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Review

Environmental reporting and accounting in Australia: Progress, prospects and research priorities

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HIGHLIGHTS

• Capacity to produce nation-wide environmental reports and accounts is reviewed.
• Several reasons for the lack of environmental data can be identified.
• Six priorities are suggested for research to help create better information.

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ABSTRACT

Despite strong demand for information to support the sustainable use of Australia's natural resources and conserve environmental values and despite considerable effort and investment, nation-wide environmental data collection and analysis remains a substantially unmet challenge. We review progress in producing national environmental reports and accounts, identify challenges and opportunities, and analyse the potential role of research in addressing these. Australia's low and concentrated population density and the short history since European settlement contribute to the lack of environmental data. There are additional factors: highly diverse data requirements and standards, disagreement on information priorities, poorly measurable management objectives, lack of coordination, over-reliance on researchers and businesses for data collection, lack of business engagement, and short-term, project-based activities. New opportunities have arisen to overcome some of these challenges: enhanced monitoring networks, standardisation, data management and modelling, greater commitment to share and integrate data, community monitoring, increasing acceptance of environmental and sustainability indicators, and progress in environmental accounting practices. Successes in generating climate, water and greenhouse gas information appear to be attributable to an unambiguous data requirement, considerable investment, and legislative instruments that enhance data sharing and create a clearly defined role for operational agencies. Based on the analysis presented, we suggest six priorities for research: (1) common definitions and standards for information that address management objectives, (2) ecological measures that are scalable from local to national level, (3) promotion of long-term data collection and reporting by researchers, (4) efficient satellite and sensor network technologies and data analysis methods, (5) environmental modelling approaches that can reconcile multiple data sources, and (6) experimental accounting to pursue consistent, credible and relevant information structures and to identify new data requirements. Opportunities exist to make progress in each of these areas and help secure a more sustainable future.

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1. Introduction

1.1. Background and objective

By one estimate, the global population uses natural resources at a rate more than 1.5 times greater than the rate of renewal (Galli et al., 2012). Australians use natural resources at more than twice this average rate (WWF International et al., 2010). If serious consequences are to be averted, economic progress must be decoupled from ecological depletion and degradation (Rockström et al., 2009). There are different approaches to improving the economic efficiency of natural resource use, but all require relevant, credible, up-to-date and comprehensive information on the condition of our natural resources and ecosystems, and on the ways in which people interact with these. The collection and provision of environmental information in Australia has been a slow journey but appears to have reached a crossroads, with several current government initiatives currently attempting to improve the evidence base for policies with environmental objectives or impacts. This has coincided with considerable advances in environmental science, technology, and analysis methods. So far, there does not appear to have been a systematic attempt to compare or integrate government and research activities, and analyse how research can help overcome obstacles on the road to comprehensive, nation-wide environmental information relevant to public and policy needs. Our goal was to address this gap: we review Australia's environmental information history (Section 2) and current capacity to produce nation-wide environmental accounts and reports (Section 3). From these, we interpret the main challenges and opportunities that the demand for national scale environmental information creates (Section 4) and suggest priorities for the research community (Section 5).

1.2. Scope and terms used

Providing environmental information in a structured way is varyingly referred to as environmental accounting, reporting, monitoring, or assessment, but these terms are not defined in any universally accepted or mutually exclusive way. Here, we define 'environmental information' as any quantitative data about the condition and functioning of ecosystems and the availability and use of the goods and services that they produce. We generally focus on water, vegetation biomass, carbon, and measures of general ecosystem health, but will occasionally discuss other aspects.

'Environmental accounting' can be seen as distinct from environmental reporting in that it provides information in the form of accounts, which impose particular standards and constraints on the definition, format, analysis and presentation of the information. Environmental accounting has its origin in the notion of 'natural capital', as a form of production capital that needs to be maintained to provide ecosystem goods or services into the future, rather than viewing it as an unchangeable quantity (Schumacher, 1973). Environmental accounts can be used to quantify the depletion or restoration of natural capital (the 'stocks') in the course of supplying goods and services (the 'flows') (Costanza et al., 1997; United Nations Statistics Division, 2013b; Weber, 2011). Accounting standards force a degree of rigour, for example through the definition of spatial and temporal accounting units and accounting terms, and promote comprehensiveness and consistency over time. An important advantage of structured accounts is that data can be progressively aggregated to higher levels to best suit the information user (Fig. 1). Environmental accounts can be designed to align with economic and social accounting frameworks and concepts, providing insight into the contribution of the environment to the economy, the impact of the economy on the environment, and the economic efficiency of

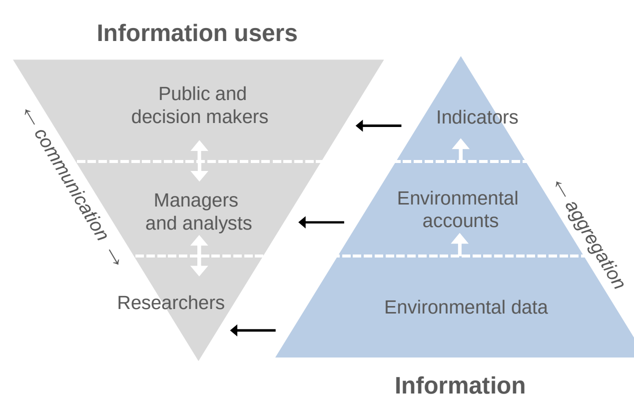

Fig. 1. Diagram illustrating how environmental data, of greatest value to a relatively small number researchers, can be summarised into structured accounts that are valuable to a larger group of managers and analysts, while the broader public and decision makers may prefer aggregated headline indicators (after Vardon et al., 2012).

natural resources use. A prominent example is the System of Environmental–Economic Accounts (SEEA, United Nations Statistics Division, 2013a).

By comparison, 'environmental reports' typically take a more interpretative and less structured form, discussing environmental trends and events and their consequences. Here, we only use the term 'monitoring' for the actual collection of environmental data, and avoid the term 'assessment' as being too generic outside a specific context (exemplified by qualified uses like 'resource assessment', 'environmental impact assessment' and 'climate change impact assessment').

We use the term 'ecosystem integrity' as broadly interchangeable with such concepts as the condition of natural capital, ecosystem functioning, ecosystem intactness, and ecosystem health (cf. De Leo and Levin, 1997; Müller et al., 2000), to indicate a holistic notion of the functional attributes that need to be maintained in order for the ecosystem to continue to provide its goods and services to humans. Biodiversity and structural and functional integrity may be considered as aspects of ecosystem integrity. Some ecosystem services require the continued integrity of the ecosystem but do not significantly change it (e.g., recreation, ecological habitat, water, air and climate regulation), while other uses have material impacts on the ecosystem and directly affect ecosystems integrity (e.g., the extraction of water or biomass, the removal of vegetation for construction or conversion to a different land use).

We limit ourselves to nation-wide environmental information. By no means do we imply that this can meet all information requirements. For example, the practical implementation of management activities and policies at lower levels of government typically demands more detailed and specific local information. We took a national view because this type of information has its own specific relevance in public debate and national government, and because it presents unique challenges of scale in terms of theory, observation, analysis and interpretation. We focus on the generation and use of information about Australia's environment by Australian individuals or organisations, but where relevant make reference to international developments and the potential relevance of our findings elsewhere.

We do not suggest that a lack of environmental information currently prevents us from identifying and changing any unsustainable practices. In many cases, environmental degradation is unambiguous and urgent and its underlying causes sufficiently well understood to support immediate action. In such cases, data collection and information generation are important to monitor the effectiveness of intervention, but should by no means delay them (e.g., Lindenmayer et al., 2013).

2. Environmental policy context

2.1. Introduction

Environmental information can help us understand the impact of our decisions on the environment, as well as help mitigate the risks and use the opportunities that it presents. At least in theory, better use of information should improve the effectiveness and efficiency of environmental measures; promote more sustainable use of natural resources (e.g., by supporting a market system); provide evidence for policy development; help identify and manage risks early; and help experts, businesses and public to understand and consider environmental functions and the trade-offs between economic, social and environmental goals.

The Australian Bureau of Statistics (ABS) estimated that environmental research received about $650 million of expenditure in 2008/09; in four approximately equal parts from business, federal government, state/territory governments, and the higher education sector. Morton and Tinney (2012) estimated that Australia's government departments and agencies together spend about $800 million per year on environmental information. A recent survey found that environmental information was required by 17 federal government departments (Environmental Information Advisory Group, 2012) for more than 300 individual activities; from the implementation of policies, plans, strategies, programmes; meeting national, bilateral and multilateral agreements, conventions and reporting obligations; to the administration or functioning of markets, funds, systems, park agencies and authorities. Perhaps less obvious activities were around border protection, energy security, gene technology, aviation, tourism, and cultural heritage conservation. Activities were classed in nine categories: to manage protected areas and conserve and protect biodiversity, ecosystems and reserves (25 activities); protect people and environment from weeds, pests and diseases (35); reduce greenhouse gas emissions and adapt to climate change (51); meet national and international reporting obligations (28); ensure sustainability and safety of infrastructure and communities (16); enable productive, innovative and sustainable use of natural resources (71); protect and manage natural and cultural heritage (25); protect human health and the environment from waste and pollutants (28); and ensure water quality and availability (23).

The report identified a vast range of environmental variables that could be categorised either by thematic area (air, biota, human, land, oceans, processes and water); the form of the data (categorical, biophysical, economical, institutional or qualitative); the spatial characteristics (cartographic, spatially continuous, area- or point-based data, or non-spatial); or by temporal characteristics (static, historical, recent and up-to-date monitoring data). Despite differences in emphasis, many policy initiatives and agencies required the same or very similar data about the atmosphere, water, biota and human activity in the landscape. Clearly then, there appears to be no lack of demand for environmental information, and the study highlights drivers of future demands that cannot be met by the existing information system (Environmental Information Advisory Group, 2012).

2.2. Brief history

Having established that there is demand for environmental information, we briefly survey the main national government actions since Australia's federation and independence in 1901 to meet this demand.

- The *Meteorology Act 1955* established the Bureau of Meteorology (BoM) as the agency responsible for collecting and supplying meteorological data, as well as the publication of meteorological reports, weather forecasting, and related functions.
- The *Census and Statistics Act* 1905 had already established the Australian Bureau of Statistics (ABS) but did not explicitly consider environmental data. However the ABS has a broad remit and released the first environmentally themed report in 1992. It has since issued annual accounts for water, energy and natural resources on the National Balance Sheet, among others.
- The *National Forest Policy Statement* 1992 committed the Australian federal and state governments to collating forestry data and producing a State of the Forests Report (SFR) every five years, starting in 1998. The SFRs provide information on Australia's forests and sustainability and meet international reporting requirements under the Montréal process.
- The *Natural Heritage Trust Act* 1997 mainly funded restoration and conservation activities, but also included the National Land and Water Resources Audit (NLWRA). The NLWRA was arguably the first attempt to produce comprehensive nation-wide environmental information using the best available observation and analysis methods. It was unprecedented in its broad scope and contributed much to the understanding of Australia's natural resources, highlighted knowledge gaps, and helped to develop new analysis methods and data products. However, when the NLWRA was finally concluded in 2008, it did not leave an operational information system and a considerable part of the information produced may already be considered out of date, although much of the knowledge and solutions developed have made their way into subsequent information products and systems.

- The *Environment Protection and Biodiversity Conservation Act* 1999 enshrined the production of a five-yearly 'State of Environment' (SoE) report, which had first been published in 1996. The SoE has no formal role in policy auditing or implementation. Instead, it has the broadly defined purpose of synthesising existing interpretation and reports on the environment, without collecting or analysing new data (though minor activities in support of its production are commissioned occasionally).
- The Murray–Darling Basin water crisis catalysed water reform, including the provision of water information. The *Water Act 2007* established the BoM as the central agency to collate, analyse and report water data and legislated its powers to do so. The BoM now produces water information products as required by the Water Act (e.g., the National Water Account) as well as other products targeting specific government or public information requirements.
- The *National Greenhouse and Energy Reporting Act 2007* led to the development of the National Carbon Accounting System (NCAS), which requires annual mapping and reporting of forest cover change to account for emissions from land-based activities as part of the Kyoto Protocol.
- *Australia's Biodiversity Conservation Strategy 2010–2030* was launched in 2010 as Australia's contribution to the UN 1993 Convention on Biological Diversity. Among ten targets for 2015, is the establishment of a national long-term biodiversity monitoring and reporting system. Although much biodiversity data are being collected, at the time of writing there does not appear to have been any concrete development of a reporting system.
- The *National Plan for Environmental Information* (NPEI) was initiated by the Australian government in 2010 to improve the quality and accessibility of environmental information for decision-makers (in first instance, the Australian government). The NPEI contains a policy component (e.g., review and development of new legislation) as well an operational component that is coordinated by BoM and includes the development of environmental information systems, data standards, products and services, environmental accounting approaches, and tools for improved data access and discovery.
- The *National Collaborative Research Infrastructure Strategy* (NCRIS) was introduced in 2004 to secure strategically important research facilities, networks and infrastructure. It included $20 million over 2009–2013 to establish a Terrestrial Ecosystem Research Network (TERN) intended to provide a nationally-consistent infrastructure to collect and manage time series data.

This brief history suggests that the potential value of environmental information is rather widely accepted, but equally, that ongoing data collection and reporting remain a major challenge. For example, the SoE and SFR reports rely on information from other sources, whereas initiatives such as the NLWRA have been project-based. There are some examples of ongoing information production, however, such as the NCAS land cover data and several products provided by BoM and ABS.

3. Current environmental accounts and reports produced for Australia

A summary of nation-wide environmental reports and accounts and other relevant products is provided in Table 1. These are reviewed to analyse the way in which data are collected, analysed and reported.

3.1. National environmental reports

The number, scope and sophistication of BoM's *climate reports* has steadily increased from the first, very brief Annual Temperature Statement in 1996, to the first Annual Australian Climate Statement in 2000, and the considerably more comprehensive climate statements

Table 1
Summary of nation-wide environmental reports and accounts and other relevant products.

National environmental reports	
Annual Climate Statements—published 1996–2012 (annually) by BoM	Weather, extreme events and climate change
State of the Environment—published 1996–2011 (5 yearly) by independent committee	Environment condition, pressures and drivers, and environmental initiatives and their impact.
State of the Forests Report—published 1998–2008 (5 yearly) by the responsible federal department	Forest ecological conservation, production, ecosystem health, soil and water resources impacts, carbon storage, and socio-economic and legal aspects
Australian Water Resources Assessment—published 2010 (frequency undecided) by BoM	Availability, quality and use of water resources for the year within a historic context
National environmental accounts	
National Greenhouse Gas Inventory—published 2008–2013 (quarterly) by the responsible federal department	Greenhouse gas emissions and removals directly associated with human activities
Water Account Australia—published in 2001, 2005, 2009, 2010* (by ABS)	Physical and monetary supply and use of water in the Australian economy
National Water Account—published 2010–2012 (annually*) by BoM	Water available to be used, water rights and water extracted and traded
Other relevant reports and accounts	
Living Planet Report—published 1998–2012 (bi-annually) by World Wildlife Fund and others	Integrates composite scores for the biodiversity of forest, freshwater and marine ecosystems
UN country data bases—several, typically annual and published by the responsible UN agency	Various environmental issues
Completing the Picture – Environmental Accounting in Practice – by ABS	Proof-of-concept demonstrating how SEEA accounts can support better decisions and policies

* For financial years, which in Australia end in June.

issued in more recent years.[1] Data underpinning the statements include station rainfall, climate and streamflow data (collected by the BoM, other agencies, and volunteers) while information on ocean conditions and global climate change is derived from global observation systems and models that rely heavily on international in situ and satellite data collected by other nations.

The most recent *State of Environment* report does not contain a structured set of quantitative data or accounts, but follows an interpretative 'drivers–pressure–state–impact–response' framework (State of the Environment, 2011 Committee, 2011). The 2011 report does have some quantitative aspects, however, and includes report cards inspired by similar reports issued for the Great Barrier Reef (Dobbs et al., 2011). The information used was derived from disciplinary experts, research publications, and government departments and agencies. The origin, status and degree of independent review of the information are not always clear but its veracity does not appear to be widely contested. The SoE 2011 makes modest use of remote sensing information to support its statements, including spatial data on ocean algae (Blondeau-Patissier et al., 2011), trends in Antarctic sea ice duration (Stammerjohn et al., 2008), fractional cover of green vegetation, litter and bare soil (Guerschman et al., 2009a), and fire frequency (from NASA). Satellite data were also involved in the original production of land use, land cover, vegetation group, forest extent, and (revised) drainage divisions that are included in the report, and some satellite images are used for apparently purely illustrative purposes. Perhaps one of the most important functions of the SoE reports is as an interpretive and illustrated catalogue of much of the environmental data available in Australia at the time of its publication, although it is not always clear if and how the data shown can be accessed.

[1] http://www.bom.gov.au/announcements/media_releases/climate/change/.

The most recent *State of the Forests Report* (2008) reported on 44 indicators representing a wide range of goods and services. Most of these data are provided by individual state and territory agencies and forestry companies, for example through the National Forest Inventory and National Plantation Inventory processes. These are collated at national scale without further independent review. Other data are taken from ABS and Australian Greenhouse Office reported figures. Where possible, the report provides relevant national scale data against each indicator; elsewhere the analysis is more interpretative or through case studies.

The *Australian Water Resources Assessment* (AWRA) report uses available water data, models and analyses and reports these in a water balance framework. Although the publication frequency has not yet been decided, the underpinning processes are designed to be repeated and consistent. Data on river flow and water quality, groundwater level, dam and lake water levels, and other hydrometric data are provided by more than 200 public and private organisations. The spatial data used in the AWRA report are primarily derived from cartographic sources, interpolated climate station data (Jones et al., 2009), and water balance terms estimated by the AWRA model system (van Dijk and Renzullo, 2011). Model estimated variables reported include evapotranspiration, soil moisture, and landscape water yield (the sum of surface and groundwater generation). The 2010 report includes a sequence of three satellite images (a progressing inland flood), but indirectly contains satellite data through the use of satellite-derived forest extent, albedo and vegetation leaf area index data in the AWRA model. Since the 2010 report, the model system has seen further development with additional satellite observations being incorporated in system configuration and parameterisation (Guerschman et al., 2011, 2012; Peeters et al., 2013), calibration (Zhang et al., 2011) and data assimilation (e.g., Renzullo et al., 2011a). National precipitation and evapotranspiration products that make direct use of satellite observations (Guerschman et al., 2009b; Renzullo et al., 2011b) have also been made operational and may be used in future reports.

3.2. National environmental accounts

The *National Greenhouse Gas Inventory* reports provide annual and quarterly updates on land-based emissions and removals derived from the Australian Greenhouse Emissions Information System (Department of Climate Change and Energy Efficiency 2012). For crop production and livestock activities, this mainly focuses on methane and nitrous oxide emissions from livestock and crop production. For land use and management activities, the National Carbon Accounting System (NCAS) mainly reports on carbon emissions and removals, estimated from satellite land cover data (Furby, 2002) and land use data combined with empirical and process-based models (Richards, 2001). The accounts report on carbon storage *changes* only, and do not attempt to estimate carbon stocks contained in the landscape (or the marine environment).

The ABS *Water Account Australia* describes who uses water, how much was used, and for what purpose, per industry class and for each reporting unit. The accounts have been used for a variety of analytic purposes, including input–output and computable general equilibrium approaches to economic modelling (Vardon et al., 2007). Most of the data used in recent water accounts were derived from statistical surveys or as a (by-) product of government administrative processes, but some terms were model estimates based on economic data, annual reports and websites (Australian Bureau of Statistics, 2012b).

The BoM *National Water Account* mainly relies on hydrometric measurements (of water levels, volumes and flows) and records of water volumes allocated and traded. The BoM accounts provide information on the amount of water in the environment and the volumes allocated and traded while the ABS accounts provide information on the use of water in the economy (e.g., the amount used for hydro-power, agriculture and households) and the economic information related to that use. As such the ABS and BoM accounts complement each other. Both accounts report over financial rather than calendar years. Unlike the ABS account, the BoM accounts do not cover the entire nation, use different spatial reporting units, and follow an accounting framework developed by the Water Accounting Standards Board. While the BoM water account does not explicitly follow the SEEA, the framework used can be mapped to it (Vardon et al., 2012).

3.3. International information products

Apart from the reports and accounts produced by Australian government organisations, there are some international information sources that demonstrably influence public debate and government functioning in Australia and that are therefore relevant here.

The *Living Planet Report* reports a ‘Living Planet Index’ (LPI) for each country, which has been adopted by the International Convention on Biological Diversity as an indicator of progress towards stopping biodiversity loss. In the most recent report, the LPI was calculated using ecological population trend data for thousands of fish, amphibian, reptile, bird and mammal species on the International Union for Conservation of Nature and Natural Resources (IUCN) Red List, gathered from science journals, online databases and government reports (Loh et al., 2005). The Living Planet Reports also published the ‘Ecological Footprint’, a number that is interpreted as the hypothetical land and sea area necessary to supply the resources that are consumed or to process the waste produced. Calculation methods vary, but typically involve a combination of statistical data on resources use and waste production and estimates of resource renewal rate (e.g., Lenzen and Murray, 2001). The footprint approach has been applied to individual countries, businesses, products and households, and in Australia has been adopted by, among others, the Environmental Protection Agency of Victoria. The LPI relies on country statistics available from the United Nations' (UN) and other inter-governmental agencies, programmes and committees. Examples include data on fisheries, agriculture, and forestry, and water resources that are collated by the UN Food and Agriculture Organization[2]; data on economic production, population, energy, water and waste collated by the UN Statistics Division[3]; data on threatened species collated by the IUCN[4]; and data on greenhouse gas emissions collated by the UNFCCC secretariat.[5] In addition to the LPI, various other analyses, accounts, and internet-accessible data bases are derived from these data (e.g., the UNSD Environmental Indicators Database[6] and Millennium Development Goals Indicator Database[7] and The World Bank's World Development Indicators[8]). Although typically compiled from numbers reported by national governments or from lesser quality global data sets, such international comparisons can have considerable influence on public debate and government activities.

3.4. New initiatives

In addition to the existing information products, there are current initiatives to expand and broaden the scope of environmental accounting in Australia. Australia has played an important role in the development of the SEEA (United Nations Statistics Division, 2013a). The SEEA Central Framework was adopted by the UN in 2012 as an international standard. Its main objective is to show the linkages between subaccounts, rather than replace current accounting approaches. The SEEA can bring together information on water, minerals, energy, timber, fish, soil, land and ecosystems, pollution and waste, production,

2 http://faostat.fao.org/, http://www.fao.org/nr/water/aquastat/dbase/index.stm.
3 http://data.un.org/, http://www.un.org/esa/population/.
4 http://www.iucnredlist.org/.
5 http://unfccc.int/ghg_emissions_data/items/3800.php.
6 http://unstats.un.org/unsd/environment/qindicators.htm.
7 http://mdgs.un.org/unsd/mdg/Data.aspx.
8 http://data.worldbank.org/indicator.

consumption and investment. The core of the framework recognises four types of accounts:

- 'physical flow accounts' represent the flows of energy and matter between environment and the economy and are expressed in relevant units of energy or mass,
- 'functional accounts for environmental transactions' relate to the financial transactions associated with environmental protection and resources management,
- 'asset accounts in physical and monetary terms' record the stocks and flows in natural resources for each accounting period, and
- 'ecosystem accounts' represent a fourth and still experimental accounting approach that attempt to capture information about the degree to which ecosystem integrity (or natural capital) is maintained in the generation of goods and services.

An important innovation of the SEEA compared to existing environmental statistics and accounts is that it aims to create consistency between all accounts in terms of concepts, methods, definitions, classifications, and temporal and spatial accounting units and coverage. The consistency is particularly valuable for linking environmental and socio-economic data to obtain combined measures of, for example, profitability and biodiversity per industry sector. Several SEEA applications are well advanced in Australia: the water, energy and natural resource accounts produced by the ABS follow the SEEA approach and parts of the greenhouse accounts are currently being recast into this mould. The ABS trialled the SEEA for a number of environmental questions and data types in '*Completing the Picture—Environmental Accounting in Practice*' (Australian Bureau of Statistics, 2012a; see also Australian Bureau of Statistics, 2013). The report explored the application areas of mitigating and adapting to climate change, sustainability, managing the Great Barrier Reef region and the Murray–Darling Basin, 'green growth', and solid waste management. The report built on accounts already produced by ABS and combined this with data reported or provided by other government departments and agencies. Apart from illustrating the value of consistent and comprehensive accounting, the report highlighted how combined SEEA style accounts help to understand interactions between the environment and economy. The many gaps in the experimental accounts also exposed the lack of observations and methods for important variables and, related to this, the need to rely on proxy measures or observations for 'representative' sites, in the absence of aggregate level data.

In addition to these national-scale accounting trials, there have been several regional trials. The Great Barrier Reef Land Account is an SEAA-based asset account developed by ABS that provides land use and land cover area statements for regions bordering the world's largest coral reef. It combines cadastre-based data (e.g., industry sector and land values) with grid-based land cover data and contains tables and maps that show the extent of different land uses and cover types along with their area and value. These land accounts quantify and locate landscape change and are being extended to other regions. The Victorian Department of Sustainability and Environment has published ecosystem accounts based on methods used in their market-based environmental management programmes (Eigenraam et al., 2013). The accounts are linked to land accounts and apply the SEEA concepts, with some adjustments. The Wentworth Group of Concerned Scientists together with a number of natural resources management bodies uses an alternative accounting approach (Cosier and McDonald, 2010; Stoneham et al., 2012). The 'Accounting for Nature' model compares the condition of an ecosystem asset to a reference condition, using a common unit. Condition is assessed by science-based measures of ecosystem health, and a reference condition is defined as the natural condition of an ecosystem in the absence of significant human impacts.

As part of the development of a national environmental accounting framework, '*The Environmental Accounts Landscape*' (Bureau of Meteorology, 2013a) surveyed environmental accounting models and their implementation in Australia and internationally. The associated '*Guide to environmental accounting in Australia*' report (Bureau of Meteorology, 2013b) categorises accounting approaches based on their perspective (e.g., economic or environmental), application (e.g., financial or economic accounting), spatial scale, accounting unit (e.g., monetary, physical or index based) and statistical reporting units (e.g., grid cells, administrative areas or economic sectors). Because of variations in these different aspects, information from one account type is not necessarily easily used to inform another type. A number of trends in accounting approaches are described, including a gradual broadening from economic accounting approaches to more environmentally-focused approaches, and in tandem with this, a change towards index-based units such as 'footprints'. The authors propose a 'Joint Perspectives Model' as an overarching framework for accounting. The concept reflects a systems approach, borrows from existing environmental accounting approaches, and aims to reconcile the alternative perspectives by describing the economic perspective (i.e., economic inputs and externalities such as pollution and waste) as nested within the social perspective (measuring human well-being). The latter in turn is nested with the overarching environmental perspective that describes the state of the physical environment and ecosystems and their functioning. The framework recognises that there are different perspectives to frame environmental accounts and that these are not necessarily always best expressed in monetary terms; that the purpose, information requirements and usefulness of any particular account type should be clearly established; and that different accounting purposes may require information at different spatial scales (Bureau of Meteorology, 2013a).

4. Prospects: challenges and opportunities

4.1. Challenges

A review of Australia's environmental performance by the Organisation for Economic Co-operation and Development (OECD, 2007) noted progress in environmental monitoring and reporting through the NLWRA, water accounts and similar activities, but found that there still is a lack of nationally coherent environmental monitoring and reporting of water resources, biodiversity, and agricultural impacts (e.g., pesticides). An obvious challenge for Australia is its modest and concentrated population and large surface area: with 23 million people living in a country of 7.7 million km^2 (similar in size to the contiguous USA and 11 times France) it is the fifth most sparsely populated country. Almost 90% of its population lives in urban areas, which also makes it one of the most urbanised nations. This lack of 'eyes on the ground' is reflected in the environmental data collection infrastructure (Fig. 2). In addition, the relatively short history since European settlement means that basic field survey data on elevation, soil and geology are not available or of limited quality for much of the nation. Without too much hyperbole, the country can still be described as it was in mediaeval times: *Terra Australis Incognita*—the Unknown Southern Land.

There are also factors that are probably less unique to Australia. Obstacles identified previous analyses (Morton and Tinney, 2012; OECD, 2007; State of the Environment, 2011 Committee, 2011) can be synthesised into seven broad categories:

1. *Environmental complexity*. The diversity of environmental information reflects the complexity and difficulty of understanding our environment, when compared to many human-constructed systems (e.g., finance and trade, traffic, or health care). The very large (perhaps almost infinite) number of variables of potential interest creates problems in terms of collecting data but also in analysing and reporting it.
2. *Missing data standards*. There is a lack of agreement on data and information standards between different levels of government (local, state and federal) and other relevant organisations, whether relating

to appropriate environmental indicators, data collection protocols, data description and transfer standards, or reporting formats. This makes national aggregation and reporting difficult.

3. *Poorly specified information requirements*. The complexity of the environment means that management objectives are frequently not clearly defined, or are defined but not measurable. The reasons may be technological, conceptual or financial. Management objectives may also change over time, reflecting new insights, perspectives or threats. Finally, where objectives are defined and measurable they tend to be highly specific to the local management context. As a result, environmental information requirements are often difficult to specify, particularly at national level.
4. *Costs, coordination and sharing*. Considerable costs can be involved in purchasing, managing, processing or developing data. If a data type has many potential users a 'tragedy of the commons' tends to occur, where individual users are reticent to cover the costs. This scenario can occur where there is not a clear responsibility with any single agency and cross-agency coordination and leadership fails. Where such investments have ultimately been made, however, they generally appear to have been well justified by the benefits derived. Recent examples include the development of a national digital elevation model (coordinated by BoM) and the atmospherically-corrected Landsat satellite imagery archive (coordinated by Geosciences Australia). It is relevant to note that a policy of free and open access to tax funded data is generally subscribed to by both state and federal governments, but has in many cases not (yet) translated to practice.
5. *Over-reliance on research and business data*. Where a clear policy context is absent, data are often collected by researchers for science applications, or by industry for internal business purposes or reporting requirements. These data may not be very suited for other purposes, not be collected in any consistent manner, or not be easily accessible due to concerns about intellectual property or commercial interests. Data collection may also be highly localised and short-term or intermittent, further limiting their usefulness in national reporting and accounting.
6. *Business engagement*. Australian private businesses collect environmental data but few of these contribute to national reports and accounts. In this area, the OECD found Australia lagging other developed countries, which it attributes to a comparative lack of knowledge or appreciation of the need for sustainability in businesses (OECD, 2007). The SoE 2011 identifies particular opportunities for coastal and marine data collected by the resources sector, and for soil, water and pests data collected in the agricultural sector.
7. *Short-termism*. Previous short-term funding has not encouraged the development of enduring information systems. A case in point is the NLWRA, which did not leave an enduring capacity for ongoing reporting. While environmental information may be useful or perhaps even fundamental to several policy areas, it is apparently not of the highest priority compared to other demands on any one agency's budget. As a result, information is mainly obtained and reported on a project and purpose-driven basis, and coordinated ongoing efforts to collect and report information are severely limited.

4.2. Success factors

Despite the challenges outlined above, there are also successful examples and it may be instructive to discuss factors contributing to their success. The BoM has collected and reported climate data for decades and, since 2008, performs a similar function for water resources data. Similarly, the ABS and federal government departments routinely collect and report data on energy use, forest cover change and associated greenhouse gas accounts. A common feature of these developments is that they are supported by financial resources and legislation, which helped resolve cultural, structural, financial, technical and legal obstacles (as defined by Morton and Tinney, 2012). For example, in water information the BoM has made progress through: investment in the improvement of the water measurement networks maintained by state agencies and other organisations in return for the adoption of data standards; negotiated water data sharing agreements between water data suppliers and BoM (supported by the Water Act 2007); and the development and implementation of data description and transfer standards (e.g., the Water Data Transfer Format), water data bases (e.g., the Australian Water Resources Information System), modelling platforms (e.g., seasonal forecasting models and the AWRA system), and information services and products (e.g., the National Water Account and AWRA report). To date, the federal government has invested more than $600 million in these and similar activities, through BoM and the National Water Commission, with additional investments from other federal and state agencies. Some of the activities have not yet been finalised or are intended to be ongoing, and hence total expenditure will increase. This arguably provides an indication of the level of investment required to establish a robust and sustainable information system of limited scope. Progress is slower and piecemeal in other areas of environmental information, where such legislated imperatives and associated investments have not yet occurred. Similar legislative instruments may be required, but with the experience and technology developed for water information, more efficient investments should be possible.

5. Suggested priorities for research

The SoE 2011 report predicts important changes in environmental monitoring and reporting in Australia, with research producing increasing volumes of environmental information ('Big Data'; Lynch, 2008), and decision makers increasingly being expected to use that information. The report advocates for the development of environmental information systems, allowing scientists and managers to analyse and understand connections between different environmental processes, and recommends that relevant socio-economic data be included. The report identifies technical, institutional and social innovations that will help future reporting: enhanced monitoring networks, increased standardisation and data management, new environmental modelling platforms, national commitments to share environmental data between jurisdictions and industry, community-based environmental monitoring, and the increasing interest and adoption of environmental and sustainability indicators. We now turn to the role of research to meet the information challenge and capitalise on these opportunities.

5.1. A quantitative, scalable ecological theory

Quantifying concepts such as ecosystem integrity and biodiversity in a way relevant to management or accounting is a major challenge. Lindenmayer et al. (2012) identified four barriers to more effective biodiversity monitoring in Australia. While three of these are applicable to environmental data collection more generally, the fourth – poor definition of management goals and hence of monitoring objectives – may be particularly relevant to the complexity of living ecosystems. This expresses itself in disagreement about what to monitor; in the implementation of ecologically comprehensive but spatially limited monitoring programmes that are expensive and not readily transferable to other locations or scalable to larger areas (let alone to national level); and monitoring strategies that change priorities and methods when management objectives change. While each of these aspects also brings certain strengths, it does create fragmentation of investment and seems likely to prevent insights at higher levels.

Defining more quantitative and comparable metrics of biodiversity or ecosystem integrity requires a similarly clear articulation of management objectives. Lindenmayer et al. (2012) propose that biodiversity monitoring should focus on providing information on trends (e.g., in abundance), impending threats, the effectiveness of conservation measures, opportunities to make management more effective, and on the return on investment in conservation. As a positive example of

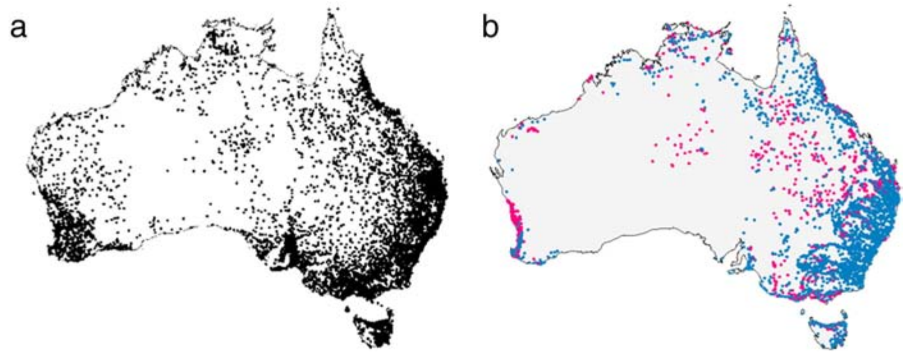

Fig. 2. Distribution of available on-ground measurements of (a) rainfall and (b) surface water (blue) and groundwater level (magenta) (data from BoM). (For interpretation of the references to colour in this figure legend, the reader is referred to the web version of this article.)

ecological monitoring, they cite the kangaroo population monitoring programmes used to determine sustainable harvesting rates (Pople et al., 2007). It involves measuring population trends, previous harvesting levels, climate conditions, non-commercial killing rates, the size of the population free from harvesting, and deaths from other causes. This particular example seems to have benefited from the definition of a sufficiently narrow objective (setting sustainable harvest rates) and from being amenable to stock-flow modelling and accounting methods. Examples of other similarly well-defined monitoring programmes exist in fisheries and forestry, in Australia and elsewhere.

In addition to taxonomically limited but tractable data collection exercises, there are promising developments in large scale monitoring of ecosystem integrity. This includes the information that can be inferred from changes in water and carbon stocks. Observation-based spatial national products have become available in both areas. Satellite remote sensing also provides new opportunities to measure metrics that are directly relevant to ecological condition, such as leaf and litter cover (e.g., Guerschman et al., 2009a). A review of approaches to map ecosystem integrity or vegetation condition (Gibbons et al., 2006) found that the best results have been achieved where regionally derived statistical relationships between field-observed condition and spatial vegetation metrics (e.g., patch size and shape) could be derived from airborne or satellite high- to very high resolution imagery (Gibbons et al., 2006; Kocev et al., 2009; Lee and Lucas, 2007; Newell et al., 2006; Zerger et al., 2009). Unfortunately, the reliance on field data and often non-routine imagery means that these techniques are currently unsuitable for recurrent, national accounting. Alternatively, land use and land use change have often been used as a surrogate for ecosystem integrity (Thackway and Lesslie, 2006). While pragmatic, the suitability of this approach is limited by the quality, frequency and consistency of land use mapping, and the underlying assumption that land use per se is a suitable indicator of ecosystem integrity.

New approaches are required, and there appear to be opportunities. For example, the amount, condition and configuration of vegetation may be assumed to have a bearing on biodiversity, and information on these can be derived from remote sensing, even if this can only provide partial information on ecosystem integrity (e.g., it does not reflect such important pressures as invasive species and pollution). The amount of habitat is a simple but powerful surrogate for ecosystem integrity (Brooks et al., 2002; Huth and Possingham, 2011; Myers et al., 2000; Radford et al., 2005; Turner, 2005), although it may have limited utility in landscapes that are not fragmented and where the principle threat to ecosystem integrity is not habitat clearing. Habitat condition also has a strong bearing on ecosystem integrity (Specht and Specht, 2002; Turner, 2005) and may be usefully interpreted with reference to minimally modified vegetation (Huth and Possingham, 2011), for example in nearby protected areas and travelling stock reserves (Gibbons et al., 2008, 2010). Finally, remote sensing data of sufficient resolution can quantify habitat configuration or connectedness (Drielsma et al., 2007), a property which may become increasingly important for biodiversity under anticipated biome shifts forced by climate change (Dunlop et al., 2012). While it is emphasised that all these approaches have obvious limitations, there would seem to be a good case to test their merit at national scale.

5.2. Data standards and measurable management objectives

The most important challenge to sourcing environmental data is not always data collection per se, but often rather that collected data are too unlike, insufficiently described, and not machine readable and therefore cannot (easily) be used in national accounts and reports. Recent data standard developments in water data provide a good example of the effort required to collect, share and combine environmental data from many different sources. Given that over 250 organisations provide water data to the BoM, the use of standards has been critical. BoM invested in the development and implementation of the Water Data Transfer Format (WDTF), a set of data standards that enhances the description and transfer of water data in a rich and machine readable format. Further investments were made to ensure that the standards used modern concepts, methods and technologies; as well as in the capacity of agencies and private businesses to implement and adopt the WDTF. Arguable success factors in the development and adoption of these standards were the presence of a legal framework for data provision, the BoM's ability to negotiate and assist, often on a bilateral basis, in the adoption of standards, and its ability to invest in its implementation where critical. From a research point of view the development of the underpinning data standard (WaterML v2.0; Walker et al., 2009) was an important technological contribution that has since been accepted as an international standard (by the Open Geospatial Consortium). Elements of this data standard are also gradually being applied to other areas of environmental information, and therefore there is likely to be considerable and enduring benefit from the initial effort.

Defining the most important environmental variables and the way in which they should be measured and interpreted is a critical first step in the development of new data collection infrastructure. Again in water data, the collaborative development of the National Water Accounts provides a useful case study. Complications arose where important accounting terms were not readily defined or measured (e.g., environmental water use), where accounting preferences lead to conceptual or practical difficulties (e.g., determining the total volume of extractable groundwater), or where different parts of the overall system act in spatially different domains (e.g., where surface water and groundwater systems do not align). Similar challenges have occurred in carbon accounting.

Challenging as these developments are, they benefit from having a common measurement unit (e.g., gigalitres of water or tonnes of carbon). More complicated situations arise if a common unit does not exist, as may be the case for example when considering different chemicals (e.g., pesticides, emissions or nutrients) or holistic and poorly quantifiable concepts such as biodiversity or ecosystem integrity. Nationally meaningful data collation and scaling can also become challenging if management objectives are locally defined as, quite reasonably, the case may be in activities and policies designed to protect specific environmental assets or functions. However, where difficult choices need to be made in the allocation of scarce national resources, the lack of a conceptual framework to measure and compare relevant environmental information across locations and management objectives must be considered a fundamental weakness. There is a need for overarching principles that can help formulate objectives for management and measure their success in a rigorous and justifiable way. There is a clear role for the research community to address these challenges. Experts in different environmental disciplines are needed to develop robust, nationally consistent and measurable concepts and accounting frameworks. Technology experts are needed to develop the data format and transfer standards and data management technologies to support consistent, open and rapid data collection, sharing, analysis and reporting.

5.3. Long-term research data collection, production and reporting

The challenges and inefficiencies associated with government project-based funding, departmental restructures and the electoral cycle are known by researchers and public servants alike. The challenges in sustaining long-term data collection, production and reporting and associated programmes internally within research organisations are less often commented on, but can be equally problematic. Research organisations may prefer to pursue continued innovation over long-term monitoring and dismiss it as a government responsibility. Individual researchers may consider it as a painstaking effort that is not justified by the opportunities for funding, publication and career improvement. Where long-term data collection occurs, it tends to be through a varying combination of luck, persistence and visionary foresight on the part of one or few individuals. Yet such records are critical to develop new insights. A case in point is the atmospheric greenhouse gas and ozone-depleting substances record from Cape Grim, Tasmania collected by CSIRO and BoM researchers. The data set has been cited more than 800 times already (Google Scholar, May 2013), illustrating the impact that research data collection can have on the research community, as well as on society and government.

There is a clear case for long-term financial commitments by Australian governments to operational agencies and research organisations alike, to ensure continuity in data collection and processing, and to dissolve the boundary between (project-based) research data collection and long-term monitoring. Elsewhere, this need is better recognised. For example, in Europe the Integrated Carbon Observation System provides government funding commitments to academic and government agencies over a period of 20 years (although in the form of 10-year contracts). In the USA, the National Ecological Observatory Network has a funding commitment from the US National Science Foundation for a period of 30 years. The closest Australian example, the Terrestrial Ecological Research Network (TERN, www.tern.org.au), was funded for six years along with several other major environmental data collection infrastructure projects, including the Integrated Marine Observing System. While the government expressed an intention to sustain the infrastructure, at the time of writing it relies on ad hoc arrangements while continued funding is being considered.

Sustained efforts to derive environmental information from publicly available time series (e.g., those collected by satellites or derived from models that integrate different observations) also provide a valuable service to researchers and even operational data users. Two examples of widely used data products are the vegetation greenness record derived from the series of AVHRR satellites (e.g., Tucker et al., 2005) and the various satellite and modelling products produced by NASA (several of which are funded from science rather than operational budgets). Australian researchers are among the many beneficiaries of this sustained data production. Continued and free global sharing of satellite observations is particularly essential for Australia, by far the largest nation without any capability to observe its own environment from space.

The lowering costs and increased robustness and automation of sensor technology and data processing means that researchers and research organisations are more than ever in a position to start the routine collection, analysis and reporting of environmental information (Zerger et al., 2010). Such efforts can be essential in demonstrating technical feasibility and information utility, before they are adopted by agencies that have a formal responsibility and can offer greater continuity in the long term.

5.4. New observational technology

When populated with on-ground measurements only, environmental reports and accounts are largely restricted to proxy or surrogate measures (e.g., indicators or reference sites or species), survey data and case studies (Australian Bureau of Statistics, 2012a). When based on biophysical modelling only, accounts tend to be highly uncertain and potentially misleading. Clearly then, national environmental accounting will require a combination of observations and models. Satellite data plays a critical role in bridging between the two information sources, providing detail and full coverage in space and time. The use of satellite observations to produce spatial and temporal weather, water, biomass and landscape carbon data has advanced to different degrees. The use of satellite observations is truly established in numerical weather prediction, which uses them together with local observations in statistical model-data integration (known as data assimilation). The resulting data products are widely used in weather prediction but also as a fully spatial and temporal record that provides an attractive alternative to weather station records. Other areas of biophysical modelling are following suit, for example in operational water balance estimation (van Dijk and Renzullo, 2011). The use of satellite observations for landscape (above-ground) biomass carbon estimation is also rapidly developing. The most prominent use in Australia to date has been the use of the NCAS forest extent data (Furby, 2002) within the FullCAM carbon accounting model to measure change in carbon stocks (Richards and Evans, 2004). More recently, additional biomass remote sensing techniques have been developed based on airborne laser (Wulder et al., 2012) and satellite-based radar (Lucas et al., 2012) and passive microwave sensors (Liu et al., 2012b). The different data sources are complementary and together provide rich information on vegetation structure, height and biomass dynamics.

A challenge in the analysis of long-term trends from satellite time series is that sensor characteristics continue to improve which makes constructing unbiased long-term records more difficult. Progress is being made here, too, however. The Australian Space Research Program funded the consistent reprocessing of historic Landsat satellite imagery for Australia going back to 1972. Importantly, the data will be publicly available, which will support a much larger range of users and applications, for example in creating multi-decadal and multi-sensor records of vegetation condition and dynamics (Beck et al., 2011; Donohue et al., 2008; Tucker et al., 2005) and soil moisture and vegetation density (Liu et al., 2011, 2012b).

The use of satellite remote sensing to monitor biodiversity or the population of particular taxonomic groups appears to be some way off. The closest applications are perhaps the monitoring of individual animals using satellite GPS tracking, and the mapping of individual forest canopy species using high resolution hyperspectral imagery. However, the ongoing development of cheaper and better technology (e.g., in situ sensors, data storage, communication, and power supplies) is rapidly creating new opportunities for ground-based ecological monitoring. Similarly, the lowering manufacturing and operating costs and increased data processing capabilities create new opportunities to establish extensive sensor networks. Promising innovations in biodiversity monitoring include rapid genomic profiling of plant, animal, soil and water samples; in situ monitoring of vegetation composition and function using field cameras and optical sensors; camera networks and automated image processing to identify the presence of species; and bio-acoustic sensors and sound recognition software to analyse the diversity in songs and calls (Zerger et al., 2010). Many of these technologies are at an early stage of development, however. Citizen science therefore remains a prominent source of primary data in this field (e.g., Kirkwood and O'Connor, 2010)

5.5. Environmental model-data integration

Integrating in situ and satellite observations within biophysical modelling platforms achieves consistency and national coverage, but also addresses the severe limitations of biophysical models in representing ecological disturbances. To date, most models only partially describe terrestrial ecosystem response to climate variability, and fundamentally do not predict discrete human and natural disturbance events (other than perhaps in a stochastic sense). Integrating satellite vegetation data makes it possible to incorporate vegetation changes and estimate their impact on stocks and flows of carbon, water, and other materials. Direct on-ground measurements remain essential as a constraint to reduce estimation error and bias.

A promising first step towards a comprehensive carbon cycle account is the REgional Carbon Cycle Assessment and Processes (RECCAP) initiative which for the first time produced a global budget of natural and anthropogenic carbon emissions and removals from large regions on land and oceans covering the world (Canadell et al., 2013). The report provides carbon balance and change over the period 1990–2009 for all subcontinents and ocean basins, including Australia (Haverd et al., 2013). Numbers were derived by comparing and reconciling observed and modelled estimates derived at smaller spatial scales with the results of continental-scale atmospheric modelling techniques.

Developing more formalised model-data integration systems is a major research challenge but progress is being made in water resources (Liu et al., 2012a; Van Dijk, 2011; van Dijk and Renzullo, 2011) and landscape carbon (Haverd et al., 2012, 2013). There is increased emphasis on ensuring consistency or perhaps even merging of the respective modelling platforms (cf. Law et al., 2012). Consistency can be achieved through the use of common observational data sets in model development, calibration, testing and data assimilation (Van Dijk, 2011) and the development of generic model evaluation protocols and infrastructure. For example, the AWRA model benchmarking system (Stenson et al., 2011) and the Protocol for the Analysis of Land Surface models (Abramowitz, 2012) have much reduced the effort required to evaluate models, by coupling directly to observational data and automatically generating reports on model estimation accuracy. The use of data standards opens the infrastructure up to data produced by any alternative method. These model and infrastructure developments bode well for future development in nation-wide water, biomass and carbon balance estimation, and there are also likely to be opportunities in related environmental areas (e.g., sediment and nutrient generation and transport).

5.6. Environmental accounting as a test of scientific understanding

Most previous assessments of Australia's environmental information system have emphasised the benefits from consistency in the granularity and extent of reporting (e.g., reporting period, time step, area, spatial units and sub-units, such as land use). Consistency is also needed between data sources, reiterating the need for data reconciliation techniques, such as model-data assimilation. Finally, there needs to be consistency between reported environmental variables, concepts and data categories. This is particularly important when data are used to compare environmental outcomes (e.g., as trade-offs, conversion efficiencies, composite indices, or footprints), where data artefacts caused by such inconsistencies are easily misinterpreted. One way to avoid this is to ensure the data are constrained by known biophysical constraints. For example, the known physiological connection between vegetation carbon uptake and water use through stomatal conductance can be used to explicitly constrain estimates of the resulting trade-off between biomass growth and water resources availability (Yebra et al., 2013). Combined environmental accounts are an effective way to force consistency in concepts and reporting units and to expose inconsistencies in the underlying data. This broadens them from an interpretative exercise to a rigorous test of scientific understanding, and should encourage biophysical and ecological researchers to take an active interest in environmental accounts.

Application of the SEEA to Australia's environmental challenges has demonstrated the value of environmental accounts (Australian Bureau of Statistics, 2012a) and similar advances have been made elsewhere. The European Environment Agency developed the Simplified Ecosystem Capital Account to road-test the practical feasibility and data needs to populate sub-accounts of biomass carbon, water and ecosystem integrity (Weber, 2011). Sub-accounts for stocks and flows of water resources and carbon contained in biomass (as food, fuel or other produce, but also as a subset of full carbon accounts) are a common feature of most environmental accounting frameworks (Galli et al., 2012; United Nations Statistics Division, 2013a; Vardon et al., 2007; Weber, 2011). An arguably greater conceptual challenge remains to capture such holistic notions as ecosystem integrity (United Nations Statistics Division, 2013b). However, every subsequent attempt to express it in measurable variables should help to better understand, value and monitor important ecosystem attributes.

Developing a similar set of experimental sub-accounts for Australia would help demonstrate what insights they can provide as well as clarify their shortcomings. Based on already available data sources, the sub-accounts could be developed using current best estimates of biomass stocks (leaf and non-leaf above- and below-ground biomass carbon) and flows (gross primary productivity, turnover, respiration); water stocks (soil and groundwater) and flows (streamflow, groundwater recharge); and ecosystem integrity (vegetation amount, condition and configuration). Estimates for many of these variables are already available at national scale from modelling or remote sensing, or could be developed over the next few years. Intellectual input is required from those that may use the accounts, develop or adopt methods to produce the accounts; or have the expertise to review, quality-assure or otherwise critically assess the methods and data. Questions that could be examined include:

- Are there realistic or artificial inter-relationships between the sub-accounts and what does this mean for their interpretation and usefulness?
- What limitations on interpretation are inherent to the observations and models being interrogated?
- What concepts are most important to capture in ecosystem accounts?
- Can these concepts be captured in a framework that helps to address real questions?
- Do the accounts and summary products provide new or deepened insights into the trajectory of Australia's environment?
- Are we able to routinely populate such a framework with sufficient accuracy for its intended use?
- How might the accounts be used in economic or political decision making?

Such an analysis should explicitly consider the different information requirements, pathways for information provision, and intended uses (Dovers, 2005).

6. Conclusions

We reviewed recent progress in Australia's capacity to produce nation-wide environmental accounts and reports. We identified challenges and opportunities presented by the demand for national scale environmental information, and discussed the role of research. Below we summarise our main conclusions.

[1] There is a strong demand for environmental information; to help guide and improve decisions that have environmental outcomes or impacts, promote sustainability, provide a basis for policy development, help identify and manage risks, and improve expert and public understanding of environmental functions and trade-offs. Federal government requirements alone already provide hundreds of examples where environmental information is needed. Some of the most widely needed data relate to climate, biota, human activities in the landscape, and water. When considered in greater detail, however, the specific data characteristics required can vary widely between purposes.

[2] An overview of the recent history of environmental policies demonstrates that data collection and reporting remain an ongoing challenge. Recurrent reporting exercises do exist but often rely on data collected and analysed with funding from other sources. Recurrent environmental accounting exists for greenhouse gases and water. In addition, influential reports and accounts are produced by national and international NGOs and UN bodies.

[3] There are several reasons for the lagging development of environmental information systems in Australia. Unique to Australia are the low and concentrated population density and the recent history of European settlement. There are also less unique factors: diverse data requirements and a multitude of data collection methods and standards; a lack of agreement on environmental data requirements and standards across different levels and parts of government and data collecting organisations; poor definition of measurable management objectives; a lack of coordination and leadership in the case of information that is (too) widely useful; lagging progress towards open data sharing; a reliance on data collected by researchers and businesses causing restrictions in availability and lack of standards; a lack of engagement of data collecting businesses in environmental issues; and the short-term project-based character of environmental information initiatives.

[4] The most successful reporting and accounting initiatives appear to have some common characteristics. They are associated with an unambiguous data requirement and a legislative instrument that require organisations to collect and provide a narrowly prescribed set of data, provide a clear responsibility to an operational agency to collect, manage, analyse and report the data, and are supported by government investment.

[5] There are several new opportunities to improve environmental information. These include enhanced monitoring networks, increased standardisation and data management, and new environmental modelling platforms; national commitments to share environmental data between jurisdictions and industry; the growth of community-based environmental monitoring; and the increasing use of environmental and sustainability indicators.

[6] Several priority areas for research are suggested. These include (1) standards in environmental data as well as in defining management objectives; (2) a more quantitative and scalable ecological theory that can be applied to measure objectives related to ecosystem integrity and biodiversity over larger scales; (3) promoting long-term data collection, production and reporting, both externally but also internally within research organisations; (4) the development of new observational technologies that can make better use of data collected by existing and new satellites and in situ sensor networks; (5) environmental modelling approaches that better integrate the range of available in situ and satellite observations; and (6) the development of environmental accounts to promote consistency and help identify priorities for research and development.

If Australia's government, research and business community can pull together to address these priorities and make use of the new opportunities that exist, then there is every reason to believe that the nation can obtain the information needed to pursue a sustainable future, in a 'Better Known Southern Land'.

Conflict of interest

We do not believe that there is any actual or potential conflict of interest including any financial, personal or other relationships with other people or organisations within three years of beginning the submitted work that could inappropriately influence, or be perceived to influence, our work.

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