It is also essential if society's objectives for biodiversity and sustainable development are to be met.

1. Introduction

The importance of biodiversity to human well-being is well established (e.g., via IPBES, 2019; MA, 2005; TEEB, 2010) and enshrined in multiple international commitments (e.g., the United Nations (UN) Sustainable Development Goals (SDGs) and the Convention on Biological Diversity's (CBD) Aichi Targets). Many of the biological entities constituting biodiversity, including individual species, contribute directly to human well-being (e.g., fisheries, non-timber forest products, wildlife watching and pollination). More generally, biodiversity as a whole is key to maintaining 'ecosystem functioning' (Devictor et al., 2010; Díaz et al., 2007; Hooper et al., 2005) and, in turn, indirectly supplying a broad set of ecosystem services that benefit people (Balvanera et al., 2014, 2006; Cardinale et al., 2012; Tilman et al., 2006). Biodiversity is also critical in maintaining ecosystem services flows during times of disturbance or stress that ecosystems may experience, for example, climate variability, pollution incidents or fires. This resilience is achieved via 'functional redundancy,' where different aspects of biodiversity (e.g., species) can perform similar ecosystem functions, but are affected by disturbance in different ways (Elmqvist et al., 2003; Mori et al., 2013).

In these ways, biodiversity is crucial for maintaining the capacity for current and future ecosystem service supply, especially as pressures on ecosystems continue to build. Despite these clear imperatives for maintaining biodiversity, the recent Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services report (IPBES, 2019), highlights continuing and substantial declines across all three components of biodiversity (ecosystem diversity, species diversity and genetic diversity, see Fig. 1). The UN Agenda for Sustainable Development explicitly recognizes that these biodiversity losses are exacerbating the development challenges humanity faces (UN, n.d.). The IPBES (2019) report identifies that declines in biodiversity undermine progress towards 80 % of the SDG Targets related to poverty, hunger, health, water, cities, climate, oceans and land. To help address these losses, IPBES

* Corresponding author.
E-mail address: steven.king@unep-wcmc.org (S. King).

https://doi.org/10.1016/j.envsci.2020.10.020
Received 13 May 2020; Received in revised form 14 October 2020; Accepted 31 October 2020
Available online 10 November 2020

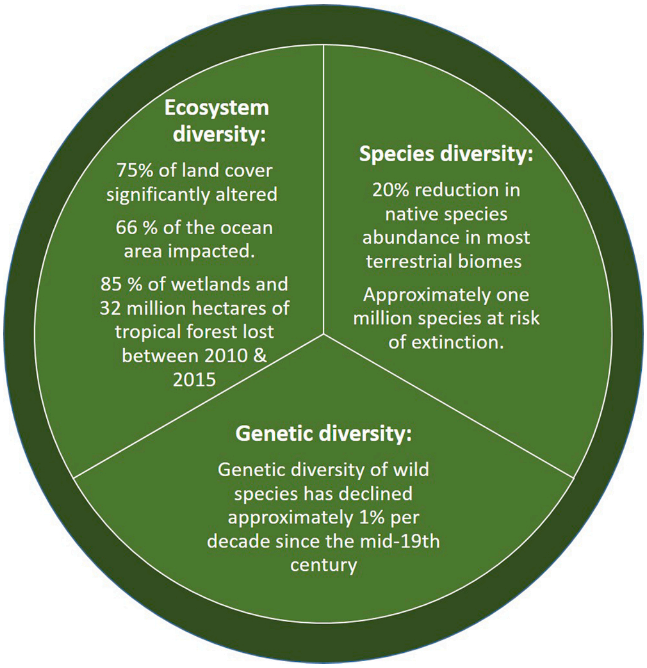


Fig. 1. Loss of the components of biodiversity (IPBES, 2019).

(2019), the CBD (via Aichi Target 2) and the SDGs themselves (via SDG Target 15.9) all call for the mainstreaming of biodiversity and ecosystem services into development planning.

In order to mainstream biodiversity into decision making, policy makers, land managers, businesses and other actors need a regularly updated and consistent supply of information on biodiversity and the benefits it provides (Hein et al., 2020; Vardon et al., 2019). The System of Environmental-Economic Accounts Experimental Ecosystem Accounting (SEEA EEA) has been developed to extend the System of National accounts and provide the information system that responds to these needs (UN et al., 2017, 2014). There is now a growing group of countries producing biodiversity-related SEEA EEA accounts (Ruijs and Vardon, 2019). Examples include the European Union (EU) via the KIP INCA project (UNEP-WCMC, 2019, 2017; Vallecillo et al., 2018), the Netherlands (Bogaart et al., 2020), Mexico (Schipper et al., 2017), the Southeast USA (Warnell et al., 2020), KwaZulu-Natal, South Africa (Driver et al., 2015) and the Great Barrier Reef in Australia (ABS, 2017). The upcoming CBD Conference of the Parties provides an important opportunity for the biodiversity community to call for other countries to also commit to producing biodiversity-related SEEA EEA accounts (Burnett et al., 2020; Nature, 2020).

The aim of this paper is to encourage the integration of biodiversity into national accounts by demonstrating a set of biodiversity indicators and statistics that might be useful to embed and link to the SEEA EEA. In Section 2, we describe the SEEA EEA framework and how biodiversity features in this accounting model. In Section 3, we present an expanded vision of the SEEA EEA, linked to indicators for different components of biodiversity and scales of biological organisation. In Section 4, we present three Species Accounting case studies. The focus on Species Accounts reflects that accounting for this component of biodiversity is underdeveloped in the SEEA EEA. In Section 5, we discuss best practice options, challenges and ways forward. Our conclusions are provided in Section 6.

2. Biodiversity and the SEEA EEA

The System of National Accounts (SNA, European Commission et al., 2009) is a tried and tested framework for organising statistics on national economic activities. It covers all economic activity associated with production, consumption and accumulation and all industrial sectors. As such, it is a fundamental source of information for national economic planning. However, the SNA fails to fully account for the environment, both in terms of the economic benefits it provides and the environmental degradation that results from various economic activities (Vardon et al., 2019, 2018). The SEEA EEA aims to address this by extending the SNA to provide integrated statistics on ecosystems and how they contribute to the economy and well-being. The SEEA EEA is currently under revision, with the aspiration to become an international statistical standard in 2021 (UNCEEA, 2019).

The SEEA EEA core ecosystem accounting model (Fig. 2) (F proposes that changes in 'stocks' of Ecosystem Assets are measured via changes in biophysical measures of their extent and condition over an accounting period (ideally a year but in current practice often longer, e.g., every 5 years). An Ecosystem Asset is represented by a contiguous area of the same Ecosystem Type. The current proposal for measuring ecosystem condition is using indicators for the abiotic and biotic characteristics of Ecosystem Assets and landscape or seascape scale characteristics that emerge across multiple Ecosystem Assets of the same Ecosystem Type.

Ecosystem Assets supply a 'flow' of ecosystem services over the accounting period. These flows are recorded within accounts showing the supply and use of ecosystem services in physical and monetary terms. Recording these transactions in services between ecosystems and different economic units (e.g., households, businesses, government) enables the full integration of ecosystem accounting with the economic accounting of the SNA (Eigenraam and Obst, 2018).

The measures for the 'stocks 'of Ecosystem Assets and 'flows' of Ecosystem Services are aggregated and presented in ecosystem extent, condition and ecosystem service supply and use accounts for particular Ecosystem Accounting Areas (EAA, e.g., country, watershed, administrative area) (UN et al., 2017, 2014). This arrangement of Ecosystem Assets (EAs), Ecosystem Types (ETs) and Ecosystem Accounting Areas (EAAs) is presented in Fig. 3.

The core accounts of the SEEA EEA are supported by thematic accounts on different topics, including biodiversity (Fig. 2). The SEEA EEA adopts the Convention on Biological Diversity's definition of biodiversity (CBD, 1992): *"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; this includes diversity within species, between species and of ecosystems"*. However, a tension exists between the definition of biodiversity in the CBD and the treatment of biodiversity in the core SEEA EEA accounting model. In the CBD definition, ecosystem *diversity* is a subset of biological *diversity*, while in the SEEA-EEA biodiversity *accounting* is a subset of ecosystem *accounting* (Vardon et al., 2015). We tackle this in next section.

3. Applying a biodiversity perspective to the SEEA-EEA

The core biophysical accounts of the SEEA EEA allow for measuring and monitoring the extent and condition of ecosystem types, which can be viewed as the fundamental entities constituting ecosystem-level biodiversity. However, the framework currently stops short of using these Ecosystem Asset accounts to derive an explicit "ecosystem diversity" account. This focus on ecosystem types and assets in SEEA EEA has important implications for any consideration of the relationship between biodiversity in a holistic sense, and ecosystem condition and services supply in ecosystem accounting. Such consideration needs to accommodate the potential roles played by diversity across the multiple levels of biological organisation, or at least by each of the entities, or components, comprising this diversity (including individual species as components of species diversity, e.g., Luck et al., 2009) and across scales (i.e., landscape as well as local, Ecosystem Asset scale) (Oliver et al., 2015; Tscharntke et al., 2005). This is because all of the components of biodiversity and the way in which they interact across scales underpins both current and future ecosystem services supply (Folke et al., 2004; Isbell et al., 2011).

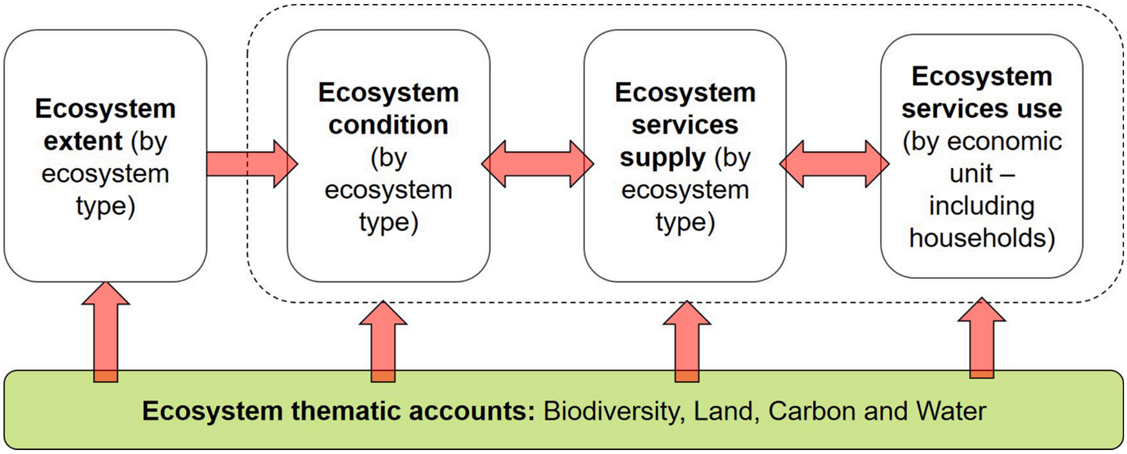


Fig. 2. Core Physical Accounting Modules of the SEEA-EEA (replication of Fig. 2.3a, UN et al., 2017). The dotted line and double arrows reflect measurement of ecosystem condition and services may be concurrent and iterative.

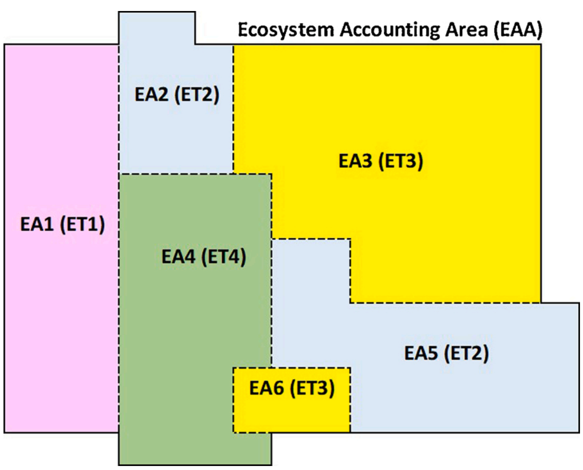


Fig. 3. Relationship between Ecosystem Assets, Ecosystem Types and Ecosystem Accounting Areas (reproduced from Fig. 3.1, UN et al., 2017).

With respect to species-level biodiversity, the SEEA EEA proposes a structure for a 'Species Abundance' Account (UN et al., 2014). This essentially comprises an inventory of abundance for different taxonomic groups and provides an opening measure and a closing measure for various species-related data items and associated changes over an accounting period. The logic of accounting for species abundance is that certain species may be directly relevant to ecosystem service supply (e.g., number of fish or pollinators), as well as conservation concern. As an alternative, maintaining species ranges of occupancy (i.e., the extent of their presence and suitable habitat) can also be implemented in order to inform on ecosystem service and conservation management goals for biodiversity (Ferrier, 2011). However, just as measures of extent and condition of ecosystem types under SEEA EEA do not adequately reflect the emphasis of variability implicit in the CBD's definition of biological diversity (CBD, 1992), the same is true of measures of distribution and abundance of individual species.

The SEEA EEA Technical Recommendations (UN et al., 2017) provides some further clarification, where measures of species-level diversity are considered a characteristic of the condition of Ecosystem Assets (i.e., areas of contiguous ecosystem type) that can be degraded or enhanced over time. Maintaining local species diversity (i.e., alpha diversity) implies more species (or more species retained) within individual Ecosystem Assets. As such, a larger number of functional traits is conferred upon the asset (or retained by the asset). Such assets are likely to be characterised as multifunctional, delivering a relatively wider range of ecosystem services (Gamfeldt et al., 2013; Wagg et al., 2014) and exhibiting higher ecosystem resilience (Elmqvist et al., 2003; Sundstrom et al., 2012).

Thus, there are two main objectives that Species Accounts may serve:1) the measurement of the 'Stocks of individual Species' that directly underpin ecosystem services supplied by Ecosystem Assets (including conservation-based values); and 2) the measurement of 'Species Diversity' as a key indicator for characterising the condition of Ecosystem Assets (i.e., its compositional integrity). However, there is an additional role for these accounts for characterising biodiversity at scale (i.e., for entire EAAs), expanded upon later.

3.1. Linking biodiversity to the core physical SEEA EEA accounts

In Fig. 4, we reproduce the model of the core physical SEEA EEA accounts in Fig. 2 and link it to different biodiversity indicators and interactions with the economy. To this end, Fig. 4 explicitly recognises ecosystems and species as different components of biodiversity and how these interact in the supply of ecosystem services. We stress that Fig. 4 is entirely compatible with the core SEEA EEA accounting model in Fig. 2. In both figures, Species / Biodiversity Accounts are cross-cutting and can inform all of the core SEEA EEA physical accounts. For instance, information on species may be used to inform the ecosystem typologies and used to delineate Ecosystem Assets when calculating ecosystem extent accounts (Arrow A, Fig. 4) or generate local (alpha) species-diversity indicators for ecosystem condition accounting (Arrow A1 & A3, Fig. 4). However, species-diversity indicators may also be estimated directly for inclusion in Ecosystem Condition Accounts (Arrow A2 and A3).

Species Accounts themselves need not be confined to measurement of species diversity within Ecosystem Assets. Rather, it is anticipated that the Species Accounts will organize information at landscape scales for different EAAs (Arrow A1). This is the approach for measuring diversity of butterfly species in the Australian case study (Table 2). Species Accounts that cover multiple Ecosystem Assets at landscape scales also provide a means of dealing with the complications of some species lifecycles and their use of different ecosystems (Tscharntke et al., 2005; UNEP-WCMC, 2016)

Arrows A and A3, between the Ecosystem Asset Accounts and the Species Accounts and Species Diversity Indicators box, are double ended. This is because Ecosystem Asset Accounts contain information that can also be used to help infer species status. For instance, on the extent of suitable habitat for species of interest (e.g., as per the Uganda case study, Section 4.1, Arrow A) or information relevant to species' responses to land use pressures (represented by Arrow A3). Species loss within Ecosystem Assets implies a loss of some ecosystem function,

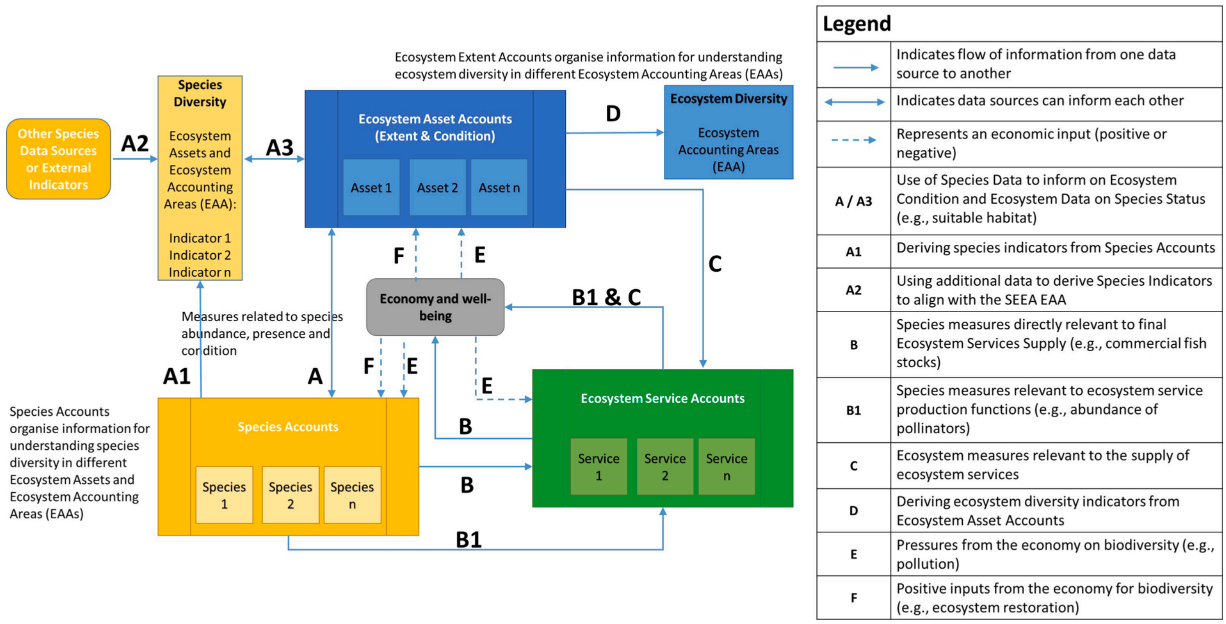


Fig. 4. Applying a biodiversity perspective to the core physical SEEA EEA accounts (Adapted from UNEP-WCMC, 2016).

which may impact ecosystem service supply now and into the future (represented by Arrow C).

Ultimately, the benefits that species provide (e.g., food, wildlife watching, pollination) will be realized at a particular location and time and attributed to an Ecosystem Asset (or combination of assets). Ecosystem service accounts are used to organize this spatially explicit information on ecosystem service supply and use. In this context, species measures may directly relate to final ecosystem service supply (e.g., harvested fish, Arrows B). Alternatively, the ecosystem services may derive from a production function in which species contribute (e.g., pollinator species contribute to the supply of nuts and fruits, Arrows B1 and B1 & C).

Arrows E in Fig. 4, represents the negative pressures from the economy on Ecosystem Assets and species (e.g., land use change, ecosystem fragmentation, pollution, species over-harvesting and poaching). Arrows F in Fig. 4, represents positive inputs from economic agents (e.g., ecosystem restoration, control of invasive species or reintroduction of native species).

Genetic diversity has been shown to have significant effects on ecological processes that underpin ecosystem services supply (Bolnick et al., 2011; Hughes et al., 2008). However, this component of biodiversity is not explicitly considered in Fig. 4. This is because of the challenges in obtaining multi-year, spatially explicit information on genetic diversity for integration with SEEA EEA (considered further in our discussion). However, where meta-populations become fragmented, Species Accounts could play a role in tracking transfers of individuals between different EEAs. This would be relevant for maintaining gene pool diversity (e.g., when translocating species between protected areas, observation from Rudd Jansen, Conservation International).

3.2. Accounting for biodiversity at scale

From a biodiversity perspective, it is also crucial to assess not only species diversity within Ecosystem Assets but also the diversity in species assemblages between these Ecosystem Assets (i.e., variation in the composition of assemblages both within and between ecosystem types). Directly relevant to this is the growing body of research on the importance of beta diversity (i.e., differences in biological composition between locations) and gamma diversity (variation in biological composition within whole landscapes) (Burley et al., 2016; Ferrier, 2002). Accounting for the complementarity of species assemblages is the core motivation here. In this sense, complementarity (beta diversity) regulates how the richness of local species assemblages (alpha diversity) combines to generate the gamma diversity of the whole, larger system (i.e., the EAA) (Colwell and Coddington, 1994). This concept is scalable, for example in relation to the species assemblages located in the root systems and canopies of individual trees to the pattern of species assemblages at landscape level (McGill et al., 2015).

Different species and species assemblages perform different functional roles. They also have varying degrees of resilience to different pressures. Understanding the complementarity between species and species assemblages with respect to the functions they perform is a concern if ambitions for resilient multi-functional landscapes are to be realized. However, making these links requires indicators that go beyond assessing the local species richness (alpha diversity) of Ecosystem Assets. Given that Ecosystem Assets are defined as discrete spatial occurrences (i.e., patches of a contiguous ecosystem type), the total biodiversity value (i.e., gamma diversity) of the larger EAA cannot be derived simply by averaging or summing the alpha diversity measures of Ecosystem Assets (recorded in ecosystem condition accounts). This is because spatial scaling of biodiversity is strongly non-additive (i.e., biodiversity is scale dependent). This means that any assessment of the collective state of biodiversity within an EAA containing multiple Ecosystem Assets must consider not only the state of biodiversity within each of these assets, but also complementarities in species composition (i.e., beta diversity) between these assets.

Consideration of complementarities in species assemblages can be achieved only through whole-landscape approaches to biodiversity assessment (e.g., Ferrier and Drielsma, 2010). This requires the calculation of appropriate biodiversity indicators directly at the EAA scale (i.e., of gamma diversity), as well as Ecosystem Asset scale (Kim et al., 2018). Ecosystem diversity measures derived from Ecosystem Extent Accounts may help in quantifying gamma diversity in EAAs (Arrow D, Fig. 4). These will be most informative where the ecosystem typology employed provides a good representation of the distribution of different species assemblages (i.e., when it is closely aligned to spatial distribution of distinct sets of organisms that form a functional unit) (UNEP-WCMC, 2016). However, this is unlikely to yield a satisfactory metric of the variation in species-level assemblages in EAAs, particularly when rather broad ecosystem typologies are employed (as is often the case when land cover is used to delineate ecosystems). As such, these types of indicators for gamma diversity should be part of the set of species diversity indicators at EEA scale included in the 'Species Diversity' box in Fig. 4. The San Martin, Peru case study in Section 4.3 presents an example of this approach.

4. Species Accounting case studies

Compiling Species Accounts to better link this component of biodiversity into national accounts is relatively novel, even in the experimental context of the SEEA EEA. In order to illustrate possibilities, this section presents a set of real-world Species Accounting case studies. These case studies present information on different selections of species and species groups that speak to different policy and land management concerns. It is essential when developing Species Accounts that these management and policy concerns are identified upfront to ensure the accounts meet the needs of users and decision-makers (Vardon et al., 2016). For instance, species could be selected due to their functional traits, being charismatic or endangered, endemism or providing direct use benefits.

The availability of appropriate data for the compilation of Species Accounts is often a challenge for their compilation. The ideal situation is for data to be from regularly compiled, consistent and representative primary monitoring of species populations. In this context, representative implies representation across ecosystems, space, time and taxonomy of species groups. This 'Direct Observation' approach is employed for the Australian case studies. It should be noted that further processing of 'Direct Observation' data may be required where populations show high inter-annual variations and where variations in species detectability and sampling intensities need to be controlled for (e.g., see Roy et al., 2019).

The emergence of Citizen science programs, such as eBird (http://www.ebird.org) and iNaturalist (https://www.inaturalist.org/) can also support 'Direct Observation' Species Accounting approaches. However, these programmes tend to suffer from spatial bias towards populated locations (Fletcher et al., 2019) and from the largely opportunistic manner in which observations are generated (Bayraktarov et al., 2019). This can pose significant challenges for any attempt to extract information on biodiversity change from such datasets.

Where 'Direct Observation' data on species are sufficiently limited, an alternative approach based on observations of changes in the spatial extent and configuration of habitat required by species may be employed (Ferrier, 2011). These 'Habitat-based approaches' for Species Accounting were employed for the Uganda and San Martin case studies.

4.1. Uganda Species Accounts

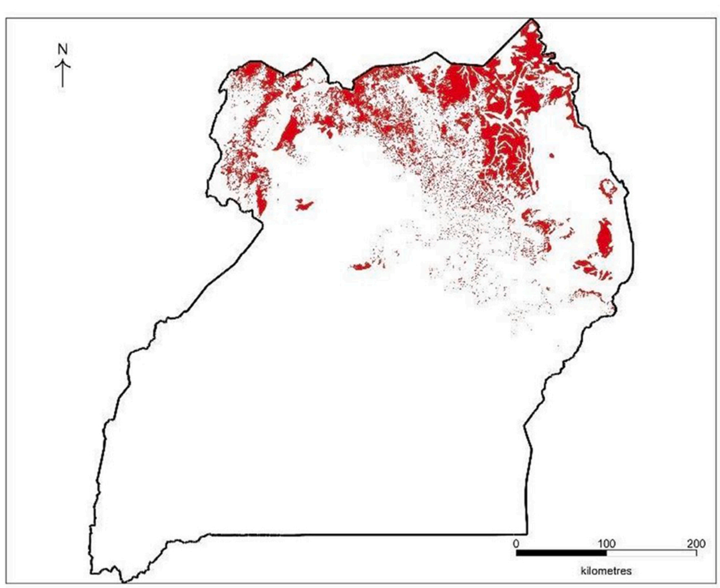
UNEP-WCMC and IDEEA (2017) presented 'Species Accounts' for iconic wildlife species (Chimpanzees and Elephants) and selected Non-Timber Forest Product species (NTFPs, including Shea Butter Nuts and Gum Arabic). These Species Accounts inform on the national debate on degazettement of protected areas, where declining biodiversity threatens ecosystem services and progress towards the objectives of Uganda's National Biodiversity Strategy and Action Plan (NBSAP II) and National Development Plan (NDP II, recently updated to ND III).

The Species Accounts were compiled using information from ecosystem extent accounts to infer the potential extent of suitable habitat for iconic and NTFP species (represented by the double headed Arrow A linking the Ecosystem Asset and Species Accounts in Fig. 4). For instance, the extent of suitable habitat for Shea Butter Nut Trees was based on the extent of Butyrospermum in Dry Combretum savannah (i.e., vegetation classes that include Shea Butter Nut Trees) in areas of natural land cover.

The Species Accounts identified large areas in the north of Uganda that provided suitable habitat for Shea Butter Nut Trees (Fig. 5). As shown via the simplified account in Fig. 5, whilst over 20 % of this habitat had been lost between 1990 and 2015, over 2 million ha still exists. A vast majority of the remaining Shea Butter Nut Tree habitat was outside of the protected areas estate.

For other species, the accounts revealed the protected area estate covered a large majority of remaining suitable habitat for Chimpanzees and Elephants in Uganda (87 % and 81 % respectively in 2015). However, when looking at sub-national EAAs, significant reductions in the areas of chimpanzee suitable habitat and elephant suitable habitat were observed in the Western sub-region of Uganda between 2005 and 2015 (-86,154 ha and -57,383 ha, respectively).

Whilst habitat suitability is no guarantee of species occurrence, the Species Accounts for Uganda direct attention to areas where ecological and economic returns on species may be most likely realized. They can



	Extent (ha)
Opening Stock (1990)	2,706,485
Net change	-605,561
Closing Stock (2015)	2,100,924
Protected Stock (2015)	442,466
Unprotected Stock (2015)	1,658,458

Fig. 5. Uganda Shea Butter Nut Tree Accounts (1990 to 2015). The red areas in the map represent the closing stock of Shea Butter Nut Tree suitable habitat in 2015.

be used to inform policy on NTFP harvesting, where the protected areas estate is safeguarding wildlife watching tourism opportunities and where it could be extended (i.e., with respect to Arrow B in Fig. 4). Species Accounts can also guide development investment plans based on sustainable exploitation of NTFP and iconic species. For example, by identifying where potential Shea Butter Nut harvesting and processing may be viable as part of a combined conservation and development programme outside of protected areas.

4.2. Australian accounts for endangered species and butterflies

A range of different accounts related to biodiversity have been produced for different parts of Australia. Keith et al. (2017) produced accounts for endangered species for the Central Highlands of Victoria as input to on-going discussions on forest management (Table 1). The change in threat category of a species represents change in its extinction risk, which can be used to infer indicative changes in biodiversity for the EAA of the Central Highlands. Table 1 reveals a steady and consistent increase in the number of species being classified as endangered in the Central Highlands. These Endangered Species Accounts were part of an integrated set of accounts that allowed analysis of the trade-off between managing the forest for timber supply versus the supply of water and carbon storage. They demonstrated that supply of water and carbon storage were compatible with management of forest for biodiversity conservation, while timber harvesting was not. They also allowed the economic costs of biodiversity conservation to be evaluated, in terms of timber harvesting revenue foregone.

For the Australian Capital Territory (ACT), Bond and Vardon (2019) prepared a set of accounts for butterflies as input to the ACT State of the Environment Report. The accounts span four decades (1978–2019), identifying 88 butterfly species in five families. Of the 88 species, 63 are endemic to Australia, 69 breed in the ACT and the other 19 species are migratory or vagrants. Of the 69 breeding species, 40 are habitat specialists and not all species are found in all years. The number of species found increased by ten between 1978 and 2019 due to the finding of six more Australian endemic species, three more non-endemics and one taxonomic reclassification. Systematic surveys were used for the period 2014−15 to 2018−19 and these show a net gain of 7 species (Table 2).

The butterfly accounts provide a useful indicator of species-level biodiversity at the state scale (EAA, Arrow A1 in Fig. 4). This indicator is spatially and temporally consistent with other economic indicators, helping to reveal sustainable development progress in the ACT as it relates to one component of biodiversity. A key practical aspect to emerge from the production of these accounts was that it is necessary to consider a range of different classifications for Species Accounts (e.g., local and national endemics, non-endemics, introduced species). In particular, it is necessary to consider more than just the threat status of species, for example the degree of endemism. This is because endemic species are often a key conservation concern and can be a surrogate for directing conservation action for biodiversity generally (Lamoreux et al., 2006).

Table 1
Endangered Species Account for the Central Highlands (species listed under the Environmental Protection and Biodiversity Conservation Act 1999).

	Regionally Extinct	Critically Endangered	Endangered	Vulnerable
2000	2	0	12	14
2005	2	1	13	15
2010	2	1	13	18
2015	2	5	14	17
Net change	0	5	2	3

Table 2
Butterfly Species Account for the ACT, 2014 – 2019.

	Native species			Introduced species	
	Endemic ACT	Endemic Australia	Non-endemic Australia	Introduced Australia	**Total**
2014−15	0	40	12	1	53
2015−16	0	40	12	1	53
2016−17	0	41	15	1	57
2017−18	0	51	10	1	62
2018−19	0	49	10	1	60
Net change (2014−15 to 2018−19)	0	9	−2	0	7

4.3. Biodiversity accounts for San Martin, Peru

San Martin is a region in northern Peru along the eastern slopes of the Andes, representing an area that is among the most biodiverse on the planet. Home to almost one million people, San Martin is characterized by a complex landscape consisting of diverse natural ecosystems and land uses, particularly forestry and agricultural production. Grantham et al. (2016) developed biodiversity indicators and accounts for the San Martin region (EAA) to inform the government's progressive green development policies that aim to curb ongoing threats such as illegal deforestation and the associated loss of biodiversity and ecosystem services. This was part of a broader pilot of developing a set of ecosystem accounts.

One of the key approaches used by Grantham et al. (2016) for biodiversity indicators and accounting was the application of Generalised Dissimilarity Modelling (GDM) (Ferrier et al., 2007) to measure change in species diversity. GDM is a community-level modelling approach that allows differences in environmental conditions to be represented in terms of their effect on species composition for whole biological groups. It is then possible to compare the expected ecological similarity of any location with all other locations in modelled environmental space (i.e., the EAA). This allows the environmental uniqueness of a location, degree of human modification, and its contribution to regional biodiversity (i.e., gamma diversity) to be assessed (Allnutt et al., 2008).

The biodiversity account produced by Grantham et al. (2016) measures the proportion of species retained between three time periods (2009, 2011, and 2013), against what would be assumed to be there in the absence of human modification (i.e., natural conditions) (Table 3). Table 3 shows a continuing decline in species retained across each major ecosystem type in San Martin for each major taxonomic group (vascular plants, vertebrates and invertebrates), as well as for species overall This represents Arrow A3 in Fig. 4, linking species diversity to condition of EAs of the same Ecosystem Type in an EAA). For the San Martin region as a whole, Table 3 also shows continuing loss of species-level biodiversity between 2009 and 2013 within all three major taxonomic groups and overall (Arrow A1 / A2 in Fig. 4 linking species data to diversity across EAAs)

An important feature of organizing biodiversity indicators by ecosystem type in Table 3, is that this allows the indicators to be linked with information in other ecosystem accounts. This reveals trade-offs and synergies among biodiversity and ecosystem services and how these are affected by changes in ecosystem extent and condition (Arrow C in Fig. 4). For example, an unexpected finding indicated that palm swamps represent exceptionally high-value ecosystems on a per hectare basis for both species-level biodiversity and ecosystem services yet have been largely transformed for rice. Consequently, and based on these results, the government has been exploring the feasibility of restoring low-value rice production areas to palm swamp. The results of the biodiversity accounts are also being used as part of an Ecological

Table 3
Proportion of species richness retained over time by taxonomic group and ecosystem type for San Martin, Peru.

Ecosystem Type	Invertebrates (% species retained)			Vascular plants (% species retained)			Vertebrates (% species retained)			All taxa (% species retained)		
	2009	**2011**	**2013**	**2009**	**2011**	**2013**	**2009**	**2011**	**2013**	**2009**	**2011**	**2013**
Palm Swamps	91.90 %	91.31 %	90.96 %	92.21 %	91.65 %	91.31 %	86.97 %	86.62 %	86.42 %	90.36 %	89.86 %	89.56 %
Humid Forest with High Hills	91.89 %	91.30 %	90.95 %	91.98 %	91.40 %	91.05 %	86.46 %	86.10 %	85.89 %	90.11 %	89.60 %	89.30 %
Humid Forest with Low Hills	91.82 %	91.21 %	90.86 %	92.08 %	91.48 %	91.13 %	86.73 %	86.36 %	86.15 %	90.21 %	89.68 %	89.38 %
Humid Montane Forest	93.94 %	93.54 %	93.25 %	94.03 %	93.63 %	93.34 %	90.53 %	90.29 %	90.12 %	92.83 %	92.49 %	92.24 %
Lowland Terra Firme Forest	91.79 %	91.23 %	90.88 %	91.47 %	90.91 %	90.56 %	85.88 %	85.52 %	85.31 %	89.71 %	89.22 %	88.92 %
Floodplain Forest	90.99 %	90.39 %	90.03 %	90.77 %	90.17 %	89.82 %	85.30 %	84.92 %	84.71 %	89.02 %	88.49 %	88.19 %
Shrubs	95.29 %	95.10 %	94.95 %	95.97 %	95.86 %	95.76 %	95.49 %	95.42 %	95.36 %	95.58 %	95.46 %	95.36 %
High Andean Grasslands	95.59 %	95.44 %	95.33 %	95.82 %	95.71 %	95.61 %	95.45 %	95.38 %	95.32 %	95.62 %	95.51 %	95.42 %
Entire San Martin Region	94.08%	93.72 %	93.47 %	94.04 %	93.67 %	93.41 %	90.89 %	90.66 %	90.51 %	93.00 %	92.68 %	92.46 %

Economic Zoning initiative which is assessing sustainable, alternative uses of forests and other ecosystems.

5. Discussion

The case study Species Accounts presented were compiled using existing data, so the potential of the accounts could be demonstrated. The use of different data types across the three case studies requires a flexible data presentation approach, yielding different accounting structures. This reflects our previous observation that Species Accounting remains relatively new, even within the experimental context of the SEEA EEA. Moving to standard structures and data sets would be very helpful for building familiarity and understanding with potential users of the accounts. A challenge is how to best consider migratory species, which may also underpin ecosystem services supply (e.g., duck hunting and pollination). This is because an international spatial disconnect often emerges between the habitats that most support these species and where these ecosystem services are used (Bagstad et al., 2019; Semmens et al., 2018). This implies the need to structure Species Accounts in a way that can inform transboundary cooperation around conservation and ecosystem service benefits for migratory species.

It is vital that direct observation and habitat-based approaches for estimating biodiversity change shown in the case studies are not viewed as mutually exclusive, or competing, alternatives. There is much to be gained by taking advantage of the complementary strengths of these information sources, and of ongoing advances in analytical techniques for more effectively integrating direct field-based and indirect remotely-sensed data streams. Statistical modelling, or machine learning, of relationships between sparse field observations and remotely-derived habitat variables offers a powerful means of extrapolating changes in species occurrence or abundance across space and time (Ferrier, 2011). Field-based monitoring should also play a key ongoing role in evaluating such model-based extrapolations, and in the progressive calibration and refinement of underpinning models.

Advances are also being made in the development of analytical approaches integrating direct and indirect data streams to assess change in ecosystem- and genetic-level diversity (e.g., Mimura et al., 2017). These offer considerable promise for more effectively incorporating these levels of organisation into future SEEA EEA accounts. Cost-effective estimation of change across large spatial extents, and at all three levels of biodiversity, is also likely to benefit enormously over coming years from rapid advances being made in the development and deployment of new cutting-edge observation technologies, both direct and indirect. For instance, high-throughput sequencing of environmental-DNA samples and satellite-borne hyperspectral sensing of plant community composition (e.g., Bush et al., 2017).

5.1. Linking biodiversity into economic accounts via the SEEA EEA

Combined presentations of indicators for the different components of biodiversity with wider economic statistics is an immediate means of using information organized by the SEEA EEA for mainstreaming biodiversity (see para 8.11, UN et al., 2017). For example, presenting information on species and ecosystem trends alongside trends in impacting economic activities (as per the Central Highlands case study). Alternatively, information on species, ecosystems and associated ecosystem services can be presented alongside information on other key development concerns, such as employment in the fisheries or wildlife watching tourism sectors, poverty, food security or environmental protection expenditure. This information can inform more holistic cross sectoral economic planning that recognises the multiple benefits biodiversity provides and mitigates economic impacts (e.g., as envisaged via Ecological Economic Zoning in the San Martin case study). As the SEEA EEA is scalable, it also opens up the opportunity to align these combined presentations with the established biodiversity assessment (e.g., Mokany et al., 2019) and integrated landscape management approaches (e.g., Meijer et al., 2019).

Valuation of ecosystem services opens up possibilities for mainstreaming the values of different aspects of biodiversity into economic planning via the monetary ecosystem service supply and use and asset accounts of the SEEA EEA (UN et al., 2017, 2014). This would also support integrated analyses for greener, central economic planning. Where the relationship between biodiversity, ecosystem services and goods recorded in the SNA can be articulated, economic modelling of the effects of increases in ecosystem service supply to economic output can be undertaken. La Notte et al. (2020) provide a relevant example, which links control of Asian Hornets (an invasive species) and to improved abundance of wild pollinators and crop pollination services. Increased ecosystem service supply is then bridged to key economic indicators using established economy-wide modelling (i.e., general equilibrium modelling). Banerjee et al. (2020) provide a similar analysis for Rwanda, modelling the effect of land use decisions on ecosystems and ecosystem service supply on standard economic indicators for Green Economy planning.

Notwithstanding the above, achieving a full integration of biodiversity into national economic accounting is challenging and requires valuing a very broad set of ecosystem services. This includes values placed by society on the continued existence of biodiversity for spiritual, religious or non-use reasons (Haines-Young and Potschin, 2018); bequest values associated with endowing future generations with adequate biodiversity (Walsh et al., 1984); option values reflecting that elements of biodiversity may prove valuable in the future (Weitzman, 1992); and, insurance values associated with biodiversity and the resilience of ecosystem services supply (Baumgärtner, 2007). Furthermore, as biodiversity represents all the different parts of the system essential for the ecological processes underpinning ecosystem service supply, it can be considered to have an infrastructure or 'glue' value (Turner et al., 2003). Many of these values are captured via the IPBES (2019) Nature's Contribution to People 1 (NCP 1) 'habitat creation and maintenance'. Whilst environmental economics has developed approaches to estimate these types of values, this often requires the deployment of so-called expressed preference survey methods. The resulting estimates are not exchange values and do not fit into a strict SNA protocol for accounting. It is also the case that some aspects of biodiversity that are essential to consider for development to proceed in balance with nature will remain beyond monetary calculus.

Building the understanding and capacity for using the SEEA EEA may then be best accomplished by building protocols as a complementary accounting framework, rather than seeking full economic integration within the SNA. The Complementary Accounts Network (CAN) idea is proposed as a pragmatic way forward here (Turner et al., 2019). This builds on the combined presentations discussed above. Rather than trying to adjust the measures of production, consumption, income and the value of assets in the SNA to reflect biodiversity losses or gains, CAN seeks to assemble 'complementary' sets of indices to sit alongside GDP and other economic statistics on the same timescale. The framework presented in Fig. 4 directly supports a CAN type approach to generating a 'dashboard' of physical and monetary indicators linked to biodiversity.

6. Conclusions

This paper highlights multiple entry points for biodiversity data in the core biophysical accounts of the SEEA EEA. It argues the importance of Species Accounts for integrating this component of biodiversity in to the SEEA-EEA. This will better inform management of the supply of ecosystem services directly related to species and the myriad of services that arise via the interactions of species with the abiotic environment.

Implementation of the SEEA EEA by national statistical offices in a way that best represents biodiversity will be challenging. Establishing and resourcing the right institutional collaborations with government agencies with the mandate for biodiversity assessment and conservation will be crucial. Such collaboration should be reciprocal, in that the SEEA EEA will integrate information from existing national and international biodiversity conservation reporting frameworks, as well as delivering information to inform them. However, building the understanding and the capacity of a wide range of decision-makers to use the accounts is an urgent investment priority if the SEEA is to deliver on its potential to steer us on a development pathway that makes sustainable use of biodiversity.

Despite the challenges in applying the SEEA EEA more broadly, the ability of the framework to integrate environmental, social and economic information make it an essential tool to recognise the benefits biodiversity provides and address its loss. The upcoming CBD Conference of the Parties, provides the biodiversity community with a key opportunity to press for better representation of biodiversity in national accounts via the SEEA and better mainstreaming of biodiversity into national planning. This will be essential for taking us a step beyond GDP, so that national economic accounting can guide decision-making for sustainable development that delivers better outcomes for people and nature.

Funding

The preparation of this paper was supported by the EU MAIA project (Project Number H2020-SC5-2018-1. Grant Number 817527). We also acknowledge funding from the UK Research and Innovation's Global Challenges Research Fund (UKRI GCRF) through the Development Corridors Partnership project (project number: ES/P011500/1). UNEP-WCMC would like to thank the Government of Norway for funding a 2016 Species Accounting workshop and the Swedish International Development Cooperation Agency (SIDA) for funding the Uganda case study. Michael Vardon's research is co-funded by the Australian Government's National Environmental Science Program through the Threatened Species Recovery Hub and Sustainable Farms, an initiative of the Australian National University.

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

We would like to thank all the participants at the UNEP-WCMC workshop on Species Accounting in 2016. Their ideas and input have contributed greatly to this paper and underpin the presentation provided in Fig. 4.

References

ABS, 2017. Experimental Environmental-Economic Accounts for the Great Barrier Reef, 2017 (No. ABS cat. no. 4680.0).

Allnutt, T.F., Ferrier, S., Manion, G., Powell, G.V.N., Ricketts, T.H., Fisher, B.L., Harper, G.J., Irwin, M.E., Kremen, C., Labat, J.-N., Lees, D.C., Pearce, T.A., Rakotondrainibe, F., 2008. A method for quantifying biodiversity loss and its application to a 50-year record of deforestation across Madagascar. Conserv. Lett. 1, 173–181. https://doi.org/10.1111/j.1755-263X.2008.00027.x.

Bagstad, K.J., Semmens, D.J., Diffendorfer, J.E., Mattsson, B.J., Dubovsky, J., Thogmartin, W.E., Wiederholt, R., Loomis, J., Bieri, J.A., Sample, C., Goldstein, J., López-Hoffman, L., 2019. Ecosystem service flows from a migratory species: spatial subsidies of the northern pintail. Ambio 48, 61–73. https://doi.org/10.1007/s13280-018-1049-4.

Balvanera, P., Pfisterer, A.B., Buchmann, N., He, J.-S., Nakashizuka, T., Raffaelli, D., Schmid, B., 2006. Quantifying the evidence for biodiversity effects on ecosystem functioning and services. Ecol. Lett. 9, 1146–1156.

Balvanera, P., Siddique, I., Dee, L., Paquette, A., Isbell, F., Gonzalez, A., Byrnes, J., O'Connor, M.I., Hungate, B.A., Griffin, J.N., 2014. Linking biodiversity and ecosystem services: current uncertainties and the necessary next steps. Bioscience 64, 49–57. https://doi.org/10.1093/biosci/bit003.

Banerjee, O., Bagstad, K.J., Cicowiez, M., Dudek, S., Horridge, M., Alavalapati, J.R.R., Masozera, M., Rukundo, E., Rutebuka, E., 2020. Economic, land use, and ecosystem services impacts of Rwanda's Green Growth Strategy: an application of the IEEM+ESM platform. Sci. Total Environ. 729, 138779 https://doi.org/10.1016/j.scitotenv.2020.138779.

Baumgärtner, S., 2007. The insurance value of biodiversity in the provision of ecosystem services. Nat. Resour. Model. 20, 87–127.

Bayraktarov, E., Ehmke, G., O'Connor, J., Burns, E.L., Nguyen, H.A., McRae, L., Possingham, H.P., Lindenmayer, D.B., 2019. Do big unstructured biodiversity data mean more knowledge? Front. Ecol. Evol.

Bogaart, P., Polman, E., Verweij, R., van Swaay, C., 2020. The SEEA-EEA Experimental Biodiversity Account for the Netherlands..

Bolnick, D.I., Amarasekare, P., Araújo, M.S., Bürger, R., Levine, J.M., Novak, M., Rudolf, V.H.W., Schreiber, S.J., Urban, M.C., Vasseur, D.A., 2011. Why intraspecific trait variation matters in community ecology. Trends Ecol. Evol. (Amst.) 26, 183–192. https://doi.org/10.1016/j.tree.2011.01.009.

Bond, S., Vardon, M., 2019. Butterfly Accounts for the Australian Capital Territory: a Report to the Commissioner for Sustainability and the Environment. Canberra, Australia..

Burley, H., Mokany, K., Ferrier, S., Laffan, S., Williams, K., Harwood, T., 2016. Macroecological scale effects of biodiversity on ecosystem functions under environmental change. Ecol. Evol. 6, 2579–2593.

Burnett, P., Vardon, M., Keith, H., King, S., Lindenmayer, D., 2020. Measuring net-positive outcomes for nature using accounting. Nat. Ecol. Evol. 4, 284–285. https://doi.org/10.1038/s41559-020-1108-7.

Bush, A., Sollmann, R., Wilting, A., Bohmann, K., Cole, B., Balzter, H., Martius, C., Zlinszky, A., Calvignac-Spencer, S., Cobbold, C.A., Dawson, T.P., Emerson, B.C., Ferrier, S., Gilbert, M.T.P., Herold, M., Jones, L., Leendertz, F.H., Matthews, L., Millington, J.D.A., Olson, J.R., Ovaskainen, O., Raffaelli, D., Reeve, R., Rödel, M.-O., Rodgers, T.W., Snape, S., Visseren-Hamakers, I., Vogler, A.P., White, P.C.L., Wooster, M.J., Yu, D.W., 2017. Connecting Earth observation to high-throughput biodiversity data. Nat. Ecol. Evol. 1, 176. https://doi.org/10.1038/s41559-017-0176.

Cardinale, B.J., Duffy, J.E., Gonzalez, A., Hooper, D.U., Perrings, C., Venail, P., Narwani, A., Mace, G.M., Tilman, D., Wardle, D.A., Kinzig, A.P., Daily, G.C., Loreau, M., Grace, J.B., Larigauderie, A., Srivastava, D.S., Naeem, S., 2012. Biodiversity loss and its impact on humanity. Nature 486, 59–67.

CBD, 1992. Convention on Biological Diversity. Article 2: Use of Terms.

Colwell, R.K., Coddington, J.A., 1994. Estimating terrestrial biodiversity through extrapolation. Philos. Trans. R. Soc. Lond., B, Biol. Sci. 345, 101–118.

Devictor, V., Mouillot, D., Meynard, C., Jiguet, F., Thuiller, W., Mouquet, N., 2010. Spatial mismatch and congruence between taxonomic, phylogenetic and functional diversity: the need for integrative conservation strategies in a changing world. Ecol. Lett. 13, 1030–1040. https://doi.org/10.1111/j.1461-0248.2010.01493.x.

Díaz, S., Lavorel, S., Chapin, F.S., Tecco, P.A., Gurvich, D.E., Grigulis, K., 2007. Functional diversity - at the crossroads between ecosystem functioning and environmental filters. In: Canadell, J.G., Pataki, D.E., Pitelka, L.F. (Eds.), Terrestrial

Ecosystems in a Changing World. Springer, Berlin Heidelberg, Berlin, Heidelberg, pp. 81–91. https://doi.org/10.1007/978-3-540-32730-1_7.

Driver, A., Nel, J.L., Smith, J., Daniels, F., Poole, C.J., Jewitt, D., Escott, B.J., 2015. Land and Ecosystem Accounting in KwaZulu-Natal, South Africa. Discussion Document for Advancing SEEA Experimental Ecosystem Accounting Project, October 2015. Pretoria, South Africa..

Eigenraam, M., Obst, C., 2018. Extending the production boundary of the System of National Accounts (SNA) to classify and account for ecosystem services. Ecosyst. Heal. Sustain. 4, 247–260. https://doi.org/10.1080/20964129.2018.1524718.

Elmqvist, T., Folke, C., Nyström, M., Peterson, G.D., Bengtsson, J., Walker, B., Norberg, J., Nystrom, M., 2003. Response diversity, ecosystem change, and resilience. Front. Ecol. Environ.

European Commission, International Monetary Fund, Organisation for Economic Co-operation and Development, United Nations, World Bank, 2009. System of National Accounts 2008. New York.

Ferrier, S., 2002. Mapping spatial pattern in biodiversity for regional conservation planning: where to from Here? Syst. Biol. 51, 331–363. https://doi.org/10.1080/10635150252899806.

Ferrier, S., 2011. Extracting more value from biodiversity change observations through integrated modeling. Bioscience 61, 96–97. https://doi.org/10.1525/bio.2011.61.2.2.

Ferrier, S., Drielsma, M., 2010. Synthesis of pattern and process in biodiversity conservation assessment: a flexible whole-landscape modelling framework. Divers. Distrib. 16, 386–402.

Ferrier, S., Manion, G., Elith, J., Richardson, K., 2007. Using generalized dissimilarity modelling to analyse and predict patterns of beta diversity in regional biodiversity assessment. Divers. Distrib. 13, 252–264. https://doi.org/10.1111/j.1472-4642.2007.00341.x.

Fletcher Jr., R.J., Hefley, T.J., Robertson, E.P., Zuckerberg, B., McCleery, R.A., Dorazio, R.M., 2019. A practical guide for combining data to model species distributions. Ecology 100, e02710. https://doi.org/10.1002/ecy.2710.

Folke, C., Carpenter, S., Walker, B., Scheffer, M., Elmqvist, T., Gunderson, L., Holling, C. S., 2004. Regime shifts, resilience, and biodiversity in ecosystem management. Annu. Rev. Ecol. Evol. Syst. 35, 557–581. https://doi.org/10.1146/annurev.ecolsys.35.021103.105711.

Gamfeldt, L., Snäll, T., Bagchi, R., Jonsson, M., Gustafsson, L., Kjellander, P., Ruiz-Jaen, M.C., Fröberg, M., Stendahl, J., Philipson, C.D., Mikusiński, G., Andersson, E., Westerlund, B., Andrén, H., Moberg, F., Moen, J., Bengtsson, J., 2013. Higher levels of multiple ecosystem services are found in forests with more tree species. Nat. Commun. 4, 1340.

Grantham, H., Juhn, D., Larsen, L., Ferrier, S., Gov. of Peru, 2016. Case study of species accounts San Martin, Peru. In: UNEP-WCMC (Ed.), Exploring Approaches for Constructing Species Accounts in the Context of the SEEA-EEA. UNEP, Cambridge, UK, pp. 145–151.

Haines-Young, R., Potschin, M.B., 2018. Common International Classification of Ecosystem Services (CICES) V5.1 and Guidance on the Application of the Revised Structure..

Hein, L., Bagstad, K.J., Obst, C., Edens, B., Schenau, S., Castillo, G., Soulard, F., Brown, C., Driver, A., Bordt, M., Steurer, A., Harris, R., Caparrós, A., 2020. Progress in natural capital accounting for ecosystems. Science (80-.) 367. https://doi.org/10.1126/science.aaz8901, 514 LP – 515.

Hooper, D.U., Chapin, F.S., Ewel, J.J., Hector, A., Inchausti, P., Lavorel, S., Lawton, J.H., Lodge, D.M., Loreau, M., Naeem, S., Schmid, B., Setälä, H., Symstad, A.J., Vandermeer, J., Wardle, D.A., 2005. Effects of biodiversity on ecosystem functioning: a consensus of current knowledge. Ecol. Monogr. 75, 3–35. https://doi.org/10.1890/04-0922.

Hughes, A.R., Inouye, B.D., Johnson, M.T.J., Underwood, N., Vellend, M., 2008. Ecological consequences of genetic diversity. Ecol. Lett. 11, 609–623.

IPBES, 2019. Summary for Policymakers of the Global Assessment Report on Biodiversity and Ecosystem Services of the Intergovernmental Science-policy Platform on Biodiversity and Ecosystem Services. IPBES secretariat, Bonn, Germany.

Isbell, F., Calcagno, V., Hector, A., Connolly, J., Harpole, W.S., Reich, P.B., Scherer-Lorenzen, M., Schmid, B., Tilman, D., van Ruijven, J., Weigelt, A., Wilsey, B.J., Zavaleta, E.S., Loreau, M., 2011. High plant diversity is needed to maintain ecosystem services. Nature 477, 199–202.

Keith, H., Vardon, M., Stein, J.A., Stein, J.L., Lindenmayer, D., 2017. Ecosystem accounts define explicit and spatial trade-offs for managing natural resources. Nat. Ecol. Evol. 1, 1683–1692. https://doi.org/10.1038/s41559-017-0309-1.

Kim, H., Rosa, I., Alkemade, R., Leadley, P., Hurtt, G., Popp, A., Van Vuuren, D., Anthoni, P., Arneth, A., Baisero, D., Caton, E., 2018. A protocol for an intercomparison of biodiversity and ecosystem services models using harmonized land-use and climate scenarios. Geosci. Model. Dev. Discuss. 11, 4537–4562.

La Notte, A., Marques, A., Pisani, D., Cerilli, S., Vallecillo, S., Polce, C., Cardoso, A.C., Gervasini, E., Maes, J., 2020. LInking accounts for ecosystem Services and Benefits THrough bridging (LISBETH). Luxembourg. https://doi.org/10.2760/480477. JRC120571.

Lamoreux, J.F., Morrison, J.C., Ricketts, T.H., Olson, D.M., Dinerstein, E., McKnight, M. W., Shugart, H.H., 2006. Global tests of biodiversity concordance and the importance of endemism. Nature 440, 212–214. https://doi.org/10.1038/nature04291.

Luck, G.W., Harrington, R., Anderson, P.A., Kremen, C., Berry, P.M., Bugter, R., Dawson, T.P., de Bello, F., Díaz, S., Feld, C.K., Haslett, J.R., Hering, D., Kontogianni, A., Lavorel, S., Rounsevell, M., Samways, M.J., Sandin, L., Settele, J., Sykes, M.T., Vandenhove, S., Vandewalle, M., 2009. Quantifying the contribution of organisms to the provision of ecosystem services. Bioscience 59, 223–235.

MA, 2005. Ecosystem Assessment: Ecosystems and Human Wellbeing. Current State and Trends. Washington D.C..

McGill, B.J., Dornelas, M., Gotelli, N.J., Magurran, A.E., 2015. Fifteen forms of biodiversity trend in the Anthropocene. Trends Ecol. Evol. (Amst.) 30, 104–113. https://doi.org/10.1016/j.tree.2014.11.006.

Meijer, J., Hill, C., Vardon, M., 2019. Integrated landscape management and natural capital accounting: working together for sustainable development. The Hague.

Mimura, M., Yahara, T., Faith, D.P., Vázquez-Domínguez, E., Colautti, R.I., Araki, H., Javadi, F., Núñez-Farfán, J., Mori, A.S., Zhou, S., Hollingsworth, P.M., Neaves, L.E., Fukano, Y., Smith, G.F., Sato, Y.-I., Tachida, H., Hendry, A.P., 2017. Understanding and monitoring the consequences of human impacts on intraspecific variation. Evol. Appl. 10, 121–139. https://doi.org/10.1111/eva.12436.

Mokany, K., Harwood, T.D., Ferrier, S., 2019. Improving links between environmental accounting and scenario-based cumulative impact assessment for better-informed biodiversity decisions. J. Appl. Ecol. 56, 2732–2741. https://doi.org/10.1111/1365-2664.13506.

Mori, A.S., Furukawa, T., Sasaki, T., 2013. Response diversity determines the resilience of ecosystems to environmental change. Biol. Rev. 88, 349–364. https://doi.org/10.1111/brv.12004.

Nature, 2020. New biodiversity targets cannot afford to fail. Nat. Editor. 578, 337–338. https://doi.org/10.1038/d41586-020-00450-5.

Oliver, T., Heard, M., Isaac, N., Roy, D., Procter, D., Eigenbrod, F., Freckleton, R., Hector, A., Orme, C., Petchey, O., Proença, V., 2015. Biodiversity and resilience of ecosystem functions. Trends Ecol. Evol. (Amst.) 30, 673–684.

Roy, C., Michel, N., Handel, C., Van Wilgenburg, S., Burkhalter, J., Gurney, K., Messmer, D., Karine, R., Clark, S., Saracco, J., Schuster, R., Smith, A., Smith, P., Selymos, P., Venier, L., Zuckerberg, B., 2019. Monitoring boreal avian populations: how can we estimate trends and trajectories from noisy data? TT - Surveillance des populations aviaires borealese: comment estimer les tendances et les trajectoires e partir de donnees bruyantes? Avian Conserv. Ecol. 14 https://doi.org/10.5751/ACE-01397-140208.

Ruijs, A., Vardon, M., 2019. Natural capital accounting for mainstreaming biodiversity in public policy making. In: Vardon, M., Bass, S., Ahlroth, S. (Eds.), Natural Capital Accounting for Better Policy Decisions: Climate Change and Biodiversity. Proceedings and Highlights of the 3rd Forum on Natural Capital Accounting for Better Policy Decisions. World Bank WAVES, Washington D.C, pp. 73–100.

Schipper, A., Tillmanns, M., Giesen, P., van der Esch, S., 2017. Compiling biodiversity accounts with the GLOBIO model. A case study of Mexico. The Hague.

Semmens, D.J., Diffendorfer, J.E., Bagstad, K.J., Wiederholt, R., Oberhauser, K., Ries, L., Semmens, B.X., Goldstein, J., Loomis, J., Thogmartin, W.E., Mattsson, B.J., López-Hoffman, L., 2018. Quantifying ecosystem service flows at multiple scales across the range of a long-distance migratory species. Ecosyst. Serv. 31, 255–264. https://doi.org/10.1016/j.ecoser.2017.12.002.

Sundstrom, S., Allen, C., Barichievy, C., 2012. Species, functional groups, and thresholds in ecological resilience. Conserv. Biol. 26, 305–314. https://doi.org/10.1111/j.1523-1739.2011.01822.x.

TEEB, 2010. The Economics of Ecosystems and Biodiversity Ecological and Economic Foundations. Earthscan, London and Washington.

Tilman, D., Reich, P.B., Knops, J.M.H., 2006. Biodiversity and ecosystem stability in a decade-long grassland experiment. Nature 441, 629–632. https://doi.org/10.1038/nature04742.

Tscharntke, T., Klein, A.M., Kruess, A., Steffan-Dewenter, I., Thies, C., 2005. Landscape perspectives on agricultural intensification and biodiversity – ecosystem service management. Ecol. Lett. 8, 857–874. https://doi.org/10.1111/j.1461-0248.2005.00782.x.

Turner, R.K., Paavola, J., Cooper, P., Farber, S., Jessamy, V., Georgiou, S., 2003. Valuing nature: lessons learned and future research directions. Ecol. Econ. 46, 493–510.

Turner, K., Badura, T., Ferrini, S., 2019. Natural capital accounting perspectives: a pragmatic way forward. Ecosyst. Heal. Sustain. 5, 237–241. https://doi.org/10.1080/20964129.2019.1682470.

UN, n.d. TRANSFORMING OUR WORLD: THE 2030 AGENDA FOR SUSTAINABLE DEVELOPMENT. A/RES/70/1.

UN, European Commission, FAO, OECD, World Bank, 2014. System of Environmental Economic Accounting 2012— Experimental Ecosystem Accounting. New York..

UN, UNEP, CBD, Norwegian Ministry of Foreign Affairs, 2017. Technical Recommendations in Support of the System of Environmental-economic Accounting 2012. White cover publication.

UNCEEA, 2019. Fourteenth Meeting of the UNCEEA [WWW Document]. Meet. Conclusions. URL https://seea.un.org/events/fourteenth-meeting-unceea (accessed 12.3.19)..

UNEP-WCMC, 2016. Exploring Approaches for Constructing Species Accounts in the Context of SEEA-EEA. Cambridge, UK..

UNEP-WCMC, 2017. Testing the Development of Species Accounts for Measuring Ecosystem Condition at EU Level. Cambridge, UK..

UNEP-WCMC, 2019. Experimental Species Accounts for the EU. Cambridge (UK). https://doi.org/10.13140/RG.2.2.32793.16483.

UNEP-WCMC, IDEEA, 2017. Experimental Ecosystem Accounts for Uganda. Cambridge, UK. .

Vallecillo, S., La Notte, A., Chiara, P., Grazia, Z., Nikolas, A., Ferrini, S., Maes, J., 2018. Ecosystem Services Accounting: Part I - Outdoor Recreation and Crop Pollination. EUR 29024 EN..

Vardon, M., Lindenmayer, D., Keith, H., Ferrier, S., Gibbons, P., 2015. Progress, challenges and opportunities for biodiversity accounting. 21st Meeting of the London Group on Environmental Accounting 32.

Vardon, M., Burnett, P., Dovers, S., 2016. The accounting push and the policy pull: balancing environment and economic decisions. Ecol. Econ. 124, 145–152.

Vardon, M., Castaneda, J.-P., Nagy, M., Schenau, S., 2018. How the System of Environmental-Economic Accounting can improve environmental information systems and data quality for decision making. Environ. Sci. Policy 89, 83–92.
Vardon, M., Keith, H., Obst, C., Lindenmayer, D., 2019. Putting biodiversity into the national accounts: creating a new paradigm for economic decisions. Ambio 48, 726–731.
Wagg, C., Bender, S.F., Widmer, F., van der Heijden, M.G.A., 2014. Soil biodiversity and soil community composition determine ecosystem multifunctionality. Proc. Natl. Acad. Sci. 111 https://doi.org/10.1073/pnas.1320054111, 5266 LP – 5270.
Walsh, R.G., Loomis, J.B., Gillman, R.A., 1984. Valuing option, existence, and bequest demands for wilderness. Land Econ. 60, 14–29. https://doi.org/10.2307/3146089.
Warnell, K.J.D., Russell, M., Rhodes, C., Bagstad, K.J., Olander, L.P., Nowak, D.J., Poudel, R., Glynn, P.D., Hass, J.L., Hirabayashi, S., Ingram, J.C., Matuszak, J., Oleson, K.L.L., Posner, S.M., Villa, F., 2020. Testing ecosystem accounting in the United States: a case study for the Southeast. Ecosyst. Serv. 43, 101099 https://doi.org/10.1016/j.ecoser.2020.101099.
Weitzman, M.L., 1992. On diversity. Q. J. Econ. 107, 363–405.

Steven King is Environmental Economist at the United Nations Environment Programme – World Conservation Monitoring Centre (UNEP-WCMC). Stevens work centres on making natures values visible and integrating these values into a wide range of decision-making. A key part of this work is developing Natural Capital Assessment and Accounting Approaches. In particular, focusing on the measurement, valuation and communication of how different aspects of biodiversity underpin economic activity and social welfare.

Vardon researches environmental accounting at the Australian National University. His knowledge spans data collection, account compilation, analysis and policy. His initial career focused on animal population dynamics. In 2000 he began work at the Australian Bureau of Statistics ultimately becoming the Director of the Centre of Environmental Statistics in 2005, a position he left in 2014, with secondments to the United Nations and the Bureau of Meteorology. He was a member of the Editorial Board of the System of Environmental-Economic Accounting and the Policy and Technical Expert Committee of the Wealth Accounting and Valuation of Ecosystem Services ('WAVES') program.

Hedley Grantham leads Wildlife Conservation Society's spatial planning program and is also a research associate at the University of Queensland. Hedley's main focus is on supporting biodiversity conservation and sustainable development planning at the landscape and seascape scale. He is a specialist on designing and integrating multidisciplinary science and priority setting analysis to support planning and decision-making process. He also works on development planning including how to improve siting of impacts, and better application of the mitigation hierarchy including the design of biodiversity offsets.

Mark Eigenraam For more than twenty years Mark Eigenraam has lead research, development and application of environmental markets and ecosystem accounting. This work has engaged a wide variety of industries, academic institutions and government agencies at regional, state and national levels. Mark has applied his market-based experience to inform Australia's approach to environmental-economic accounting. He produced Australia's first set of experimental ecosystem accounts and continues to develop new systems and processes to publish Australian environmental accounts in line with SEEA.

Simon Ferrier is a Chief Research Scientist with CSIRO (Australia's national science agency) and is also recognised as an Honorary Professor at the Australian National University, and an Honorary Fellow at the UNEP World Conservation Monitoring Centre. He was an early pioneer, throughout the 1980s and 1990s, in the development of species- and community-level biodiversity modelling, and of techniques for applying such models to conservation prioritisation, land-use planning, and natural resource management. More recently he has been leading development of a whole new generation of macroecological approaches to biodiversity modelling, monitoring, scenario-analysis, and decision-support, and applying these techniques at local, national and global scales.

Daniel Juhn provides scientific and administrative leadership to Conservation International's (CI's) Nature's Values and Priorities (NVP) team which develops innovative and visible applied multidisciplinary research projects through seven integrated programs: Ecosystem Values and Accounting (Natural Capital Accounting), Spatial Priority Setting and Planning, Scenario Development, Freshwater Science Program, Rapid Assessment Program, Biodiversity Assessment Unit, and Wildlife Insights. NVP supports governments, businesses and communities in their efforts to achieve their development and sustainability goals by incorporating nature's values into their planning, decision making, and balance sheets.

Trond Larsen is the director of Conservation Internationals (CI's) Rapid Assessment Program at the Moore center for Science. At CI, Trond has worked on a broad range of projects regarding the causes and consequences of biodiversity loss across the tropics, often using invertebrate taxa as a model. Trond is also a founding director of the Amazon Conservation Association. As Science Director for the non-profit Friends of the Osa, he established a new center for research, education and conservation of terrestrial and marine biodiversity on the Osa Peninsula in Costa Rica.

Claire Brown has worked with the at the United Nations Environment Programme – World Conservation Monitoring Centre (UNEP-WCMC) since 2004. Claire overseas a portfolio of projects on ecosystem services and assessment, including Building capacity for national ecosystem assessments: linking science and policy, the technical support unit on policy support for IPBES and ecosystem accounting projects at different scales.

Kerry Turner is a Professorial Fellow in the School of Environmental Sciences, University of East Anglia and Director of the CSERGE research centre. He has over 300 publications in the fields of environmental and ecological economics and management. He has combined an academic career with a range of roles in public sector environmental protection agencies and the policy process, since the 1980's. These roles have included: National Board Membership of UK environmental management agencies: Chair of one of the UK Foresight Programme Committees, Chair of a National Park Authority, and most recently joint chair of the UK National Ecosystem Assessment Follow On initiative.