








Taking our Environmental Pulse

A strategy for monitoring ecosystems in Australia

Technical Report

Ecosystem Science Council

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A strategy for monitoring ecosystems in Australia

"Help address the loss of species, ecosystems and genetic diversity – a truly global and generational threat to human well-being"

Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES)
Executive Secretary, Dr. Anne Larigauderie 2019

Ecosystem Science Council

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Enabling Ecosystem Surveillance, which this strategy addresses, is a goal of *Foundations for the future: A long-term plan for Australian ecosystem science*[1].

Ecosystems are communities of living organisms and non-living components such as atmosphere, water, and soil.

Australia's ecosystems are essential for people and all species.

Healthy ecosystems provide fundamental ecosystem services to people.

Our decisions and actions impact our ecosystems, and we have a responsibility to manage them well for current and future generations.

Biodiversity is key to the delivery of multiple ecosystem services in our rapidly changing world.

Ecosystems are vital national assets, and like all important assets we need to understand how they are changing if we are to manage them well.

Monitoring provides the information to inform us about changes.

Australian, State and Territory governments recognise that urgent action is needed to identify, prevent and reverse ecosystem and biodiversity decline.

Australia needs a systematic, continental-scale ecosystem surveillance network that monitors the condition of our terrestrial and marine ecosystems.

1 Contents

Synthesis

The Ecosystem Science Council proposes a national surveillance monitoring program that measures the health of our ecosystems.

This goal was established in *Foundations for the Future: A long-term plan for Australian ecosystem science*.

This requires national commitments to five enabling conditions.

Condition 1:	Socio-Political commitment
Condition 2:	Financial commitment
Condition 3:	Robust consistent methodology and program design
Condition 4:	Leveraging and adapting existing monitoring systems
Condition 5:	Communication and engagement

Priority recommendations

- Establish a national ecosystem surveillance network that is accessible, adaptable, integrated, consistent, long-term and secure.

- Coordinate the network through an independent national environmental commission, in cooperation with state and territory environmental and ecosystem management agencies.

- Work towards a commitment from all political parties, decision-makers and influencers for on-going monitoring.

- Resource the ecosystem surveillance network through legislation, policies and long-term binding plans.

- Secure financial investment from Federal and jurisdictional environmental agencies, starting with reinstatement of funding of the environment portfolios that have been cut over recent years.

- Harness the innovations and opportunities afforded by advances in big data, technology and expertise in the science of ecosystems, and invest in research to implement new technologies in the field.

- Build on existing Government environment institutions to provide long-term support for scientists implementing monitoring, and maintaining databases and network infrastructure.

1 Ecosystem monitoring

1.1 The need for ecosystem surveillance monitoring

Our ecosystems are vital national assets, supporting us all, and can be managed effectively only if we have an ongoing capacity to track and monitor their condition.

Effective monitoring of assets is a core requirement of any business management.

The same is true for the business of ecosystem management.

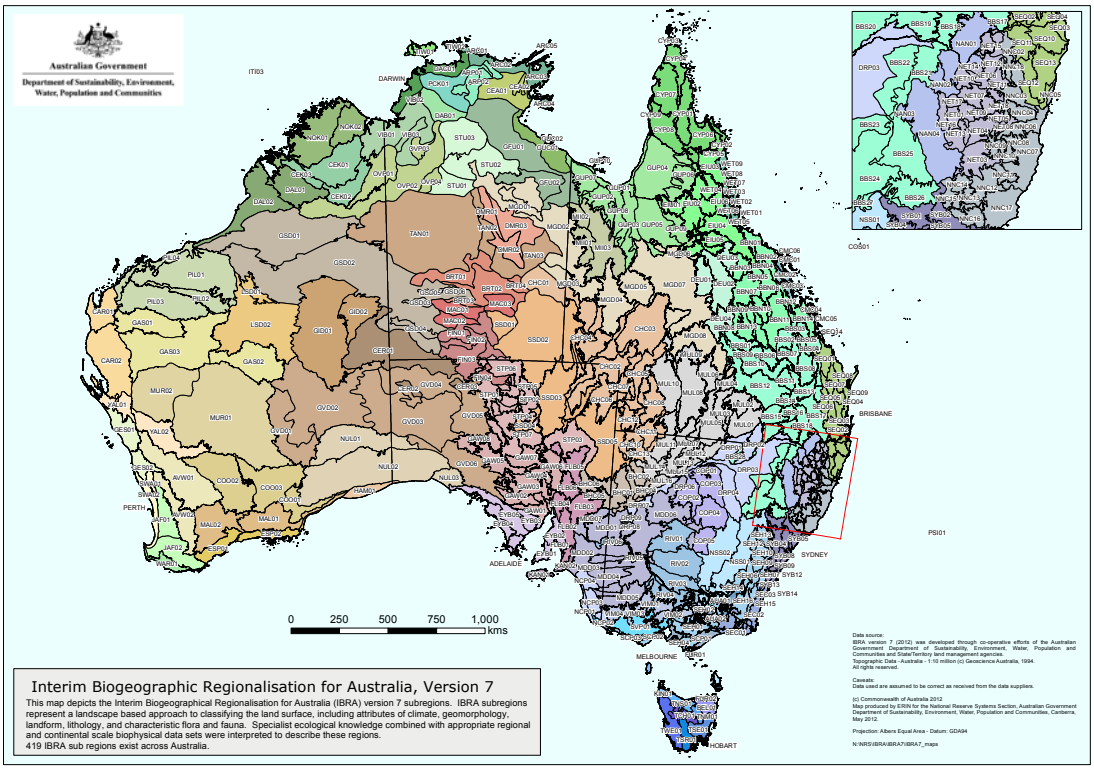

Fig. 1 Australia's terrestrial biogeographic regions encompass ecosystems, which are nested within the coloured biogeographic regions depicted on the map**.**

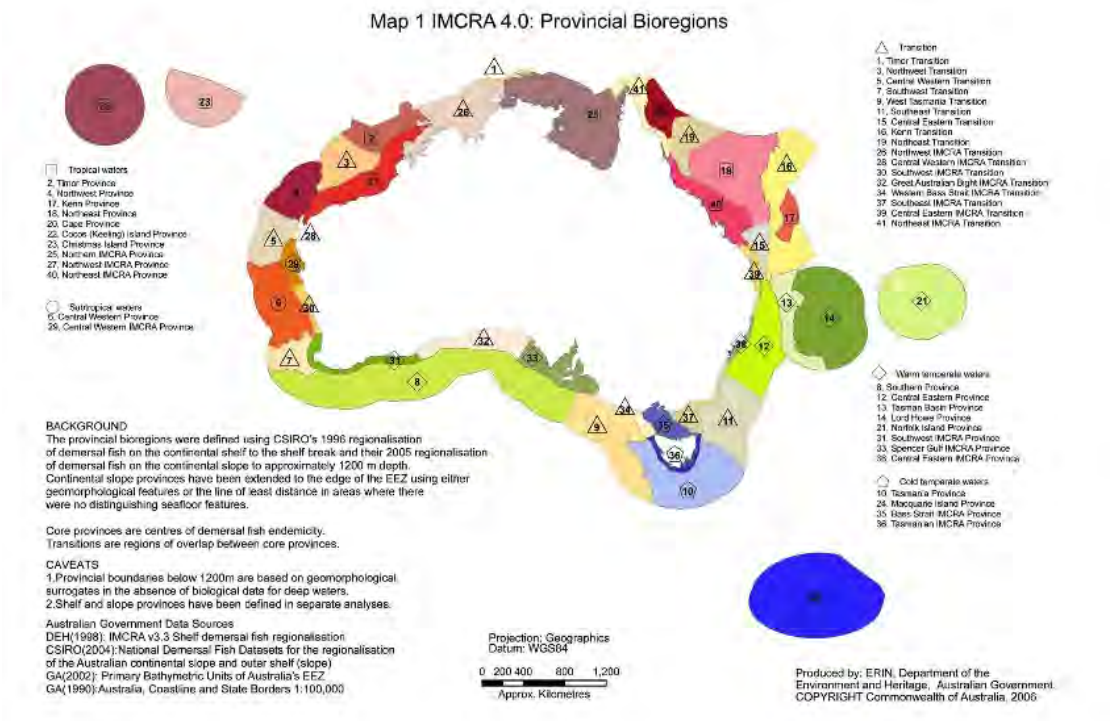

Fig 2. Marine bioregions of Australia include ecosystems at smaller scales

Australia is unique in the world for its diversity of terrestrial, freshwater and marine ecosystems.

Many of these terrestrial, freshwater and marine ecosystems are in poor condition and are degrading further. Deteriorating ecosystem condition is detrimental to us and our land, water and wildlife[2].

The limited ecosystem monitoring to date has demonstrated this time and again for decades[2].

Terrestrial, Freshwater and Marine ecosystems

Ecosystem science is multi-disciplinary. Marine, freshwater and terrestrial eco-sciences require different skills and different methods and approaches. The challenge in designing an all-embracing ecosystem surveillance monitoring program is that one approach would become too complex.

This blueprint therefore addresses terrestrial and freshwater ecosystems. Marine ecosystems are being addressed by the National Marine Science Committee. Monitoring of marine ecosystems is addressed in the National Marine Science Plan.

Climate change, exotic pests and diseases, intensive agricultural practices, altered fire regimes, changed hydrological processes, significant losses of native species and communities, over-extraction and pollution of surface and groundwaters and many other threats affect Australian ecosystems.

While ecosystem restoration is increasingly important, for example in agricultural landscapes, we need to prevent degradation and conserve ecosystems as a first priority.

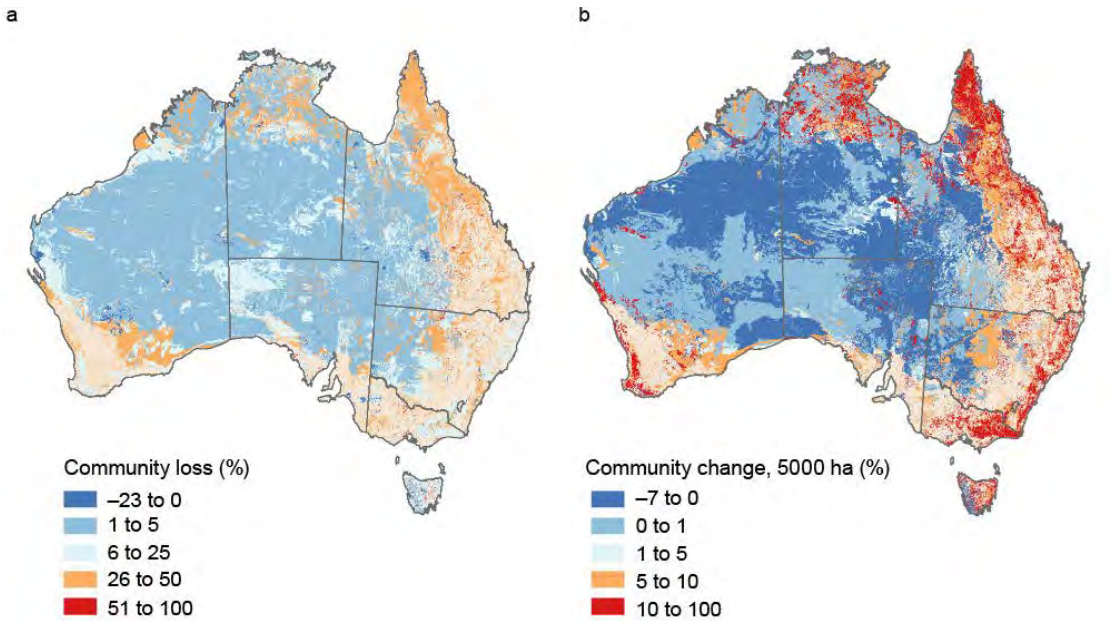

Fig. 3 Loss of vegetation and ecosystems across Australia (from SoE 2016).

We need more comprehensive monitoring to inform management policy in an effort to prevent further ecosystem degradation and species losses [2-4].

Current and future generations of Australians need to understand patterns of change in ecosystems, and to make informed decisions about the use and management of land and sea-scapes[1].

Agriculture depends on healthy ecosystems
Half our ecosystems occur on agricultural lands

Healthy ecosystems are essential for agriculture and ecosystem services such as clean water, healthy soils and air quality.

Conversely, over half our ecosystems occur on agricultural lands, and depend on farmers to maintain them.

The Global Assessment Report of the Biodiversity and Ecosystem Services (IPBES) Science-Policy Platform recognizes the critical importance of agricultural lands for ecosystems and biodiversity.

Importantly, actions and pathways to achieving healthy ecosystems require:

- promoting good agricultural and agroecological practices
- multifunctional landscape planning (which simultaneously provides food security, livelihood opportunities, maintenance of species and ecological functions), and
- cross-sectoral integrated management[5].

Surveillance monitoring is normal practice on agricultural lands that cover more than 55% of Australia[6], although it is often informal and *ad hoc*.

Farmers and agricultural land managers, for instance, usually monitor pest animals, weeds, insect attack on crops, diseases and other biosecurity matters.

Monitoring of ecosystems and wildlife, some of the most important elements of agricultural biosecurity, however are uncommon in national biosecurity considerations.

Encouragingly, recognition of the linkages between wildlife and ecosystems, agriculture and people is rising and is now on the national biosecurity agenda[7].

Ecosystem management depends on monitoring

Monitoring biodiversity and ecosystems is essential to:

- support rigorous, evidence-based policies and decision-making around terrestrial, marine and freshwater environmental use and management;
- measure environmental performance;
- trigger management actions to protect and maintain biodiversity and ecosystems;
- assess effectiveness of management actions;
- inform our legislative obligations and precautions;
- communicate with our national and international community and the public about ecosystems and biodiversity and their management [8-11].

We have committed to international and national monitoring of ecosystems

Ecologically sustainable development is a core commitment of the Australian government. It was recognized in the *Environment Protection and Biodiversity Conservation Act 1999*, and the United Nations General Assembly.

On a global scale, the issue of ecologically sustainable development has been on the agenda for decades. In September 2015, the United Nations General Assembly (and the Australian Government) adopted the 2030 Agenda for Sustainable Development (2030 Agenda).

The 2030 Agenda's 17 Sustainable Development Goals cut across disciplines, sectors and institutional mandates[12,13].

*"22 of 44 targets under **Sustainable Development Goals** are being undermined by negative trends in nature and its contribution to people"*
(IPBES 2019)

Achieving Sustainable Development Goals depends on ecosystem surveillance monitoring. Without adequate monitoring, we have limited means of establishing whether we are ecologically sustainable and whether we need to take action to repair damaged ecosystems.

Achieving the 2030 Agenda will take new thinking:

work will be no longer conducted in silos, but will be intrinsically linked.

A healthy environment, social development, and sustained and inclusive economic growth are all essential for achievement of each of the goals[2].

Australia also has international obligations to sustainably manage all inland aquatic, estuarine and nearshore marine ecosystems under the Ramsar Convention.

The Ramsar Convention in Australia is supported by the *Environment Protection and Biodiversity Conservation Act 1999* (EPBC Act), the *Water Act 2007* and state and territory based land and water planning legislation.

Australia has 66 Ramsar-listed wetlands. The Australian Ramsar Management Principles promote national standards of management, planning, environmental impact assessment, community involvement and monitoring for all Australian Ramsar wetlands.

Australia's State of Environment

The State of Environment reporting system, which Australia has undertaken for decades, reported in 2016 that many of our commitments and goals have not been achieved[2] (see Box).

Inadequate Ecosystem surveillance monitoring features highly in State of the Environment Report 2016

Environmental policies and management practices have achieved some improvements over the past half-decade but, alarmingly, the condition of the environment is poor and deteriorating and concern was expressed about:

- biodiversity continuing to decline across Australia
- recent extinctions of native species
- more populated coastal areas deteriorating
- rapidly growing cities where environmentally-sensitive urban planning could improve outcomes for ecosystems
- the extensive rangelands that comprise the dominant land use in Australia, where over-grazing is considered **a major threat to biodiversity**
- the Murray-Darling Basin where over-allocation of water remains a major issue
- abandoned mined lands: 60 000 by recent estimates [14,15]
- forest and woodland ecosystems affected by altered fire regimes.

Since 2016, our marine environments have deteriorated further, with mass coral bleaching of the Great Barrier Reef and other Australian coral reef systems. The back-to-back (2016 and 2017) mass bleaching was unprecedented and collectively affected two thirds of the Great Barrier Reef (Australian Institute of Marine Sciences, 2018).

The main pressures facing the Australian environment today are the same as in previous decades: **climate change, land use change, hydrological change, pollution, habitat fragmentation and degradation,** and **invasive species**.

In addition, the interactions between these and other pressures are resulting in *cumulative impacts*, amplifying the threats faced by Australian ecosystems.

Key challenges to the effective management of Australian ecosystems remain:

- no overarching national policy
- poor collaboration and coordination of policies, decisions and management
- follow-through from policy to action is lacking
- **data and long-term monitoring are inadequate**
- **resources for environmental monitoring, data synthesis, management and restoration are insufficient.**
- **understanding of, and capacity to identify and measure, cumulative impacts is inadequate**
- limited public awareness of ecosystem services and intrinsic value of Australia's diverse, native ecosystems.

Meeting these challenges requires:

- national leadership
- integrated policies and adaptive management actions
- improved support for decision-making
- a more strategic focus on planning for a sustainable future
- new, reliable sources of financing
- improved communication and public eduation of value of ecosystems.

Monitoring ecosystems and biodiversity

Australia ratified the United Nations Convention on Biological Diversity in 1993, recognizing the importance of our unique natural ecosystems and biodiversity

The Convention on Biological Diversity (CBD) is an international legally-binding treaty with three main goals:

- conservation of biodiversity;
- sustainable use of biodiversity;
- fair and equitable sharing of the benefits arising from the use of genetic resources.

Its overall objective is to encourage actions which will lead to a sustainable future.

Unless Australia recognises the role of ecosystems in the support and maintenance of our diverse plant, animal and microbial species, then it will fail to meet these three goals.

The CBD contains five strategic targets:

- Strategic Goal A: Address the underlying causes of biodiversity loss by mainstreaming biodiversity across government and society
- Strategic Goal B: Reduce the direct pressures on biodiversity and promote sustainable use
- Strategic Goal C: To improve the status of biodiversity by safeguarding ecosystems, species and genetic diversity
- Strategic Goal D: Enhance the benefits to all from biodiversity and ecosystem services
- Strategic Goal E: Enhance implementation through participatory planning, knowledge management and capacity building

Australian governments developed the first *National Strategy for the Conservation of Australia's Biological Diversity* in 1996 - a national approach to biodiversity conservation[16]. This was preceded by the *National Conservation Strategy for Australia* (1983)[17].

Australia's Biodiversity Conservation Strategy 2010-2030[16] commits to establishing a national long-term biodiversity *monitoring* system to determine the status and trends of Australia's biodiversity and ecosystems.

To date, we have not developed nor implemented this system.

Our survival is critically dependent on looking after our natural environments and their biodiversity – the many different kinds of animals, plants and microbes, and the ecosystems that support them.

This web of life represents our store of natural capital and from it we get the things we take for granted each day… clean air … fresh water … foods and fibres.

We get artistic and spiritual inspiration from biodiversity…

They are fundamental to our physical, social, cultural and economic well-being [16]

1.2 What is ecosystem surveillance monitoring?

Ecosystem monitoring spans spatial scales to encompass ecosystem processes that operate at these different scales. Monitoring at different scales and intensity are used in combination to produce reliable analyses of the state of the ecosystems and predictive models[18].

Ecologists generally apply three scales of monitoring from coarse remote sensing such as from satellites, to detailed ground-based investigations (Fig 1).

There are no sharp boundaries between the three scales of monitoring, and each commonly informs others and can use the full range of tools available to ecologists. It's the focus and purpose that differ.

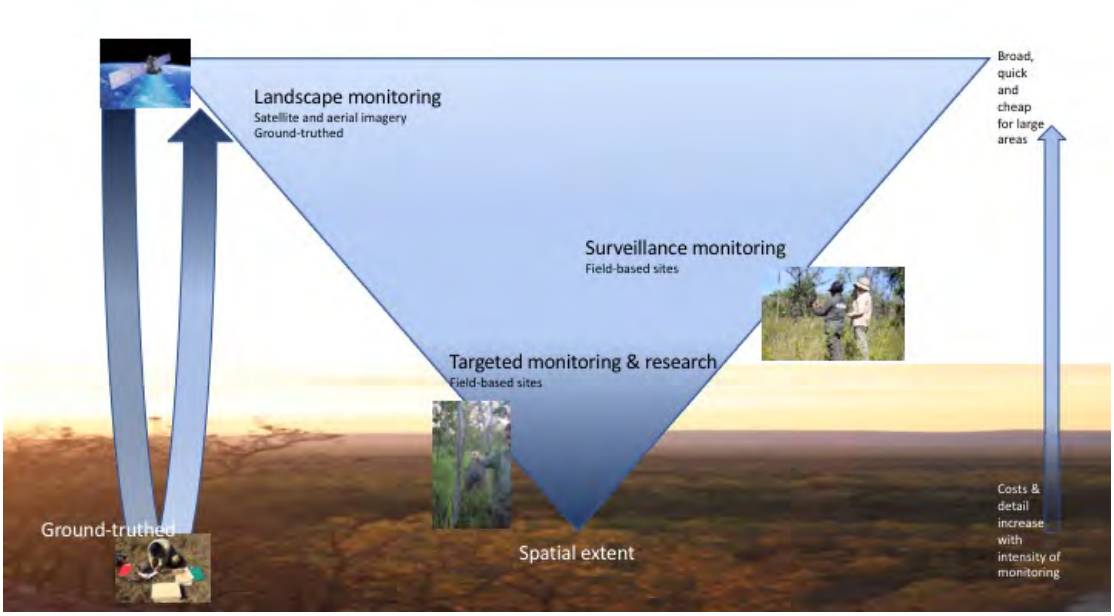

Fig. 1 Three scales of monitoring; adapted from Eyre et al. 2011[18].

Ecosystem surveillance monitoring detects change over time in ecosystems and species, providing early warning of unexpected changes, so that management responses can be initiated.

Surveillance monitoring can occur at all spatial scales: landscape (e.g. aerial imagery to track cloud formation), multiple sites (e.g. TERN SuperSites) and single sites (e.g. rare species monitoring programs) (Figure 1).

Essential to effective monitoring are:

- robust and flexible design and methods;
- continuity over reasonable time periods that match temporal scale of ecosystem dynamics under scrutiny;
- adequate resources;
- capable data management systems, particularly accessibility;

- integration with management;
- multi-organisational support;
- leadership and highly skilled staff;
- effective communication and engagement with people[10,19].

Surveillance monitoring has been influential in triggering and informing urgent conservation actions[20].

Importantly, *surveillance monitoring provides early warning of detrimental change*[21] to the ecosystems and species under study.

Ecosystem surveillance monitoring programs must have clear questions and objectives[22] – how are our ecosystems changing?

These can include the effects of different management practices, or trends in species and ecosystems due to climate change. They are not usually designed to test scientific hypotheses[23]. If a change is detected, targeted monitoring and research is required to examine the causes.

Landscape monitoring provides broad overviews of soils, vegetation and hydrological change, and very large areas can be monitored relatively inexpensively through remote sensing.

Ground-based sampling is required to validate the models that interpret outputs from remotely sensed technologies. Australia already has a number of robust landscape monitoring systems in place, including programs such as those run by the Terrestrial Ecosystems Research Network.

Landscape monitoring by remote sensing ***does not substitute*** for point-based surveillance monitoring. It does not identify species or even ecosystems but uses information obtained from point-based studies and remote sensed technologies.

Landscape monitoring instead detects change in patterns and signatures such as cover and greenness of vegetation, sea surface temperatures and the extent of waterbodies holding freshwater.

Targeted monitoring, by contrast, focusses on particular species or ecosystems, and often is designed as a ***research*** project to answer specific research questions, especially those that inform management.

Targeted monitoring is all about process – why are things changing, and what action do we need to take to influence that change? Targeted monitoring may use landscape monitoring for planning and analysis, and surveillance monitoring to frame questions and determine the broader applicability of targeted research.

A substantial amount of targeted monitoring is undertaken by government agencies, universities and related institutions, often focussed on threatened species and communities[9].

1.3 How long will it take?

Monitoring of ecosystems to detect changes in condition is an on-going process. It takes considerable time and can differ markedly depending on ecosystem type and how strongly the drivers of change are acting.

Monitoring may span decades to centuries, because we always need to monitor our ecosystems. It needs to be repeated over periods of years to decades, according to the need to detect change in species or ecosystems[9].

It is just like monitoring our human health, water, air, population trends and weather which are all on-going.

Ecosystem surveillance monitoring therefore needs to become standard long-term practise for environmental, natural resource and conservation agencies. It's not a stop-start process.

1.4 What will be monitored?

Deciding on what to monitor is crucial in the approach to monitoring. Practitioners have generally reached consensus about the purposes, benefits and constraints of monitoring[19]. Significant advances in monitoring have been made recently [9,24].

Data collection is focussed on the species and ecosystems that respond to a wide range of factors that cause change[21].

Monitoring needs to be fit for purpose[9,25,26] and adapted to the locations, species and ecosystems being monitored. Surveillance monitoring often addresses a broad array of measured variables determined by underlying theories of changing species or ecosystem properties[27], such as declines of species across a landscape, or concerns about effects of land-uses, climate change or altered disturbance regimes such as fire, flood or nutrient input regime.

As an example, the Essential Biodiversity Variables program helps to resolve inconsistencies world-wide in approaches to what to monitor. It takes the approach that each variable requires monitoring at time scales, frequencies and durations appropriate to each variable. So, annual monitoring of some elements may be appropriate, and monitoring at 5 to 10 year intervals may be more appropriate for other elements[28].

Essential Biodiversity Variables allow observation and reporting of biodiversity change[29]. EBVs characterize aspects of biodiversity, functioning as the interface between raw data and indicators[30] (Table 1).

Table 1 - Examples of candidate Essential Biodiversity Variables [28]

EBV Class	EBV examples	Measurement and scalability	Temporal sensitivity
Genetic composition	Allelic diversity	Genotypes of selected species	Generation time
Species populations	Abundances and distributions	Counts of presence surveys for groups of species	1 to >10 years
Species traits	Phenology	Timing of leaf coloration	1 year
Community composition	Taxonomic diversity	Consistent multi-taxa surveys and metagenomics at selected locations	5 to >10 years
Ecosystem structure	Habitat structure	Remote sensing of cover	1 to 5 years
Ecosystem function	Nutrient retention	Nutrient output/input ratios	1 year

These measurement variables need to be adapted to the individual needs of countries and regions, and the species and ecosystems of interest.

Monitoring is essential to understanding ecosystem cycles and trends and frequently leads to research questions [31,32]. Monitoring requires the same skill-sets and methodological thinking as other research.

1.5 Benefits of ecosystem monitoring/surveillance

Big wins from monitoring

Returns on investment in the monitoring of ecosystems[33] can be substantial.

For example, monitoring of the threatened Burrowing Bettong, a medium-sized marsupial, in the Arid Recovery project enabled management of the populations to allow recovery[34]. Monitoring of coral reef bleaching[35] and crown of thorns starfish[36] have enabled people to take action on climate change, water pollution and reef damage.

Insect populations across Germany have crashed by 75% as observed by monitoring and reviews of citizen science reports[37]. Tropical insects in natural rainforests in Puerto Rico have also crashed over the past 40 years[38]. These insect crashes are alarming ecologists and the agricultural industry.

In Australia we have no idea whether or not insect populations have crashed because there is no systematic monitoring. Insects and other arthropods drive most of our agriculture, so the consequences of crashes of populations are likely to be severe.

Case Study:

Critically endangered Woylie – the Brush-tailed Bettong

Woylies, small wallabies, were once common across southern and south-western Australia, but populations crashed and by the 1960s, only small isolated populations remained. Energetic efforts to control their main predators, the introduced Red Fox, enabled their populations to recover, so that their endangered status was down-graded from Vulnerable to Conservation-Dependent in 1996.

Image of Woylie here – this one is a WWF image and I haven't asked for permission to use. Perhaps Adrian Wayne has one he could donate.

Surveillance monitoring over the next decade by people familiar with the populations raised concerns that the population appeared to have dropped in the early 2000s. A Recovery Team re-established former monitoring sites to investigate, and found that the population had, alarmingly, crashed by over 90%. The species is now considered ***Critically Endangered****, with at least one population functionally* ***extinct***[39,40]*.*

Intense recovery activity has been underway with expert teams addressing the research and management needs to help the Woylie recover from near-extinction[41]*. Surveillance monitoring was critical to taking action to prevent the Woylie from going extinct.*

Big losses from not monitoring

Conversely, many crises have been missed due to inadequate or absent monitoring.

Extinctions of hundreds of species of frogs and other amphibians in Australia[42] and world-wide[43] are the result of a devastating epidemic caused by Chytrid fungus which originated in Asia. By the time it was detected, many species were either extinct or approached extinction, all because we weren't looking.

Devastating losses of mangroves in the Gulf of Carpentaria were detected by chance by Aboriginal rangers and environmental consultants[44]. Mangrove decimation was an early warning of the devastation caused by global heating.

Crashes of flying fox populations due to heatwaves and diseases, resulting in loss of pollination vectors for eucalypts and for fruit crops[45] were observed by numerous citizens and reported in newspapers, but because we don't have systematic monitoring of this group of species, detection was slow. The deaths of tens of thousands of flying foxes was another warning of the effects of global heating.

1.6 The challenges of ecosystem surveillance monitoring

We cannot measure everything, so what we measure has to be appropriate and meaningful. This challenges scientists, because we are trying to distil the complexity of biodiversity into a limited number of essential variables.

Challenges include:

- identifying critical variables for tracking ecosystems,
- translating information between different biological and geographical realms (e.g. terrestrial, freshwater and marine),
- harmonizing different methods and data for measuring and recording different components of ecosystems and biodiversity,
- selecting appropriate units and scales of measurement to ensure comparability between Essential Biodiversity Variables [30,46],
- identifying early warning signals of ecosystem decline,
- tracking and interpreting ecosystem dynamics that exceed lifetimes of scientists,
- timely action on monitoring outcomes[47].

Processes and decisions, such as the selection of ecosystems and species to monitor, are often influenced by external factors and internal priorities[19]. These factors include finances and politics[19].

2 Enabling ecosystem surveillance

2.1 The current state of ecosystem monitoring in Australia

We need a nationally consistent, integrated ecosystem surveillance monitoring program that crosses jurisdictional boundaries

Australia has multiple localized ecosystem monitoring projects and programs focussed on particular management issues or jurisdictions. They are conducted by government departments, non-government organisations, universities, resource and primary industry businesses and consultants.

However, we have very few long-term ecosystem monitoring programs over areas larger than ecosystems or catchments, at regular time periods, and in standardised ways. Regrettably, we have no national system for the collection, analysis, evaluation and reporting of ecosystem measurements[2,3,48-52].

This is in stark contrast to our well-established weather-station network, our census of households and our reporting of economic indicators[1].

Each of the State of the Environment reports[48] and strategies that Australia has developed since 1983 has recognized the *urgency* of the need to address biodiversity conservation. The government's 5-year review of the Biodiversity Conservation Strategy found similar problems.

A number of key challenges to the effective management of the Australian environment remain:

- an overarching national for the protection and sustainable management of Australia's environment is lacking. This needs:
    - specific action programs and policy to preserve and restore natural capital and our unique environments, taking into account climate change
    - complementary policy and strengthened legislative frameworks at the national, state and territory levels
    - efficient, collaborative and complementary planning and decision-making processes across all levels of government, with clear lines of accountability
    - the understanding of, and capacity to identify and measure cumulative impacts is inadequate, which reduces the potential for coordinated approaches to their management

- collaboration and coordination of policies, decisions and management arrangements exists across sectors and between different managers (public and private) must be improved

- follow-through from policy to action is necessary

- ***data and long-term monitoring must be improved***

- monitoring timeframes are too short

- resources for environmental management and restoration are insufficient

- existing monitoring efforts need to be leveraged or adapted to meet these challenges

2.2 A national ecosystem surveillance monitoring and reporting system

The Australian government's National Science Statement of 2017 recognizes the importance and value of long-term science and monitoring, as does the Developing Northern Australia policy and Australia's Terrestrial Biodiversity Assessment of 2009 [4].

The recent roadmap developed for Australia's National Collaborative Research Infrastructure Scheme requires the development of a national environmental prediction system.

We are not achieving these commitments and the urgency of action to protect habitat and save ecosystems and species has increased. Without long-term data, meeting our goals and the development of an environmental prediction system[53] are impossible.

Each jurisdiction, and the Federal Government, have in place legislation that protects biodiversity and the environment. Most of the legislation is in need of major revision to reflect the current urgency of environmental deterioration and loss of biodiversity [54].

A long term national ecosystem surveillance monitoring and reporting system is essential

Existing ecosystem surveillance monitoring differs substantially across jurisdictional borders, and needs to be made more compatible and consistent. A national body will provide this oversight and much needed consistency. A national body would also seek alignment with global efforts to enable global comparisons.

Sharing monitoring data and analyses are essential if we are to provide a national picture of the state of our ecosystems and species[33] and to engage the voting public. Species and ecosystems distributions don't stop at state borders.

They are dependant on more than one jurisdiction's management actions in order to survive and thrive[33].

A suitable platform for data sharing needs to be developed. This platform needs to accommodate different approaches used by academic researchers, government monitoring scientists and consultants. A national body could design and implement this system.

Enabling Condition 1. Socio-Political commitment

Society, Governments, Institutions and Scientists must be committed to the principle of ecosystem surveillance monitoring

Healthy ecosystems are important to all of us, for our own health, and for safeguarding the air, water, food and fibre quality associated with them.

Healthy ecosystems are vital to healthy agriculture[18], our economy and society.

Ecosystem surveillance monitoring keeps checks on the health of ecosystems. Ecosystem science provide robust, relevant information to connect monitoring and research with policy[46].

It needs the support of politicians, policy-makers and the public. Ecosystem monitoring is an urgent priority and needs to be funded and resourced over the long term[55,56].

The challenge for government is to set priorities and develop coherent policies that respect the diversity of interests in the environment and natural resources, and at the same time ensure healthy ecosystems.

Collaboration between ecologists, policy-makers, social scientists, government, industry stakeholders and the community is needed to produce a long-term vision that facilitates ecological sustainability and inclusive and adaptive approaches to land use and management[57].

There are many competing interests for funding and resources. 'Cultural barriers' need to be overcome to accommodate the influence of different natural resource use industries, ecological science, and cultures inherent to education, Indigenous Australia, economics and policy [57].

Attaining a national commitment to monitoring our ecosystems is an on-going challenge[56, 58]. Australia needs to overcome the lack of accountability and responsibility for preventing declining ecosystem and biodiversity condition [8,9,59].

Enabling Condition 2. Financial commitment

Funds and resources must be committed to ecosystem surveillance and to long-term ecological research

Investing on our ecosystems is an investment in our sustainable future

Australia should be aiming for investment in environment and biodiversity conservation to be increased substantially so that we are able to monitor the state and trends of ecosystem condition. A significant proportion of this investment must be allocated to ecosystem surveillance monitoring in order to monitor change and inform management.

A lack of transparency makes it 'impossible'[60] to calculate exactly how much is spent by Australian governments due to double dipping and a lack of uniform accounting practices among the three levels of government [60,61].

The Commonwealth environment budget should be restored to at least 2013 levels, reversing the 40% decline of recent years that has undermined the Government's ability to effectively plan or manage for healthy and resilient ecosystems [9,62]. The amount needed to be restored is around $450 million, totalling around $1.4 billion which was the 2013 budget allocation in real dollars (not counting for inflation).

Severe cuts are not confined to the Federal budget, but have been made in each State and Territory[62].

Allocation of funds to specific actions and targets must be based on the best scientific advice to ensure that ecosystem monitoring goals are achieved and the investment is used wisely.

Learning lessons from past programs

Australia's surveillance and monitoring efforts are recognized as being inadequate for our sustainability[1,63]. We have a history of spending money and resources on conservation and of commencing new initiatives and then stopping them [64]. This is *wasteful* as breaks in continuity of long-term ecological datasets significantly reduce their value and disrupt key information on environmental and ecosystem change.

We have a history of substantial funding, through programs such as the Natural Heritage Trust program, with a total investment of $2.8 billion over more than a decade[65]. Unfortunately the program did not strengthen the capacity to monitor or report on real trends in biodiversity[66, 65]. There was limited information to support intermediate or longer term environmental outcomes [18].

Subsequent major programs, such as Caring for Our Country (which subsumed the NHT program) and the Biodiversity Fund shared similar problems. The Biodiversity Fund was worth around $900 million over 2011-2019, but monitoring and evaluation of project outcomes were considered to be inadequate and funding was 're-allocated' [67].

For accountability, all ecosystem management programs need robust monitoring of ecosystems and biodiversity. Funding should be allocated on a strategic and systematic basis for the enduring outcomes required.

Enabling Condition 3. Robust consistent methodology and program design

There must be consensus on the surveillance monitoring network and on the methods used.

We need a robust ecosystem surveillance monitoring program and consistent methods that allow us to interpret data across temporal and spatial scales.

The many analyses of monitoring and surveillance programs across Australia have focussed strongly on the methods and procedures [18,25,33,57,68,69]. These are vital in ensuring that ecosystem surveillance monitoring is scientifically rigorous, produces meaningful and unambiguous results, addresses ecosystem and community needs, and is communicated well to government policy-makers, politicians and the public.

But they are not sufficient in themselves.

The program must be consistent and comparable across jurisdictional boundaries and across disciplines and institutions. This extends to consistent national and regional monitoring and sharing of such information [28], and consensus about what to monitor [28,70,71].

This problem is not confined to Australia. There is no global, harmonized system for delivering regular, timely data on ecosystem change [28] and this is being addressed by the international community, including Australia, through processes such as the United Nations Environment Program.

These are problems that the scientific community can and will resolve, given the opportunity. For example, a similar set of key components for good monitoring is recognized by practitioners[19]. They can be used to build a robust and harmonized program.

The limits to enabling ecosystem surveillance monitoring are not scientific or technical, but financial, institutional and related to society and government perspectives and priorities[55].

Enabling Condition 4. Leveraging and adapting existing monitoring systems

The ecoscience community and governments need to overcome identified shortcomings in coordination and harmonization of monitoring, and resolve 'transboundary environmental issues' [2,58]

Monitoring protocols and standard methods have been established for decades, so a lot of time and effort has been invested in establishing monitoring[9].

Numerous long-term and short-term ecosystem and species studies have been established across Australia[68,21]. National, State and Territory departments and programs could be utilised for a national framework of cost-effective ecosystem surveillance monitoring.

To this end, efforts to achieve agreement across jurisdictional boundaries are being made. These include the National Collaborative Research Infrastructure Scheme and the Terrestrial Ecosystem Research Network.

The Australian Dynamic Ecosystem Models Project of the Department of the Environment and Energy and CSIRO is developing approaches to surveillance monitoring.

The Ecosystem Science Council's proposal for an Environmental Monitoring and Management Agency or independent Commission could also take a coordinating role.

Other potentially useful monitoring programs include Ausplots Rangelands and Ausplots Forests, Auscover and the former Australian Collaborative Rangeland Information System (ACRIS) monitoring sites.

Re-establishing older monitoring sites has provided excellent data on trends in population and abundance of multiple species, even if the sites had not been monitored for a period of years[32].

The Indigenous Protected Area network protects almost half our national conservation estate, and employs a substantial number of Indigenous Rangers and advisers across Australia.

In addition to rangers on the national parks and reserves protected area network, Indigenous Rangers could provide a substantial workforce for ecosystem monitoring. Some are already providing this service, albeit on limited recurrent funding.

Collation and review of these monitoring activities should be undertaken to provide a comprehensive picture of sites that could be re-established for ecosystem surveillance monitoring.

All existing monitoring programs are in need of restored funding to continue[24,72]. Increased funding is needed to provide full ecosystem coverage and adequate representation, as most ecosystems and species are poorly monitored[24,34].

Enabling Condition 5. Communication and engagement

Ecologists have recognized that communicating the value and importance of monitoring and research [18,25,56] is critical to changing community attitudes to ecosystems and biodiversity and the threats impacting upon them.

The Biodiversity Strategy, for instance, recognized the need to engage, guide and communicate its objectives to all audiences [58].

Engaging all Australians in ecosystem and biodiversity conservation is a top priority [16].

Ecosystem scientists generally publish their work in a range of forums, including scientific peer-reviewed articles, but also through policy and management advice at many levels. We also work with managers and decision makers to determine research and investigation needs.

But most people don't read or engage with these forms of communication. We need to re-think how we convey our messages, through social media, and through 'traditional' media.

We need to advocate for ecosystem science in more effective and engaging ways, from pub chats to radio, television and other media interviews and stories.

We also need to make our stories more accessible, through dashboards and other visual means.

To gain the support of people and governments of the necessity of ecosystem monitoring, ecologists need to demonstrate the value of the expenditure on monitoring, and real, positive and clear outcomes of monitoring to society [56]. These may relate to informing management actions, or to demonstrate an improvement in populations of threatened species, or warn of deteriorating ecosystem condition[19].

We need to develop common languages among all involved in ecosystem monitoring and management.

Farmers and graziers manage ecosystems for production across 55% of Australia. They understand and talk the language of conservation of the diversity of genes, varieties, cultivars, breeds, landraces and species[5] of cattle, grains and other crops, for instance. Relating these knowledges to ecosystem health in terms that all sides understand is essential.

Indigenous and non-Indigenous rangers manage around 19% of Australia's lands and seas. They see and manage ecosystems daily. Many are involved with ecosystem monitoring and are well-placed to contribute to the monitoring. Appropriate engagement is also in need of improvement.

Box

Language of the science of a rare possum is not influencing decision-makers

The beautiful Leadbeater's Possum *Gymnobelideus leadbeateri* has been studied intensively for over 30 years. More than 220 scientific publications and eight books have been published about the species.

Photo Tim Bawden, supplied to Atlas of Living Australia, CC-BY

Yet critical forest habitat has continued to be harvested, successive laws and policies detrimental to the species have been implemented, and the Leadbeater's Possum has been downgraded from *Endangered* to *Critically Endangered* over the same period [73].

Clearly, the impending extinction of the Leadbeater's Possum has not attracted sufficient attention of the community and political decision-makers for action to be taken.

Social media campaigns, articles in magazines and newspapers, and on TV and radio are needed more than ever to gain public support for this special animal.

Urban people often lack contact with land and ecosystems, yet they have a strong influence over policies that affect ecosystems and natural resources. They also lack the language and understanding of people who work with the natural world.

Relating urban people's daily lives to their dependence on natural ecosystems that include agriculture is necessary. Concepts and terms need to be much better developed and explained, so that the language is understood by urban dwellers.

We all need to improve communication and engagement between these sectors. One approach is *citizen science* programs. Landcare has been active in engaging city-based and country people. Community conservation groups have also had positive impacts. Ecosystem scientists can also contribute to these shared understandings and improved engagement.

3 Program Design

Society expects that scientific investigation will result in a high level of certainty. Rigour in investigations and analyses is crucial.

An ecosystem surveillance program needs to be explicit in what it hopes to achieve.

It needs clear objectives and outcomes.

Ecosystem surveillance monitoring should provide Australians with a clear, unambiguous picture of the state and trends of our environment, species, ecosystems and variables associated with them.

The monitoring program must provide both the evidence of the state of our ecosystems and a predictive tool that enables us to anticipate the results and consequences of business-as-usual or changes in practices.

Sampling needs to be capable of detecting surprises [21,74]. It also needs to be adaptable and provide evidence-based solutions and proposed actions to remedy detrimental changes to our ecosystems[9].

Ecosystem surveillance monitoring should provide information on the status and trends of ecosystems and species, relationships between populations and distributional trends and their threatening processes. It should provide evidence for the effectiveness of management to recover ecosystems and species where they have been affected by anthropogenic factors[33], that is, actions taken by us.

Box

Monitoring design principles

Monitoring design principles that are common for species and ecological communities[21] include:

- being fit for purpose;
- building conceptual models of factors that potentially influence change;
- taking place across sites that represent the species' and ecosystems' distribution and environmental range;
- selecting sites for study at spatial and thematic scales adequate to detect change;
- building in adequate replication and randomising locations of sample sites;
- selecting practical, closely associated and sensitive response variables to measure [75];
- sampling sufficiently regularly to detect change of the ecosystems and species of interest;
- running for time periods that are long enough to detect trends[33];
- managing data systematically and using appropriate methods of statistical inference [21];
- being designed with sufficient statistical power for detecting change[76];
- being coordinated across jurisdictions, organisations and stakeholders;
- producing monitoring data that are publicly available and regularly reported;
- including demography, life history, abundance and distributional data of species where possible [33];
- being clearly linked to management;
- having an effective and explicit communications strategy.

Many management agencies have adopted the monitoring, evaluation and reporting (MER) framework to integrate monitoring with management[56]. This framework is useful and can be improved with an management approach[77].

4 Appendix – Policy brief

Key Issues for decision-makers

Ecosystems, species and ecosystem quality now and into the future require our urgent attention

- Australia's ecosystems provide our life-support system. They underpin all our food, water, clean air and soils. They also support our native species and our agricultural products.
- Ecosystems are changing for the worse due to our actions, and we need to monitor them so that we can manage and restore them.
- It is to our detriment if we don't know the state of our ecosystems.

Australia's ecosystem surveillance systems will take advantage of 21st century environmental management and innovation technologies

- Enormous potential exists for big data, innovation and technology contributing to ecosystem science
- Returns through **regional jobs** and **growth** can be substantial, including through Indigenous and other regional employment

Australian governments have previously committed to ecosystem monitoring that has never eventuated

- Implementing those long-standing commitments requires support beyond election cycles
- Stopping and starting monitoring programs has resulted in massive losses of information and wasted investment

Resources and finances are needed to conduct monitoring

- Monitoring costs money, but the cost of doing nothing is far greater when ecosystems collapse and affect our agriculture, water, soils, air and native plants and animals

Ecosystem surveillance monitoring should provide Australians with a clear picture of the state and trends of our environment, species, and ecosystems

- The scientific community has the knowledge and skills to implement a national monitoring system
- Monitoring programs must provide evidence of the changing state of our ecosystems as well as for evidence-based solutions
- Monitoring should have predictive capacity to enable us to anticipate the results and consequences of business-as-usual and changes in practices
- Ecosystem monitoring must be able to inform policy[46] at all governance levels and inform alternative policy pathways

Good monitoring is guided by the rules of scientific rigour

- Ecosystems are complex, but our strong knowledge base eables us to design monitoring programs that produce reliable and meaningful results
- Sampling must be sufficient to account for natural variation; methods must be fit for purpose and provide consistent information on measured variables; and analyses must reflect the most recent science

Scientific communication and engagement is crucial to a successful monitoring program

- Scientists should seek wide consultation and collaboration in ecosystem surveillance monitoring. Early engagement and buy-in is key to successful programs.
- Communication and engagement between landholders, managers, ecosystem scientists, advisers, policy-makers and society at large improves monitoring focus and outcomes.
- Advances in citizen-science have contributed to better communication and understanding.
- Commitment is needed by scientists to communicate outcomes in a way that meets the needs of government and the public.

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Ecosystem Science Council

The Ecosystem Science Council works with all individuals, groups and organisations within the ecosystem science and management communities providing scientific advice and advancing the goals of the long-term plan for Australian ecosystem science, Foundations for the Future.

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