

Key concepts for accounting for biodiversity

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Prepared for the Technical Expert Meeting on Ecosystem Accounts.

5 – December 2011, London, UK

Hosted by the Office for National Statistics and the Department of Environment, Food and Rural Affairs of the United Kingdom.

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A. Introduction

1. The System of Environmental-Economic Accounts (SEEA) Experimental Ecosystem Accounts have been proposed to address elements of the SEEA Central Framework for which there is no current statistical standard. The SEEA defines an environmental asset as “naturally occurring living and non-living components of the Earth, together comprising the bio-physical environment, that may provide benefits to humanity” [1].
2. Biodiversity is therefore in the scope of SEEA. Some biodiversity, for example, farm animals and wild species subject to commercial harvest, are covered by the SEEA Central Framework. However, biodiversity for which there are no direct economic benefits is not included and hence needs to be addressed in the development of the SEEA Experimental Ecosystem Accounting.
3. A road map has been developed to guide this process [2]. It lists ten issues to be resolved. This paper will largely address Issue 6: Biodiversity accounts and indexes, and Issue 1: Policy applications of ecosystem accounts.
4. In this paper I will explore where biodiversity fits into an environmental accounting framework. I will review the biophysical and economic perception of biodiversity with the intention of clarifying the role of biodiversity in environmental accounting for both economic and ecological audience. I will highlight where progress can be made towards a comprehensive environmental accounting system.

B. Objectives

5. The tasks outlined for Issue 6: Biodiversity Accounts and Indices are:
 - *Propose methods for calculation of a biodiversity index*
 - *Propose the structure of a biodiversity diagnostic account*
 - *Outline the data requirements for compiling biodiversity accounts*
 - *Investigate current data availability to meet these requirements and identify potential gaps or related challenges for producing accounts globally.*

In this paper I will address these tasks by describing the role of biodiversity in ecosystem accounts, including as a diagnostic for ecosystem condition.

Once the purpose of the biodiversity account is established then we can start to investigate appropriate indices, data requirements and challenges.

C. Types of biodiversity

6. How biodiversity is defined greatly influences its place (and scope) in accounting. Biodiversity has been defined in practical terms as ‘the variability among living things and the ecosystem they inhabit’ [3]. The scientific community has categorised levels of biodiversity: genes, species and ecosystems [4, 5]. The Millennium Assessment included ‘populations’ because it included the diversity within a species, between populations.
7. Policy often divides biodiversity into some of the components that comprise that diversity, for example, individual species, which may be referred to as components of diversity [6]. Biodiversity for the purposes of accounting can be defined as genes, populations, species and ecosystems and the components of which they comprise (see Table 1. Further references to biodiversity in this paper will have this meaning.

Table 1: Types of biodiversity and their components.

		Types of BIODIVERSITY			
	LEVEL of biodiversity	COMPONENT of biodiversity	Examples of economic COMPONENTS	Examples of non-economic COMPONENTS	Measures of Biodiversity
Biodiversity	Ecosystem	Diversity of ecosystems Individual ecosystems Other levels of biodiversity within this level - species - populations - genes	Harvested ecosystems such as Some ecosystem services	Cleared ecosystems Native forests Rivers Streams Wetlands Forests Many ecosystem services	Area of ecosystem Condition of ecosystem - Structure - Composition - Process and function - Internal diversity
	Species	Diversity of species Individual species Other levels of biodiversity within this level - populations - genes	Commercial species such as fish and trees for timber	Non-commercial species Species diversity Threatened species	Species Richness Abundance of individual species Functional trait of species Composition of species Distribution
	Populations				
	Genes				

8. The lowest level of disaggregation of biodiversity for accounting should be determined by the scientific, policy or economic relevance of that information.
9. All of these levels (or components) of biodiversity can be included in environmental accounting but for the purposes of pragmatism it is likely that the higher levels of this hierarchy such as populations, species and ecosystems will be the focus of environmental accounting. Indeed, it has been proposed that landscapes (featuring multiple ecosystems) are an appropriate scale for managing biodiversity [7]. Accounting at the ecosystem level is the subject of an issues paper at this meeting (Cosier 2011) and previous meetings (Cosier and McDonald 2010) [8, 9].
10. This paper largely concentrates on the diversity of species of flora and fauna, as well as the abundance, function, community composition and distribution of these species. There are four good reasons for this: a) species are the subject of most international treaties and national policy on biodiversity, b) species are relatively conspicuous and c) there is considerable research on species, decades of science on the measurement of species and there are many long-term monitoring programs for species and d) species are often used as a surrogate for biodiversity in general.
11. Biodiversity is essentially multi-dimensional and any assessment (and accounting standards) need to approach it as such [6]. Each level of biodiversity will require accounting standards because neither species, ecosystems nor genetic diversity will act as a good indicator for biodiversity as a whole [6].
12. A strong case could be made to eliminate the use of the word biodiversity from accounting due to the confusion regarding its meaning and the frequency of its misuse. However, I do not want to throw the baby out with the bathwater and instead encourage careful consideration in the use of the word and recommend a step-by-step process to determine what component of biodiversity are being accounted for and why. This will help inform how you might account for it, and what measures are appropriate.

D. Why account for biodiversity

13. As the decline of particular species and habitat has provoked the desire to conserve biodiversity, it has also resulted in examination to why biodiversity is important, how it affects life on earth and what role it plays in human civilization. Below is a list of the main findings of the role of biodiversity in the literature:
 1. An intrinsic part of the natural world (that ought to be protected) [10]
 2. Responsibility of humanity
 3. Critical to achieving sustainability [3]
 4. The essential foundations upon when humanity depends [3]
 5. Representative of conservation as a whole
 6. Aesthetic qualities – Ehrlich 1981 Extinction).
 7. Biodiversity is a ‘good’ [11]
 8. Essential for the functioning of ecosystems that underpin the provisioning of ecosystems that affect human well being [6]
 9. Insurance against future unknown threats
 10. Unknown potential future source of benefits for example pharmaceuticals
 11. An indicator of ecosystem condition [12]
 12. A measure of only species extinctions (ref)
 13. A measure of all of biology [13]
 14. A major factor affecting ecosystem stability ([14-17]
 15. Correlated to productivity (more diverse communities are more productive) [18] [19]
 16. A input influencing many ecosystem properties [20] [21]
 17. Important element in the functioning of ecosystems
 18. Critical to the viability of indigenous communities [22]
 19. Unique and irreplaceable part of our world
 20. Providing incalculable benefits of genetic variability that people everywhere use daily and depend upon [23]
 21. Is inherent in all ecosystems and is not an entity that can be separated.
 22. Contributes to security, resiliency, social relations, health and freedom of choices and actions [6].
 23. Biodiversity is synonymous with ecosystem services [24]
 24. Supports cultural value

E. Accounting rationale

14. The constraint that accounting imposes (albeit a positive one) is to sort the established relationships from the theoretical ones. The difficulty comes when we try to quantify even these best-understood relationships. For the purposes of accounting these can be distilled into 5 categories:
 1. *An environmental asset*
 2. *An input into economic production*
 3. *An input into the ecosystems, which generate of ecosystem goods and services.*
 4. *An indicator of ecosystem condition*
 5. *An ecosystem service.*
15. The System of National Accounts is based on stock and flow accounts, which if suitable for ecosystem accounting, provide a platform to link economic accounts to environmental accounts. The test is whether (or to what degree) these constructs designed based on economic models can be used for ecosystem accounts.
16. Stock accounts measure the quantity and quality of assets at a given time (measured as physical units and monetary value respectively in the SEEA Central Framework) [25].
17. Flow accounts are designed to measure inputs to the economy, their use within the economy and the outputs, or release. Physical flow accounts measure natural inputs into the economy and the release from the economy of residuals such as waste [26].

F. Measurement Units

18. There are currently three broad accounting units available for accounting for biodiversity: monetary, physical and condition metrics.
 - **Monetary accounting units** (for example, national currencies) can be employed as they are in the System of National Accounts, using prices at which assets, goods and services are exchanged to value (with a monetary unit) each item in the account [27]. Other methods are also available for assigning monetary values to items not necessarily in the market place.
 - **Physical accounting units** (for example tonnes, cubic metres) describe assets, goods and services in physical measures,. Physical accounting units have been developed in SEEA to give a more holistic representation of assets, good and services [1], and provide a mechanism for measurement where no monetary value applies.
 - **Condition accounting units** (for example indices of condition from 0-100) are metrics that describe the state or condition of environmental assets using fit-for-purpose indicators, against a benchmark to create a scalable unit of measure. The need for these accounting units arose from the recognition that many environmental assets do not have a monetary value and are best described with indicators. Importantly, physical units are not amenable to aggregation[1] and do not provide a measure of state or condition necessary for accounting for the environment ([9, 24, 28, 29])

In this paper I will concentrate on the applications of physical and condition measurement units.

G. How to account for biodiversity

1. Biodiversity as an environmental asset

19. Some biodiversity is considered an environmental asset under the definition in the SEEA Central Framework, being included under aquatic and other and other biological resources. Farm and zoo animals are also included as inventories in the System of National Accounts. However, a large part of biodiversity is not explicitly included in the asset classes described in the SEEA Central Framework or System of National Accounts, because they do not provide defined benefits to humanity.
20. The System of National accounts defines assets as: “a store of value representing a benefit or series of benefits accruing to an economic ownerIt is a means of carrying over value from one accounting period to another” (p. 617). Items of value to society are the source of inputs to the economy, to society and also to ecosystems [1]. Assets are accounted for as stocks in order to measure their depletion and degradation. Asset accounts seek to measure the quantity, value (and condition in the case of ecosystem accounting) in order to record and explain changes in value over time.
21. There are numerous international agreements binding nations to reach biodiversity conservation targets including the Convention on Biological Diversity which mandated “to achieve by 2010 a significant reduction of the current rate of biodiversity loss” [3]. A policy goal of preserving biodiversity is part of environmental policy and national legislation of most major economies. These are a reflection of the values of society places on biodiversity assets (and the land asset in which they are contained) and provide a clear indication that humanity derives some benefit from the persistence of biodiversity. At the 2010 Conference of the Parties to Convention on Biological Diversity (COP 10) a s target relating to the recording of value of biodiversity was included:
 - “Target 2. “By 2020, at the latest, biodiversity values have been integrated into national and local development and poverty reduction strategies and planning processes and are being incorporated into national accounting, as appropriate, and reporting systems.” [30]
22. Accounting for biodiversity with as physical asset is arguably the most straightforward and intuitive method of accounting, and most likely to appeal to the scientific (and wider) audience. Asset accounting is based on an opening stock and closing stock at the end of the accounting period.
23. Ecosystems, species, populations and genes can be accounted for as stock. In scientific terms a stock can be thought of as a measure of state or a state variable.
24. Measuring depletion and degradation is an important application of stock accounts. Net reductions in biodiversity as observed in the change in stock accounts are measured as depletions. With renewable resources the depletion rate depends on both the rate of additions and reductions. There will be no additions to a non-renewable resource and those reductions can be counted as consumption (see below, biodiversity as an input). That biodiversity can be renewable and non-renewable is important to how depletion is measured.
25. At a local scale biodiversity is renewable because inputs can occur from surrounding area or by natural regeneration. For example, in the case of a population, the input would be the number of births and immigrations, translocations. In the case of species

diversity, it would be any increase in species (from surrounding areas or reintroductions).

26. In the case of large-scale (national or global) measures of species diversity, it is a non-renewable resource because once a species becomes extinct, it will not be renewed. Therefore, measures of the depletion of biodiversity (extinction rate) become extremely important to policy makers.
27. The classification of assets in the SNA and SEEA Central Framework as produced and non-produced offer some interesting opportunities for biodiversity accounting. Produced and non-produced assets can be broadly interpreted as managed and non-managed systems. This is important because the biodiversity in anthropomorphised systems must be accounted for. Even highly modified environments have some biodiversity [6]. It is critical that biodiversity in modified landscapes are accounted for as it is in these landscapes where biodiversity is typically most affected, where most improvements in biodiversity conservation can be made and the interface between economics and the environment occurs.
28. Aligning the information on the physical asset accounts alongside the financial accounts can inform a suite of environmental/economic analyses. For example, hybrid accounts can present the total physical and condition stock of the asset with the financial stocks embedded in that asset. In the case of ecosystems, there can be many financial assets with its boundaries. For example, a native forest can provide timber and carbon.
29. Changes in stock of biodiversity, may or may not be transacted in the economy. A proportion of positive and negative changes in species diversity as a result of economic activity such as extraction, development, harvesting etc and will flow through the economy (consumed or produced). A large proportion of observed change in stocks will be a result of non-economic variables such as climate, disease, pests and fire (as well as natural stochasticity) [6] and as a flow will not interaction with the economy. It is important to account for all flows, whether they flow into the economy or not.
30. Functional accounts for environmental transactions provide an opportunity to investigate the link between environmental protection activities (and associated financial transactions) and the change in the environmental asset of interest. Environmental activities are defined in SEEA as ‘the prevention, reduction and elimination of pollution and other forms of degradation of the environment’ [1]. One such account is the Environmental Protection Expenditure Accounts [1].
31. Linking financial transactions resulting from environmental protection activities and change in biodiversity will have significant policy implications. Environmental expenditure is increasingly under scrutiny for return on investment [31] and becoming relevant to all environmental policy decisions as we attempt to optimise scarce (and essentially inadequate) investments for environmental protection [32, 33]. For example, environmental protection activities to halt the decline of species can be linked to actual rates of decline. This would apply to activities to protect and restore habitat, which would be accounted for in the stock accounts.
32. The advantage of the traditional stock accounting (as outlined in SEEA) is that it attempts to delineate and attribute the additions and reductions to the stock. In many cases environmental data are not available to account for these but conceptually it illustrates the importance of the magnitude of the additions versus reductions. In

particular, when the efficacy of environmental interventions are analysed, it can be misleading to only look at the net change in the stock. The environmental interventions (additions) can be effective but will not result in a positive trend if outweighed by reductions. For example, an organisation is revegetating a vegetation community and at the same time it is being cleared at five times the rate for development, those additions and reductions would be explicitly described in the accounts.

33. Marrying economic and environmental information through accounting is a critical element in understanding the interactions of these systems. The Australian Land Account pilot presents spatially explicit economic and social information [34] which provides a platform to link to spatially explicit stock accounts on biodiversity change

2. Biodiversity as an input into economic production

34. Biodiversity and its components cross many economic boundaries.
35. Accounting for individual commercially harvested species is also described in SEEA Central Framework [1] but this can be applied to individual threatened species or species of interest/concern.
36. Biodiversity can also be considered to be an ‘input absorbed by the economy’ as described in the SEEA Central Framework for air and energy inputs[25].
37. Biodiversity currently interfaces with the economy in the two observable ways. Biodiversity is depleted/consumed during economic activity and Government (companies and individuals) invest in biodiversity. A simple first step would be to have these interactions reflected in the accounts.
38. Biodiversity can be accounted for as a natural input in a flow account as described in SEEA. The quantity of the input is accounted for, as its flow through the production system (how much of it is used and how much of it is discarded). This process can be captured in supply use tables. The discarded or waste must also be accounted for at the other end, i.e. where are the residuals collected or discarded to. Examples such as timber and fish are addressed in the SEEA Central Framework.
39. This accounting concept provides an opportunity for the impact of economic activity on biodiversity to be measured as biodiversity ‘consumed’ by activity. For example, the development of land resulting in the loss of a number of species is not currently accounted for. For all intents and purposes, those species are inputs into that development and should be accounted as such. In the case of species lost, it would be completely ‘used’ in production.
40. Importantly, flow accounts allow measurement of the relationship between flows of natural inputs and economic activity. Supply and use tables can measure all flows from the environment, within the economy and back to the environment, although the scope of the Central Framework did not extend beyond physical flow accounts for water, energy and material flows [26].

3. Biodiversity as an input into the ecosystems, which generate of ecosystem goods and services.

41. The loss of biodiversity has prompted much research into the consequences of that loss and the loss of inputs. Ecologically, there is a strong relationship between biodiversity and ecosystem function and processes, but it is considerable variation in that correlation which makes it difficult to quantitatively link cause and effect. Changes in the populations of commodity species may result directly in a measurable

change of a provisioning service such as fish but the link to other services can be problematic [21].

42. Nevertheless, it is known that species composition and relative abundance, local extinctions, introduction (and removal) of species which impact on interactions in an ecosystem all impact upon ecosystem services [6].
43. The recent UK National Ecosystem Assessment [35] outlines a framework to describe how groups of flora and fauna underpin ecosystem services and might provide direction for quantifying inputs.

4. Biodiversity as an indicator of ecosystem condition

44. Indicators of ecosystem condition measure the outputs of that system to assess the overall function of that system. Biodiversity is one of those outputs that can be measured to gauge the condition of the ecosystem of which it is part.
45. This aspect of biodiversity accounting is the focus of the work of Weber [36] and outlined in the experimental framework for ecosystem capital accounting in Europe and methods are being developed as part of the Australian Environmental Accounts model based on ecosystem condition [8, 9, 36]. However, it might be helpful to review the science from a biodiversity perspective.
46. Since it was recognised that measuring and describing the condition of ecosystems is critical to quantifying the state of an ecosystem, to understanding the extent of human impact, evaluating the effectiveness of conservation actions [37] and estimating the quantum of services provided by ecosystems, there have been several useful developments in the definition of ecosystem condition and methods for measurement.
47. Evolving from the concept of stress ecology, Rapport et al [38] identified ecosystem 'health' as a measure of 'system organisation, resilience and vigor as well as the absence of signs of ecosystem distress' [38]. To operationalise these concepts they recommend the following list of broad indicators to measure ecosystem health:
 - vigour, which refers to the level of activity, metabolism or primary productivity;
 - organisation, which refers to the structure or number of interactions within an ecosystem; and
 - resilience [39], which refers to an ecosystem's ability to recover following disturbance.
48. Concurrent with the development of the field of ecosystem health was the development of aquatic bioassessment, primarily in the form of the index of 'biotic integrity' for American rivers [40, 41] and the efforts in Great Britain to classify rivers using biological assessments [42]. Both were responding to a policy need to understand, measure and contribute to the management of the quality of national rivers.
49. The great contribution of this work was recognising and establishing a common baseline. That each metric was based on a comparison to a regional reference site with relatively little modification was an innovation in the Index of Biological Integrity [43] but implicit in the Wright et al river assessment methods which are based on identifying unpolluted rivers [42].
50. The incorporation of biogeographic variation, also identified by Karr et al 1991, inherently changed the capacity of bioassessment methodology to contribute to

environmental accounting. The fundamental difference was sites could now be compared, change observed on the same scale and very simply, provided ‘criteria for what is excellent and what is poor’ [44]. Using a reference condition benchmark recognised that ecosystems exhibit natural variation in productivity, structure, diversity etc and what might be considered a low condition for one ecosystem, based on these measures, could be healthy for another if that is the natural levels expected for that system (eg rainforests vs deserts) [45].

51. Studies that have adopted the Rapport indicators of ecosystem health have applied similar benchmarks [46]
52. It is well known that it is not plausible or even desirable to directly measure all the components of an environmental asset. The ecosystem or biological system that make them up are far too complex. Conversely, there is not single indicator that would act as a comprehensive surrogate for ecosystem condition. For these reasons, an integrated approach involving several indicators is best [41].
53. There are many biodiversity indices that are used to reflect the condition of the ecosystem. In order to ensure that the indicator reflects condition it is critical that the role of the component of biodiversity being measured in ecosystem condition is understood and that the measures are relevant to the specific ecosystems [47]. Each ecosystem will exhibit different variations and combinations of biodiversity. One ecosystem will be high diversity and another low. That does not mean that one is in better condition than the other. It is necessary to measure biodiversity in the ecological context. For example, it is not that useful to know the absolute number of species or number of individuals (whether a community has 500 species or 50 is of little relevance) [48]. It is the relative frequency that ecologists have traditionally been interested in [48].
54. Measures of diversity have been used widely to measure the state of biodiversity and have been identified as an important component of an index of ecosystem health [38]. There is now general consensus that condition can be assessed by measuring indicators of composition, structure, diversity and function against a reference condition [46, 49, 50].

5. Biodiversity as an ecosystem service

55. Recently, the concept of ecosystem services has received attention and gained traction as a result of the Millennium Assessment, the emergence of environmental markets and interest in environmental accounting. The leap from concept to implementation requires consideration with regard to biodiversity to avoid confusion and retain policy relevance.
56. In the last several decades substantial efforts to understand how ecosystems provide goods and services, and more recently, to start to quantify and value those services [6, 24]. However, the understanding of the quantitative links between biodiversity and ecosystem services is still significantly lacking [21, 51].
57. An almost infinite number of services can be attributed to ecosystems. The services that flow from ecosystems have been categorised into provisioning, regulating and cultural (supporting services is considered here as an input in this framework). The UK Ecosystem Assessment created a new subcategory of ‘wild species diversity’ [35].

58. There is scope for further measures of biodiversity to be expressed as a flow. For example, the Habitat Hectares metric, has been used as a surrogate for biodiversity in Victoria, Australia [52]. This is an index of vegetation condition, extent and connectivity relative to an 'undisturbed' benchmark. An Environmental Benefits Index is another method of measuring bundles of services of which habitat for flora and fauna is one [53].
59. Valuation of ecosystem services is currently the focus of work by the World Bank, and many others. Flows will interact with the economy where markets are established for their trade. Eigenraam et al are currently using ecosystem services (bundles of flows as measured as Environmental Benefit Indices) to distribute stewardship funds for the Victorian Department of Sustainability and Environment [53].

H. Policy applications

60. Biodiversity accounts first and foremost can be used to set and track progress towards (or away from) policy targets.
61. Other applications which may have a direct relevance to environmental policy include identification of high quality areas [37, 42, 54] and the diagnostic capacity [54] afforded in the long term as we interpret measured environmental change in the context of known human impact.
62. Accounting with a measure of biodiversity condition facilitates the setting limits for a 'safe operating distance' for biodiversity condition and identifies thresholds for policy targets. One of the major policy failings for biodiversity is that the 'costs of changes in biodiversity have historically not been factored into decision making' [6]. Whilst there is continuing discussion on valuation of biodiversity, these 'costs' can just as equally be quantified by changes to biodiversity itself.
63. Aligning economic and biodiversity accounts will enable us to look at the interaction between biodiversity condition and economic indicators (beyond valuation). With this spatially explicit information we can analyse how to improve or maintain biodiversity at the least cost to the economy (or perhaps even vice versa). Accounting for biodiversity will provide a unit to measure 'biodiversity return' for our investment and hence inform overall investment and intervention.
64. The costs of declining biodiversity is largely borne by society, rather than the individual [6]. Until these costs are distributed to the individuals, costs will continue to be borne by society and society will also foot the bill for management, repair and mitigation. In this case, society is paying for biodiversity return, not an economic return. Stock accounts can reveal these transactions as consumption or depletion.
65. Equally, we know that healthy ecosystems continue to provide services, so it is possible to use these accounts to set (and measure) limits to ecosystem change ensure a sustainable flow of services.

I. Measuring biodiversity for accounting

66. Given that it is practically impossible to measure all elements of biodiversity, as it is also practically impossible to measure all the transactions in the economy, indicators of biodiversity are particularly important [47]. Indicators are an accepted mode of measurement in the SEEA Central Framework [1] and will be employed extensively in accounting for biodiversity.
67. Ecologists have long been in the business of attempting to find governing patterns in ecology and in turn find common indicators to measure biodiversity. Species richness,

function and abundance have been identified as important and measurable components of the condition of terrestrial biodiversity. Species richness is perhaps the most observable component of biodiversity and the simplest to measure [55].

68. The limitation with measuring species richness alone is that it can mask declines in populations of individual species, accounts equally for rare and common species and does not recognise when disturbances (ie decrease in certain species) is offset by an increase in other species [56].
69. Indicators are distinguished from statistics by the use of a reference point or baseline, allowing the significance of the statistic to be gauged [57]. Identifying appropriate indicators and establishing benchmarks are an important process [47] and will greatly affect the utility of the accounts. The phenomena of shifting baselines has been undermining measures of biodiversity based on arbitrary baselines[58].
70. While it is possible to express many physical environmental assets as quantities, there is no established unit for measuring the condition (quality) of biodiversity and ecosystems [29, 59].
71. Identifying a reference condition provides a scale to understand the current observations, as well as to simplify, quantify, communicate and most importantly standardise information. This scale is very useful in analysing change over the gradient of human disturbance, as we try to understand the relationships between human activity and ecological disturbance. This is also a significant progression from earlier binary assessment that measured whether a site was degraded or not [12]. It is also an appropriate measure for describing where ecosystems are approaching critical thresholds, which are common in complex ecosystems. [60-63].
72. The functions of benchmarks (baselines) in a biodiversity index are clearly articulated by ten Brink 2006[57] (below):
 - *Give meaning to raw data*
 - *Allow aggregation of different indicators into coherent composite indicators*
 - *Make biodiversity indicators comparable within and between countries*
 - *Simplify communication with politicians and the public*
 - *Provide a fair and common denominator for all countries, being in different stages of economic development.*
73. There are well-established indices, implemented to varying degrees of success, that combine different measures of biodiversity (see Table 2). The use of all indices will be limited by the quality of the data available to populate them but an index should attempt to capture many of the measures of species biodiversity as possible (see Table 1).
74. There are a least four criteria for measures of biodiversity that should be used as a guide to inform choice in existing biodiversity metrics and the design of new ones:
 1. Established measures of component of interest
 2. Measures change
 3. Scalable
 4. Scientifically robust

Table 2: Biodiversity indices.

Index	Measure	Baseline	Purpose	Scale
Living Planet	Abundance of birds [64]	Approx. 1980	Indicator of biodiversity	Global
Red List	Change in rareness (IUCN) status [65]	Now	Indicator of biodiversity	Global (possibly national)
Wild Bird Index	Abundance of common birds [66]	Approx. 1970	Indicator of biodiversity and wildlife in general	National
Biodiversity Intactness	Abundance of species [67]	Natural or low impacted	Indicator of biodiversity	National
Natural Capital Index	Area of ecosystem and mean abundance of core set of species [68]	Pre-industrial or low impact	Indicator of 'quality' of ecosystem	Regional
Mean Species Abundance	Abundance based on modeling [69]	Pristine or primary vegetation	Indicator of 'quality' of ecosystem	Regional
Index of Biotic Integrity	Species composition and relative abundance of fish [41]	Natural state	Indicator of ecosystem condition	Regional
Sustainable Rivers Index	Functional diversity of macroinvertebrates and nativeness of fish [70]	Reference condition (undisturbed)	Indicator of ecosystem condition	Regional
Nature Index	All/any biological measure [71]	Undisturbed or sustainably managed	Indicator of biodiversity	Any scale
Simpson Index	Species richness and relative abundance [72]	Now	Indicator of biodiversity	Any scale
Shannon Index	A measure of richness and evenness (relative abundance) [73]	Now	Indicator of biodiversity	Any scale

Examples of data availability in the Australian case are provided in Appendix 1.

J. Challenges for global biodiversity accounts

75. Arguably the most important issue for measuring and accounting for biodiversity is the operating scale of biodiversity, the economy and the interface between them. Large-scale, broadstroke measures of biodiversity will fail to detect the changes and interactions that we are attempting to account for. Too fine scale will become logistically prohibitive for national (and global) scale accounting.
76. Flexible systems for defining national and sub-national biodiversity indicators are likely to be necessary due to the biogeographic variation across the globe. Standards in methods and setting common benchmarks are more likely to be areas for commonality and grounds for globally consistent accounts (as you would have different items in your basket for a CPI calculation, so would you for indicators).

In order to have confidence in the accounting of biodiversity, we need to have confidence in the science underpinning the measurements of biodiversity and their links to ecosystem condition and ecosystem goods and services. There needs to be a scientific process in place to ensure the rigor of these accounts. Endeavor to relate and engage with the scientific community. Central to the development of accounts for the

environment (with a great deal of complexity and some level of uncertainty) is transparency in accounting measures, data and methods.

K. Discussion and recommendations for the future

77. Although it is helpful to conceptually understand all the links between biodiversity and other accounts and in some respects crucial in making a policy link between the flow on affect of modifying ecosystems, I would warn against overstating the confidence in the relationship that is not currently reflected in the science. This could lead to misinterpretations and perverse outcomes. Indeed, ecosystem modification is but one of several factors influencing the state of biodiversity. Other important factors include climate change, non-native species invasions, overexploitation and pollution [6]. Additionally, the time lag between generic changes in biodiversity and a resulting change in ecosystem condition and a subsequent change in other services can be long and complex [6].

L. Recommendations for framework and process of development

- The five options for approaches to biodiversity accounting are as: 1. an environmental assets; 2. as an input into production; 3. as an input into ecosystems which generate services; 4. as an indicator of ecosystem condition; and 5. as an ecosystem service itself. All five are valid inclusions in the SEEA Experimental Ecosystem Accounts.
- The diagnostic capacities of biodiversity indices need to be tested on their merits to reflect an aspect of ecosystem condition (composition, structure, function and process or diversity).
- Technically, it is easiest to describe biodiversity as an asset and interrogate how changes in that asset interacts with the economy including changes in the relation to environmental activities and associated financial investment, changes in relation to economic activity as measured in the pilot Australian Land Account and in individual production pathways (see above for details).
- There is greater certainty and scope for quantification in the relationship between biodiversity and the use of certain species as an input into production and between biodiversity in general as an input into economic activity.
- Build upon the powerful concept in SEEA of combining monetary and physical units in an account and also combine condition indices in these accounts.

Acknowledgements

Dr Michael Vardon (Australian Bureau of Statistics), Dr Phil Gibbons (Australian National University), Dr Richard Mount (Bureau of Meteorology) and Peter Cosier (Wentworth Group of Concerned Scientists).

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Appendix 1

Measuring biodiversity in Australia as a case study

78. There are very few nation-wide comprehensive biodiversity data sets in Australia, and this is true for most nations. There is, however, a vast amount of data, housed in various institutions and agencies, and collected for disparate purposes. Environmental accounting should be a mechanism for drawing out that data, make best use of what is currently available (not waiting for perfect data) and also highlighting areas where data gaps are significant.
79. Existing national, or sub-national datasets that will significantly contribute to biodiversity accounting in Australia are vegetation extent, large vertebrates aerial surveys, waterbirds surveys and the Bird Atlas of Australia [74]. Vegetation condition and the extension of these existing surveys across the country would significantly assist in the long term measurement of biodiversity [74].
80. Given the lack of information and the complexity of biological systems, surrogates are often used to great an umbrella measure for biodiversity. This is the case with the Living Planet Index and the Wild Bird Index which uses bird abundances to make inferences about changes in biodiversity. It is perhaps recommended for the purposes of accounting that it is best to more explicit about what is being measured so the information can be interpreted correctly. With this said, almost all aspects of biodiversity that are measured are surrogates of some kind and will be an essential part of ecosystem accounting.

Vegetation

81. Australia has broad vegetation communities mapped and national coverage of pre-European mapping of extent of vegetation which facilitates condition metric development [75]. The National Carbon Accounting System (NCAS) now provides measures of extent change of woody vegetation for the purposes of calculating above ground carbon stores [76]. Analogous data are available globally via freely available Landsat archive.
82. Work currently being undertaken by the University of Queensland and Australian National University to use these data to estimate change in native species richness for via species area curves [77], which have strong empirical support [e.g. 78]. The Millennium Assessment also used the Species-Area Relationship (in combination with IMAGE 2.2) to measure biodiversity loss. Other measures will be investigated as although species richness is an important measure of biodiversity it must be integrated with other metrics improve its representativeness of biodiversity [6].

Species

83. Birds are conspicuous, well studied taxa that can potentially be used as indicators of biodiversity or as a surrogate for the condition of ecosystems and change in the environment [79].
84. The Birds Atlas of Australia collects bird observations from all over the country, which provides an opportunity to use this data to a measure biodiversity condition and change in condition, spatially and temporally.
85. It is highly unlikely that a single measure alone can accurately reflect the condition of biodiversity or ecosystems and that a number of measures will be appropriate.

Richness, endemism, rarity and functionality may be measures that can be used to build a biodiversity index using birds.

86. Using birds as an indicator presents some challenges. Birds will exhibit a time lag in change and there is likely to be an extinction debt in many cases of high disturbance [80]. However, in terrestrial systems, birds are thought to be the best option for measuring the condition of biodiversity – “if we can't make it work for birds, we can't make it work with anything”².
87. The minimum criteria for an accounting metric are that it measures change, is amendable to aggregation and are scientifically robust. Attributing the change between natural variation, climatic change and direct human activities can be difficult and is probably beyond the scope of these metrics (i.e. we are not attempted to measure change only due to human activity). It is important however that the change we detect is not be a function of sample size [81]. This is particularly important when using a volunteer collected data set such as the Birds Australia data where greater average diversity could be a result of more surveys, not necessarily more species.
88. Other datasets exist that may assist with the data on fauna abundance include kangaroos which are collected by aerial survey for the purposes of setting culling quotas.

Ecosystems

89. There are several well-established methods for measuring ecosystem condition, especially in the case of aquatic ecosystems (see, [12, 42, 70] for methods). Large scale implementation is evident in the Sustainable Rivers Audit for the 1 million km² of the Murray-Darling Basin and the Water Directive Framework for the EU Rivers [70, 82].
90. There are examples of measuring terrestrial ecosystem condition, in particular a pilot measuring the condition of terrestrial assets in Australia, which build upon the work done in aquatic systems (see Cosier 2011)[8]. All these measures of condition use biodiversity as an indicator and a common benchmark but have slightly different scientific methods of selecting and combining indicators. An option would be to outline principles of best practice as a guide for index development for the ecosystem accounting standards. A set of ‘accreditation measures’ are being developed as part of the Australia Regional Environmental Accounts trial and could inform this process.
91. The key to index development for ecosystem accounting is transparency. All methods, supporting data and metadata should be incorporated in an ecosystem account and it should be possible for users to ‘drill down’ to interrogate the origins of data and indices.
92. One of the great deficiencies with environmental information in Australia is the lack of a central framework to store, analyse and avoid duplication of environmental data. The wealth of environmental information is collected at regional and sub-regional levels. For example, universities, State and Local Government, regional Natural Resource Management Groups all collect biodiversity information at scales relevant to their purposes. One of the challenges is to capture that data. This can be achieved through accounting for assets individually. The Sustainable Rivers Audit does not currently extend beyond the Murray-Darling Basin but should be accounted for as an asset. Regional or locally specific data can also be utilised in building composite

² Pers comm Dr Denis Saunders 8/07/11

metrics of condition. Each data set is commensurate through standardisation on a common baseline. This is particularly important in Australia where the landscape is so vast and varied.