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Foundations for the future: A long-term plan for Australian ecosystem science

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Abstract Australia's ecosystems are the basis of our current and future prosperity, and our national well-being. A strong and sustainable Australian ecosystem science enterprise is vital for understanding and securing these ecosystems in the face of current and future challenges. This Plan defines the vision and key directions for a national ecosystem science capability that will enable Australia to understand and effectively manage its ecosystems for decades to come. The Plan's underlying theme is that excellent science supports a range of activities, including public engagement, that enable us to understand and maintain healthy ecosystems. Those healthy ecosystems are the cornerstone of our social and economic well-being. The vision guiding the development of this Plan is that in 20 years' time the status of Australian ecosystems and how they change will be widely reported and understood, and the prosperity and well-being they provide will be secure. To enable this, Australia's national ecosystem science capability will be coordinated, collaborative and connected. The Plan is based on an extensive set of collaboratively generated proposals from national town hall meetings that also form the basis for its implementation. Some directions within the Plan are for the Australian ecosystem science community itself to implement, others will involve the users of ecosystem science and the groups that fund ecosystem science. We identify six equal priority areas for action to achieve our vision: (i) delivering maximum impact for Australia: enhancing relationships between scientists and end-users; (ii) supporting long-term research; (iii) enabling ecosystem surveillance; (iv) making the most of data resources; (v) inspiring a generation: empowering the public with knowledge and opportunities; (vi) facilitating coordination, collaboration and leadership. This shared vision will enable us to consolidate our current successes, overcome remaining barriers and establish the foundations to ensure Australian ecosystem science delivers for the future needs of Australia.

Key words: cooperation, ecosystem science, long term, national priorities, strategy.

INTRODUCTION

Our natural and managed ecosystems form the world we live, play and work in; the settings for our industry; and the distinctive natural heritage that characterizes the Australian nation. They are the basis of our current and future prosperity, and our national well-being. However, growing human populations, continuing habitat loss, moving climate zones and increasing global competition for resources are applying unprecedented and cumulative pressures to Australian ecosystems. A strong and sustainable Australian ecosystem science enterprise is vital for understanding

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and securing these ecosystems in the face of current and future challenges.

In this context, this Plan was developed to establish a basis for improved and continuing leadership, coordination and collaboration across Australia's diverse ecosystem science community. It defines the vision and key directions for a national ecosystem science capability that will enable Australia to understand and effectively manage its ecosystems for decades to come.

INTENT OF THE PLAN

This Plan sets out the vision, key directions and priorities for Australian ecosystem science over the coming decades. This time scale is required to effect the cultural change required to implement the Plan. It recognizes the need for long-term (more than 10 years) commitment to supporting activities that study ecosystem dynamics due to the time scales over which our ecosystems change. The Plan's underlying theme is that excellent science supports a range of activities, including public engagement, that enable us to understand and maintain healthy ecosystems. Those healthy ecosystems are the cornerstone of our social and economic well-being.

The Plan was developed to:

- Establish a basis for improved and continuing leadership, coordination and collaboration across the ecosystem science community
- Establish an enduring process that provides a cohesive, nationally representative 'voice' from the ecosystem science community
- Collaboratively identify clear priorities and directions for the future, and the actions needed to support those
- Produce a 'live' resource that can be used to advise and direct activities in ecosystem science and management, and enable its long-term use in policy and decision making in government and industry.

The Plan has been developed through extensive consultation and engagement with the wide diversity of people who make up the Australian ecosystem science community (see Appendix S1). It represents their concerns, priorities and hopes for the future of ecosystem science, of Australia's ecosystems and of the country's national well-being. The collaborative development of this Plan in itself is a significant achievement for Australian ecosystem science, as it is the first time the collective 'voice' of this diverse community – which encompasses all science that contributes to the understanding of ecosystems – has been achieved, captured and shared.

This Plan is intended to inspire and direct the efforts of the Australian ecosystem science community for years to come. It is also intended to provide insight for the key groups that enable and influence ecosystem science – the private sector, the Commonwealth, our State agencies and our universities. Many of the goals and recommendations outlined in this document will require the engagement and support of these bodies over the coming decades.

Looking forward to 2035 the Plan sets broad long-term priorities, but also identifies the first short-term steps that will be needed to make meaningful progress towards these priorities. More detailed planning will be undertaken by the ecosystem science community to ensure successful implementation of actions in both the short (1–5 years) and long (more than 10 years) term.

ECOSYSTEM SCIENCE IN AUSTRALIA

Ecosystem science benefits national well-being

Australian ecosystems encompass landscapes, coasts and marine areas, the living things that occupy them, their water, soils and atmosphere, and the dynamic interactions among all of these parts. Ecosystems occupy natural, agricultural and urban settings. They provide the environments where we live, play and work; the settings for our industry, agriculture, fisheries, tourism and resource extraction; and the distinctive flora and fauna that characterize the Australian continent.

Globally, the benefit from ecosystem services has been valued at approximately $125 trillion per year compared to a global GDP of $75 trillion (Costanza *et al.* 2014). This means that if we assess how natural capital is used in conjunction with built capital, social capital and human capital, ecosystem services make a contribution to human well-being that is at least as great as the contribution from traded goods and services. Australian governments over the past two decades have recognized ecosystems and their sustainability as high research priorities.

Many disciplines contribute to ecosystem science (Fig. 1). Our national capability combines four types of activity: (i) observations and data acquisition; (ii) analysis of processes and mechanisms, including manipulative field experiments; (iii) synthesis across multiple processes and space-time scales, often by modelling; and (iv) support for decision-making. These four scientific activities reinforce each other and integrate across all activities required to ensure ecosystem health.

Ecosystem science delivers benefits for Australia in a range of contexts. For example, ecophysiology informs production of food crops, fibre and timber. Population dynamics underpins programs for pest control, fisheries, wildlife management and conservation. Biogeochemistry is a basis for tracking carbon storage, managing wildfire fuel, maintaining soil health, food security and water yields, and reducing erosion, nutrient runoff and algal blooms.

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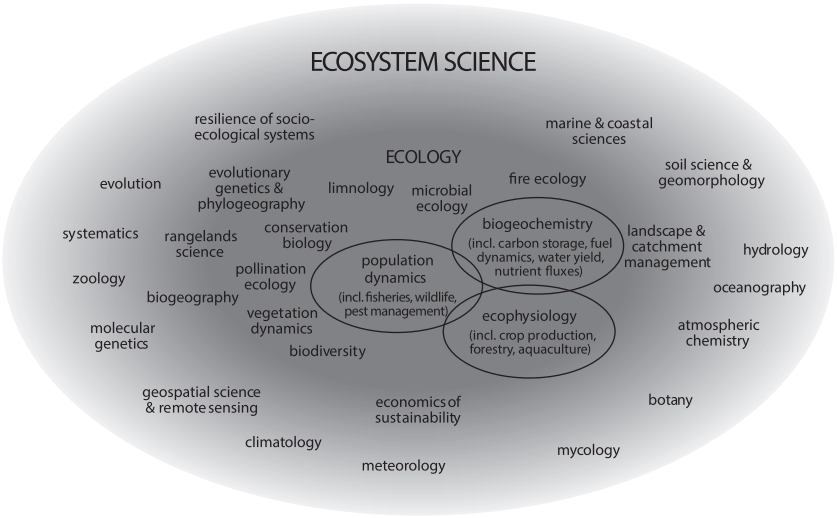

Fig. 1. Ecosystem science draws on a large number of disciplines, some of which are shown here. Some are applied and others are basic sciences. They work across terrestrial, marine, freshwater, coastal and atmospheric domains. They study plants, animals and microorganisms in each of these settings. They can link together via ecology, including its three main sectors of population dynamics, biogeochemistry and ecophysiology.

Ecosystem science in Australia today

Australia has a proud history in ecosystem science. Australia was the fifth-ranked nation worldwide in Ecology and Environment for total citation influence 2003–2013, according to Thompson-ISI Essential Science Indicators 14 Feb 2014. Eight Australian universities were rated 'well above world standard' in ecology, ecological applications, or environmental science and management through the national research excellence assessment (ERA) in 2012. Within the Commonwealth Scientific and Industrial Research Organisation (CSIRO), environment and ecology is one of the four highest-ranked areas of publication impact (CSIRO 2014).

A wide range of groups undertake ecosystem research in Australia. Almost all Australian universities have ecosystem research activity. There are public research agencies at both State/Territory and Commonwealth levels, and also bodies responsible for particular environments that have research arms as well as management arms. For example the CSIRO, Australian Institute of Marine Science, Geoscience Australia, Bureau of Meteorology, Australian Nuclear Science and Technology Organisation, and the various state herbaria and natural history museums. Additional examples include the Great Barrier Reef Marine Park Authority, Murray-Darling Basin Authority, Australian Antarctic Division and Parks Australia at Commonwealth level; and at state level all the agencies responsible for lands, water, forestry and fisheries.

Traditional owners contribute indigenous knowledge and are involved in environmental management. Private firms, for example in the resources industry, may conduct some research internally as well as contracting with universities or agencies for research. Similarly, regional natural resource management groups, catchment management authorities, non-government organizations and community groups may involve themselves in research directly as well as by sponsoring research. Examples of such groups include Birdlife Australia, Landcare, Australian Conservation Foundation, Australian Wildlife Conservancy, Greening Australia, Earthwatch and Bush Heritage.

Most research involves some form of partnership with stakeholders and end-users, and much also involves financial contribution from industry. In recent years the level of ecosystem science activity in the Higher Education sector has been roughly equal to the level of ecosystem science activity in Commonwealth and State governments combined, but even this combined activity is a comparatively small fraction of the value of ecosystems and the services they provide. This is based on best available data from the Australian Bureau of Statistics for 2011–2012 (Government) and 2010 (Higher Education) using Field of Research (FOR) Codes '05 Environmental Sciences' and '0602 Ecology'. These data indicated research activity in Higher Education sector valued at $339M, Commonwealth Government $239M, and State and Territory governments $105M. Other FORs encompass activity relevant to ecosystem science (e.g. oceanography), however were excluded in our assessment as we are not in a position to estimate what share of their expenditure should be attributed to ecosystem science. At the time of writing data were not available for research conducted with private non-profits, private enterprise and consultancy firms. Total research

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expenditure across all FORs in Government and Higher Education sectors for these years was $11 000–12 000M per year.

Challenges and opportunities for ecosystem science in Australia

Growing human populations, continuing habitat loss, moving climate zones and increased global competition for resources are applying unprecedented and cumulative pressures to Australian ecosystems. The future will demand new depth of understanding to manage faster-changing systems sustainably. Although Australian ecosystem science is already successful within Australia and influential on the world stage, we can do better than the status quo, and we will need to.

Long-term perspective is a key ingredient missing from the Australian research mix. Many ecosystem processes play out over decades to centuries. So for ecosystem science it is especially important to take a long view, with some projects providing consistency and continuity over very long time scales. Yet long-term projects should be only one component within an overall research strategy, and by no means the majority. Ecosystem science should remain agile to respond to new knowledge and circumstances. Fresh ideas about mechanisms, fresh models or fresh management priorities can replace older ideas within 3–5 year time scales.

Science culture worldwide is moving towards 'open access' data management. Benefits include reduced duplication, increased opportunities for re-use, new insights from cross-discipline collaboration, a better-organized evidence base for end-users and a more transparent research process. The Australian ecosystem science community similarly is taking steps toward increased data sharing. Continued steps along this path will be important.

New capacities are emerging from areas like genomics, environmental sensing both from satellites and at close quarters, machine learning and data synthesis, and from citizen-science initiatives where anyone with a mobile device can collect and contribute some types of ecosystem data. Through facilities within Australia's National Collaborative Research Infrastructure Strategy (NCRIS), open access infrastructure is being established including continuing field sites, environmental monitoring systems, informatics facilities and mechanisms for knowledge exchange across science and policy arenas. These facilities include the Terrestrial Ecosystem Research Network, the Integrated Marine Observing System, the Atlas of Living Australia, BioPlatforms Australia and the Australian National Data Service. These community-wide activities work in powerful synergy with the mainstream of individual research projects pursued by individuals and small teams. They make each project more efficient by providing background data. They strengthen application of the nation's ecosystem evidence base to wider spatial scales and longer time scales, and link it more strongly to end-users. If these community-wide resources can develop a dependable continuing presence, their adoption will accelerate and benefits from them will flow faster.

In summary, there is opportunity to add specific new strands to Australia's ecosystem science research mix that can work together with established strengths and build stronger capability for tomorrow.

SNAPSHOTS OF ECOSYSTEM SCIENCE APPLICATIONS IN AUSTRALIA

Snapshot 1: Managing fire in the Australian landscape

Wildfires impact almost every facet of life in Australia, and activities in ecosystem science help us better understand how fires behave in Australian ecosystems and to develop fire management strategies. These activities range from the use of satellite image data to map and monitor fire at landscape scales, to direct field observations and experiments, to modelling of the ways that fires interact with different ecosystems. Alongside this, historic information and indigenous knowledge are integrated with new knowledge to expand our understanding of fire.

Environmental managers and agencies can use this knowledge to develop fire management strategies that help to protect ecosystems and public safety. Just one example is the Landscape Conservation Initiative (http://www.dpaw.wa.gov.au/management/kimberley-strategy/conserving-the-unique-kimberley-environment/164-the-landscape-conservation-initiative) in Western Australia's iconic Kimberley region, where large wildfires can threaten the natural qualities of the area. Using improved knowledge of the interaction between ecosystems and wildfire, a number of management initiatives have been implemented to reduce the damaging effects of late season wildfires.

Snapshot 2: Understanding reef condition in the Great Barrier Reef

Australia's Great Barrier Reef is one of the seven wonders of the natural world, globally recognized as an Australian icon, and makes an economic contribution of over $5 billion annually (Deloitte Access Economics 2013). Ongoing monitoring of the reef and its condition by ecosystem scientists plays a vital role in understanding pressures and informing the development of management strategies.

Annual surveys to measure coral cover across the Great Barrier Reef since 1985 have built the world's

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most extensive time series data on reef condition across 214 reefs. Researchers have used this long-term data to assess patterns of change and to determine the causes of change such as tropical cyclones, coral bleaching events and disturbances due to Crown of Thorns Starfish (De'ath *et al.* 2012). Understanding the causes of change helps management agencies like the Great Barrier Reef Marine Park Authority to develop targeted strategies to respond to threats to the reef. They can also use this knowledge to evaluate and adjust management actions over time, ultimately enhancing the long-term protection of the reef.

Snapshot 3: Improving liveability of Australian cities

More than 70% of Australians live in major cities (as at June 2013, Australian Bureau of Statistics). Ecosystem scientists measure temperature and other climatic properties within cities to understand where high and low temperatures occur and where storm-water run-off is highest. This information is used to examine the effects that increasing urban tree cover and 'green spaces' have on temperature extremes and runoff.

Knowledge from these monitoring and modelling programs is used in several major Australian capital cities to implement tree planting or green roof/wall programs that increase shade, reduce temperature extremes, reduce run-off, and increase habitat and biodiversity (e.g. http://www.brisbane.qld.gov.au/environment-waste/natural-environment/plants-trees-gardens/brisbanes-trees/brisbanes-urban-forest and http://watersensitivecities.org.au/resource-library/publication-download/). This results in cities with reduced temperature extremes, increased visual amenity of streetscapes, increased biodiversity and urban wildlife habitat, decreased stormwater runoff, and reduced energy consumption. And at the end of the day that means cities that are more healthy and easy for us all to live in.

Snapshot 4: Informing the kangaroo harvest

Kangaroos are harvested across Western Australia, South Australia, New South Wales and Queensland as a means of pest control and for sale of skins and meat. Working in both Commonwealth and State Government agencies, ecosystem scientists use population models together with annual aerial surveys of kangaroos to predict expected numbers of kangaroos year-to-year across Australia. This knowledge is used to establish a harvest quota for each state in each year that maintains kangaroo populations within sustainable limits and provides a viable harvest for Australia's commercial kangaroo harvest export industry (for more information see http://www.environment.gov.au/system/files/resources/11b7d7c8-7a25-45fc-81ea-f672e14d1fec/files/kangaroo-harvest-factsheet.pdf).

The use of ecosystem science to monitor and model kangaroo populations underpins the sustainability and continuity of the kangaroo harvest, and is part of the reason that the Australian kangaroo harvest is viewed globally as a leading example of wild harvest operations.

A VISION FOR THE FUTURE OF AUSTRALIAN ECOSYSTEM SCIENCE

Vision statement: Our aspiration is that by 2035, the status of Australian ecosystems and how they change will be widely reported and understood, and the prosperity and well-being they provide will be secure. To enable this, Australia's national ecosystem science capability will be coordinated, collaborative and connected. Knowledge from ecosystem science will be available and essential to government, industry, the general public, and for research and educational institutions.

Our vision for Australia 20 years from now is a society with a wide-ranging appreciation of terrestrial, marine and freshwater ecosystems. Scientific knowledge provides the basis for an increased public understanding about ecosystems – how they operate, what goods and services they provide, what threatens them. Just as medical science is used to inform the community and protect the health of people in our society, ecosystem science provides the basis for protecting the health of our ecosystems and supporting national well-being and prosperity. Decisions about how ecosystems are used and managed will flow from effective policies to ensure we support current human populations and secure future community prosperity. Realization of the vision will benefit Australian society through sustaining the essential environmental services we rely upon (Fig. 2).

KEY DIRECTIONS FOR THE FUTURE OF AUSTRALIAN ECOSYSTEM SCIENCE

Australian ecosystem science has a strong history, and exciting opportunities lie ahead. The need has never been greater for ecosystem science to deliver the evidence, knowledge and tools to respond to the current issues and future trials facing the protection and sustainable use of Australia's ecosystems.

The six key directions outlined below have been identified through extensive consultation with the Australian ecosystem science community through surveys, town hall workshops and online contributions (see Appendix S1). The directions connect with the three key themes of the vision: excellent science, public

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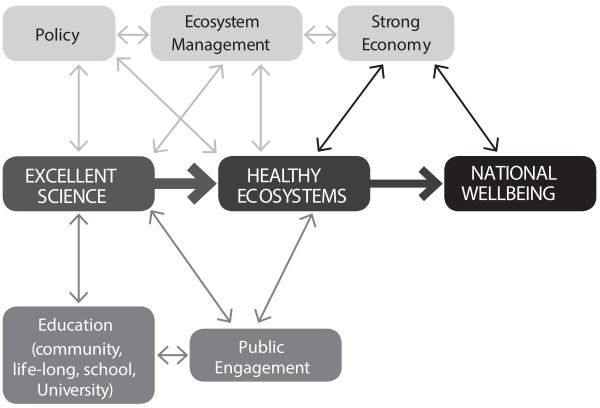

Fig. 2. This diagram outlines the relationships among the components that form the basis for our vision. This Plan identifies priorities for building *excellent science* that supports a range of activities, including *public engagement*, that collectively enable us to understand and maintain *healthy ecosystems*. A range of other activities link with these components, ultimately influencing national well-being.

engagement and healthy ecosystems. All directions deserve equal attention as an integrated package. Recommended actions to be taken in support of these directions are outlined in Section 5 'Giving Life to the Plan'.

Delivering maximum impact for Australia: enhancing relationships between scientists and end-users

Priority: Improved communication and collaboration between ecosystem scientists, and people who can use the knowledge and other outputs generated by ecosystem science.

An ongoing challenge in the implementation of ecosystem science has been the delivery of relevant scientific output in ways that are meaningful and useful for end-users of science, such as environmental managers and policy-makers. There is often a lack of effective communication between researchers and end-users, with the consequence that business, management and policy decisions are often not based on the best science, and science is not focussed on priorities for end-users. Stakeholder input throughout the development of this Plan indicated that both scientists and end-users often have limited understanding of the context and limitations that each party works within. Despite these challenges, some projects have had great success in delivering useful science in ways that have impact and meaning for end-users.

Ecosystem science needs to deliver meaningful outcomes and impact to ensure that it contributes to healthy ecosystems and national well-being. There are no easy solutions, and effective interactions between researchers and end-users are essential in achieving this goal.

Supporting long-term research

Priority: Dedicated funding for long-term (a decade or longer) ecosystem research, complementing existing support for short-term research.

Many ecosystem processes operate over decades to centuries, yet so far the nature of ecosystem research in Australia has been overwhelmingly short-term and focussed on questions that can be answered by single projects in the context of 3–5 year or shorter funding cycles. The relatively few long-term research projects have been especially valuable in advancing our understanding of Australian ecosystems in ways that were not previously possible (e.g. De'ath *et al.* 2012).

Long-term studies can be particularly important for distinguishing impacts of human activities from the impacts of natural variability. This is especially important for Australia, given that our climate is so highly variable.

The existing 3–5 year research funding schemes should be continued. Indeed, work funded through such schemes has already put Australia at the leading edge of research in this area. But there is also a pressing need to support longer term studies that give perspective to the short-term projects. There are successful international examples of long-term funding programs for ecosystem research that could serve as models for Australia.

Enabling ecosystem surveillance

Priority: Development of systematic, continental-scale monitoring of essential ecosystem variables that reflect the health of our ecosystems.

Our ecosystems are vital national assets, and can only be effectively managed if we have an ongoing capacity to track and monitor their status. Future generations of Australians will need access to this information to understand patterns of change and ongoing ecosystem processes, and to make informed decisions about the use and management of landscapes and seascapes.

Australia has many ecosystem monitoring programs focussed on particular management issues. However, we have very few long-term ecosystem data sets collected over areas larger than catchments or states, at regular time periods, and in a standardized manner in the context of long-term surveillance. We have no national system for the analysis, evaluation and reporting of ecosystem measurements. Indeed, there is currently no consensus on what aspects of ecosystems should be measured, or on what methods to employ for measuring ecosystem health. This is in stark con-

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trast to our well-established weather-station network, our census of households and our reporting of economic indicators.

Making the most of data resources

Priority: Sustained infrastructure and capacity for consistent collection, publication and archiving of ecosystem science data sets and meta-data in standard, easily accessible formats in publicly accessible websites.

Australia needs sustained infrastructure and capacity-building to maintain and facilitate the publication of and access to ecosystem science data. We can get better value from our collective data resources by properly describing and storing data in ways that enable discovery, access and re-use. Significant gains have been made in recent years, but there is currently no coordinated national strategy for collecting, storing and accessing core ecosystem science data across terrestrial, aquatic and atmospheric domains. Moving Australian ecosystem science to a position of open access to both historical and current data can enable research communities to build time series at a scale well beyond that which they could achieve individually. Synthesis, analysis and modelling of collective data will help to deliver essential outputs for government, industry and society.

Inspiring a generation: empowering the public with knowledge and opportunities

Priority: A general public that is inspired, informed and empowered with knowledge and understanding of Australian ecosystems.

Healthy ecosystems play a key role in the production and delivery of food, clean air and water, as well as the survival of our iconic plants and animals. Indigenous Australians recognize this value through their deep connection with country. However, many people do not fully appreciate the link between ecosystems and the goods and services they provide, nor do they understand the threats that ecosystems face.

To put the Australian community in a position to make judgements and decisions about the use and management of their ecosystems, they need to be engaged with and informed about these ecosystems. Better engagement of the Australian community with ecosystems and ecosystem science requires a fresh effort to develop and harness talent in the ecosystem science community to inspire, inform and empower the wider community with knowledge and understanding of their world, and their role in it. Integration of indigenous and western knowledge will ensure a broad approach to understanding ecosystems.

Facilitating coordination, collaboration and leadership

Priority: A more collaborative and coordinated ecosystem science community including the formation of an 'Ecosystem Science Council' to offer leadership to implement the Plan, working with all relevant discipline areas, organizations, societies and professions.

Australia's ecosystem science research is conducted by many organizations operating at spatial scales ranging from local to global. The ecosystem science community includes many professional societies and bodies for specific disciplines and areas of interest. A range of government agencies in the states, territories and Commonwealth undertake ecosystem science activities, and make decisions concerning ecosystem science and management. This diverse community offers a wealth of knowledge and perspectives for ecosystem science and management.

Enhanced integration across previously silo-ed disciplines and organizations would bring significant national benefit. A new body is needed to facilitate this, acting as a forum where different disciplines and organizations can determine how best to collaborate, as a national voice that can speak for ecosystem science as a whole, and to coordinate the many specific initiatives that will arise from this Plan.

The development of this Plan was grounded in collaboration, with an open and transparent consultation process that engaged the full diversity of the Australian ecosystem science community (see Appendix S1). Continuing to build this collaborative approach to ecosystem science and the coordination of ecosystem science in Australia will be important to implement the key directions highlighted here, and to make the most of the talent and resources available to Australian ecosystem science.

GIVING LIFE TO THE PLAN

This section presents the guiding process for the implementation of the Plan (Fig. 3), the interconnections and major activities needed across the six directions (Fig. 4), and the key actions for implementation in the first five-year period.

The key principles guiding the development of this Plan have been openness, inclusivity and transparency through clear communication. These are essential for cohesion and shared vision across the community of researchers, empowering active involvement and collaboration. By pulling in the same direction towards our shared vision, we establish foundations to address challenges and sustain ecosystem science into the future.

The implementation phase of the Plan will remain a consultative and collaborative process, shaped by the agreed content of this Plan, but responsive to new

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input and circumstances. The invitation to participate will be disseminated widely as part of ongoing communication with the ecosystem science community. This open and transparent communication will ensure our collective vision stays focused into the future.

Implementation of the Plan requires its activities to be staged over shorter time intervals with set milestones to monitor progress. Some of the key actions are for the research community itself to carry forward; others will need input and involvement of government(s) and other groups. An overview of the proposed actions is provided in Figure 4, with further detail and outcomes listed in Table 1.

During the Plan's development there were clear directives from the ecosystem science community for making fresh efforts towards long-standing challenges. For each priority there will be an assessment or review of current capabilities in each area followed by a process that develops recommendations and seeks appropriate resources. As these priorities will be progressed in parallel in an open and inclusive manner there is scope for wide participation and collaboration with existing programs and groups.

Alongside the wealth of ideas and proposals submitted through the consultation for this Plan, the next steps outlined in Table 1 set a course for changing the future of Australian ecosystem science. These actions will be first steps toward outcomes to be achieved over a 20-year time period and beyond.

After the initial five years, this Plan and progress towards the key directions will be reviewed in consultation with the ecosystem science community, to enable us to adjust as needed and continue working towards our shared vision.

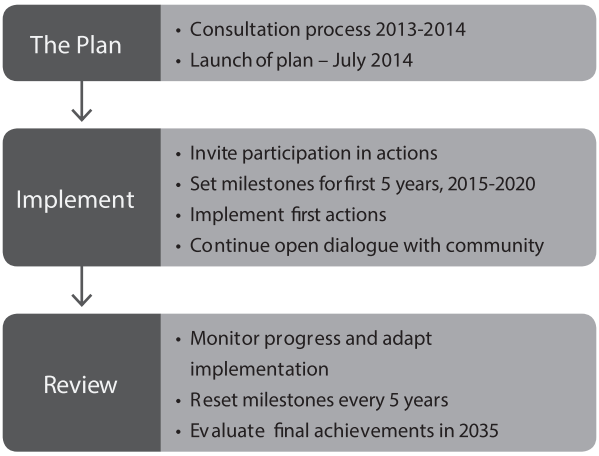

Fig. 3. Guiding process for implementation, monitoring and review of the Plan. The strategy for delivering the outcomes of the Plan reflects the consultation and leadership process followed to establish the basis for the Plan.

ACKNOWLEDGEMENTS

This document arises from activities undertaken by the Australian ecosystem science community over more than a year. More than 600 people across the country took part in surveys, workshops, and working groups that contributed to the final product. The Terrestrial Ecosystem Research Network, the Ecological Society of Australia, and the Australian Academy of Science's National Committee for Ecology, Evolution and Conservation conceived the project and coordinated development and delivery of the Plan. The following groups are also acknowledged for their public support and assistance in developing the Plan: the Atlas of Living Australia, the Commonwealth Scientific and Industrial Research Organisation, Birdlife Australia, Geoscience Australia, Global Change Institute, Integrated Marine Observing System, Soil Science Australia, University of Sydney Faculty of Science and School of Biological Sciences, and the Wet Tropics Management Authority.

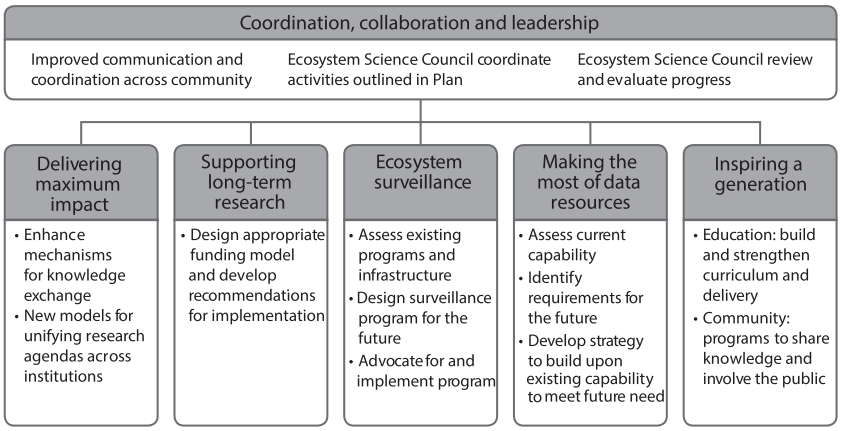

Fig. 4. Some of the major, interconnected activities needed to implement the key directions identified in this Plan. One of the priorities that will support all other achievements is to establish coordination, collaboration and leadership, and this is shown by the overarching link to all other priorities.

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Table 1. Key directions, priorities, long-term outcomes and key actions arising from this Plan

Key direction and priority	Long-term outcome (by 2035)	Key actions for first 5 years
Delivering maximum impact for Australia: enhancing relationships between scientists and end-users Priority: *Improved communication and collaboration between ecosystem scientists, and people who can use the knowledge and other outputs generated by ecosystem science*	Improved interactions and knowledge exchange between producers and users of ecosystem science to strengthen management and policy	1. Identify elements of success, and pitfalls to avoid, from previous interactions and experiences in knowledge exchange between researchers, practitioners and policy-makers working in ecosystem science and management. 2. Generate advice and guidelines for designing and implementing science activities that enhance mutual understanding and knowledge exchange between researchers, practitioners and policy-makers in the context of ecosystem science. 3. Implement targeted projects to enhance synthesis and integration across groups working on critical ecosystem issues. 4. Advocate for improved training in science communication at undergraduate and postgraduate levels. 5. Develop new models for identifying research priorities across universities, government and industry.
Supporting long-term research Priority: *Dedicated funding for long-term (a decade or longer) ecosystem research, complementing existing support for short-term research*	Mechanisms to support long-term studies of processes and dynamics in Australian ecosystems	1. Review funding models from around the world, alongside current Australian arrangements, and develop recommendations about how selected long-term ecosystem research can be dependably supported in Australia. 2. Advocate recommendations to appropriate government and other relevant parties.
Enabling ecosystem surveillance Priority: *Development of systematic, continental-scale monitoring of essential ecosystem variables that reflect the health of our ecosystems*	Systematic, continental-scale monitoring of essential ecosystem variables that reflect the health of our environments	1. Catalogue and assess existing ecosystem monitoring programs that have potential for contributing to ecosystem surveillance. This assessment is to be collaborative across local, state and national agencies and organizations, across different disciplines, and across terrestrial, freshwater, atmospheric and marine domains. 2. Discuss widely the options and priorities. Consistency and continuity of monitoring will be the priority as the aim is for future generations to be in a position to look back objectively over past changes. To achieve continuity over 100 years or more, proposals need to be modest enough that sustained bipartisan government commitment can be forthcoming. Alternatives could be developed adapted to different levels of resourcing. Our commitment is to resolve internal debates about what to measure, and to bring forward agreed proposals. 3. Advocate to relevant parties for implementation and long-term support of proposed surveillance program.
Making the most of data resources Priority: *Sustained infrastructure and capacity for consistent collection, publication and archiving of ecosystem science data sets and meta-data in standard, easily accessible formats in publicly accessible websites.*	National infrastructure facilitates consistent collection, publication and archiving of ecosystem science data sets and meta-data in standard, easily accessible formats in publicly accessible websites. Active programs to synthesize the evidence base and apply it to policy and management.	1. Assess current national capability for ecosystem data publishing, archiving and management, identifying existing infrastructure, training programs, and other activities. 2. Specify requirements for the future including infrastructure, support personnel, and training activities needed. 3. Develop a proposal to bridge gaps to desired future capability, using current infrastructure, programs and people as a foundation. 4. Advocate for implementation and long-term support of proposed infrastructure, programs and people.

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Table 1. *Continued*

Key direction and priority	Long-term outcome (by 2035)	Key actions for first 5 years
Inspiring a generation: empowering the public with knowledge and opportunities Priority: *A general public that is inspired, informed and empowered with knowledge and understanding of Australian ecosystems*	The value of healthy ecosystems, and the science underpinning that, is recognized by society at large. This understanding secures a long-term foundation for healthy ecosystems and national well-being.	1. Identify elements of success, and pitfalls to avoid, from past experiences of informing, inspiring and engaging the general public about ecosystems and/or ecosystem science. 2. Across the country, assess the way that ecosystem science is addressed in schools (primary and secondary) and develop recommendations for strengthening both curriculum and delivery, drawing upon the many ideas included in the proposals produced during development of this Plan. 3. Implement targeted projects identified amongst the proposals produced during the development of this Plan. 4. Advocate for improved training in science communication at undergraduate and postgraduate levels.
Facilitating coordination, collaboration and leadership Priority: *A more collaborative and coordinated ecosystem science community including the formation of an 'Ecosystem Science Council' to offer leadership to implement the Plan, working with all relevant discipline areas, organizations, societies, and professions*	Australia's national ecosystem science capability will be coordinated, collaborative and connected across all relevant discipline areas, organizations, societies, and professions. Through open communication and collaboration the ecosystem science community will tackle challenges and implement activities to deliver excellent science and engage the public to maintain healthy ecosystems.	1. Maintain the Plan's website (http://www.ecosystemscienceplan.org.au) to enable open communication, engagement and sharing of ideas and information. 2. Approach relevant professional societies, organizations and agencies to discuss the Plan's key recommendations, and opportunities for ongoing input and involvement from these groups. 3. The existing Steering Committee will oversee formation of a National Ecosystem Science Council to lead implementation of priorities and actions outlined in this document. Similar organizations in other science communities include Astronomy Australia Ltd, the Australian Earth Observation Coordination Group, and the Ocean Policy Science Advisory Group. The Steering Committee will draft Terms of Reference, Council Composition, Operating Guidelines, and an Annual Review process for the Council, which will start operating in January 2015. 4. The newly formed Ecosystem Science Council will establish action plans and expert working groups to deliver on the priorities and actions outlined here. 5. Every five years the Ecosystem Science Council will implement a review of the Plan and evaluation of progress to date, leading to a revised plan of activities for the following 5 years.

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SUPPORTING INFORMATION

Additional Supporting Information may be found in the online version of this article at the publisher's web-site:

Appendix S1. Electronic attachment.

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