Ecosystem condition – Preliminary review from six Australian case studies

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Note: This is a preliminary review done for the purpose of informing discussions on ecosystem condition accounting of the London Group on Environmental Accounting September 2016. The plan is to update and expand the review.

Content

Introduction and background

1. Introduction

More clearly defining ecosystem condition and how to measure it, along with how does it related supply of ecosystem services and the measurement of degradation and depletion are key issues for the System of Environmental-Economic Accounting Experimental Ecosystem Accounting (SEEA-EEA).

This is clear from the SEEA EEA Research Agenda has two items specifically on ecosystem condition:

- Item 2. Indicators of ecosystem condition (including the role of composite condition indicators)
- Item 8. Articulation of the links between ecosystem assets (and their condition) and the supply of ecosystem services

Other items are also related, including 13 Defining and measuring degradation.

This paper examines how ecosystem condition has been measured in Australia in six different ecosystem accounting exercises shown in Table 1.

Organination	Reference	Title
ABS	ABS (2014)	Experimental Ecosystem Accounts for the Great Barrier Reef
ACT Government and ANU	Van Dijk and Summers 2016	Australia's Environment
ANU	Keith et al 2016	Experimental Ecosystem Accounts for the Central Highland of Victoria
DSE	Eigenraam et al 2013	Victorian Experimental Ecosystem Accounts
Parks Victoria	Varcoe el al 2015	Valuing Victoria's Parks
Wentworth Group	Sbrocchi et al 2015	Accounting for Nature

2. Background – condition in the SEEA-EEA

Before moving to the case studies it is worth recalling the some of the key definitions and guidance from the SEEA-EEA on the concept and measurement of ecosystem condition. This is found Chapters 2 and 4 of the SEEA-EEA:

> "2.31 *Ecosystem assets are spatial areas comprising a combination of biotic and abiotic components and other characteristics that function together*. Ecosystem assets are measured from two perspectives–that of *ecosystem condition* and *ecosystem extent*; and that of *ecosystem services*. A particular combination or "basket" of ecosystem services will be generated at a particular point in time from a specific ecosystem asset. The aggregation of all future ecosystem services for a given basket provides an estimated stock of expected ecosystem service flows, at a point in time.

….

2.35 *Ecosystem condition reflects the overall quality of an ecosystem asset in terms of its characteristics*. The assessment of ecosystem condition involves two distinct stages of measurement with reference to both the quantity and the quality aspects of the characteristics of the ecosystem asset. In the first stage, it is necessary to select appropriate characteristics and associated indicators of changes in those characteristics. The selection of characteristics and associated indicators should be carried out on a scientific basis so that there is an assessment of the ongoing functioning, resilience and integrity of the ecosystem asset. Thus, movements of the indicators should be responsive to changes in the functioning and integrity of the ecosystem as a whole.

2.36 Measures of ecosystem condition may be compiled in relation to key ecosystem characteristics (e.g., water, soil, carbon, vegetation, biodiversity) and the choice of characteristics will generally vary depending on the type of ecosystem asset. Further, the selection of characteristics should take into account current and expected future uses of the ecosystem (e.g., whether for agriculture, forestry, carbon sequestration, recreation), since these uses are likely to impact most directly on certain characteristics and hence on the overall condition and capacity of the ecosystem asset to generate alternative baskets of ecosystem services. Usually, there will not be a single indicator for assessing the quality of a single characteristic. Both the selection and measurement of characteristics and associated indicators are likely to present measurement challenges.

2.37 In the second stage, the indicators are related to a common reference condition or benchmark. Several alternative conceptual bases for determining the reference condition are described in chapter IV. The use of a common reference condition relative to all indicators for an ecosystem asset may allow an overall assessment of the condition of the asset."

Chapter 2 of the SEEA-EEA also presents a stylized table (Table 2.2 of the SEEA-EEA but Table 2 below).

Table 2. SEEA-EEA condition table

Measures of ecosystem condition and extent for an EAU at end of accounting period

Type of LCEU	Ecosystem extent	Characteristics of ecosystem condition				
		Vegetation	Biodiversity	Soil	Water	Carbon
		Examples of indicators				
	Area	Leaf area index, biomass, mean annual increment	Species richness, relative abundance	Soil organic matter content, soil carbon, groundwater table	River flow, water quality, fish species	Net carbon balance, primary productivity
Forest tree cover						
Agricultural land[a]						
Urban and associated developed areas						
Open wetlands						

a Medium to large fields of rain-fed herbaceous cropland.

Paragraph 2.94 of the SEEA-EEA makes it clear that the characteristics shown are indicative only and that ecologists and other scientists should be involved in the selection and testing of characteristics and indicators for ecosystem.

Chapter 4 elaborates on the links between ecosystem condition and ecosystem service flows:

> “There will not be a clear-cut or simple relationship between these two forms of measurement. Instead, the relationship is likely to be non-linear and variable over time.” For example, if an ecosystem asset such as a river basin has the capacity to provide a significant amount of water for human consumption, then it may be that increases in population (up to a certain point) will not lead to a change in ecosystem condition but will lead to a rise in ecosystem services. Also, dependencies between ecosystem assets may be such that declines in ecosystem condition in, say, spawning grounds for salmon ultimately induce declines in ecosystem services from fishing in other locations. More generally, a full appreciation of the impact of human activity on ecosystem assets may often not become apparent for considerable periods of time.” (SEEA-EEA Para 4.2).

Addition excerpts from Chapter 4 of the SEEA-EEA relating to ecosystem condition are found in the Annex.

The description of condition in the SEEA-EEA and the stylized table provided a starting point. Applying the concept of condition and producing ecosystem condition tables in Australia has raised both theoretical and practical issues about the metrics that could be used.

Theoretically condition can be viewed from two perspectives: condition for what people value or condition for on-going functioning or health of the environment (without reference to people). In general this is anthropocentric verses non-anthropocentric view of the world (see Saner and Bordt 2016).

The non-anthropocentric view is aligned with the notion of reference condition and in particular "natural" or "pre-industrial" conditions, while the anthropocentric view is related to flow of ecosystem services. In some cases the two views might converge to give similar condition scores, for example forests for water provisioning or for "nature". But in others they may not, for example: (1) Antarctica for food provisioning or for "nature" and (2) urban parks for recreation or for "nature".

The practical aspect of selecting metrics for tables of condition has started with the existing metrics available that have been developed for other purposes and sometimes then synthesized (e.g. into State of the Environment Report). The metrics have from the physical sciences (including ecology) that generally assess condition without consideration of human uses and with "natural" benchmarks. The metrics specifically for the measurement of ecosystems tend focus on either particular ecosystems (e.g. woodlands, coral reefs, wetlands) or particular parts of ecosystems (e.g. water, soil, species). The metrics from either may be combined into an aggregate measure of condition (i.e. and index) and the experience from Australia is outlined briefly below.

Before outlining this experience, it is important to note that the measurement of condition is closely related to the notions of ecosystem capacity and ecosystem potential, both of which are related to the possible future flows of ecosystem services and are addressed by Hein et al (in press). The concepts of ecosystem capacity and potential are aligned with an anthropocentric view of condition, and could be considered specific metrics of condition.

Australia experience of measuring condition

3. ABS Great Barrier Reef Experimental Ecosystem Accounts

The ABS (2015) developed condition indicators as part of a suite of accounts prepared for the terrestrial and marine areas of Great Barrier Reef region. This area encompassed all land draining into the Great Barrier Reef Marine Park, and the Marine Park itself. The Great Barrier Reef World Heritage marine area is 348,000 km^2 and the terrestrial area draining to the reef is in excess of 424,000 km^2. Existing data and indicators measures were sought and used. No new field observations or data collections of any kind (e.g. via survey) were undertaken as part of the preparations of the accounts

For the marine areas, suitable indicators for inshore areas were identified as part of Reef Plan Report Cards, compiled annually by the Queensland Government. The three marine indicators used for seagrass, water quality and coral were all composite indictors, with contributing metrics ranging from a percentage of area meeting guideline levels (for chlorophyll and suspended solids), to measures of abundance and reproduction, to measures of change over time.

To extend the spatial coverage of coral condition indicators (to also include offshore areas), the percentage of reef area covered in hard coral, collected as part of the Long Term Monitoring Program of the Australian Institute of Marine Science, was used as a stand along, single component indicator. These observations are geocoded with latitude-longitude co-ordinates, and were therefore able to be allocated to a range of output regions.

Fish abundance indicators were taken from observations at reefs in inshore and offshore areas as part of existing monitoring programs by the Australian Institute of Marine Science.

The riverine indicators are also the result of work done by the Queensland Government as part of the Great Barrier Reef Catchment Loads Monitoring Program. Metrics selected as indicators were Total Nitrogen, Total Phosphorous, and Total Suspended Solids.

All condition measures were indexed to 100 at the beginning of the reference period and presented over annual timeseries of at least six years (financial).

Table 3 below presents summary information by indexing measures of condition of terrestrial and marine ecosystems, as well as the flow of river loads to provide an overview of the ecosystem characteristics within the GBR Region. The table uses 2007-08 as the base year for indexing, as each of the input datasets have observations for this time period.

Table 3 Terrestrial and marine ecosystem condition and river loads, Great Barrier Reef, 2007-08 to 2012-13, Index (2007-08 =100)

	Terrestrial Condition	River Loads			Marine Condition			
	Average NPP	Solids	Nitrogen	Phosphorous	Coral	Water Quality	Seagrass	Fish numbers
2007-08	100	100	100	100	100	100	100	100
2008-09	97	67	64	57	102	102	97	99
2009-10	91	37	51	58	96	115	94	101
2010-11	110	105	176	197	81	73	53	92
2011-12	98	29	48	47	67	na	53	101
2012-13	94	na	na	na	73	na	78	93

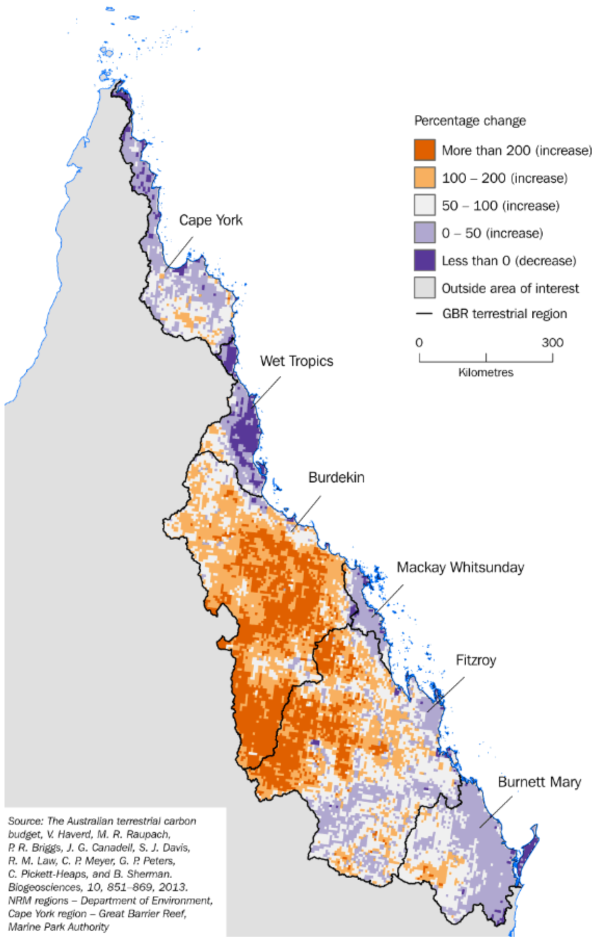
na - not available, NPP - Net Primary Productivity, Source: ABS (2014)

For terrestrial vegetation condition the Net Primary Productivity (NPP) was chosen as the indicator. Net primary productivity (NPP) is defined as the net flux of carbon from the atmosphere into green plants per unit time. It is a fundamental ecological variable. It not only measures the energy input into the biosphere and terrestrial carbon dioxide assimilation, but also indicates the condition of the land surface area and the status of a wide range of ecological processes.

The term 'net' refers to the balance (over time) between the rate of gain of carbon in leaves, stems, and roots by photosynthesis (known as gross primary productivity or GPP) and the rate of loss of biomass via respiration. It is positive in cases where the photosynthetic rate exceeds the respiration rate and negative where the respiration rate exceeds the photosynthetic rate.

Figure 1 shows the differences in net primary productivity across the terrestrial area of the GBR Region between the very dry year, 2002-03 and the very wet year, 2010-11. The coastal area of Burdekin NRM Region and the inland area of Fitzroy NRM Region show some of the greatest variations in NPP between the two years.

Figure 1: Net primary productivity, Great Barrier Reef Region 2002-03 to 2012-13 Percentage Change (%)



NPP is also applicable to marine areas but was not used. There are a range of possible derivation methods for estimating changes in area of seagrass, coral and mangrove but the required time series data are not available. Chlorophyll concentration is used in some derivation methods to measure marine NPP, and was included in the water quality indicator.

4. Australian Capital Territory – Environment Condition Score

The environmental condition score (ECS) is experimental composite metric that incorporates a series of environmental indicators developed as a part of the 'Australia's Environment' data and information system (Van Dijk and Summers 2016).

'Australia's Environment' is an online tool and data repository where users can view, evaluate and access comprehensive, national-scale information on specific environmental indicators. The objective in developing Australia's Environment was to make a time-series of national-extent spatial information about the environment available in a format that is fast and easy for users to access without specialist software. Through the website users can view and download national scale gridded data, regional summaries and time series comparisons of 13 environmental indicators (Table 4). The regional summaries available through the website are based on different boundaries: political (e.g. states and territories, local government areas), management (e.g. natural resource management regions), statistical (e.g. Australian Bureau of Statistics areas) and natural or ecological (e.g. catchments, bioregions).

Table 4: Environmental indicators and their sources from Australia's Environment.

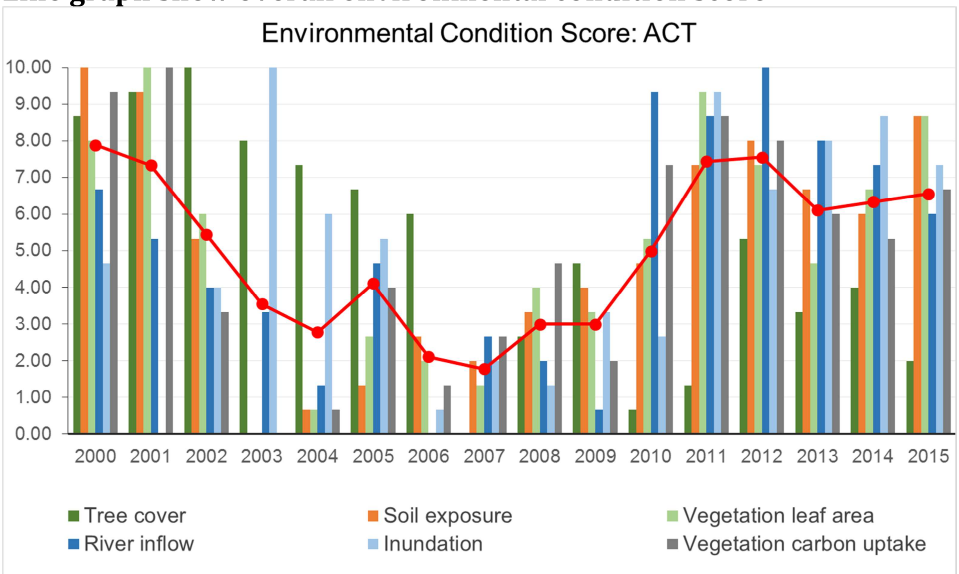
Indicator	Description
Tree cover*	Determined as the percent of area classified as forest at 25 metre resolution mapping using Landsat imagery following the National Carbon Accounting System (NCAS) classification (Furby, 2002).
Land cover	Land cover classification from Geoscience Australia Dynamic Land Cover Data (Lymburner et al., 2011).
Soil exposure*	Annual mean percentage of soil that is unprotected by living vegetation or litter. Derived from a fractional cover algorithm that exploits MODIS satellite imagery to estimate fractions of photosynthetic vegetation, non-photosynthetic vegetation and exposed (Guerschman et al., 2015).
Fire intensity and occurrence	Annual maximum fire intensity (°C) and average frequency, respectively, of fire mapped at 2.5 km resolution as derived from the Geoscience Australia Sentinel system. (Geoscience Australia, 2014).
Inundation*	Percent of area covered by water at least once during the year as mapped from MODIS satellite observations following the methodology of Guerschman and colleagues (CSIRO) (Guerschman et al., 2011).
Vegetation leaf area*	Annual mean leaf area index (area of leaf per area of ground) (m^2m^{-2}) as estimated from MODIS satellite imagery (Yang et al., 2006).
Carbon fire emissions	Annual emission of carbon from wildfire estimated the Global Fire Assimilation System v1.2 (Kaiser et al., 2012).
Vegetation carbon uptake*	Gross primary production, the amount of carbon taken up by the vegetation through photosynthesis, as estimated by the OzWALD model-data fusion system (Yebra et al., 2015).
Precipitation, soil moisture, runoff and river inflow*	The OzWALD model-data fusion system was used to populate precipitation (rainfall and snowfall), soil moisture, runoff and river flow (van Dijk, 2010).

(*denotes indicators included in environmental condition score)

The ECS was developed as a composite of six environmental indicators provided through the website. It is calculated as the average of ranking in the indicators, each scored from zero to ten. Thus, the ECS provides a time series where each year can be viewed relative to the whole dataset. The ECS can be calculated for any of the regions available from the data tables in Australia's Environment.

The ECS for the Australian Capital Territory (ACT) was calculated from 2000 to 2015. The individual indicators (bar chart) and the ECS (line graph) (Figure 2) demonstrate the changing environmental condition over this period. The effects of a major drought between 2001 and 2010 and a significant bush fire in 2003 can be seen in the data. The environmental indicators that had been declining as the drought began to take hold in 2001 and 2002 were impacted further in 2003 following an extensive bush fire. Record high rainfall in 2010 broke the drought and two subsequent years of above average rainfall saw most of the indicators return to high levels. Following the above average years, rainfall returned to average levels and has been relatively stable since, a pattern also reflected in the environmental indicators. Over this period the ECS falls from a high of 7.9 in 2000 before the drought to 1.7 in 2007, the year after the lowest rainfall of the drought. From 2007 the ECS increased steadily until 2012 when it reached 7.6, before falling again in 2013 (6.1) but by 2015 it had risen to 6.6.

Figure 2. Environmental condition score for the Australian Capital Territory. Bar chart shows the condition score for individual indicators. Line graph show overall environmental condition score



5. Central Highlands of Victoria Experimental Ecosystem Accounts

This study was prepared to feed into a decision-making process around the extension of the protected area network in the Central Highlands of Victoria. It produced ecosystem asset and ecosystem service accounts.

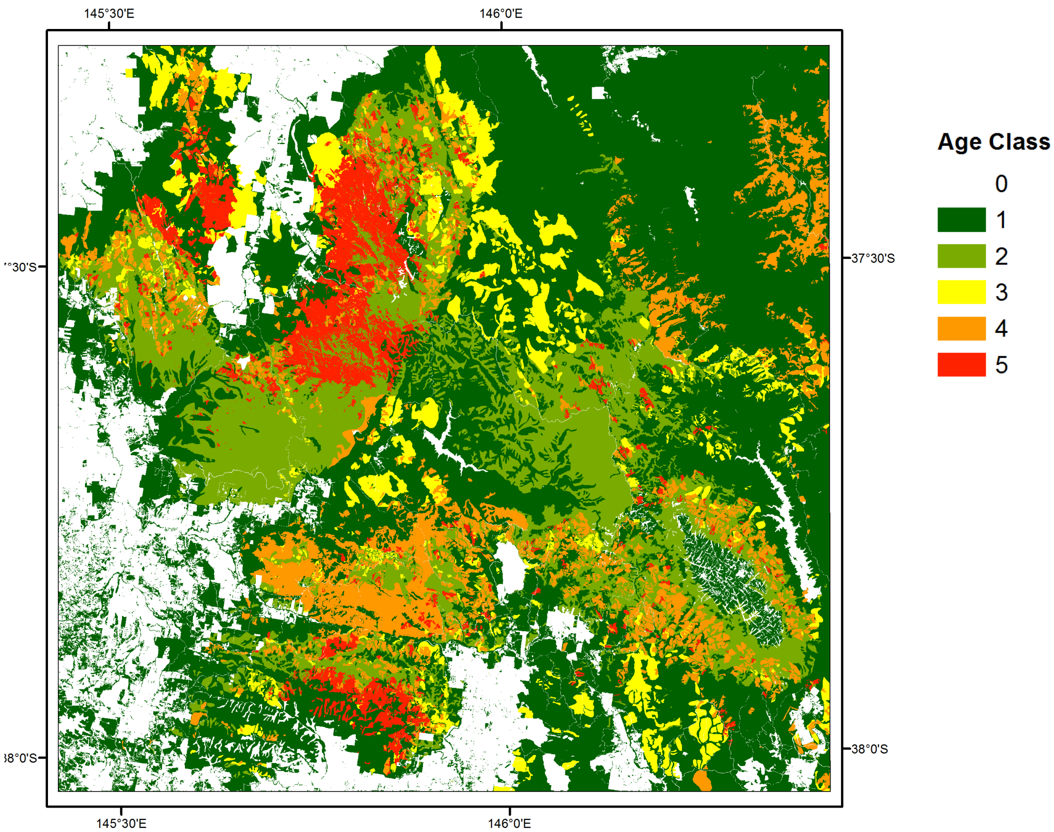
In the study by Keith et al (2016) forest age was used as a indicator of ecosystem condition because age of the trees is related to the quantities of ecosystem services such as water provisioning, timber provisioning, carbon sequestration, as well as habitat provisioning for possums. In the cases of water and carbon and the condition describing services for people were aligned with those for nature (in this case hollow trees used by possums). Timber provisioning, however, only provides a service for people.

Catchment water yield is higher where trees are older and have lower evapotranspiration. Biomass carbon is highest in woody stems of large trees. A key habitat attribute is hollows that form in large, old trees that provide nest sites and protection for arboreal marsupials and birds. Additionally, older forests have complex structure with multiple vertical layers and composition of vegetation that provide a range of habitats, food sources and transport routes for animals. The value of the forest for timber provisioning is greatest in a mature forest but then declines as larger older trees have more decayed wood.

Forest age was determined from the time since disturbance events that resulted in stand replacement, and the spatial distribution is shown in Figure 3. These events included high severity wildfire or clearfell logging for montane ash and rainforest; and clearfell logging for wet mixed, open mixed, woodland and montane woodland. Additionally, age was separated into regeneration events from fire or from logging because these disturbance types affect characteristics of ecosystem condition, such as the number of residual trees.

Figure 3. Spatial distribution of forest age in 2015 based on regeneration times from wildfire and logging.

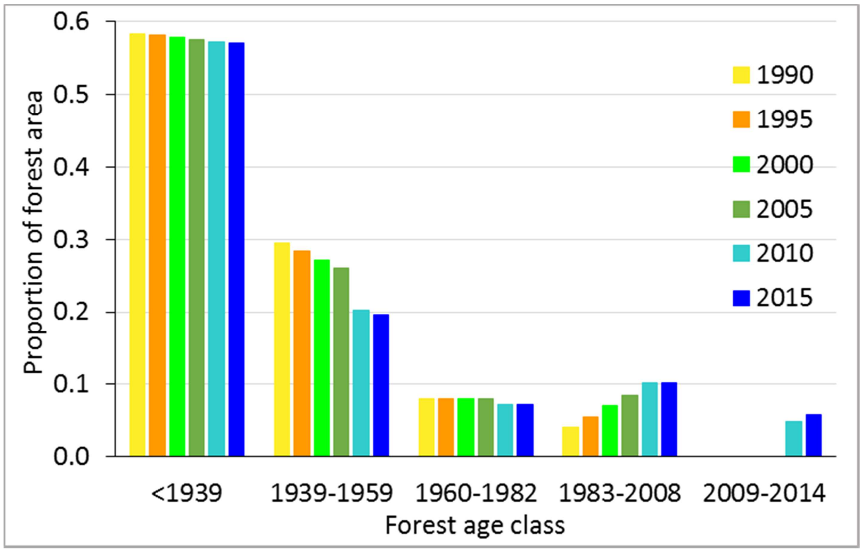
Age classes: 0: non-forest; 1: before 1939; 2: 1939-1959; 3: 1960-1982; 4: 1983-2008; 5: 2009-2015.



Change over time in forest age was calculated from the disturbance history of fire and logging events each year. Older age-classes are associated with better condition for biodiversity conservation, timber provisioning, carbon stocks and water provisioning. Changes in areas of age class from 1990 to 2015 in each forest type category are shown in Figure 4. The general trend is a reduction in area of older age classes and increase in area of younger age classes in all forest types that are subject to logging. The ash species and rainforest have particularly small areas of older forest because they are also killed by high severity wildfire. The overall change in forest age over time is illustrated by the proportion of the total forest area in each forest age category, showing the result for each 5-year period (Figure). More than half the area is shown as forest older than 75 years because the wet mixed and open mixed forests were assumed not to be killed by fire. The proportion of area in the two oldest age categories has declined in each 5-year interval, and the area in the youngest two age categories has increased.

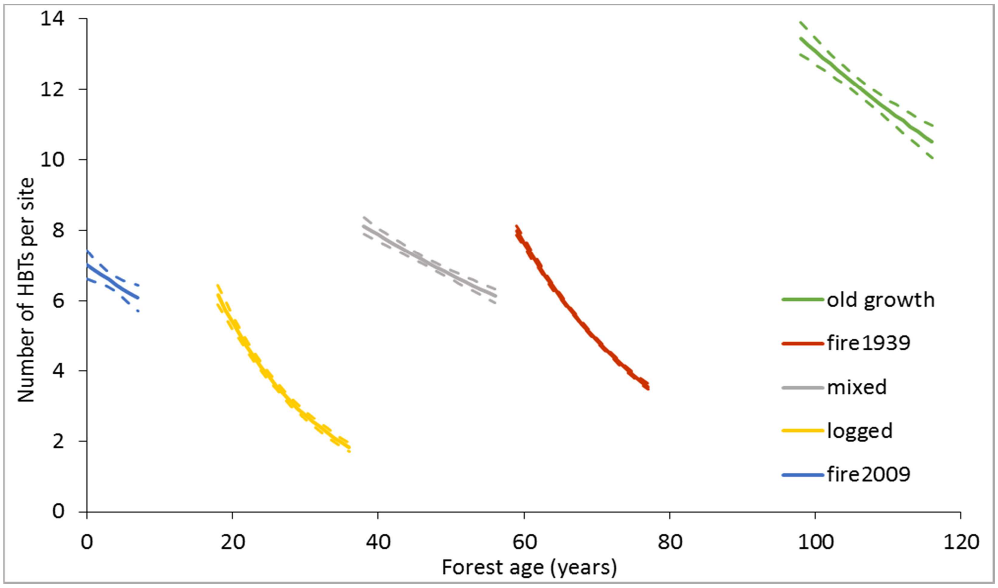
Thus, the ecosystem condition, as described by forest age, has declined over the last 25 years.

Figure 4. Change in area of each forest type and age class over time from 1990 to 2015



Metrics for ecosystem condition for biodiversity conservation can be selected for groups of species. In the tall, wet forests of the Central Highlands, the key habitat attribute that can be used as a metric related to the biodiversity of arboreal marsupials and birds is the number of hollow-bearing trees. The number of arboreal marsupials is related to the number of hollow-bearing trees, with the number of hollow-bearing trees increasing with forest age, with old growth forest having 2 – 3 times the number of HBTs than regrowth forests. Trees remain standing after wildfire, such as in 1939 and 2009, and form hollows. However, the number of trees with hollows is greatly reduced in areas that are salvage logged after fire or clear-felled. The loss of hollow-bearing trees in regrowth forest was four times the rate in old growth forest. The gain in hollow-bearing trees in old growth forest was about three times higher than in regrowth forest, and logged forest had the lowest number of new trees. Numbers of hollow-bearing trees have declined over 25 years of monitoring in all forest age categories, but the rate of decline is greatest in logged forest. The key threatening process for arboreal marsupials is the accelerated loss of existing hollow-bearing trees and the impaired recruitment of new cohorts of these trees.

Figure 5. Change over time in number of hollow-bearing trees per 1 ha site in each forest age category



Solid lines represent mean values and dashed lines are the upper and lower confidence limits.

6. Victorian Experimental Ecosystem Accounts

The Ecosystem Asset Accounts for Victoria (a State of Australia) by Eigenraam et al (2013) were the first ecosystem accounts produced in the country. They provide a record of the extent and condition of Victoria's ecosystem assets that are defined by vegetation cover as defined by: Major Vegetation Groups (MVG) or the more detailed Ecological Vegetation Classes (EVC). Table x shows the extent and condition of the Major Vegetation Groups.

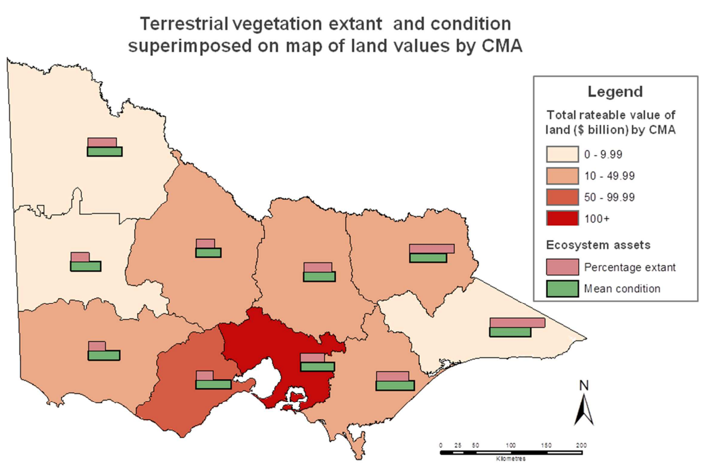
Table 6 presents two sets of estimates for 2005, based on different sources: column "2005(a)" was based on estimates published in 2006 Native Vegetation Information System (NVIS Version 3.1), whereas column "2005(b)" was based on revised estimates published in 2013 (NVIS Version 4.1) to supersede the "2005(a)" estimates. The "2005(a)" estimates were included in the Eigenraam et al (2013) for consistency with the source data for the ABS Experimental Land Accounts. They are included here to show significant differences in the estimates from the two data sets. For example, column "2005(a)" shows approximately 1.5m Ha of Eucalypt Woodlands with a mean condition of 0.57/Ha compared to the 1750 benchmark, whereas column "2005(b)" shows approximately 2.5m Ha with a mean condition of 0.46/Ha. The discrepancies illustrate how improvements in data quality can lead to significant revisions to the estimated stocks of ecosystem assets.

Table 6 Victorian terrestrial extent and condition classified by Major Vegetation Groups: 1750, 2005

Major Vegetation Group (NVIS)	1750 Extent (Ha)	1750 Mean condition/Ha	2005 (a) Extent (Ha)	2005 (a) Mean condition/Ha	2005 (b) Extent (Ha)	2005 (b) Mean condition/Ha
Native vegetation						
Acacia Forests and Woodlands	22,885	1.00	41,237	0.60	18,845	0.64
Acacia Open Woodlands	271	1.00	NA	NA	256	0.61
Acacia Shrublands	15,874	1.00	109	0.35	10,053	0.59
Callitris Forests and Woodlands	5,549	1.00	464	0.33	1,934	0.40
Casuarina Forests and Woodlands	1,003,122	1.00	186,411	0.48	190,513	0.51
Chenopod Shrublands, Samphire Shrublands and Forblands	214,488	1.00	55,516	0.51	113,563	0.56
Eucalypt Open Forests	6,346,166	1.00	3,899,116	0.65	4,976,481	0.63
Eucalypt Open Woodlands	1,223,235	1.00	1	0.60	250,677	0.46
Eucalypt Tall Open Forests	53,605	1.00	632,333	0.68	53,576	0.71
Eucalypt Woodlands	7,532,842	1.00	1,559,369	0.57	2,459,569	0.46
Heathlands	299,343	1.00	35,914	0.63	244,461	0.59
Low Closed Forests and Tall Closed Shrublands	206,330	1.00	NA	NA	35,241	0.44
Mallee Open Woodlands and Sparse Mallee Shrublands	213,785	1.00	NA	NA	43,380	0.53
Mallee Woodlands and Shrublands	3,395,152	1.00	1,509,023	0.56	1,577,654	0.56
Mangroves	7,025	1.00	1,010	0.53	5,006	0.55
Melaleuca Forests and Woodlands	89	1.00	14,910	0.50	65	0.57
Naturally bare - sand, rock, claypan, mudflat	4,619	1.00	3,066	0.35	4,459	0.44
Other Forests and Woodlands	63,290	1.00	287,940	0.59	55,756	0.69
Other Grasslands, Herblands, Sedgelands and Rushlands	202,082	1.00	142,010	0.59	97,547	0.54
Other Open Woodlands	122	1.00	NA	NA	77	0.41
Other Shrublands	295,419	1.00	103,193	0.61	159,251	0.58
Rainforests and Vine Thickets	44,109	1.00	36,630	0.71	40,164	0.70
Tussock Grasslands	1,302,356	1.00	28,486	0.33	139,989	0.40
Unclassified native vegetation	45,808	1.00	1	0.73	8,074	0.61
Total native vegetation	**22,497,566**	**1.00**	**8,536,739**	**0.61**	**10,486,591**	**0.57**
Land not classified as native vegetation						
Sea and estuaries	*1,677*	*NA*	*-*	*NA*	1,613	*NA*
Inland aquatic - freshwater, salt lakes, lagoons	*197,128*	*NA*	*177,406*	*NA*	243,637	*NA*
Cleared, non-native vegetation, buildings	*-*	*NA*	*365,180*	*NA*	11,955,418	*NA*
Unknown/no data	*-*	*NA*	*575,185*	*NA*	10,166	*NA*
Unclassified	*2,976*	*NA*	*13,044,837*	*NA*	1,922	*NA*
Total non-native vegetation	*201,781*	*NA*	*14,162,608*	*NA*	*12,212,756*	*NA*

The study produced estimates for different sub-regions of Victoria (Figure 6). The big red area of figure 6, indicating high land value, is where the city of Melbourne is located.

Figure 6. Extent and condition of native vegetation and land value by region of Victoria.



Separate to the calculation of condition for terrestrial areas, a wetland condition indicator was used. (Table 7) Again the indicator of condition was reference to 1750.

Table 7. Victorian wetland extent and condition classified by wetland system and origin: 1750, 1994, 2012

	1750		1994		2012	
Wetland system type and origin (2012)	Extent (Ha)	Average condition	Extent (Ha)	Average condition	Extent (Ha)	Average condition
Origin - Naturally occuring wetlands						
Estuarine	41,001	1	31,455	unknown	35,467	0.71
Lacustrine	152,437	1	138,998	unknown	169,083	0.65
Marine	3,216	1	3,160	unknown	3,302	unknown
Palustrine	218,763	1	187,497	unknown	289,405	0.78
Palustrine or Lacustrine (unknown specifics)	3,745	1	1,005	unknown	6,919	0.40
Unclassified	250,418	1	-	unknown	-	NA
Total natural wetlands	**669,580**	**1**	**362,115**	**unknown**	**504,176**	**0.70**
Origin - Non-naturally occuring wetlands						
Estuarine	-	NA	25,331	unknown	26,860	0.71
Lacustrine	-	NA	84,606	unknown	98,399	0.57
Marine	-	NA	41	unknown	633	unknown
Palustrine	-	NA	11,535	unknown	26,169	0.72
Palustrine or Lacustrine (unknown specifics)	-	NA	47	unknown	2,015	unknown
Unclassified	-	NA	46,499	unknown	-	NA
Total non-natural wetlands	**-**	**NA**	**168,059**	**unknown**	**154,076**	**0.64**
Total wetlands	**669,580**	**1**	**530,174**	**unknown**	**658,252**	**0.69**
Land not classified as wetland	*22,029,767*	*NA*	*22,169,173*	*NA*	*22,041,095*	*NA*

Site level condition data was also used to assess condition of native vegetation. For this Eigenraam et al (2013) used the indicator of "habitat hectare" described by Parkes *et al* (2003). This approach assesses vegetation or habitat quality based on explicit comparisons between existing vegetation features and those of 'benchmarks' representing the average characteristics of mature stands of native vegetation of the same community type in a 'natural' or 'undisturbed' condition. Components of the index incorporate vegetation physiognomy and critical aspects of viability (e.g. degree of regeneration, impact of weeds) and spatial considerations (e.g. area, distribution and connectivity of remnant vegetation in the broader landscape).

Table 8. Components and weightings of the habitat score Component Max. value (%) Site condition Large trees 10 Tree (canopy) cover 5 Understorey (non-tree) strata 25 Lack of weeds 15 Recruitment 10 Organic litter 5 Logs 5 Landscape context Patch size* 10 Neighbourhood* 10 Distance to core area* 5 Total 100 *Components may be derived with assistance from maps and other (e.g. GIS) information sources.

Table 8. Components and weightings of habitat score.

Table 1. Components and weightings of the habitat score

	Component	Max. value (%)
Site condition	Large trees	10
	Tree (canopy) cover	5
	Understorey (non-tree) strata	25
	Lack of weeds	15
	Recruitment	10
	Organic litter	5
	Logs	5
Landscape context	Patch size*	10
	Neighbourhood*	10
	Distance to core area*	5
	Total	**100**

*Components may be derived with assistance from maps and other (e.g. GIS) information sources.

7. Valuing Victoria's Parks

The Varcoe et al (2015) study provided an assessment of the value of ecosystem services of the protected area network in Victoria, one of the States of Australia. Parks Victoria manages this network consisting of over 3.7 million hectares of protected areas as well as almost 206,000 hectares of non-protected areas. The purpose of the accounting exercise was to build experience in environmental accounting and to provide consistent and comparable information on ecosystem assets and the services they provide, along with performance measures of resource use and emissions in the economy (e.g. water, energy, carbon). The primary focus of the study was on ecosystem services and their valuation. The study builds on previous work by Eigenraam et al (2013)(see above).

While ecosystem services were the primary focus of the study, accounts of ecosystem extent and condition were also produced for this study. The indicators of condition used were:

- Native Vegetation Condition score – a normalised value in a 100-point scale to assess the quality of native vegetation, based on DEPI's modelled condition (as per Eigenraam et al 2013).
- Index of wetland condition with a 10-point score scale based on six characteristics for wetland catchment, physical form, hydrology, soils, water properties and biota[1]
- Index of stream condition is based on a 50-point score scale made up of indicators of hydrology, streamside zone, physical form, water quality and aquatic life[2]

[1] http://www.depi.vic.gov.au/__data/assets/pdf_file/0017/204083/IWC_Conceptual_Framework_and_Selection_of_Measures_2005.pdf

[2] http://www.depi.vic.gov.au/water/water-resource-reporting/Third-Index-of-Stream-Condition-report

- Marine condition based on Parks Victoria's marine monitoring program and marine report cards which assesses condition of key habitats across multiple parks[3]

Table 9 shows the extent and condition of the native vegetation, wetlands, rivers and marine areas. The metric used are substantially the same as those used by Eigenraam et al (2013).

Ecosystem assets	**Native vegetation 2010**		**Wetlands 2014**	**2011**	**Rivers 2011**		**Marine 2014**	
	Extent	Condition	Extent	Condition	Extent	Condition	Extent	Condition
Assets measures	Hectare	Native Vegetation score	Hectare	Index of wetland condition	Hectares with river	Index of stream condition	Hectare	Marine Habitat condition
Protected Areas (IUCN PA Categories)								
IA Nature Conservation Reserves	254,255	71	16,009	7	2,911	29	-	-
IB Wilderness Parks	200,094	82	22	1	1,000	41	-	-
II National and State Parks	3,061,274	79	68,681	7	31,874	32	52,809	VG
III Natural Features Reserves	63,097	62	1,788	7	4,026	28	231	F
IV Bushland Reserves	41,287	61	1,821	6	512	27	-	-
V Protected landscape		62		-			-	-
VI Wildlife Reserves	111,078	63	112,867	6	1,926	25	-	-
Non-protected areas								
Conservation reserve	113,140	62	61,854	6	2,600	29	-	-
Port and coastal asset	1	7	194	10			-	-
Urban, regional and other parks	92,784	63	11,598	7	3,056	25	-	-
Parks total	**3,937,010**	**65**	**274,834**	**7**	**47,905**	**29**	**53,040**	**-**
Parks share of total assets in Victoria (%)	**38%**		**42%**		**16%**			

Table 9. Valuing Victoria's Parks - stocks and condition of ecosystem assets in parks network – extent and condition by IUCN category

[3] http://parkweb.vic.gov.au/park-management/environment/research-and-scientific-management/marine-monitoring

8. Wentworth Group – Accounting for Nature

The Wentworth Group of Concerned Scientists in partnership with a range of experts devised an Accounting for Nature model that can be linked with the SEEA. The Accounting for Nature model was tested in 10 Natural Resource Management Regions of Australia (Fig 7).

Fig 7. Study areas in the accounting for nature trial

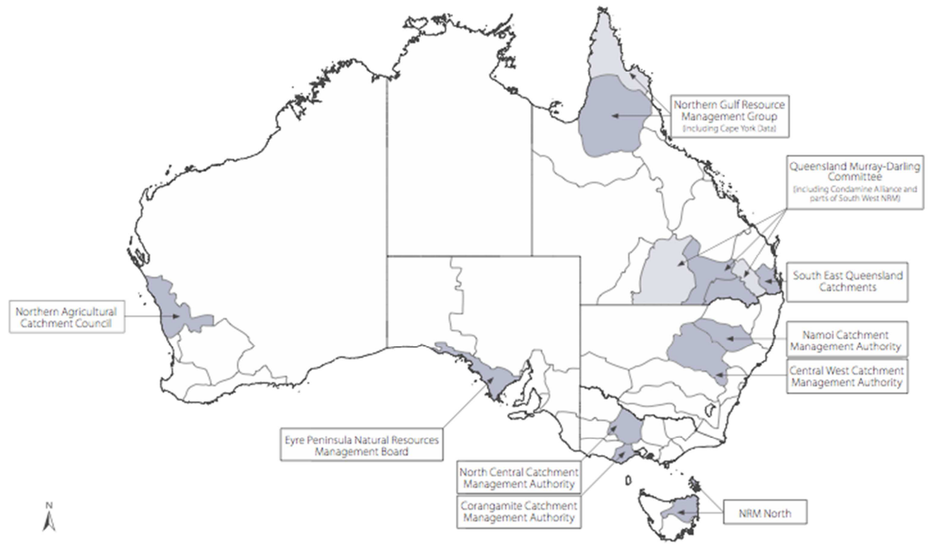
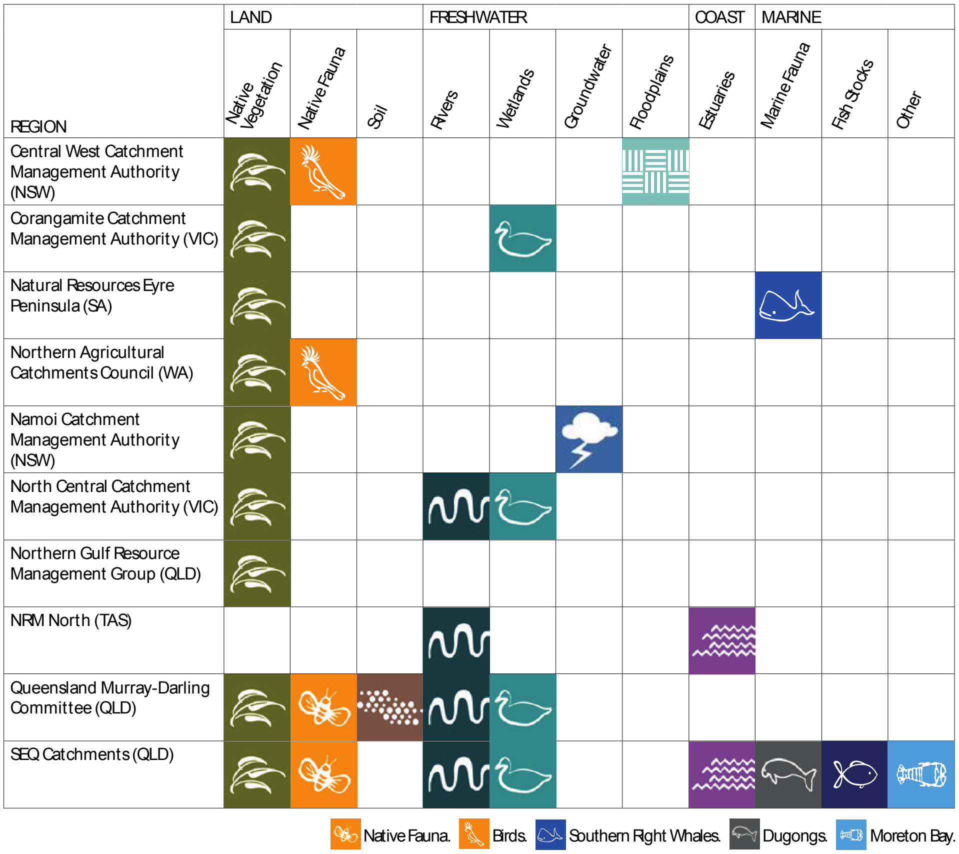


Figure 2: Ten NRM regions tested *Accounting for Nature* as part of the environmental accounts trial, but also covered some assets in adjoining regions (light grey areas)

Four assets were identified for measurement – land, freshwater, coast and marine – and indicators compiled to measure these assets. The assets identified broadly correspond to the characteristic identified in the SEEA-EEA. It should be noted the Wentworth Group approach is focused solely on assets and not on ecosystem services. It would seem possible to add in ecosystem service to their model but they are not integral to their accounting model and hence not considered in the assessment of condition.

Not every region measured every asset (characteristic) class and the indicators used for each asset (characteristic) also differed in each region (Table 10). Indicators were selected locally and submitted to a scientific panel for accreditation. All indicators were indexed to obtain a number between 0 and 100, with 100 being 'natural' or without human degradation. For example, for native vegetation the extent in 1750, pre-European settlement was taken as benchmark.

Table 10 Indicators used in the 10 regions of the Wentworth Group Trials



Native vegetation was used in 9 of 10 regions but with three of indicators – native fauna, river and wetlands – used in three regions. The South-East Queensland had the largest number of indicators – 15 in all – spanning all of the assets (Table 11).

Table 11. Regional asset account for the SEQ Catchments.

REGIONAL ASSET ACCOUNT
SEQ CATCHMENTS, QUEENSLAND

Summary Table

Class	Asset	Econd & ICS	2003	2004	2005	2006	2007	2008	2009	2010	2011
LAND	Native Vegetation	**Econd**				**29**					
		Extent				53					
		Composition				53					
		Configuration									
FRESH-WATER	Rivers	**Econd**	**74**				**70**	**76**	**78**	**79**	**81**
		Physical/chemical index	82				77	84	85	86	91
		Nutrient cycling index	64				60	75	70	73	61
		Macroinvertebrates index	76				69	74	79	82	88
		Fish index	62				68	65	69	71	76
	Wetlands	**Econd**				**33**					
		Extent				62					
		Composition				59					
COASTAL	Estuaries	**Econd**		**57**		**55**	**42**	**44**	**39**	**41**	**41**
		Physical/chemical index	51	57		57	39	40	34	36	37
		Biological Health Rating		58		51	50	53	51	53	49
		Foreshore / riparian habitat extent					48	51	51	51	51
	Moreton Bay	**Econd**		**87**	**83**	**82**	**81**	**81**	**68**	**75**	**75**
		Physical/chemical index		90	85	84	83	82	69	78	77
		Biological Health Rating		73	74	74	74	75	64	64	66
MARINE	Dugong	**Econd**			**11**						
		Dugong population			11						

The Wentworth Group is currently completing an update to its model to take into account the experience so far with a view to scaling up to cover all of Australia.

Discussion and conclusion

9. Discussion

A range of condition indicators have been used in Australia for ecosystem accounting. Table 12 is work in progress but provides an indication of the indicators used to assess the characteristics in the studies. While there was some overlap in the characteristics of interest and the indicators used, vegetation was the only characteristic common to all studies and no indicator was common to all case studies. Several indicators were found in more than one study:

- Runoff
- Nutrient and sediment loading
- Net primary production or gross primary production
- Tree cover but measured at different levels (at site level or via remote sensing)
- Leaf area but again measured at a site level or via remote sensing

All studies provided information on the extent of different ecosystem types and included maps showing the location of these ecosystems. Victoria Experimental Ecosystem Accounts, Valuing Victoria's Parks and the Wentworth Group included landscape variables (patch size, location and distance to core area, configuration) as indicators of vegetation condition. The Great Barrier Reef study used changes in the extent of sea grass as *a measure of condition*. Similarly the Wentworth Group used ecosystem extent as one of the components of the their composite indicator (Econd). In previous work the ABS has used the proportion of native vegetation remaining (i.e. that existing now compared to 1750) as a measure of vegetation condition in land accounts (ABS 2012). **Changing extent of ecosystems, either by itself or as one component of composite indictor, has been used as a *measure of condition* in Australia, as has the *location, size and shape* of ecosystems. Both could usefully be elaborated and standardized approaches developed.**

Only the ABS explicitly framed the accounts around the distinction between Ecosystem assets, characteristics of ecosystems assets and the indicators used to measure these characteristics.

There were differences in scale with which data were collected. All studies made use of large scale, remotely sensed data. Site level data were also in all studies. Except the ACT, which has only recently begun work on accounts and site level data are expected to be added in final accounts.

Table 12. Summary of condition measures used (work in progress)

	Ecosystem extent	Ecosystem condition								
		Characteristics								
	Extent	Vegetation	Biodiversit y	Soil	Water	Carbon	Marine	Site condition (Not in SEEA)	Wetlands	Composite indicator
Australian Capital Territory	By ecosystem type for all of ACT	Tree cover, land cover, leaf area, vegetation carbon uptake (gross primary production)		Soil exposure, soil moisture	Runoff, inundatio n, river flow		NA			Environment condition score (6 indicators)
Central Highlands	By ecosystem type for all of area	Extent, net primary production, age since disturbance	Hollow bearing trees		Runoff		NA			Age since disturbance*
Great Barrier Reef	By ecosystem type for subdivisions within area	Net primary productivity			Water quality (sedimen t, N and P loads)		Hard coral cover, water quality, seagrass cover, Fish abundance			No
Victoria experimental ecosystem accounts	By ecosystem type for subdivisions within area	Large trees, Tree (canopy) cover, lack of weeds, recruitment, Patch size, neighborhood, distance to core area						Large trees, Tree (canopy) cover, lack of weeds, recruitment, organic litter, logs	Reference extent	Habitat hectare (10 indicators)
Wentworth Group	By native vegetation type	Extent, composition, configuration			Chemical index		Species abundance (e.g. dugongs)		Extent, Composition	Econd (combination of all indicators)
Valuing Victoria's Parks	By native vegetation type	Extent, large trees, Tree (canopy) cover, lack of weeds, recruitment, Patch size, neighborhood, distance to core area			Index of stream condition				Index of wetland condition	Habitat hectare (10 indicators)

In the central highlands, several biophysical aspects were measured but the only measure of condition used was age since disturbance. Age since disturbance is related to range of services and the condition of the forests to support biodiversity (and in particular hollow dependent animals).

In Australia, the two different views of condition converged most strongly in the work on the Central Highlands, where the metric of age of the forest since disturbance was closely correlated with the generation of several of the ecosystem services (water provisioning, timber provisioning, carbon sequestration and habitat provision). There is also likely convergence in the ACT, where the components of the ECS are also aligned with ecosystem services of water provisioning, water filtration and carbon sequestration).

10. Conclusion

The six Australian case studies examined used a large number of condition indicators. The characteristics measured correspond broadly to those identified in the SEEA-EEA and hence the theory can be put into practice. Landscape indicators (size, shape and location) were a group of characteristics, linked to vegetation that where not considered in the SEEA. While there was some overlap in the indicators used in the six studies, particularly for vegetation, there were a large number of different indicators used.

There is a difference in perspectives about measure of condition that are important to understand. This is not just for theoretical reasons, but for engaging with the suppliers and users of information. In practice the different perspectives of condition can result substantial difference in condition scores where there is no human use or the environment is heavily modified (e.g. urban areas).

A key area for research is how biodiversity is related to condition. Species level accounting is developing (WCMC 2016) but how species level biodiversity measure can be incorporated into the condition metrics is little explored. This is also related to fact that habitat provision services are not recognized in the SEEA-EEA because they are not final services enjoyed by people.

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Annex. Selected paragraphs from SEEA-EEA Chapter 4 on ecosystem condition

4.2 There will not be a clear-cut or simple relationship between these two forms of measurement. Instead, the relationship is likely to be non-linear and variable over time." For example, if an ecosystem asset such as a river basin has the capacity to provide a significant amount of water for human consumption, then it may be that increases in population (up to a certain point) will not lead to a change in ecosystem condition but will lead to a rise in ecosystem services. Also, dependencies between ecosystem assets may be such that declines in ecosystem condition in, say, spawning grounds for salmon ultimately induce declines in ecosystem services from fishing in other locations. More generally, a full appreciation of the impact of human activity on ecosystem assets may often not become apparent for considerable periods of time." (SEEA-EEA Para 4.2).

4.3 Given this situation, the standard asset accounting models, which assume relatively direct links between streams of economic benefits and the condition of assets, are insufficient.

…

4.10 Measures of ecosystem condition are compiled in two stages. In the first stage, a set of relevant key characteristics such as water, soil, vegetation, biodiversity, carbon, nutrient flows are selected and various indicators concerning these characteristics are chosen. In the second stage, the indicators are related to a reference condition.

4.11 The selection of characteristics and indicators should be made on a scientific basis to ensure that there is an overall assessment of the ongoing functioning and integrity of the ecosystem asset. Thus, movements in the indicators should be responsive to changes in the functioning and integrity of the ecosystem as a whole. Generally, there will not be a single indicator for assessing a single characteristic. It is therefore important that both the ecosystem service flows and the ecosystem condition and extent be assessed in tandem.

4.12 The specific spatial location of an ecosystem asset, particularly its relation to other ecosystem assets, is an important consideration in identifying and measuring inter-ecosystem flows and hence in understanding the condition of an ecosystem asset. Inter-ecosystem spatial features, such as connectivity and landscape configuration, constitute one type of ecosystem characteristic.

Where there is a strong understanding of the various processes operating within an ecosystem, it may be possible to identify specific indicators (e.g., measures relating to a specific critical species) that can represent the overall condition of an ecosystem asset. Such proxy measures may be of particular use in providing indicators of change in ecosystem assets that are suitable for high-level (national or regional) ecosystem accounting purposes.

4.15 As regards the second stage, there are a number of options available for determining a reference condition, each with different conceptual underpinnings. One approach, reflecting a purely accounting perspective, is to measure changes relative to the condition at the beginning of the accounting period. Thus, when accounts are compiled for any given accounting period, the measure of change in condition would refer to the change from the beginning of the period to the end. This reference condition is sufficient for accounting purposes but is limited in providing an assessment of the relative condition of multiple ecosystem assets since, when this approach is used, all ecosystems are assumed to have the same condition relative to their specific characteristics at the beginning of the period.

4.16 An alternative reference condition of particular importance for ecosystem accounting reflects the degree or nature of human influence on an ecosystem. Thus, a reference condition may reflect an ecosystem that is relatively undisturbed or undegraded by humans, or a situation in which the ecosystem is in relative stability. For example, long-standing agricultural areas may be considered ecosystem assets that are relatively stable and not undergoing degradation in terms of their ecosystem characteristics (e.g., soil condition) or their capacity to provide a stable flow of agricultural products.

4.17 The use of these types of reference condition approaches recognizes that ecosystems that are naturally more structurally diverse or more species-rich (e.g., tropical rainforests) are not necessarily considered to have a higher condition than ecosystems that are naturally less structurally diverse or less species-rich (e.g., an Arctic tundra).

4.18 One means of utilizing the concept of a reference condition is to relate all of the relevant indicators to the same point in time (usually by setting the values of the indicators equal to 100 at that time). By using the same point in time for different ecosystem assets, it is possible to make assessments of the relative condition of those assets. Within the context of this approach, one might select a point in time before which significant patterns of recent landscape change due to human activity were not in evidence. Note that selecting more recent periods as reference conditions would effectively entail treating equally ecosystem assets ranging from the relatively natural to the relatively human-influenced.

4.19 Very significantly, while reference condition accounting leads to the recording of ecosystem condition scores between 0 and 100, those scores cannot be used to determine whether the condition of the ecosystem is good or bad. Ecosystem condition may be assessed independently of the use of an ecosystem but, a priori, any given level of condition is not necessarily good or bad.

4.20 Relevant to this subject
The other means of measuring an ecosystem asset entails focusing on assessment of the capacity of the asset to generate an expected combination (or basket) of provisioning, regulating and cultural services. Because the generation of some ecosystem services involves the extraction and harvest of resources, and

since ecosystems can undergo regeneration, there will be a need to estimate the extent of the extraction and regeneration that will occur, and the overall sustainability of human activity within the ecosystem.

…

4.27 There are relationships existing among the condition of an ecosystem asset, its pattern of use and the expected basket of ecosystem services. However, while ecosystem condition may be assessed without considering measures of ecosystem services, the measurement of ecosystem assets in terms of their capacity to generate ecosystem services must involve assessment of ecosystem condition.

4.28 It is not necessarily the case that ecosystems with relatively lower condition will generate fewer ecosystem services. However, there is likely to be a close relationship between reductions in condition on the one hand, and the capacity of an ecosystem to generate ecosystem services sustainably on the other. At the same time, a change in condition may lead to a decrease in the capacity to supply some services, but an increase in its capacity to supply others.

Table 4.4 SEEA EEA

Changes in ecosystem condition for an LCEU

	Characteristics of ecosystem condition				
	Vegetation	Biodiversity	Soil	Water	Carbon
	Examples of indicators				
	Leaf area index, biomass, mean annual increment	Species richness, relative abundance	Soil organic matter content, soil carbon, groundwater table	River flow, water quality, fish species	Net carbon balance, primary productivity
Opening condition					
Improvements in condition					
Improvements due to natural regeneration (net of normal natural losses)					
Improvements due to human activity					
Reductions in condition					
Reductions due to extraction and harvest of resources					
Reductions due to ongoing human activity					
Catastrophic losses due to human activity					
Catastrophic losses due to natural events					
Closing condition					