Submission
2016 National Research Infrastructure Roadmap
Capability Issues Paper

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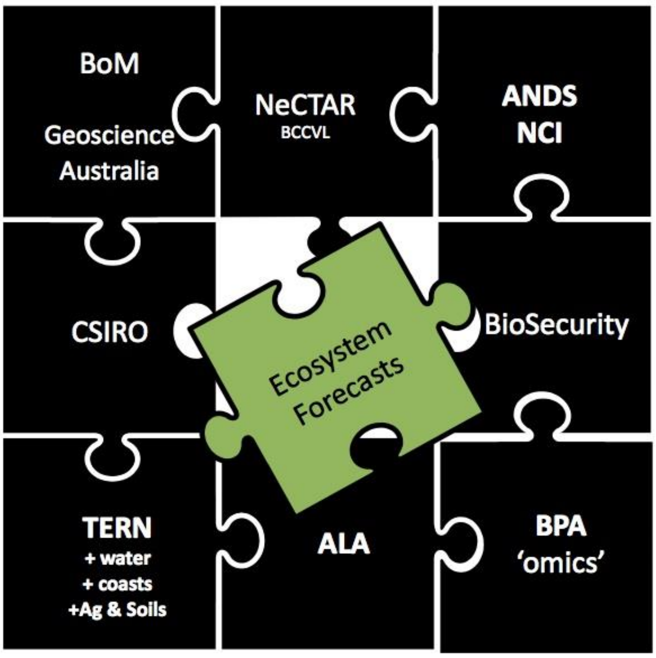
A new Landmark capability

Australia requires new research infrastructure to enable the science to forecast ecosystem change to improve risk analysis in support of economic and social development. This is a global grand challenge Australia can lead. (Details of existing institutions on page 6).

Ecosystem Forecasts is a proposed program built as a consortium to meet the needs of industry, government and everyday people.



Ecosystem Forecasts

for better Risk Analysis

Executive summary

The Ecosystem Science Council is an independent elected body that represents the ecosystem science community of Australia. Our strategic plan, *Foundations for the future: a long-term plan for Australian ecosystem science*[1], was formed from extensive national consultation across the research, industry, not-for-profit and government sectors.

This submission has been prepared with an open on-line national survey and call for input from the wider ecosystem science community (the environment sector), discussions with leads from many of the NCRIS facilities (IMOS, TERN, Groundwater, Atlas of Living Australia), the Academy's National Committee for Ecology, Evolution and Conservation, Ecological Society of Australia, Australian Earth Observation Community Coordination Group, Australian Energy and Water Exchanges (OzEWEX – a research community organisation with wide reach in the climate and water fields), the Fenner School of Environment and Society at The Australian National University, the Centre for Carbon, Food and Water and the School of Life, Environmental Sciences at The University of Sydney, and others.

Three reasons for investment in ecosystem forecasting science

1. The environment sector has the leadership, expertise and drive to undertake a landmark project of global significance, which complements and builds from existing NCRIS capabilities.
2. The NCRIS program has helped develop maturity in the environment sector, and accelerated progress would accrue from enhanced future investment.
3. Productivity, efficiency and innovation will result if infrastructure needs are reprioritised toward strategic ecosystem forecasting-research of global significance, and if the support is sustained.

Recommendations:

A. Launch a grand challenge to focus extra resources and creativity on the science of forecasting ecosystem change to underpin new industries, to sustain current industries and markets, and to improve risk analysis for adaptation planning.

B. Restore adequate funding, and continue to prioritise the existing plot networks of *in situ* observations and instrumentation, associated satellite monitoring, and open access data streams that enable scientists to quantify changing processes and functions in Australian ecosystems.

C. Increase resources to expand capability for inclusion of *in situ* observational capabilities into inland waters (rivers, wetlands, lakes and groundwater-dependent ecosystems), coastal systems and production landscapes.

[1] www.ecosystemscienceplan.org.au

Structure of the submission:

Our submission has three parts, starting with the most novel ideas first. In answer to Question 1, we outline a landmark capability in Ecosystem Forecasting; Part 2 provides background to better inform the thinking behind our comments relevant to the environment sector; and Part 3 addresses the other questions in the Issues Paper where we can contribute most usefully to the roadmapping exercise.

Part 1 Answer to Question 1: Are there other capability areas that should be considered?

Yes. We need a landmark capability to Forecast Ecosystems for risk analysis (see figure page 1) (Full name of existing institutions listed on page 6).

There are three key elements required to enable forecasting: (1) a predictive understanding of how systems work; (2) rigorous monitoring of ecological assets – the essential natural capital that underpins economic prosperity; and (3) comprehensive data management and reporting at appropriate fine scales for land management decisions. In parallel with forecasting, the projected changes need to be placed within a well-structured ecological-social-economic framework to complete the risk analyses.

Mission: to meet the global emerging need to monitor and forecast ecosystem change for the benefit of people, industry and governments

Why is the mission to monitor and forecast ecosystem change needed now? Foresight is forewarned, and forewarned gives us preparedness. Preparedness equips industry with options and opportunities to make better use of our natural capital. For example, If this capability had been in place we would have saved money by avoiding the loss of productive landscapes and expensive rehabilitation efforts to reverse the effects of dryland salinity resulting from rising water tables due to the conversion of deep rooted vegetation to annual plants changing the water balance. For example, costs in WA due to salinity damage are estimated at $344 million per annum[2]. Instead, the balance of vegetation-soil-water interactions within the ecosystem could have been used to plan and support production industries without detrimental and costly environmental consequences. Ecosystem forecasting, for instance, can take into account the dynamic climatic and biodiversity components of the ecosystem, together with any feedbacks, and integrate these trends with changes in external factors such as fluctuations in demands in the market for agricultural products, all reported with levels of uncertainty.

To meet industry, government and social requirements, the environment sector must address the knowledge gap that exists in <u>ongoing data collection on the</u> <u>biological as well as the physical observations of ecosystems, and allow further integration of these for holistic understanding of our environments, and how human activities are changing them, and will in-turn be impacted by them.</u> To do this we need to continue and extend ongoing, decades-long observations on the ground to complement and validate remotely sensed data. One of these components alone is insufficient and all are essential.

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[2] https://www.agric.wa.gov.au/soil-salinity/dryland-salinity-extent-and-impact

Firstly, therefore, research infrastructure needs to encourage excellent hypothesis-driven research in addition to surveillance monitoring: it is essential for such data to be collected, curated, shared and synthesised. Second, to meet the emerging need to forecast ecosystem change, it is necessary to have national and comprehensive baseline data on biodiversity and the state of ecosystems through time. Finally, it is necessary to retain skilled scientists who possess expertise to translate knowledge for practical applications and who can pass these skills to the next generation of scientists.

It must be reinforced here that the scope, and indeed the resource requirements for these activities, are beyond that available to any individual researcher or single institution, university, or government. The NCRIS experience with IMOS and TERN, which has resulted in new nationally standardised approaches and environmental data products, has shown this clearly. Indeed, it is also clear that success requires attention from the full breadth of ecosystem science. Hence, our proposal is bold and necessarily Landmark in scope. It is similar, but moves beyond other nations' attempts such as the National Ecological Observing Network (NEON)[3] in the USA, and the integrated terrestrial and marine capability of the South African Environmental Observation Network (SAEON)[4], to name two. Internationally, Australia already delivers high value for investment in environmental research and with this initiative could lead the world in Ecosystem Forecasting.

It is from a strong foundation of existing capabilities (Figure on first page) that the **Forecast Ecosystems** program can be initiated. The benefits to society will eventually be immense, as we will be able to plan ahead to manage and safeguard our natural resources, to provide safe and quality food and clean water and air with greater certainty for a growing population. A greater capacity to provide expert knowledge and analytical services for evidence-based decision making will deliver new economic opportunities and safeguard long-term prosperity.

The existing infrastructure capabilities we need to retain and expand to meet this need include:

- clever reuse and deployment of existing surveillance programs, including remote sensing, monitoring plots, and flux towers
- large networks of devices (e.g. acoustic sensors, soil moisture probes) which are integrated with on-ground measurements taken by skilled technicians and ecologists
- standardized data collection methods for detecting and recording ecosystem change
- advanced data infrastructure with search and analysis tools for storing, visualising, accessing and analysing big data
- advanced data-driven models of current and predicted ecosystem function and condition
- a skilled workforce of field ecologists, data analysts and curators, and statisticians
- nationally coordinated governance underpinned by skilled and decisive leadership
- strong domestic and international partnerships with industry, governments and research communities

The additional knowledge gaps are in:

(1) freshwater ecosystems, including rivers, wetlands, lakes and groundwater-dependent ecosystems

[3] http://www.neonscience.org

[4] http://www.saeon.ac.za/

(2) agricultural and other managed parts of the landscape, especially soil ecosystems

(3) coastal landscapes, particularly in association with urban and productive landscapes

(4) integration with social, human processes

Significance and scope of Ecosystem Forecasting

There has not been such a galvanizing and inspiring challenge in the environmental disciplines since meteorologists ventured beyond simple reporting of weather to forecasting it.

(1) Rising to this grand challenge is essential for Australia's economy and social wellbeing, both of which are ultimately tied to our environment. This bold mission, therefore, can act as a much-needed catalyst to build a consortium among the strong existing capabilities already delivering in more limited domains and to invest in a measured and effective expansion to address existing knowledge gaps and drive innovation.

(2) This mission is of national relevance: it falls under the NCRIS focus area of *Environment and Natural Resource Management*; it is tightly aligned to the *National Science and Research Priority* areas of Food, Soil and Water, Resources, and Environmental Change; and it is also relevant to the Energy and Health priority.

(3) The scope of the proposed **Forecast Ecosystems** program is broad across terrestrial, freshwater, groundwater, urban, coastal, atmospheric and marine domains and reflects the interdependence of the functions and processes that shape these ecosystems.

- Ecosystem and social scientists, more than anyone, work with complex, interconnected systems; they can both simplify and translate complexity into quality information through data products and services at national and international scales.
- Ecosystem scientists must encompass a diverse range of disciplines operating across large spatial and temporal scales; it is likely that new modes of communication will be necessary and we will see the merging of traditional disciplines.
- The scope should encompass natural and managed areas, (primary industries, forestry, agricultural, mining, fisheries), as all land and seascapes contribute to ecosystem function.
- The investment would build upon a consortium from existing capabilities and identify major priorities that can be achieved by high-level integration of knowledge and services.
- The scope is landmark in scale.

(4) International interest in ecosystem forecasting is high[5], and the science community are keen[6], both of which indicate that this initiative has the potential for high value-add outcomes that would reinforce the progress already made under NCRIS in stimulating world-class research in Australia.

(5) There is clear pull from across Commonwealth, State and Local Governments, and industry alike, for reliable, long-term, unbiased synthesis and data services from national monitoring to underpin evidence-based decision making and to evaluate options for adapting and developing for the maximum benefit of society. This pull reflects growing appreciation of the risks in managing the continent without information about our environmental assets, on how they are changing, and in

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[5] Future Earth is a major international research platform providing the knowledge and support to accelerate transformations to a sustainable world. More here

[6] Clark et al. 2001 Ecosystem Forecasting: an emerging imperative. *Science* 293 (5530), 657-660

the absence of fundamental knowledge on what makes them function effectively in response to adaptation by human populations. The need to meet legislative and reporting requirements demonstrates the need for this capability.

(6) Paddock-to-plate is a good model to understand how the science supply-chain works. It begins with discovery and publication, proceeds through the essential steps of communicating knowledge to practitioners, industry partners and government, and thereby is translated into practical outcomes for the public good.

- The best establishment model for the **Forecast Ecosystems** program will be to engage from the outset with stakeholders in industry and the wider science community to understand infrastructure needs, and then to build these capabilities in a flexible and collaborative way. Consultation is required to get this right!
- The science supply-chain approach will be essential to the success of the **Forecast Ecosystems** program. As it will deliver training and inspiration for the next generation of scientists by embedding early career opportunities into the development and delivery of the infrastructure.
- This structure of the **Forecast Ecosystems** program will not place the initiative beyond the scope of NCRIS. In the environment sector, programs such as this need to be flexible enough to serve different players effectively, and not just those with a reliance on a single large piece of infrastructure. This need for flexibility is evident in the Issue Paper where social/government need vs the science need are more heavily conflated than for the other discipline sections.

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Glossary of existing facility names and potential role in Ecosystem Forecasting

<u>Existing NCRIS anchor facilities for biological ecosystem data (bottom row of Figure):</u>

TERN (Terrestrial Ecosystem Research Network) + expansion into water (including marine if consultations indicate this is beneficial), coasts, urban, agriculture and soils. Contributions of continental observations from fine-scale plot based, integrated with instruments, fluxes, remotely sensed spatial layers), long-term trends in states and function and modelling, and eResearch targeted and suitable for the diverse types of ecosystem data.

ALA (Atlas of Living Australia) - links the collection records of biodiversity and phenology (climatewatch) to both TERN and to BioPlatforms Australia (BPA).

BPA (Bioplatforms Australia) - biodiversity and processes delivered through the 'omics' capability, also capacity to track evolutionary adaptive change, invasive species, and pathogens.

<u>Interconnecting institutions (middle row of Figure):</u>

CSIRO (Commonwealth Scientific and Industrial Research Organisation) Ecosystem and climate capabilities.

BioSecurity Australia (Department of Agriculture and Water Resources) - for invasives, pests, pathogens, primary industries and risk analysis.

<u>Climate and physical environment, modelling and NCRIS data services (top row of Figure):</u>

BoM (Bureau of Meteorology) - climate data and forecasts**; Geoscience Australia** - earth data.

NeCTAR (National eResearch Collaboration Tools and Resources), Biodiversity and climate modelling virtual lab (BCCVL) - for computations and modelling.

ANDS (Australian National Data Service, NCRIS) Data access and storage + **NCI** (National Computational Infrastructure) for computational support.

Part 2 Background comments for Environment and Natural Resource Management

To evaluate and then prioritise the emerging directions in the environment sector, it is critical to: (a) understand the science context; (b) clarify the state of existing infrastructure and innovation; (c) acknowledge the excellent outcomes already achieved; and (d) recognise and support emerging leadership in the environment sector.

(a) The science context

We affirm that the environment sector is willing[7] to do the heavy lifting in knowledge to "*improve our understanding of the plants, animals and mineral resources that underpin our agricultural and resource sectors to ensure a balance between development and the environment*"[8]. To achieve this, however, it is necessary for the model of success to be clear, and for the NCRIS investment in this sector to be assessed accordingly.

The environment sector is strongly driven by science, but this reality is less well reflected in the Paper than for other sectors. For example, there are several steps in the iterative process of translating investment in research infrastructure into societal benefits. However, in the paper there appears to be an under-appreciation of the requirements for investment in the environment sector[9], and also of the necessary step of actually creating the corpus of scientific data before enabling or delivering outcomes in policy and government reporting.

In places, the 2016 National Research Infrastructure Capability Issues Paper presents confusing guidance to the environment sector. It is clear that the NCRIS program ($150M annually[10]) is about providing infrastructure that enables research, but the Paper does not clearly articulate what constitutes the 'infrastructure' needed to support the 'science research' agenda. The Paper also does not clearly differentiate research agendas that are within the scope of NCRIS from policy and management outcomes. For instance, the Paper looks for *'an evidence based national system to understand and manage water, carbon, soil and air resources*' (p. 21). This outcome is highly desirable, and NCRIS should play a key role in enabling Australia to understand and monitor environmental assets (e.g. State of the Environment reporting); however, although the data provides decision support, the necessary utilisation and translation of this data to enable implementation of national management systems is apparently beyond the scope of NCRIS investment. If this is the case, this is something we respectfully challenge, and encourage the Australian Government to reconsider.

b) Infrastructure and innovation

Ecosystem science innovation is as much about ideas as it is about hardware. Confusion about what is needed for research infrastructure may result from a focus on built infrastructure and instruments, which have a fixed higher capital cost that is much greater than the typically lower operational cost. This shape-of-funding model is not appropriate for much of the infrastructure required in the environment sector. What is required is a step change in resourcing to redress the

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7 Our survey results indicate that 95% of respondents agree with this statement.

8 Quote from Issues Paper, page 21.

9 Contemplating the future: Acting now on long term monitoring to answer 2050's questions. D B Lindenmayer et al. *Austral Ecology* (2015) 40:213-224

10 https://www.education.gov.au/national-collaborative-research-infrastructure-strategy-ncris

underfunding in the sector, and a consistent level of ongoing resourcing to collect the observations that become the raw material for research to build upon[11]. Breaking this continuity, changing the focus of activity with shifts in political climate, or short-term on-and-off programs, are all particularly destructive in the environment sector because natural systems are dynamic and require ongoing measurements, and because the required expertise is system-specific and not easily transferable. It is more sustainable to think of the environment research infrastructure needs as a consistent and appropriate oxygen level for sustaining life, rather than turning on the life support only when there is an emergency.

c) This is what innovation looks like and delivers in the environment sector

Here are ten examples of innovation and inspiration:

1. Nature knows best

Biomimetics, a name coined by Otto Schmitt for the transfer of ideas and analogues from biology to technology, has produced many successful devices and concepts. Examples include velcro, stable wing design, self-cleaning surfaces, dry adhesive tape, antireflective surfaces, robotic control systems, camouflage, and hull design of sailing boats[12]. The Biomimicry Institute complied over 2000 examples of technologies inspired by basic research[13], many from ecology – for example, information on whale biology informing wind-power design, or termite mounds informing sustainable architecture.

2. Ecology leads molecular innovation

PCR techniques, critical to all DNA research, grew out of basic field research on the ecology of bacteria able to live in hot-springs[14].

3. Collections of plants for climate research

The evidence that a tree species can adapt to less water when CO_2 is increased came first from analysis of density of stomata (leaf pores) of herbarium specimens across 100 years.

4. **Spikey plant prophylactics**

Spinifex botany research has been important to nanocellulose technology[15]. This technology is of potential interest to latex manufacturers across a multi-billion-dollar global market.

5. Collections of animals save human health

The discovery that the pesticide DDT affects calcium metabolism in vertebrates (including humans) came first from investigations of thickness of eggshells over previous 50 years in museums.

6. See you later alligator

Research into alligator populations drove innovation in endocrine-disruption science and generated evidence of chemical disruption of the endocrine system; a body's internal

[11] Key direction: **Supporting long-term research,** page 9 in '*Foundations for the Future - A long term plan for Australian ecosystem science*'. Ecosystem Science Council has an working group active on this recommendation

[12] http://rsif.royalsocietypublishing.org/content/3/9/471

[13] https://biomimicry.org/biomimicry-examples/#.V7T8FHqBmkk

[14] https://en.wikipedia.org/wiki/Thomas_D._Brock

[15] https://www.uq.edu.au/news/article/2016/02/native-grass-could-be-key-super-thin-condoms

messaging that uses hormones to regulate reproduction, growth and immune functions in people and animals[16].

7. Botanists cure what ails you

Allergy prevention is being enabled in Australia by ecology, botany, and climate change scientists working with allergy, immunology, public health and biostatistics scientists and clinicians[17].

8. Medical drug discovery

A KPMG report, *Biodiversity and ecosystem services: risk and opportunity analysis within the pharmaceutical sector*[18], reveals the potential business risks facing society from our current reliance on natural resources. It is estimated that 60% of antitumor and antimicrobial drugs are of natural origin but, for millennia, medical practitioners have harnessed substances from nature for treatments and cures: aspirin from the willow and, more recently, Taxol – the groundbreaking anti-cancer drug – from the bark of the Pacific yew[19]. Foundational to enabling this knowledge transfer has been ecological research.

9. Economy of being eaten

The predator-prey dynamics developed by ecologists are now being used in a wide variety of applications from industrial economics to political economics[20].

10. Birds and bees make your food

Recent estimates of the global value of pollination to agriculture is 153 Billion Euro per year. Understanding the ecology of pollination is essential to protect this industry.

As has been the case for centuries, environmental and life scientists foster innovation in societies. Their work inspires invention and technical advancements to mimic nature, but equally importantly it provides foresight capability, which enables preparedness and adaptation. This drives efficiency through avoidance of losses, and provides industry with options and opportunities. Theory and concepts from ecology and ecosystem science are used increasingly in the physical sciences to describe interactions and structure in complex systems: for example, 'On the global ecology of elliptical galaxies'[21], and "Galaxy ecology: an environmental impact assessment"[22].

d) Leadership

The ecosystem science community is quite capable of meeting the grand challenges of the future in a way that benefits Australia and the global scientific community. With appropriate resources, national environment research infrastructure can flourish to enable modern innovation, productivity and job creation. Under the Ecosystem Science Council, the environment sector has the necessary leadership[23] within its ranks to coordinate decision-making and to prioritize actions to get the job

[16] (http://www.orlandosentinel.com/news/os-louis-guillette-scientist-dies-20150813-story.html and https://www.sciencedaily.com/releases/1998/02/980209154754.htm)
[17] http://www.tern.org.au/Towards-an-Australia-wide-pollen-monitoring-network-bgp3846.html
[18] http://www.business-biodiversity.eu/default.asp?Menue=49&News=503
[19] http://www.chgeharvard.org/resource/killing-cures
[20] http://www.springer.com/us/book/9783642040221
[21] http://adsabs.harvard.edu/full/1989AJ.....97...42M
[22] http://www.astro.yale.edu/vdbosch/ecology_hd.pdf
[23] http://www.ecosystemscienceplan.org.au/Council-pg30470.html

done. This leadership has been demonstrated and enhanced through the *Ecosystem Science Long Term Plan* cited here and launched by the previous Chief Scientist in 2014. The Ecosystem Science Council is able to lead the discussion and to reach broad agreement across the environment sector. We acknowledge the foresight and leadership shown by TERN, and of course the funding provided to TERN under the NCRIS program, in assisting this process. Other examples of plans include the National Marine Science Plan 2015-2025, "*To live within Earth's limits: AN AUSTRALIAN PLAN TO DEVELOP A SCIENCE OF THE WHOLE EARTH SYSTEM 2010*" and the Agricultural Decadal Plan which is underway.

However, it is fair to recognise that the environment sector has taken some time to achieve this necessary level of maturity. Perhaps based on out-of-date perceptions, some may still believe that coherence and commonality of purpose are lacking in the environment sector. Of course there is much work for us to do in achieving all the scientific, economic and social benefits for which coherence and common purpose are essential. But it would be a mistake on grounds of such misperceptions to downplay the importance of environmental infrastructure, or reduce support for key capabilities such as TERN or ALA, just at the point where the sector is progressing so strongly. Such an approach would hold Australia back, in terms of economic prosperity and social wellbeing, over the next decades. Therefore, we outline here our determination to drive forward for a cohesive and collaborative capability for the environment sector.

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Part 3: Answers to other selected relevant questions

Question 5: Should research workforce skills be considered a research infrastructure issue?

Most definitely yes. We emphasize that to maintain data from consistent observations is the top priority! Therefore, keeping the trained technical staff in jobs is clearly important if we are to protect the integrity of the methodology used and collect the data in a consistent and efficient manner. Working in diverse ecosystems requires skills specific to that ecosystem e.g. correct sample handling is absolutely critical to the quality and reliability of the emergent data. Consider also the different skills required to monitor soil ecosystems in comparison to marine ecosystems. The need for trouble-shooting and problem solving in remote ecosystems is also a critical skill as is the ability to describe ecosystem condition, which requires multidisciplinary expertise. For example, working in soil ecosystems requires expertise in soil pedology, agronomy, chemistry, physics, and botany to ensure critical metadata is recorded. There is a certain interdependency in skill set requirements for a successful outcome. In addition, there is an emergent need for more environmental statisticians and their training in modern 'big data' models and analyses analytics at universities. These specialists would be invaluable if embedded in capabilities such as the proposed **Forecast Ecosystems** program or other synthesis capabilities within existing NCRIS projects. [24]

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[24] http://www.jonniwalkerdatablog.com/?page_id=93 , http://project-ukko.net/more-info.html

Question 8: What principles should be applied for access to national research infrastructure, and are there situations when these should not apply?

Provision of major national research infrastructure is critical for Australia and therefore resourcing remains the responsibility of government. We concur with the National Committee on Ecology, Evolution and Conservation that it is unlikely that long-term strategic public-good research can be funded by the private sector, or even as a shared public-private shared responsibility, due to the often short-term demands of the private sector.

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Environment and Natural Resource Management

Question 18: Are the identified *emerging directions* and research infrastructure capabilities for Environment and Natural Resource Management right? Are there any missing or additional needed? Are there any missing or additional needed?

Emerging Directions

The gaps identified are not entirely correct. There is already reasonable capability in alpine and tropical ecosystems. Deserts are still poorly resourced, relative to the area of the continent that they cover but there is still some existing NCRIS capability within deserts. That said, what the gaps might be is not clear. For example, plot networks might be in some systems but not flux towers, so we need improved clarity in what constitutes a gap. Note, arid regions will be increasingly important in providing knowledge on coping with increased climatic extremes and more rapid shifts in state from boom to bust conditions. In our view, the largest gaps in NCRIS investment within ecosystem types are freshwaters and coasts and their integration with terrestrial components of ecosystems.

Integration of high value data on the environment

Many of the greatest challenges facing humanity over the next decades are environmental in nature – climate change, loss of plants, animals, microbes and ecosystem services, emerging pathogens, and management of fisheries, forests and agriculture. Solving these challenges will require environmental scientists to be able to tackle increasingly complex problems with appropriate data and experimental infrastructure. We are moving towards parameter estimation and asking "how much" and in "what direction" ecosystem processes are affected by different mechanisms. High-value data on the environment such as essential living and biophysical attributes[25], land uses, human populations, health and welfare and their emergent properties are critical to government[26]. Data requirements in the environment sector pose significant challenges and uncertainties. The barriers are:

Data characteristics specific to the environment sector:

[25] https://www.environment.gov.au/science/essential-environmental-measures-australia

[26] https://www.dpmc.gov.au/sites/default/files/publications/public_sector_data_mgt_project.pdf

- Observational ecological *in situ* data are often messy and may contain numbers of explanatory biophysical variables many of which may be correlated with each other and therefore manipulative experiments often complement this approach to help unravel causal factors.
- Data cover a diverse range of context dependent concepts that create challenges for secondary users in terms of interpretation and integration.
- Interpretation is challenging when different collection protocols, measurement standards and classification systems are in use, and in many cases are not described in enough detail to be intelligibly reused – which leads to data entropy.

While significant progress has been made under NCRIS, for example in the collation of existing biodiversity records by ALA, the untapped potential of environmental data is enormous and it is critical that it is exposed to support modern environmental sciences. Surviving data records (including sensor records) are often incomplete and unusable because of the lack or scant metadata for intelligible reuse. While data archiving should have improved in the electronic age, in some areas it has deteriorated because of the high turnover rate of storage media with rapidly changing technology. The ability to access knowledge is an essential requirement of any field, and this makes the efficient exchange of information of fundamental importance if it is to deliver national benefits. This is widely appreciated, but the definition and expression of electronic data remain poorly coordinated in science. This poses major obstacles to efficient data interoperability.

For a data exchange approach to be successful it has to be efficient and flexible. It must cope with the increasing volume and complexity of data generated by rapidly advancing technology. This makes data storage a minor consideration compared with extensibility and portability of data management processes. Most importantly, improvements in computing technology continue to generate new approaches to harnessing semantic information contained within data collections, and to promoting new strategies for knowledge management. Ontology-based data management is a modern solution. Data ontologies record the metadata for data items used in a specific information domain – they are unique to their domain/subdomain. Ontologies have been built for many domains (chemistry, powder diffraction, molecular biology)[27].

An example of the success of NCRIS investment, and a world-first for the environment is TERN's innovative AEKOS that is already informing the Department of Environment's Essential Measures program[28]. The benefits of such systems are:

- Interoperability – all databases, software packages and graph tools can read data via web services.
- Extensible syntax enables new data items to be added without corrupting existing data archives.
- Ontology-based data management is extensible, efficient and better for innovative complex data analyses.
- Other domains can develop their ontologies and talk to AEKOS-like ontology in a virtual laboratory.
- Automatic data validation, underpinnings of artificial intelligence and google style processes.

[27] http://datascience.codata.org/articles/10.5334/dsj-2016-003/print/#B15
[28] https://publications.csiro.au/rpr/pub?pid=csiro:EP164395

Climate and water resources

We agree that water management is important, but the description of this 'emerging direction' fails to identify scientific or research infrastructure needs. This direction should be expanded to encompass sustainable use of natural resources – particularly water, carbon, soil and biodiversity – under conditions of climate change and greater resource demand. Knowledge of these matters are equally important to meet the identified Science and Research priorities. The 'emerging direction' that is actually needed is whole-of-system thinking and associated coherent experimentation towards adaptation and mitigation strategies. To this end we support the comments in the submission from the Australian Energy and Water Exchanges (OzEWEX) that call for greater collaboration and networking between water and energy research groups and the broader ecosystem areas already supported by NCRIS.

Current Capabilities and Emerging Capability Needs

Marine environment

IMOS and the National Marine Science Committee will take responsibility for commenting in this domain. We note only that coastal environmental research cannot be fully covered by any one existing facility. Australia's coastal environments are dynamic and transitional between marine and terrestrial. They have not received the full attention they require in scientific coordination, and progress in this area depends upon linkage across terrestrial and marine environments.

Terrestrial systems

The suggestion that 'essential environmental variables' need to be agreed is correct. To this end, it is important that current terrestrial data streams are retained and built upon to avoid duplication and inefficiency, especially those involving long-term repeat-measures. The need for consistency over time from current capabilities surpasses any other needs (as is evident from the use of consistent long-term data to resolve climate debates).

We strongly agree that the Terrestrial systems capability remains a high priority. We note that its previous lack of investment relative to marine science is not reflective of need and we hope to not see a continuation of this inequity going forward. Adding more focus on soils is important particularly as they deliver ecosystem services critical to the health of ecosystems and to food and fibre production. To date NCRIS investment in soil science has been limited and constrained. For example, TERN's AusPlots facility has collected soil samples but these samples have primarily been archived in the National Soil Archive - rather than published as usable data for the science community. Limited and cheap physical measurements have been taken in the field and published through AEKOS but full chemical analysis is needed to enable others to produce the science. This approach, albeit sensible and necessary with the constrained investment does not allow for future analyses of soil microbial diversity which would require storage of frozen soil (or DNA/RNA) samples.

Desirable New Capabilities

As outlined in reference to the new capability for ecosystem forecasting, yes, we agree that national capability objectives should include explicit emphasis on people and their networks of collaboration. In addition, Australia would benefit from a dedicated synthesis capability, building upon the success of the TERN Australian Centre for Ecological Analysis and Synthesis (ACEAS) that had to be closed after a couple of years due to significantly reduced funding. This short-lived facility was an exemplar of how national open infrastructure can spur innovation and synthesis of world standard. Such a centre has also been proposed by Future Earth Australia, in order to focus on the Sustainability Goals for Development, which Australia has signed up for under the Paris Agreement.

It is clear that it is not lack of will that has held back the environment sector in terms of capability development. Rather, the problem is chronic under-resourcing over decades compared to other fields of science and other countries. It seems prudent for us to point out that new capabilities must come from new and additional investment, and not at the expense of existing capabilities particularly the top priority of *in situ* observations on plots, and instrumented data.

Nationally integrated automated database

The case for an automated capability and associated database is not well supported and potentially ill advised. The Issue Paper states, *'Gathering large amounts of essential data automatically is the most cost effective solution to data gathering needs, given gaps in observing networks have been identified across the atmosphere, soils (carbon, water and nutrients), coasts, oceans, freshwater and groundwater domains.'* This seems poorly thought through. Understanding of field situations, and of differences in ecological processes between environments, are critical for interpreting data. There is value in automation but it should not be invested in at the expense of more holistic survey data.

National model systems

Modelling capabilities have been resourced in many programs and institutions, e.g. CSIRO, NCAARF, BoM, TERN and NeCTAR, as well as Universities. Modelling is important, but there seems to be a divergence of capabilities rather than integration. The catalyst for harnessing this effort would be to launch the **Forecast Ecosystems** program, with the full inclusion of biological and ecological attributes, feedbacks and complexities. It is important to highlight that observations collected across coordinated networks that are continent-wide and decades-long are needed to parameterize, to validate and to test hypotheses and predictions from forecasting. Again, therefore, we emphasize that <u>data from consistent long-term research and observations</u> are the top priority! Keeping trained technical staff in jobs is clearly important if we are as a community to be able to collect data in a consistent and efficient manner. Constant churn, with financial ups and downs, drains stretched resources in the national capabilities.

Integrated biological facilities for plant, animal and microbial sciences

We agree that keeping taxonomic expertise is important. There is a need to enable the 'omics' capabilities to reach out and contribute more to the understanding of the function of ecosystems along the lines of the BASE project that is characterizing soil microbial communities.

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Question 19: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

The major environmental challenges facing Australia are global in scope. Therefore Australia needs to increase its capacity to engage with the international monitoring and modelling infrastructure in the environment sector. Ecosystem science experts in Australia need to contribute to wider understanding of the contributions of southern lands and oceans to global processes. Australian data are essential to global climate and vegetation models, for example, and while some of this information is acquired through international remote sensing capabilities, Australian researchers are best placed to interpret and use it. In contrast, other data streams that underpin our capacity to maintain distinctive biodiversity and fully functioning ecosystems are tasks for Australia, and these data cannot be 'bought off the shelf'. The joint delivery of internationally relevant knowledge that can only be generated here in Australia remains a core focus of the infrastructure requirements for researchers and industry in the environment sector.

Australia is already a key player in many of the coordinated global efforts. Therefore, it is critical that Australia maintains strong international engagements. Under increased NCRIS investment, Australia has an opportunity to lead the region, and to retain its capabilities to deliver innovations, technical expertise and essential data streams for our continent to meet these needs.

Listed below are the priority international projects where Australia's role is critical.

- Intergovernmental Platform on Biodiversity and Ecosystem Services
- Future Earth and Future Earth Australia
- International Long Term Ecological Research Network United Nations System of Environmental-Economic Accounting
- IUCN Red List of Ecosystems
  Global Forest Survey with the FAO part of the United Nations
- Group on Earth Observations Biodiversity Observation Network (GEOBON)
- Fluxnet network
- Terrestrial Lasar Scanning International Interest Group (TLSIIG, www.tlsiig.bu.edu/)
- Committee on Earth Observation Satellites
- Research Data Alliance data informatics, policy and standards
- International Council for Science Union's CODATA data informatics, policy and standards working groups

Distributed global experiments with existing Australian investment

- Droughtnet
- Nutrient network
- BioDesert

Other groups of interest:

- National Ecological Observatory Network (NEON)
- European Environmental and Earth System Research Infrastructures
- Global Land Project
- Global Collaboration Engine
- International Nitrogen Initiative
- PECS- Programme on Ecosystem Change and Society
- United Nations Educational, Scientific and Cultural Organisation (UNESCO)
- Critical Zone Observatories
- Earth Microbiome Project (www.**earthmicrobiome**.org)
- EU Global Soil Biodiversity Initiative (https://**globalsoilbiodiversity**.org)

It appears from comments during the consultation with the Expert Group that the international engagement of some existing NCRIS facilities is under-appreciated. For example, TERN is seen internationally as leading in the delivery of standard methods, surveillance monitoring, and free and open data, and its expertise is being sought to translate that influence into global programs. For example, the Food and Agriculture Organization of the United Nations is utilizing TERN's national monitoring infrastructure, data and expertise to complete the Oceania component of the Global Forest Survey.

Question 20: Is there anything else that needs to be included or considered in the 2016 Roadmap for the Environment and Natural Resource Management capability area?

Return on investment

An area where the Paper appears unclear is measurement and valuation of Return on Investment. Return on Investment in a program that is about resourcing *to enable science* should take account of what is achieved scientifically. That is, the strategic intent and the desired outcomes, as well as how these will be measured is critical to effective investment. Investment on public good science, like what is being asked for through the Issues Paper, should then be expected to repay in terms of the wellbeing and prosperity of the nation, *and be enabled to do so*. Past and present ROI procedures for NCRIS have not captured these elements well and it would be beneficial to see improvements and clarity in future investment.

An example of excellent ROI is the TERN-led collaboration for continental environmental monitoring products from the satellite image data. The value derived from this collaboration was coordinated access to the European Space Agency's Copernicus 20yr+ satellite monitoring program – with assured access to data over Australia. For a limited investment in ground-work and processing in Australia, through TERN Auscover we now have access to billions of dollars of foreign research infrastructure to use in our environmental monitoring.

For public good science, there are fewer options for industry to pay the way for the science that is expected to flow from investment in research infrastructure. The ARC is not able to make up the shortfall and many worthy applications go unfunded. Australian ecosystem scientists are world-leading[29] and they are highly capable of organising their discipline effectively, as seen in *Foundations for the future: a long-term plan for Australian ecosystem science*[30].

There have been considerable achievements and progress made under NCRIS on the gargantuan task of continental-scale monitoring that has challenged not just Australia but many international programs. For example, the USA equivalent of TERN was funded at $US111M per annum, an order of magnitude higher than in Australia, although for a comparable land area[31].

The broader societal context is highly relevant to decisions about how critical continuing NCRIS investment is in the environment sector. We agree with the NCEEC that the environment sector may be seen as less important given the apparent decline in government support of environmental research, as exemplified by the recent cuts to CSIRO and similar losses across many State level institutions over recent years. This is in stark contrast to the excellent international reputation in environmental research in Australia, and its importance for underpinning the economy.

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29 https://conservationbytes.com/2014/10/13/australia-should-have-a-more-vibrant-ecological-culture/

30 http://www.ecosystemscienceplan.org.au/The-Plan-pg29369.html

31 http://science.sciencemag.org/content/349/6255/1436

Data for Research and Discoverability

Question 33 Are the identified emerging directions and research infrastructure capabilities for Data for Research and Discoverability right? Are there any missing or additional needed?

We commend the integrative nature of the ideal research system. We add that there are benefits to an ontological data management system that in reality adopts the FAIR principals (Findable, Accessible, Interoperable and Reusable)[32] and is driven by researchers working with relevant stakeholders and not solely by IT technology experts if it is going to deliver national benefits. For example, discoverability is of little value if the data cannot be used intelligently. Availability is more important than discoverability, which is more of an IT push and not a pull to build capacity in research. Investment in data cultural shifts to more acceptance and rewards for data publishing and training in ontological data management systems is critical; we recommend setting up a working group within the International Council for Science Union's CODATA on environmental community to develop domain-specific vocabularies.

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Question 34: Are there any international research infrastructure collaborations or emerging projects that Australia should engage in over the next ten years and beyond?

In the eResearch domain, TERN's ÆKOS is a recommended repository for publishing data through the Nature Research journal *Scientific Data*. However, resourcing to enable better integration of the International Council for Science Union's CODATA data principles to reflect science practices would be welcomed. Representation for Research Data Alliance exists but a stronger science representation is an opportunity to ensure technology aligns with science practice.

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[32] http://www.nature.com/articles/sdata201618