Experimental Biodiversity Accounting in Australia

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1. Introduction

1. This paper presents experimental biodiversity accounts in accordance with the System of Environmental-Economic Accounting Experimental Ecosystem Accounts (SEEA EEA). The accounts were prepared in order to test the feasibility of preparing biodiversity accounts and to identify actual or potential issues with compilation as well as to begin to examine ways in which the accounts may be used in policy making or evaluation.

2. A variety of issues were identified concerning measurement, differences between data sources as well as the effects of scale and spatial boundaries. In this it is clear that data quality assessment will play an important role in the production and use of biodiversity accounts.

3. The examination of potential uses of biodiversity accounts was also instructive and will help to inform the development of the accounts and in particular to ensure that the accounts are relevant to key users in government.

4. The experience in compiling these accounts will be useful when preparing future accounts and in any guidance material prepared to support the development of biodiversity accounts in countries.

Defining, measuring and accounting for biodiversity

5. The SEEA EEA defines biodiversity as the variability among living things and the ecosystems they inhabit, and is composed of three levels: genes, species and ecosystems[4]. Ecosystems are further defined as 'a dynamic complex of plant, animal and micro-organism communities and their non-living environment interacting as a functional unit'[5].

6. The measurement of biodiversity is a resource intensive task and consequently regular large scale systematic species level surveys to collect primary data are not undertaken. As a result, the approach commonly taken is to sample particular species groups, and usually the ones most amenable to detection such as vertebrates and vascular plants. The nature of the surveys undertaken varies from a relatively simple approach recording the presence and absence of species to find the total number of species occurring, which is called species richness. More sophisticated approaches also include measures of the abundance of each species or the number of individuals of each species found. Many surveys are undertaken for the purpose of academic research while a large body of information is also available from bird watchers and field naturalists. The methods used to gather this information varies greatly.

7. Because of the practically difficulty of collecting primary data a range of biodiversity metrics have developed. These commonly measure some aspect of species richness and abundance as well as evenness (the proportional abundance of species). These measures may then be combined in diversity metrics such as the Simpson Index or the Shannon Index (Simpson 1949; Spellerberg & Fedor 2003). Some measures concentrate just on abundance such as the Living Planet Index (Loh 2002), the GLOBIO index (Alkemade et al. 2006) and the Nature Index (Certain et al. 2011). A table of biodiversity indices is presented in the Appendix 1.

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[4] After Convention on Biological Diversity, 2003 http://www.cbd.int/convention/articles/default.shtml?a=cbd-02

[5] Again after Convention on Biological Diversity, 2003

8. The SEEA EEA describes two biodiversity accounts: one for species abundance (Table 4.7) and the other for threatened species (Table A4.1). In the accounts described, species are grouped according to taxonomy under the main Linnean groupings (e.g. birds, animals, reptiles, etc.) and categorised by species status as defined by the IUCN Red List categories. Accounts using the composite indices listed in Appendix 1 of this paper are not presented in the SEEA EEA although the indices are mentioned (e.g. in paragraph 4.120).

9. Ecosystems are one of the identified levels of biodiversity and can also be represented in accounts. As ecosystems may be approximated using land cover types, then the land cover accounts of the SEEA Central Framework are a type of biodiversity account (and this is recognised in the SEEA EEA in paragraph 4.117). It is also possible to use land cover information, and in particular the percentage of land cover existing now compared to the past, as a proxy for the number of species remaining using the relationship between remaining habitat and remaining species, commonly known as the species-area curve (see Brooks et al., 2002).

10. The scope of biodiversity accounts includes terrestrial and marine biodiversity. While accounts for marine species are no different than for terrestrial species, they may prove to be more problematic on a global scale, with many lesser-known species (particularly deep sea or open ocean species). The equivalent of ecosystem (land cover) accounts for marine species are not contemplated in the SEEA EEA or SEEA Central Framework but would appear possible. It will, however, require the delineation and classification of marine ecosystems (e.g. coral reefs, seagrass, sand, deep sea, etc.). There are already such classifications so the tasks for a variety of purposes so this is largely a matter of obtaining agreement of which classifications are most appropriate.

11. Biodiversity is also identified as part of the tables of describing ecosystem condition and changes in ecosystem condition (Table 4.3 and 4.4, respectively). In these tables indicators of biodiversity (see Appendix 1) are listed as examples of the metric to be used.

Data sources in Australia

12. Land cover data is available regularly from a variety of satellites, with coverage starting in about 1972 and extending through to today. Satellite data are available and have been processed into a number of land cover data sets in Australia and can be presented at different spatial scales and for different boundaries (e.g. water catchments or local government areas). The primary satellite data are available at a range of resolutions and the secondary data sources based on the satellite images generally use more than one primary source of data.

13. For Australia, two of the available national sources of land cover data are:

- National Vegetation Information System V3 (NVIS)
- Dynamic Land Cover

14. NVIS is produced by the Department of the Environment and is a data system that contains information on the extent and distribution of vegetation types in Australian landscapes[6]. NVIS has been produced for the years 1750 and 2006. Dynamic Land Cover mapping is annually produced by Geoscience Australia in collaboration with the Australian Bureau of Agricultural and Resource

[6] http://www.environment.gov.au/erin/nvis/

Economics and Sciences[7], and provides a nationally consistent and comprehensive land cover data for Australia, providing a base line for identifying and reporting on change and trends in vegetation cover and extent. These data sources contain sufficient detail to enable classes to show the structural character of vegetation from cultivated and managed land covers such as crops to natural land covers such as closed forest or open grasslands.

15. For Australia, the publicly-available data sources for species include the:
    - Environment Protection and Biodiversity Conservation (EPBC) Act[8] which lists threatened species;
    - Atlas of Living Australia[9];
    - Australian Natural Heritage Assessment Tool (ANHAT)[10];
    - International Union for the Conservation of Nature's (IUCN) Red List[11] which now lists all species, not just threatened ones; and
    - And various state based sources.

16. The data contained within each source is not necessarily consistent. For example, the IUCN Red List has two bird species listed as critically endangered in Australia, while the EPBC Act has three species listed (with only one species overlapping with the IUCN Red List).

17. In addition, these different sources of species data are available for different scales (NRM, state, national, and international), and there are time lags between national and international listings of species to higher or lower threat categories. For example state listings are ahead of national listing and national listing is ahead of international listing. There can also be different threat categories depending on the scale of data, for instance the discrepancy between the Queensland data and national data categories.

18. In the two species accounts developed in this study, although both represent species at a regional scale (Natural Resource Management Regions or NRMs, ranging from 2,358 – 1, 850, 000 km^2), different data sources were used. For Queensland, non-public data were obtained from the former Department of Environment and Resource Management for each NRM, while for Victoria data was from the publicly-available ANHAT website.

19. Using data from different sources means that they are unlikely to be directly comparable, particularly when considering the different methods used to collect and record data and the different spatial scale and boundaries used. Sometimes the categorisation of species by threatened species status is due to discrepancies between state listing categories, and then state and national listing categories. There can also be nomenclature issues between different jurisdictions too, with different species names being used in different regions, or different recognition of species (e.g. one species may be split into two or more species, or conversely two or more being lumped together into one species).

20. For national biodiversity accounts a regular and consistent national source of data is needed but the trade-off to comparability is that the potential sources may not be as accurate or up-to-date as

[7] http://www.ga.gov.au/earth-observation/landcover.html
[8] http://www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl?wanted=fauna
[9] http://www.ala.org.au/
[10] http://www.environment.gov.au/heritage/anhat/summaries/index.html
[11] http://www.iucnredlist.org/

local sources of information. The ultimate goal would be to have a workable set of biodiversity accounts that are adaptable enough to be used in any country at any scale.

21. For marine species, which were not considered in this study, there are some data available (e.g. EPBC Act, IUCN Red List), and there are classifications of marine ecosystems already in use for particular purposes (e.g. the management of the Great Barrier Reef). For the marine ecosystems the area of these could be used as the equivalent of the land cover accounts for terrestrial species. At present it seems that regular information (e.g. annual) on marine ecosystem area is unavailable.

2. Biodiversity accounts for the terrestrial environment adjacent to the Great Barrier Reef

22. The Great Barrier Reef (the reef) is a globally significant marine ecosystem, and is listed on the register of World Heritage sites. It is the world's most extensive stretch of coral reef and is one of the richest in terms of faunal diversity. It provides habitat for a range of endangered and iconic species, including major feeding grounds for the endangered dugong, nesting grounds for two endangered marine turtles, and is an important breeding ground for whales. In 2006, there were just over one million people living in the reef area. Human activity, and in particular agricultural activity and land management practices can lead to increased nutrient and sediment loads in the water discharged into the sea and impact on the health of the marine ecosystems, including the condition of marine biodiversity of the reef.

23. Accounts were prepared by the ABS for Great Barrier Reef region to demonstrate the links between the environment and economy[12]. As part of this work species and land accounts were prepared for the five NRMs that have water that drains onto the reef: Wet Tropics, Burdekin, Mackay Whitsunday, Fitzroy and Burnett Mary (Map 1). The land accounts are not presented here. Separately to the ABS work, data on bird species richness was developed as part of study by University of Queensland in association with the Australian National University and the ABS.

Species accounts

24. Table 2 is species status account for the year 2000 for the Burdekin NRM, one of the GBR regions. Similar tables could be constructed for all of the NRMs in Queensland. The data used are from the Queensland Department of Environment and Resource Management. It shows species grouped under animals, plants, fungi and protista. Animals are mostly limited to vertebrates, although it does show some insects. It further distinguishes species occurring in each NRM by whether they are introduced or native, rare or endangered, and protected or not by state laws. Table 2 also shows that most of the species in the Burdekin NRM are protected, native species.

25. A feature of table 2 is that not all species known to occur in the region are included. This is clearly seen for insects, where 11 are recorded as unprotected and cartilaginous fish for which information was not available.

[12] ABS 2012. *Completing the Picture – Environmental Accounting in Practice.* ABS cat. no. 4628.0.55.001

Map 1: Region of experimental ecosystem accounts for the Great Barrier Reef Region.

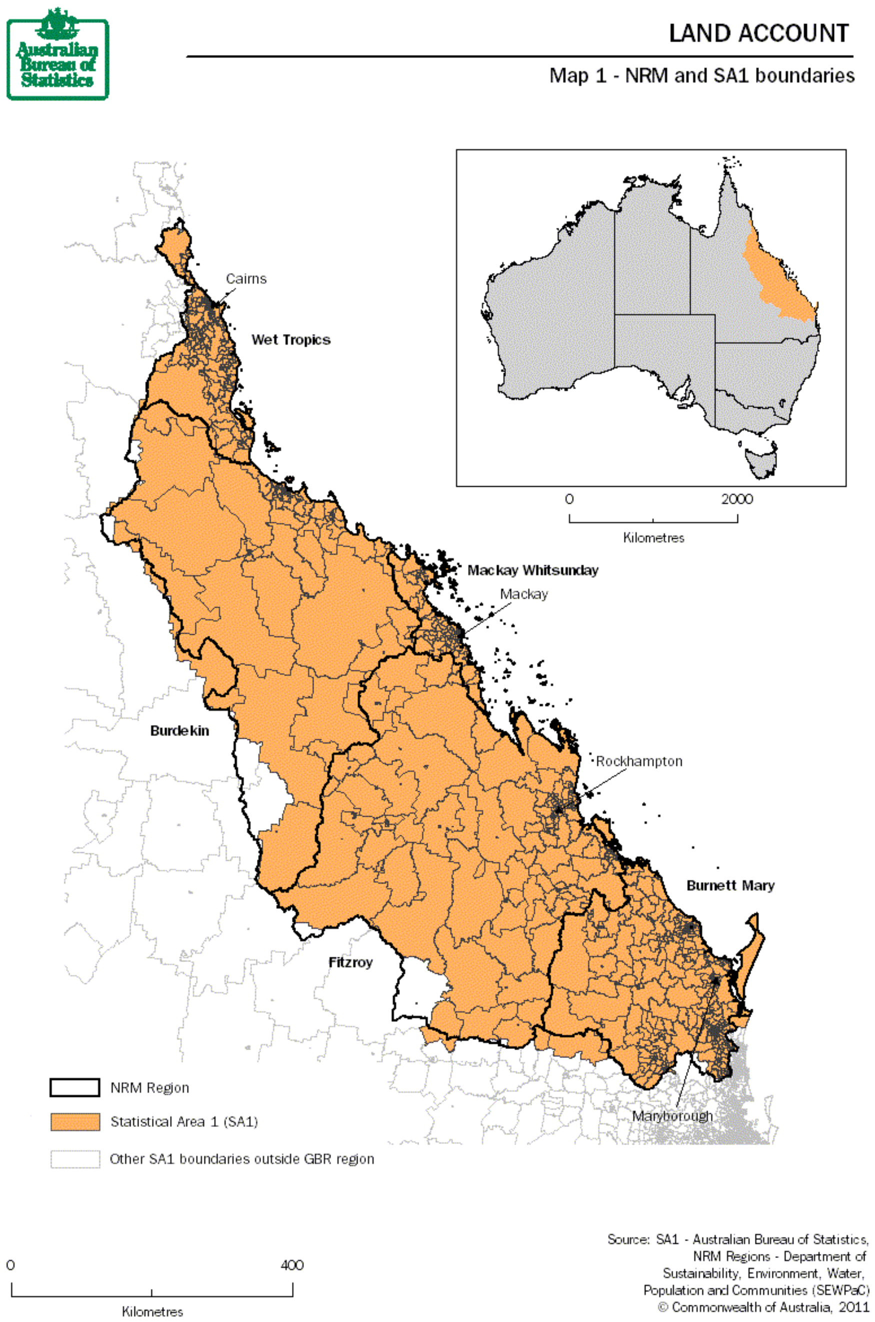


Table 2: Burdekin NRM species status 2000

	Introduced species	Native species				
		Unprotected	Protected	Rare and endangered	*Total native species*	Total species
Animals						
Vertebrates						
-Mammals	15	2	112	20	114	129
-Birds	10	0	458	33	458	468
-Reptiles	2	0	202	26	202	204
-Amphibians	1	0	51	9	51	52
-Bony fish	4	56	0	0	56	60
-Cartilaginous fish	NA	NA	NA	NA	NA	NA
-Insects	0	11	2	0	13	13
Subtotal	*32*	*69*	*825*	*88*	*894*	*926*
Plants	**376**	5	3239	91	3244	6320
Subtotal	*376*	*5*	*3239*	*91*	*3244*	*6320*
Fungi	**0**	0	68	0	68	68
Subtotal	*0*	*0*	*68*	*0*	*68*	*68*
Protista	**0**	0	148	0	148	148
Subtotal	*0*	*0*	*148*	*0*	*148*	*148*
TOTAL	**408**	**74**	**4280**	**179**	**4354**	**4762**

27. Table 3 outlines a biodiversity asset account for the Burdekin NRM with the opening stock in 2000 and the closing stock in 2011. The large gap between years was chosen based on data availability but also because it was thought that large changes might be seen (and they were). Distinguishing human-induced changes from natural variations in the distribution and abundance of species and from changes in knowledge is the aim of this account. However, while it shows that there has been an overall increase in species in every category between 2000 and 2011, the reasons for the changes could not be readily determined. This table includes lines for additions to the opening stock of categories, such as species being reclassified from other categories, the discovery of new species or re-discoveries of species thought to be extinct, or when a species is reclassified and split into two species. It also covers the reductions to the opening stock categories, such as species being reclassified from other categories (including extinctions), and from a taxonomic perspective, merged into another existing species. In no cases were we able to use the data source provided to attribute the cause of the change.

Table 3: Biodiversity asset account for Burdekin NRM

Burdekin NRM	Introduced	Native species				
		Unprotected	Protected	Rare and endangered	*Total native species*	Total species
Opening stock 2000	408	74	4280	179	4354	4762
Additions						
-from lower threat categories (ie increased risk of extinction)	NA	NA	NA	NA	NA	NA
-from higher threat categories (ie reduced risk of exinction)	NA	NA	NA	NA	NA	NA
-discoveries of new species	NA	NA	NA	NA	NA	NA
-rediscoveries of extinct species	NA	NA	NA	NA	NA	NA
-reclassifications(a)	NA	NA	NA	NA	NA	NA
Total additions	NA	NA	NA	NA	NA	NA
Reductions						
-to lower threat categories (ie reduced risk of extinction)	NA	NA	NA	NA	NA	NA
-to higher threat categories (ie increased risk of exinction)	NA	NA	NA	NA	NA	NA
-reclassifications(b)	NA	NA	NA	NA	NA	NA
Total reductions	NA	NA	NA	NA	NA	NA
Net change	*121*	*34*	*353*	*30*	*387*	*508*
Closing stock 2011	529	108	4633	209	4741	5270

(a) Where one existing species is now recognised as two or more distinct species.

(b) Where two or more existing species are now recognised as one species.

Bird species richness

28. A metric of bird species richness was created using modelling based on the relationship between area (habitat) and species richness using data on forest cover from remote sensing[13]. Bird species richness for each 100 x100 metre cell was estimated using the area of habitat for birds in the local landscape (Fahrig 2013) and applying the species-area curve (after Brooks et al 2002, see below). Due to the breath of scientific integration of this pattern and empirical testing, the species-area curve is widely considered a robust broad-scale model explaining how species richness changes with area (Holt et al. 1999; Lomolino 2000). Many studies use the species-area relationship described to predict the proportion of species lost (Brooks et al. 2002; Brooks et al. 1997; Brooks et al. 1999; Thomas et al. 2004).

[13] The method is very briefly described here. For more information please contact Jane McDonald.

29. To estimate the proportion of bird species remaining the following equation is used:

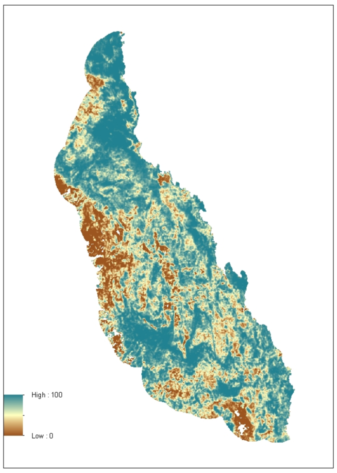
$$S_{new}/S_{original}=(A_{new}/A_{original})^{z}$$

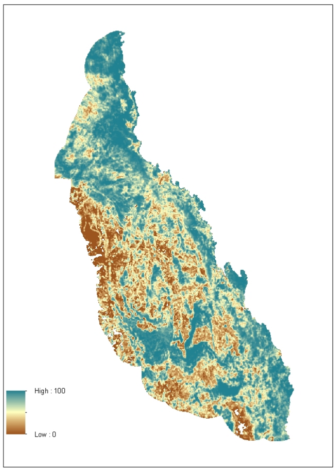
Where S is species and A is area and z is a constant and in this case equal to 0.25.

30. The score for each 100 x 100 m cell for the year 1972 and 2011 is shown in Map 4. The year 1972 was chosen because it was the year for which the earliest satellite data on land cover were available.

31. The lessons from the biodiversity accounts prepared for the Great Barrier Reef are discussed further in Section 4

Map 4: Index of bird species richness for the Great Barrier Reef 1972 and 2011





a) The map of biodiversity spatial units in 1972 and b) 2011 where 0 is no biodiversity and 100 is the full complement of species prior to significant disturbance.

3. Biodiversity Accounts for Victoria

32. Biodiversity accounts for land cover and species were prepared for Victoria. This included a threat status account for birds for Victoria, detailing changes that have occurred between two points in time and well as land cover accounts for each NRM region of Victoria.

33. Birds were chosen for the species accounts because there are many species in Victoria, and birds as an animal group are well-known (probably the best known of all animal groups). The bird data were obtained directly from the Australian Natural Heritage Assessment Tool (ANHAT)[14] and data for all the Victorian NRM regions were compiled. The summaries themselves were produced by the Department of Environment (then known as the Department of Sustainability, Environment, Water, Populations and Community or SEWPaC) for the Natural Resource

[14] http://www.environment.gov.au/heritage/anhat/summaries/index.html

Management Spatial Information System, and were produced using ANHAT, which analyses data from a range of plant and animal surveys and collections from across Australia to generate reports for each NRM region.

34. Data contained in these SEWPaC summaries is drawn from a range of sources, including from national and state herbaria, museums, state governments, Commonwealth Scientific and Industrial Research Organisation (CSIRO), Birds Australia, and a range of surveys conducted by or for SEWPaC. Potential limitations of this data for comprehensive species accounts (i.e. covering all known taxa) are that it only covers birds, mammals, reptiles, frogs, fish, vascular plants and a limited range of invertebrate animal groups. In general, the data has come from authoritative sources, but is not perfect. In this all species names have been confirmed as valid species names, but it was not possible to confirm locations all species listed in the database. The summary of the input data reflects any errors in the received data. Also, the level of detail is currently insufficient to fully inform status and changes in biodiversity – for example, it does not provide the range of years when species have been recorded in surveys, which would indicate when and where the changes have occurred.

35. The data used was from the EPBC Act (1999) species classification, with listings of those species which are:

    - Vulnerable
    - Critically endangered
    - Endangered
    - Conservation dependent

36. The EPBC Act[15] does not align directly with the international threatened species classification standard of the International Union for the Conservation of Nature (IUCN) Red List[16] but it may be concorded. In terms of spatial scale, the data is provided at NRM level per state / territory.

37. The data contain numbers of various species of flora and fauna, and are organised by the national threat status of each species. They were collected in respect of NRM regions and relate to a point in time. The methodology used allows us to produce a picture of broad changes in biodiversity using an accounting approach – that is, we record the number of species at two points in time, and provide details of flows to explain changes between these points in time. Data are aggregated across species and across NRM regions.

38. More specifically, once the bird species data was obtained from the ANHAT website, it was then checked over to improve the quality of the data. Some of the species records were omitted for the following reasons:

    1. Species being very unlikely to have been recorded in the NRM due to their current distribution range, taking into account whether the species is typically sedentary (e.g. thornbills) or not (as those species which move around the landscape would be more likely to be detected outside their normal range and distribution). The reason for the existence of these records may be from incorrect identification in the field, or there may have been an incorrect entry of the record into the database.
    2. Species which have undergone changes to their Latin name which has somehow led to the inclusion of both the old and new names. These old Latin name species records have been omitted so that only the recent name exists (for example, the New Zealand fantail

[15] http://www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl?wanted=fauna
[16] http://www.iucnredlist.org/

Rhipidura fuliginosa and the Pacific robin *Petroica multicolor* have been deleted while the grey fantail *Rhipidura albiscapa* and the scarlet robin *Petroica boodang* have been retained).

3. Species which are potential vagrants have been given the benefit of the doubt and left in, even if the NRM is not part of their usual range.

39. No introduced species (e.g. European starling) were included in the original data, and so they are not represented in these tables. This is unfortunate, as their presence/absence can be indicative of the 'quality' of the habitat they are in – that is, where the greater number of exotic species detected indicates a more degraded habitat. It would therefore be useful, if possible, to have the inclusion of introduced or exotic species data to get an indication of ecosystem degradation.

40. The years chosen to illustrate a five year interval were 2001 and 2006. These years were chosen as the data provided on the SEWPAC ANHAT website only goes to 2009, and even then not for most species - most of the recent records are however complete up to 2006. The assumption with the data in the table was that if a species was recorded in 2006 it was also likely to have been present in 2001 - this assumption has been made to maintain a logical presentation of the data, and although for the majority of species this may well be the case, it would be preferable to have the actual first records for all species; however there is no access to this on the web display, only the most recent records.

Table 5: Birds account for Victoria – 2001 and 2006.

		Extinct	Ex wild	Cr end	En	Vuln	L risk	Near thr	Data def	Least concern	Total
Opening stock	2001	0	0	1	4	10	0	0	0	363	378
Additions											
from lower threat categories											
from higher threat categories											
discoveries of new species											
rediscoveries of extinct species											
reclassifications											
updated assessments											
new additions to list											
Total additions		0	0	0	0	0	0	0	0	0	0
Reductions											
to lower threat categories											
to higher threat categories											
reclassifications											
local extinction											
updated assessments											
Total reductions		0	0	0	0	6	0	0	0	45	51
Closing stock	2006	0	0	1	4	4	0	0	0	318	327

41. Table 5 provides information on bird species in Victoria for 2001 and 2006. In total there were 51 fewer species in 2006 (327 species) than in 2001 (378 species), while within the threat categories, there was a reduction of six vulnerable species. The loss of species between 2001 and 2006 is suspected to mostly be due to either a delay in the entry of records to the database or that no surveys were conducted between the two time periods, rather than actual losses of species between these two points in time. This suspicion arises because there are no recent records of common species in areas where they should occur.

It is unclear as to the reasons why the number of "Vulnerable" species has been reduced. These cannot be termed 'losses' as they may have, for example, improved their threat status category to Least Concern. Further investigation may be able to resolve these anomalies but for the time being they remain unresolved. If this information become known, it would be possible to construct flow tables showing the movement of species form one listing class to another. This would assist interpretation of the tables.

Table 6: Snapshot of birds by threat status for Victorian NRMs, 2006.

	Extinct	Ex wild	Cr end	En	Vuln	L risk	Nr thr	Data def	L concern	Total
Corangamite	0	0	1	0	0	0	0	0	187	188
East Gippsland	0	0	0	2	0	0	0	0	197	199
West Gippsland	0	0	0	0	1	0	0	0	179	180
Mallee	0	0	0	0	1	0	0	0	136	137
Port Phillip	0	0	0	0	0	0	0	0	212	212
Glenelg-Hopkins	0	0	1	1	0	0	0	0	170	172
Goulburn-Broken	0	0	0	1	0	0	0	0	156	157
North Central	0	0	0	1	1	0	0	0	177	179
North East	0	0	0	2	1	0	0	0	172	175
Wimmera	0	0	0	0	1	0	0	0	72	73
Victoria (total)	0	0	1	4	4	0	0	0	318	327

42. Table 6 provides information on bird species status at the NRM level for 2006. An analytically useful aspect of this table is that comparisons can be made between NRM regions (although see the cautionary note below regarding different NRM regions). The usefulness of this table would improve over time (i.e. with a time series). In the meantime, the summary of species status for 2006 will have to suffice and as such Table 6 is not strictly an account.

43. Table 6 shows that the Wimmera had the fewest bird species (73) while Port Phillip had the most (212) bird species. All of the NRMs except for Port Phillip had a threatened species. Corangamite and Glenelg-Hopkins had species in the most at risk category of extinction, 'Critically Endangered'.

44. In interpreting this table it is important to recognise that not all NRM regions are equal in terms of area, accessibility and human population. The variation in area is from over one million square kilometres to just over two thousand square kilometres. They also vary in terms of the ability of people to access different parts of the NRM for the purpose of observing birds, with geophysical barriers such as steep terrain or remote sand desert. This means that more accessible areas are likely to have more data. Some NRMs, such as Port Phillip, have greater human populations (it contains the city of Melbourne), which translates to more observers and greater chances for the detection of species. In addition each NRM region has a different composition of ecosystems: for example East Gippsland possesses forest ecosystems while the Wimmera has mainly cleared farmland ecosystems. Thus, the comparison of species numbers between NRMs must be drawn acknowledging these differences.

Land cover accounts

45. The land cover accounts for Victoria where prepared as part of the Land Accounts, Victoria Experimental Estimates. These provide a series of tables showing land cover for the years 1750 and 2006, for each natural resource management region in the state and a well as the state as a whole. The data were also presented in maps (see Maps 6 to 8). As there is a correlation between native vegetation extent and number of species (Brooks et al., 2012), the area of native vegetation

was used to predict the number of species in a particular region and this is summarised in Figure 8.

46. Different spatial boundaries may be used to present information on number of species or area of vegetation. The most appropriate boundary will depend on the type of analysis being undertaken. The selection of boundaries is a key decision. There are many issues that need to be addressed including problems with scaling, boundary choice (e.g. gerrymander) and spatial autocorrelation (or the 'pattern' problem). These are mentioned in paragraph 2.103 of SEEA EEA along with the recommendation that geospatial specialists should be involved in the design of the spatial units and analytical methods.

47. A particular problem is that different aggregations of individual data points produce different results. This is known as the Modifiable Areal Unit Problem (e.g. Openshaw 1984) and it has been recognised for some time (Gehlke and Biehl 1934). A key aspect of the problem is while it is usual to define the object of study ahead of the measurement of the characteristics of the object, it is often the case that individual units are measured and then aggregated after measurement, as is the case with, for example, the characteristics of households or farms are measured population censuses and agricultural surveys and farms and household are then aggregated into regions after measurement.

48. The experimental land accounts for Victoria presented information on native vegetation area aggregated according to three different boundaries:

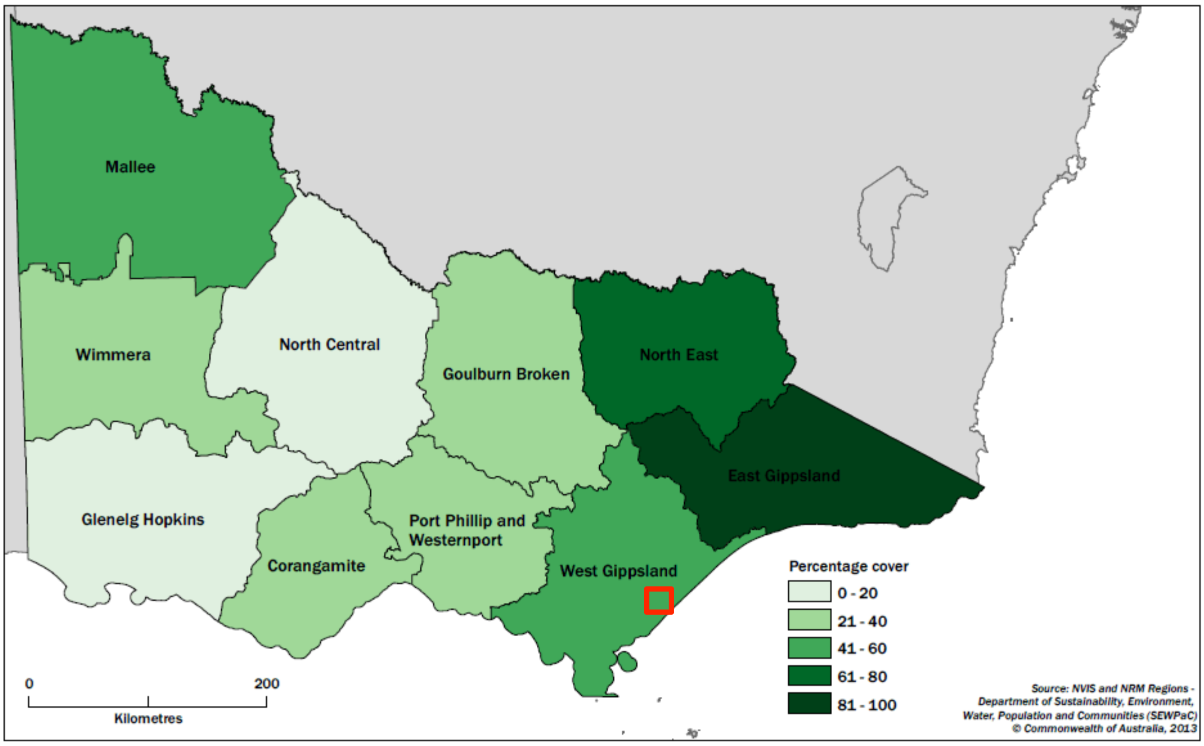
- Natural Resource Management (NRM) regions,
- Statistical Areas (SA4) and
- Interim Bioregional Assessment regions (IBRA).

49. The resultant maps and tables provide an example of the Modifiable Areal Unit Problem, whereby the same base data can tell a different story depending on the boundary used for aggregation. The problem is clearly seen when looking at the Maps 7, 8 and 9. Note the red box on the right hand side of Victoria, which is shown in each map. The area within the box does not move, yet for Map 7 (NRM Regions) the score is 41-60, for Map 8 (IBRA regions) it is 0-21, while in Map 9 (SA4 regions) it is 61-80. They are all correct calculated, but which is “best” depends on the use of the data.

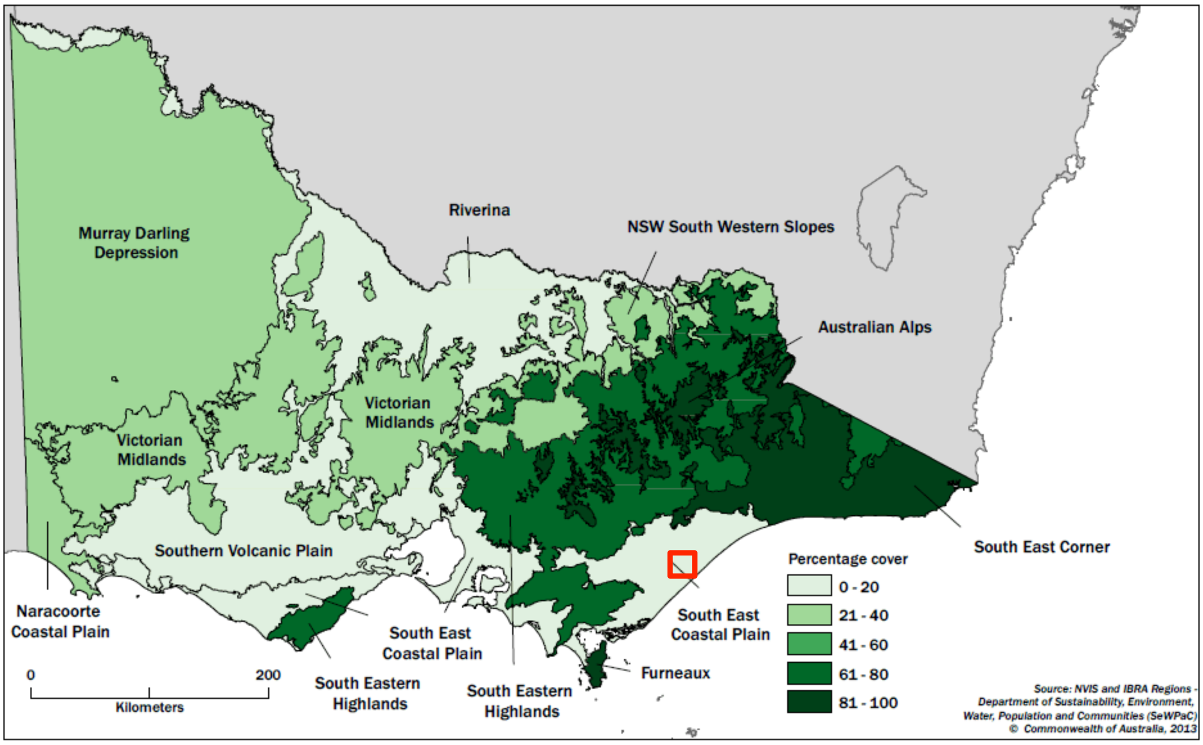
50. NRM regions are useful because they represent the boundaries of the Catchment Management Authorities that are responsible for land management. SA4 are useful because these are the boundaries that link to the social and economic data of the ABS, while IBRA regions are defined by physical characteristics.

51. Another challenge when using information based on different spatial boundaries is that because of differences in coverage, and in particular where the boundary is drawn with respect to the shoreline, there are slight differences in the area shown for Victoria when the native vegetation data are intersected with other data layers.

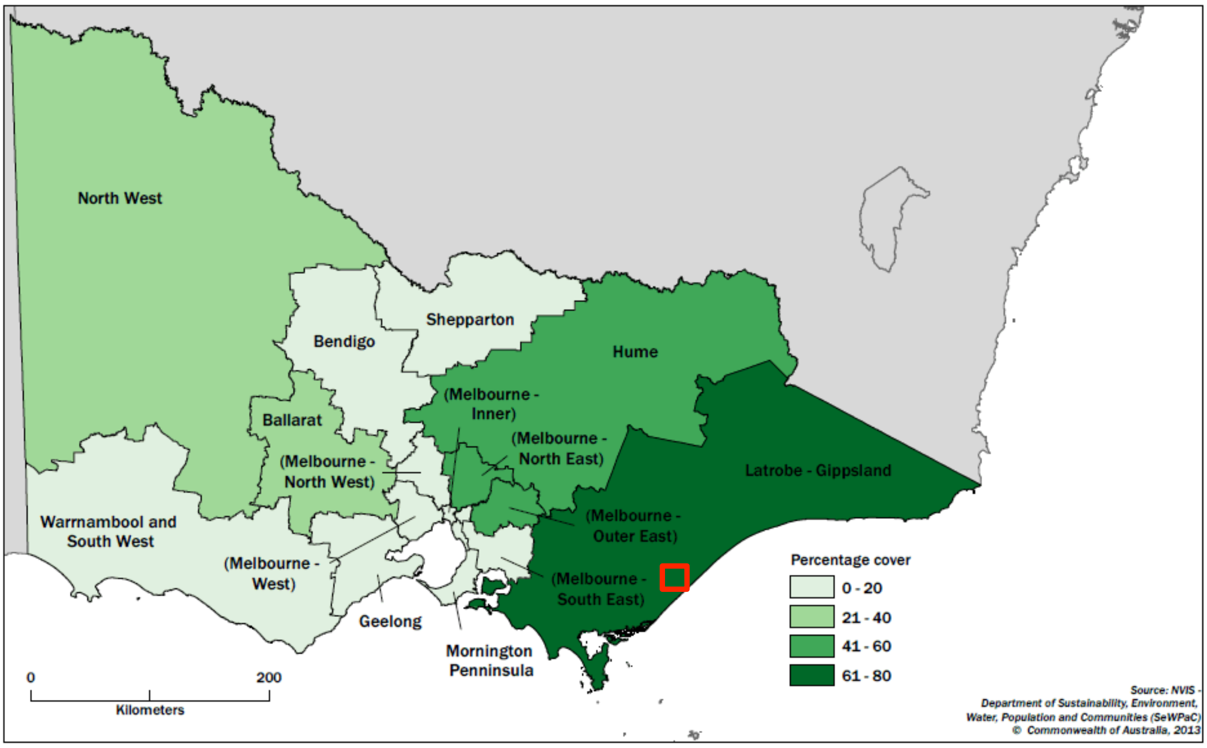
Map 7: Percentage of 1750 native vegetation cover remaining in 2006 by NRM (from ABS 2013).



Map 8: Percentage of 1750 native vegetation cover remaining in 2006 by IBRA (from ABS 2013).

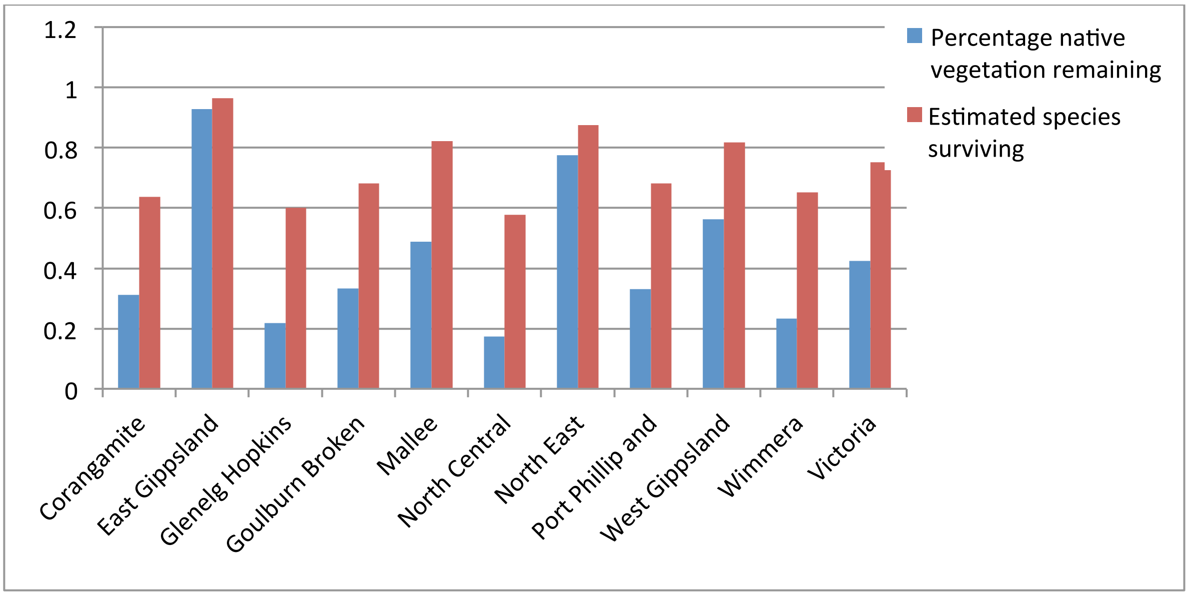


Map 9: Percentage of 1750 native vegetation cover remaining in 2006 by SA4 (from ABS 2013).



52. Land cover was used to estimate the percentage of species remaining in each of the NRM (Fig. 10). Again the species area relationship described by Brooks et al. (2002) was applied to each native vegetation type remaining in the NRMs in 2006. This result was then weighted by the proportion that each vegetation type occupied in each NRM in 1750 to provide a total estimate of species remaining for each NRM. In this, it the relative number of species, not total number of species remaining in each vegetation type that was used to score the NRM, which is different from the total number of species remaining, since each habitat type will have different original number of species. For example, Mallee Woodlands and Shrublands have fewer species than Rainforest and Vine Thickets. The absolute number of species estimated to be remaining is the desired metric and could be found by including the number of original species found in each NRM in the calculation.

Figure 10. Estimated fraction of species surviving based on native vegetation area.

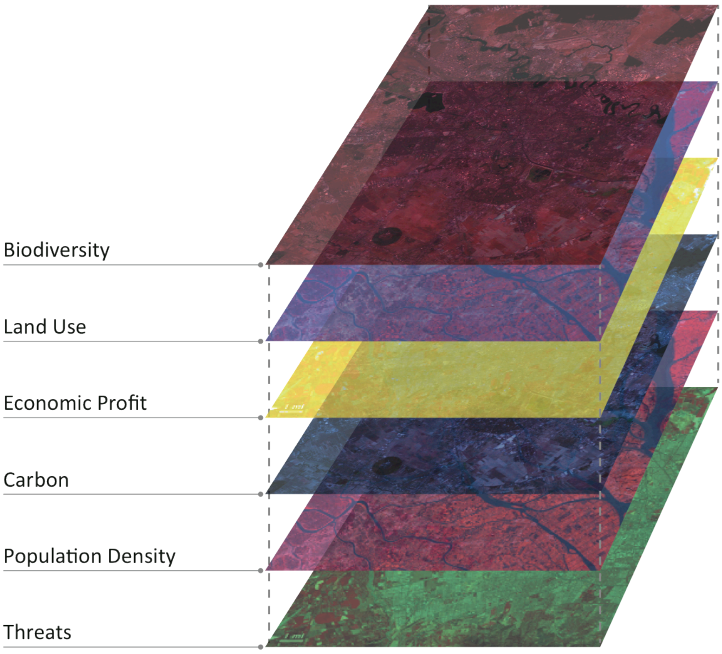


4. Linking biodiversity to policy and decision –making

53. Developing a spatially-based accounting system is an opportunity to integrate biodiversity information and data to inform policy and decision-making (Figure 11). For example:

1. Land use and profitability can inform land use planning and conservation planning.
2. Land use information also provides the link between biodiversity and industry allowing policy makers to identify high (and low) impact industries (Prugh et al. 2010).
3. Profitability of different land uses is a key variable as the opportunity cost in making land use decisions at the local level.
4. Land use and profitability accounts in conjunction with biodiversity accounts facilitates the analysis of where in the landscape high profits and food can being produced for a given level of biodiversity (Polasky et al. 2008).
5. Trade-offs analysis, especially between ecosystem services, is an important consideration in decision-making (Raudsepp-Hearne et al. 2010; Rodríguez et al. 2006). It is especially critical to biodiversity where optimization of many more utilitarian services may come at the expense of biodiversity (Nelson et al. 2009) and would be an important function of accounting.
6. Proposed environmental expenditure accounts (UNCEEA 2012) in conjunction with biodiversity stock accounts could provide a systematic return on investment information to inform cost-benefit analysis (UNCEEA 2013).
7. Spatially linking biodiversity accounts to mapped threats can assist in the identifying where to invest in threat management for the greatest return for biodiversity at least cost (Carwardine et al. 2012; Evans et al. 2011).

Figure 11: Linking biodiversity to other accounts and information through space.



Linking biodiversity to economic data

54. As an example, bird species richness is spatially linked to agricultural land use and more specifically to the commodities produced. In this, the data are preliminary and the tables designed to show the potential for comparisons[17]. Table 12 the average stock of biodiversity (as measured by bird species richness) on the land producing particular commodities is shown against the profit made from that land, similar to the methods of Polasky et al (2008) and Nelson et al (2009). The average bird species richness is estimated via the methods described in paragraph 28 and allocated to land use through spatial overlay. The agricultural profits layer was calculated using the same land use layer from the Australian Department of Agriculture, estimating the quantity of commodity produced per hectare from the Australian Bureau of Statistics agricultural census and using average commodity price and average farm costs to estimate profit at 1km^2 scale (Marinoni et al. 2012). Table 13 shows the estimated change in biodiversity between two time periods, 1998 and 2006, compare to agricultural profits.

[17] The method is very briefly described here. For more information please contact Jane McDonald

Table 12: Bird species richness stocks (0-100) compared to agricultural profit by agricultural commodity in the GBR for 2006. (Preliminary results)

Commodities	Bird species richness per ha (Biodiversity stock per ha)	Profit per ha
Cereals	37	$4,000
Cotton	45	$2,000
Sugar cane	65	$1,100
Grazing	67	$25
Vegetables	70	$11,000

Table 13: Change in biodiversity stock between 1998 and 2006 compared to agricultural profit in the GBR for 2006. (Preliminary results

Commodities	Change in Bird species richness 1998 to 2006 per ha (biodiversity stock)	Profit per ha
Cereals	-12.3	$4,000
Cotton	-9.2	$2,000
Sugar cane	-6.4	$1,100
Grazing	-4.3	$25
Vegetables	1.2	$11,000

5. Discussion

55. The compilation of the data available for species and land cover into biodiversity accounts as well as the examination of various biodiversity metrics demonstrate that it is possible to construct biodiversity accounts in a relatively short period of time. This work has suggested a number of ways in which such data could be used and in particular integrated with other information. It has also, however, highlighted a number of deficiencies and discrepancies with the data which will have to be addressed as well as raised a number of issues concerning scale and boundaries.

Data deficiencies

56. The accounts complied used a variety of data sources. In particular the data sources for both land cover and species use a range of classifications which do not perfectly align. For example the species threat categories and land cover types. These problems can probably be overcome through the use of concordance tables.

57. On the basis of these initial investigations there is less data for species than for land cover and that the data for species is less well organised at present (although there are initiatives underway to address this, e.g. the Atlas of Living Australia). In general the data on species is for occurrence (i.e. presence) but absences of species previously found in particularly areas cannot be readily determined. In this the question that arises when examining the data is: are there no records because no survey was undertaken and hence no chance of recording or were surveys undertaken the species found to be absent? For example, when examining the data for Victorian, there where unusual recent absences of common species from the summaries for some of the regions, which would indicate that rather than the species no longer existing there, that the data is not up to date.

58. In general, the method from which records of species were obtained (e.g. systematic survey or opportunistic sighting) is usually unknown as is total survey effort. As such changes in the data may simply reflect survey effort. Two other points to note are that species abundance measures are lacking for all but a few species and that records for animals are mostly for vertebrates (with an emphasis on birds).

59. These issues point to the generally ad hoc way that species data are gathered and stored in data bases. It seems there is no regular or systematic update of species data and the meta-data available is not usually enough to determine the fitness of the data for environmental accounting.

60. In contrast, land cover data is available regularly and the methods used to collect and process the data are well described (although not without problems). Indeed this is one reason why habitat extent as proxy for species richness may be useful for biodiversity accounting.

61. For both land cover and species accounts the reasons for change between opening and closing stocks is the most difficult to populate. For land cover a change from forest to crop or from crop to urban areas can be reasonably interpreted to due to human influence. However, other changes, for example in the distribution, abundance or threat status of species are less clear. Changes to threat status can probably be determined from the documents used to formally list species through administrative processes but this was not attempted.

62. A range of alternative data sources are available but were not investigated thoroughly. For example citizen science projects such as: Frogwatch in Australia[18]; the Big Butterfly Count in United Kingdom[19], and; Bird Atlas of Australia[20]. Also very recently (October 2013) a new report on biodiversity profiling became available[21].

Spatial scale and boundary issues

63. Maps 7 to 9 demonstrate that the choice of boundaries for the collection and presentation of data is important. It underscores the importance of spatially referencing the primary data to as finer level as possible to enable aggregation to different spatial boundaries to support different kinds of investigations.

64. The species accounts prepared at a local level highlight the need to incorporate within the tables a category for "locally extinct". In this a species may have been previous found in the region, but has not been found for some time in that region, but is found elsewhere. While range changes are an indication of changes is the population dynamics of species, the national level accounts described in the SEEA EEA do allow for this possibility.

65. Related to this is the status of species are depend on context. For example, a species which has a small population and a restricted range within one region or country may in fact be common and widespread if the entire (global) population where taken into account. This can lead to the impression of species being under threat when they are not. A solution would be to add a column in the threatened species table for species that locally extinct. Another solution would be to present species local status as a cross-tabulation of national or global status.

Marine biodiversity

66. The work to date has focused on terrestrial species biodiversity. Data are available for marine species and for marine habitat types. Conceptually it would be a relatively straightforward to task to prepare biodiversity accounts for marine species and ecosystems along the lines of those suggested for terrestrial species. Practically, data availability is likely to be a challenge.

6. Conclusion

67. Biodiversity accounts as described in the SEEA can be produced from existing information, albeit with a range caveats. For biodiversity accounts to be regularly produced and for their quality to fit for incorporating in decision-making processes a range of theoretical and practical issues will have to be addressed. While a large amount of information is available it is not easily shaped in into accounts. Better arrangement and access to information will help, but it seems likely that there is a need for regular systematic primary information on the distribution and abundance of species and their habitats.

[18] Frogwatch http://www.ginninderralandcare.org.au/frogwatch
[19] Butterfly Conservation http://www.bigbutterflycount.org
[20] Birds Australia http://birdlife.org.au/projects/atlas-and-birdata
[21] Zerger, A. et al. (2013). Biodiversity Profiling: Components of a Continental Biodiversity Information Capability. Bureau of Meteorology, Canberra.

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8. References

Alkemade, R., M. Bakkenes, R. Bobbink, L. Miles, C. Nellemann, H. Simons, and T. Tekelenburg. 2006. GLOBIO 3: Framework for the assessment of global terrestrial biodiversity.

Atlas of Living Australia. http://www.ala.org.au/

Australian Bureau of Statistics (2012). Completing the Picture – Environmental Accounting in Practice. ABS cat. no. 4628.0.55.001

Australian Bureau of Statistics (2012). Land Accounts, Victoria Experimental Estimates. ABS cat. no. 4628.0.55.001

Brooks, T. M., R. A. Mittermeier, C. G. Mittermeier, G. A. B. Da Fonseca, A. B. Rylands, W. R. Konstant, P. Flick, J. Pilgrim, S. Oldfield, G. Magin, and C. Hilton-Taylor. 2002. Habitat Loss and Extinction in the Hotspots of Biodiversity Pérdida de Hábitat y Extinciones en Áreas Críticas para la Biodiversidad. Conservation Biology **16**:909-923.

Department of Environment ANHAT summaries. http://www.environment.gov.au/heritage/anhat/summaries/index.html

Department of Environment NVIS. http://www.environment.gov.au/erin/nvis/

Department of Environment EPBC Act. http://www.environment.gov.au/cgi-bin/sprat/public/publicthreatenedlist.pl?wanted=fauna

Brooks, T. M., S. L. Pimm, and N. J. Collar. 1997. Deforestation Predicts the Number of Threatened Birds in Insular Southeast Asia. Conservation Biology **11**:382-394.

Brooks, T. M., S. L. Pimm, and J. O. Oyugi. 1999. Time Lag between Deforestation and Bird Extinction in Tropical Forest Fragments

Espacio Temporal entre la Deforestación y la Extinción de Especies de Aves en Fragmentos de Bosques Tropicales. Conservation Biology **13**:1140-1150.

Carwardine, J., T. O'Connor, S. Legge, B. Mackey, H. P. Possingham, and T. G. Martin. 2012. Prioritizing threat management for biodiversity conservation. Conservation Letters **5**:196-204.

Certain, G., O. Skarpaas, J. W. Bjerke, E. Framstad, M. Lindholm, J. E. Nilsen, A. Norderhaug, E. Oug, H. C. Pedersen, A. K. Schartau, G. I. van der Meeren, I. Aslaksen, S. Engen, P. A.

Garnasjordet, P. Kvaloy, M. Lillegard, N. G. Yoccoz, and S. Nybo. 2011. The Nature Index: A General Framework for Synthesizing Knowledge on the State of Biodiversity. Plos One **6**.

Evans, M. C., J. E. Watson, R. A. Fuller, O. Venter, S. C. Bennett, P. R. Marsack, and H. P. Possingham. 2011. The spatial distribution of threats to species in Australia. Bioscience **61**:281-289.

Fahrig, L. 2013. Rethinking patch size and isolation effects: the habitat amount hypothesis. Journal of Biogeography.

Gehlke, C. and Biehl, H. (1934). Certain effects of grouping upon the size of the correlation coefficient in census tract material. Journal of the American Statistical Association Supplement, 29, 169–170.

Geoscience Australia Dynamic Land Cover. http://www.ga.gov.au/earth-observation/landcover.html

Holt, R. D., J. H. Lawton, G. A. Polis, and N. D. Martinez. 1999. TROPHIC RANK AND THE SPECIES–AREA RELATIONSHIP. Ecology 80:1495-1504

International Union for the Conservation of Nature, Red List. http://www.iucnredlist.org/

Loh, J. 2002. Living Planet Index 2002. World Wildlife Fund International, Gland, Switzerland.

Lomolino, M. V. 2000. Ecology's Most General, Yet Protean Pattern: The Species-Area Relationship. Journal of Biogeography **27**:17-26.

Marinoni, O., J. Navarro Garcia, S. Marvanek, D. Prestwidge, D. Clifford, and L. Laredo. 2012. Development of a system to produce maps of agricultural profit on a continental scale: An example for Australia. Agricultural Systems **105**:33-45.

Nelson, E., G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D. Cameron, K. M. A. Chan, G. C. Daily, J. Goldstein, P. M. Kareiva, E. Lonsdorf, R. Naidoo, T. H. Ricketts, and M. Shaw. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment **7**:4-11.

Openshaw, S. (1984). The Modifiable Areal Unit Problem Geo Books Norwich. http://qmrg.org.uk/files/2008/11/38-maup-openshaw.pdf

Polasky, S., E. Nelson, J. Camm, B. Csuti, P. Fackler, E. Lonsdorf, C. Montgomery, D. White, J. Arthur, B. Garber-Yonts, R. Haight, J. Kagan, A. Starfield, and C. Tobalske. 2008. Where to put things? Spatial land management to sustain biodiversity and economic returns. Biological Conservation **141**:1505-1524.

Prugh, L. R., A. R. E. Sinclair, K. E. Hodges, A. L. Jacob, and D. S. Wilcove. 2010. Reducing threats to species: threat reversibility and links to industry. Conservation Letters **3**:267-276.

Raudsepp-Hearne, C., G. D. Peterson, and E. M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. Proceedings of the National Academy of Sciences of the United States of America **107**:5242-5247.

Rodríguez, J. P., T. D. Beard, E. M. Bennett, G. S. Cumming, S. J. Cork, J. Agard, A. P. Dobson, and G. D. Peterson. 2006. Trade-offs across space, time, and ecosystem services. Ecology and Society **11**:28.

Simpson, E. H. 1949. Measurement of diversity. Nature **163**:688.

Spellerberg, I. F., and P. J. Fedor. 2003. A tribute to Claude Shannon (1916–2001) and a plea for more rigorous use of species richness, species diversity and the 'Shannon–Wiener' Index. Global Ecology and Biogeography **12**:177-179.

Thomas, C. D., A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A. S. van Jaarsveld, G. F. Midgley, L. Miles, M. A. Ortega-Huerta, A. Townsend Peterson, O. L. Phillips, and S. E. Williams. 2004. Extinction risk from climate change. Nature **427**:145-148.

UN et al. 2012. System of Environmental-Economic Accounting Central Framework.

UN et al. 2013. SEEA Experiemental Ecosystem Accounting Draft subject to editing. Department of Economic and Social Affairs Statistics Division United Nations.

Appendix 1 . Biodiversity indices.

From P. A. Garnåsjordet, McDonald, J., Cosier, P., ten Brink, B., Saltelli, A., Magnusson, B., Nybø, S., Skarpaas, O., Aslaksen, I., "Biodiversity accounts and indices," *Expert Meeting on Ecosystem Accounts* (Melbourne, Australia, 2012).

Index	**Measure**	**Characteristics**	**Baseline**	**Purpose and scale**	**Source**
Wild Bird Index	Abundance of birds	Group of birds f.ex. Farm birds, Seabirds, Wood-land birds	UK 1970, Eurostat 1990	Indicator of biodiversity, National	Gregory et al (2004). Eurostat 2011
Living Planet,	Abundance of different species	7953 species, interpolations and extrapolation	WWF, UNEP 1970,	Indicator of biodiversity, Global, Regional	Loh (2002) Loh et al (2005)
Species Assemblage Trend Index	Abundance of species	Can be different group of species, taxonomic groups, endemic species or threathened species.	CBS,NGO's Various years	Indicator of biodiversity, Regional	Brink (2006)
Red List Index	Change in rareness status	Species extinction risk by weighting the extinction risk of all species of a particular taxonomic group	IUCN, Now	Indicator of biodiversity, Global, National	Butchart (2004)
Simpson Index	Statistical measure of species richness and relative abundance	The probability that two randomly selected individuals belong to two different species	Now	Indicator of biodiversity, Any scale	Simpson (1949)
Shannon Index	Statistical measure of richness and evenness (relative abundance)	Measuring the order/disorder in a particular system (entropy)	Now	Indicator of biodiversity, Any scale	Shannon (1948)
Natural Capital Index	Area of ecosystem and mean abundance of core set of species	Quantity and quality, both natural and cultural ecosystems	Netherland, Pre-industrial or low impact	Indicator of 'quality' of ecosystem, Regional	Brink (2002)
Mean Species Abundance	Abundance based on modeling	Pressure factors from human activities impacting on different land use and physical characteristics	UNEP,OECD, Pristine or primary vegetation	Indicator of 'quality' of ecosystem, Regional	Alkemade et al (2009)
Index of Biotic Integrity	Species composition and relative abundance of fish	Trophic function and organi-sation, reproductive behaviour. Expert judgements of quality	Natural state	Indicator of ecosystem condition, Regional	Karr (1981).
Sustainable Rivers Index	Functional diversity of macro-invertebrates and nativeness of fish	Functional and structural links between ecosystem components, biophysical condition and human intervention. Sampling and modelling.	Reference condition (undisturbed)	Indicator of ecosystem condition, Regional	Davies et al (2010)
Marine Trophic Index	Position of species in the food chain	Replacement indices used to describe the interactions between fisheries and marine ecosystems	FAO,CBD. Now	Biodiversity composition' Regional	Pauly (1998) Watson et al (2004)
The Water Quality Index	Quality of inland surface waters, transitional waters, coastal waters and groundwater	Indicator species and physico-chemical parameters for ecological classification and how to deal with uncertainty	EU, calibrated 2008, close to undisturbed conditions	Indicator of ecosystem quality, Regional, National	Kallis et al (2001)
Biodiversity Intactness	Abundance of species, constructed for data-poor regions	Calculated from land use and land cover data based on expert judgements. May be disaggregated in terms of taxa, ecosystems and land-uses. Uncertainty measures.	Naturalness as observed in national parks	Indicator of biodiversity, Any scale	Scholes and Biggs (2005) Biggs et al (2006) Hui et al (2008)
Nature Index	Species or proxy for species, cover both terrestrial and marine ecosystems	Based on data, models and expert judgments (125 scientists). Data for 1950, 1990, 2000 and 2010. 308 indicators - representation of all major trophic levels. Uncertainty measures.	Norway, Undisturbed or sustainably managed	Indicator of biodiversity, Any scale	Certain et al (2011) Nybø et al (2012) Skarpaas et al (2012)

Alkemade, R., M. Bakkenes, R. Bobbink, L. Miles, C. Nellemann, H. Simons, and T. Tekelenburg. 2006. GLOBIO 3: Framework for the assessment of global terrestrial biodiversity.

Brooks, T. M., R. A. Mittermeier, C. G. Mittermeier, G. A. B. Da Fonseca, A. B. Rylands, W. R. Konstant, P. Flick, J. Pilgrim, S. Oldfield, G. Magin, and C. Hilton-Taylor. 2002. Habitat Loss and Extinction in the Hotspots of Biodiversity

Pérdida de Hábitat y Extinciones en Áreas Críticas para la Biodiversidad. Conservation Biology **16**:909-923.

Brooks, T. M., S. L. Pimm, and N. J. Collar. 1997. Deforestation Predicts the Number of Threatened Birds in Insular Southeast Asia. Conservation Biology **11**:382-394.

Brooks, T. M., S. L. Pimm, and J. O. Oyugi. 1999. Time Lag between Deforestation and Bird Extinction in Tropical Forest Fragments

Espacio Temporal entre la Deforestación y la Extinción de Especies de Aves en Fragmentos de Bosques Tropicales. Conservation Biology **13**:1140-1150.

Carwardine, J., T. O'Connor, S. Legge, B. Mackey, H. P. Possingham, and T. G. Martin. 2012. Prioritizing threat management for biodiversity conservation. Conservation Letters **5**:196-204.

Certain, G., O. Skarpaas, J. W. Bjerke, E. Framstad, M. Lindholm, J. E. Nilsen, A. Norderhaug, E. Oug, H. C. Pedersen, A. K. Schartau, G. I. van der Meeren, I. Aslaksen, S. Engen, P. A. Garnasjordet, P. Kvaloy, M. Lillegard, N. G. Yoccoz, and S. Nybo. 2011. The Nature Index: A General Framework for Synthesizing Knowledge on the State of Biodiversity. Plos One **6**.

Evans, M. C., J. E. Watson, R. A. Fuller, O. Venter, S. C. Bennett, P. R. Marsack, and H. P. Possingham. 2011. The spatial distribution of threats to species in Australia. Bioscience **61**:281-289.

Holt, R. D., J. H. Lawton, G. A. Polis, and N. D. Martinez. 1999. TROPHIC RANK AND THE SPECIES–AREA RELATIONSHIP. Ecology **80**:1495-1504.

Loh, J. 2002. Living Planet Index 2002. World Wildlife Fund International, Gland, Switzerland.

Lomolino, M. V. 2000. Ecology's Most General, Yet Protean Pattern: The Species-Area Relationship. Journal of Biogeography **27**:17-26.

Marinoni, O., J. Navarro Garcia, S. Marvanek, D. Prestwidge, D. Clifford, and L. Laredo. 2012. Development of a system to produce maps of agricultural profit on a continental scale: An example for Australia. Agricultural Systems **105**:33-45.

Nelson, E., G. Mendoza, J. Regetz, S. Polasky, H. Tallis, D. Cameron, K. M. A. Chan, G. C. Daily, J. Goldstein, P. M. Kareiva, E. Lonsdorf, R. Naidoo, T. H. Ricketts, and M. Shaw. 2009. Modeling multiple ecosystem services, biodiversity conservation, commodity production, and tradeoffs at landscape scales. Frontiers in Ecology and the Environment **7**:4-11.

Polasky, S., E. Nelson, J. Camm, B. Csuti, P. Fackler, E. Lonsdorf, C. Montgomery, D. White, J. Arthur, B. Garber-Yonts, R. Haight, J. Kagan, A. Starfield, and C. Tobalske. 2008. Where to put things? Spatial land management to sustain biodiversity and economic returns. Biological Conservation **141**:1505-1524.

Prugh, L. R., A. R. E. Sinclair, K. E. Hodges, A. L. Jacob, and D. S. Wilcove. 2010. Reducing threats to species: threat reversibility and links to industry. Conservation Letters **3**:267-276.

Raudsepp-Hearne, C., G. D. Peterson, and E. M. Bennett. 2010. Ecosystem service bundles for analyzing tradeoffs in diverse landscapes. Proceedings of the National Academy of Sciences of the United States of America **107**:5242-5247.

Rodríguez, J. P., T. D. Beard, E. M. Bennett, G. S. Cumming, S. J. Cork, J. Agard, A. P. Dobson, and G. D. Peterson. 2006. Trade-offs across space, time, and ecosystem services. Ecology and Society **11**:28.

Simpson, E. H. 1949. Measurement of diversity. Nature **163**:688.

Spellerberg, I. F., and P. J. Fedor. 2003. A tribute to Claude Shannon (1916–2001) and a plea for more rigorous use of species richness, species diversity and the 'Shannon–Wiener' Index. Global Ecology and Biogeography **12**:177-179.

Thomas, C. D., A. Cameron, R. E. Green, M. Bakkenes, L. J. Beaumont, Y. C. Collingham, B. F. N. Erasmus, M. F. de Siqueira, A. Grainger, L. Hannah, L. Hughes, B. Huntley, A. S. van Jaarsveld, G. F. Midgley, L. Miles, M. A. Ortega-Huerta, A. Townsend Peterson, O. L. Phillips, and S. E. Williams. 2004. Extinction risk from climate change. Nature **427**:145-148.

UNCEEA. 2012. System of Environmental-Economic Accounting Central Framework.

UNCEEA. 2013. SEEA Experiemental Ecosystem Accounting in U. N. C. o. E. o. E.-E. Accounting, editor. The System of environmental-economic accounting (SEEA) Draft subject to editing. Department of Economic and Social Affairs Statistics Division United Nations.