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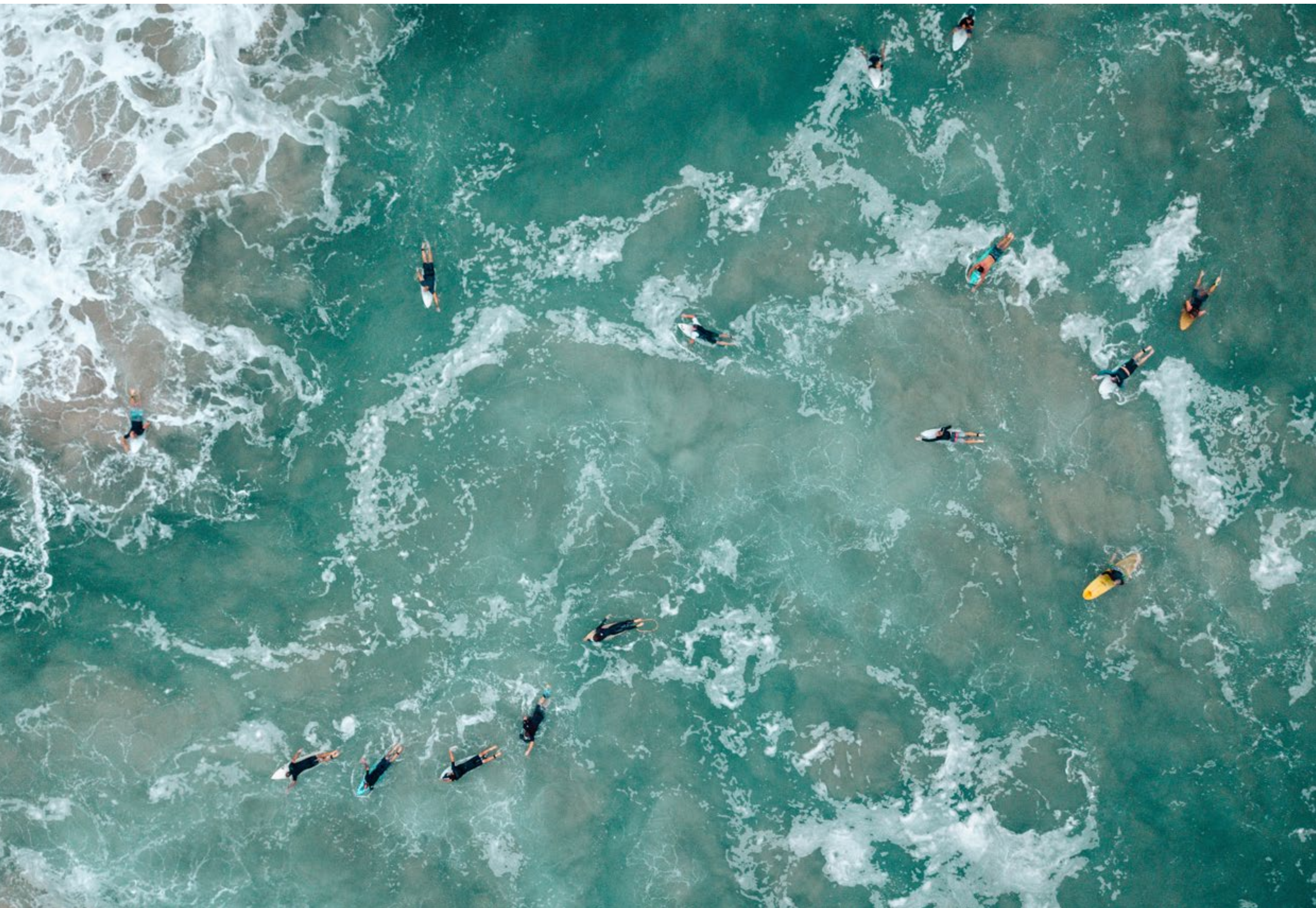
Environmental Prediction Symposium Synthesis

4–5 June 2019, Canberra

This document provides an informal synthesis of symposium discussions. It is intended to capture key contributions and the breadth of thinking, and to serve as a resource document to draw on in future development of ideas. It is not intended to be a complete formal record of symposium proceedings.



Citation

Pirzl R, Doerr V, Lemon D, McDonald W, Ahmad M, Grigg N, Fletcher C, Mokany K, Schandl H, O'Connell D, Palmer R, and Woodward E (2019) Environmental Prediction Symposium Synthesis. CSIRO Land and Water, Australia.

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Executive summary

In an increasingly interconnected and rapidly changing world, planning for a sustainable future requires future-focused and integrative approaches. Our ability to envision alternative futures, to evaluate between them, and to develop plans and make decisions, is crucial for building pathways to a future that balances thriving social, financial, and environmental systems.

As a step towards engaging with this challenge, CSIRO hosted an Environmental Prediction Symposium on the 4th and 5th of June 2019 in Canberra. The Symposium attracted about 90 national and international attendees, from a range of government agencies, universities and industry organisations including the Department of the Environment and Energy, the Bureau of Meteorology, a number of Australian universities and the Australian Research Data Commons.

The Symposium explored environmental prediction and foresighting science for Australia and pathways toward future-focused science, policy and investment through four themes:

1. **Future and problem framing:** what are the different ways people think about the future and what are the theoretical and real-world constructs underpinning prediction, foresighting, and scenario creation?
2. **Information infrastructure:** what is needed from a social, information and technical perspective, to take advantage of modern and emerging technologies such as artificial intelligence and machine learning, digital twins and new data streams to enable prediction and scenario science?
3. **Modelling for prediction science:** what is the role of conceptual and formal models and what is the state-of-play in integration and multi-model frameworks, modelling approaches and assessments to address real-world issues?
4. **From prediction science to application:** what are the social processes and institutional relationships that can connect scientific expertise with application expertise (policy and planning, business, and management) to mutually catalyse progress on future-focused sustainable pathways?

New horizons of future-focused science and application

'Have the confidence to imagine and courage to act on it. Acting on your predictions requires individual courage but also an enabling environment to encourage you to be brave.' Mark Crosweller, National Resilience Taskforce.

Discussion during the symposium emphasised that environmental prediction capability is urgently needed to inform decision making, to support transformational leadership, to support leaders to be agile and responsive as the world changes faster than we can keep up, and to support us to deal with increasingly uncertain futures. We need people engaging across disciplines and different domain areas and starting to work together in spaces that they are not comfortable in. We need to learn how to navigate a world that is changing rapidly.

Our knowledge, models, tools and standards are becoming insufficient for the challenges of the future. A national prediction capability will help us learn, explore the limits of possibility, understand how ecosystems are changing and understand future uncertainties and risks. It will inform choice and better decisions, inform adaptive planning, effective interventions and understanding of cumulative impacts. It will give credibility to decisions and provide a basis for action and learning.

We also need to grapple with what we don't know. The flipside of knowledge is uncertainty and its always going to be there. It is dangerous to extrapolate beyond data, but we are moving faster than our datasets. We have uncertainty, specificity, nonlinearity, long time frames – we need to learn to work with uncertainty, complexity and not having all of the answers.

Data doesn't change minds as much as storytelling – we need to use prediction capability to cleverly weave a narrative that engenders trust and engages people, developing future scenarios that anyone can use to understand the future and to plan how they respond. Generic predictions could be enough to drive policy change if people were able to understand them and they help identify things to focus on.

The Symposium highlighted that this is a collective effort. Focusing prediction science efforts to achieve impact and benefit for society requires an understanding of the diversity of actors and their needs, motivations and benefits. The challenge is not technical but about bringing people and domain knowledge along together. This requires co-development of knowledge, practices and tools and modelling across many dimensions – qualitative scenarios, quantitative investigation, integrated modelling.

What would prediction be used for?

Avoiding futures we don't want and working towards futures we do want

What must a usable prediction capability provide?

Meaningful and trust worthy guidance on complex, uncertain and high priority challenges for Australia

Ability to adapt what prediction delivers as the world evolves, our understanding of it, and our aspirations

Enabling environment for collaboration, learning and adaptive decision making

What have you heard that you will keep in mind?

Solutions are only ever partial and temporary

Interdisciplinarity requires its own specific expertise

Collective ownership will be required for predictive models to work

Develop the tools that cover the scales that managers care most about

What are the key challenges in achieving a national research and/or operational capability for environmental prediction and why are they not already being addressed?

Value proposition for the community

Environmental data is local, purpose specific and does not necessarily scale

We need to understand what people are trying to predict or would like to be able to predict

Does prediction introduce new challenges?

One past, many futures

We need an evidence base to help people assess whether a model is reasonable

Articulate predictions so that they can be used responsibly

Relationships and knowledge from past data may not apply well to the future

Environmental Prediction Symposium overview

Need

Focusing prediction science to achieve impact and benefit for society.

Understanding the diversity of actors and their needs, motivations and benefits.

How environmental prediction could help overcome key challenges.

Future and problem framing

Diverse approaches for exploring environmental futures, multidisciplinary perspectives on uncertainty and risk, and future ready problem-framing and objective setting.

Information infrastructure for prediction science

Assessing the information infrastructure (technical, information and social) needs of prediction science, current capabilities and solutions to fill gaps.

Modelling for prediction science

Understanding the current modelling capabilities of environmental prediction science both within and across domains.

Prediction science to application

Building a knowledge base for decision makers and practitioners to support more future-focused decision-making relies on new science to understand how to link science and application.

Team challenge

Bringing it all together

How would you combine leading-edge science in problem framing, information infrastructure, modelling and bridging science into application to provide new predictive solutions.

1 Exploring the need for prediction science

Mark Crosweller

'All of risk is about anticipating the future. Have the confidence to imagine and the courage to act upon it.' Mark Crosweller, National Resilience Taskforce.

Resilience and vulnerability: two sides of the same coin

Resilience is often championed as a key strategy for managing the inevitable impacts of natural hazard events. However, without balancing efforts in resilience with efforts in risk reduction, resilience will become increasingly difficult to achieve and sustain.

Resilience and vulnerability are two sides of the same coin. The Australian vulnerability profile challenges norms. We can't solve a catastrophe, but we can get better at responding to it. Our problems start with where and how we place ourselves in the landscape and the attitudes we bring. Six drivers for action:

1. Natural hazards are more frequent and intense.
2. Essential services are more interconnected and interdependent.
3. People and assets are more exposed and vulnerable.
4. Disaster impacts are long term and complex.
5. The costs of disasters are growing.
6. Momentum to address financial impacts of a changing climate is building.

Decision making needs to be informed by a future state that is reliable, adaptable, flexible, and able to move with changing circumstance. Prediction needs to be flexible and adaptable. How do we get better at making decisions and accessing better knowledge? All of risk is about anticipating the future. The future is exciting but also contestable – have the confidence to imagine and the courage to act upon it.

We often face reluctance to embrace the future. Risk may be ignored on the basis that it is unlikely, meaning that we don't adequately prepare for rare events. We can't trade our way out of managing risk, and modelling has to contemplate unlikely occurrences. Public policy usually stops at the point of impact, and rarely looks at the full potentiality of loss and suffering and how to understand and come to terms with it and how to recover fully from the loss.

Beth Fulton

'Our story telling had been a big part of how we make sense of our world. Dangerous to extrapolate beyond data, but where we are living is moving faster than our datasets. Managing fisheries is like managing forests, except that you can't see anything, and everything keeps moving around.' Beth Fulton, CSIRO.

What an exciting (terrifying) time to be a modeller!

For generations environmental prediction (biophysical and ecological modelling) has centred on the scales we live at – the population to regional landscape scale that typify 'ecosystem scale'. This has seen models focus on the mechanisms shaping the spatial and temporal patterns characterising these ecosystems. It can be argued that over the last 20 years in particular, modellers had become relatively comfortable with the capacity to model these scales, though there was still a lot of devil in the detail at the margins. However, the new challenges facing society are drawing environmental prediction into those margins, into new scales (the very large and very small) and new processes, such as dynamic evolution. This is seeing the development of new analytical and modelling methods. A lot of effort in the coming decades will go into mastering these methods, weaving in the new scales and processes and revolutionising the way we communicate the results so that it truly supports informed decision making.

Our story telling is a big part of how we make sense of our world. We are facing a world not many have thought about beyond science fiction. Story telling is a big part of how we make predictions, so it is important that we don't shy away from imagination; there is richness in alternative knowledge systems and Indigenous knowledge. We now have new processes to consider – evolution happens in real time. Models help synthesise information. Mathematicians, ecologists and psychologists together need to develop new solutions. We need to make models more effective as challenges leave us with fewer buffers.

How do we make models more meaningful? It is dangerous to extrapolate beyond our data but we are changing faster than our datasets. People have a static view of the world and a distrust of models. Safe messages can be very comforting, but trade-offs are our new reality and are less palatable. Uncertainty, specificity, nonlinearity, long time frames – we have computing power and smarter approaches.

Rob Vertessy

'We broke the Holocene. Users have a whole heap of urgent worries, but they struggle to specify what they need that will help them make a better decision. Story telling is important for shaping the public view of how our environment is trending.' Rob Vertessy, University of Melbourne.

National environmental prediction system (NEPS)

The Australian Government Department of Education and Training has commissioned the NEPS Scoping Study to provide technical assessments and requirements analysis for a NEPS, and to define implementation costs and timeframes to establish and manage a NEPS as national research infrastructure to meet researcher and operational user needs. The NEPS Scoping Study involves undertaking targeted consultations with key experts and stakeholders, including relevant areas of the existing National Collaborative Research Infrastructure Strategy (NCRIS) network.

Vision: infrastructure that entrains the research community in helping decision makers utilise environmental intelligence for public benefit. NEPS will provide infrastructure that satisfies research needs and operational systems suitable for agencies. We need environmental prediction more than ever before tailored to the requirements of decision makers. NEPS will be important for linking research and decision-making communities more tightly together. Users struggle to get down to the level of specifying what they need. Science communities need to build on what they do well. We have examples in the Bureau of Meteorology, Geoscience Australia, and the water resources sector where stakeholders value the science underpinning their predictive capacity and they want to invest more in it and become champions for it.

Jill Edwards

'Knowledge, models, tools and standards are becoming insufficient for the challenges of the future. Stability and social and natural systems can't be taken for granted. I think we've got this. We have good capability and knowledge, enthusiasm and talent.' Jill Edwards, National Resilience Taskforce.

Beyond business as usual

It is more and more evident the world can no longer rely on the stability of social, economic and natural systems affected by the growing resource demands of more than seven billion people and a changing climate. This situation gives rise to a growing and urgent need to make transformative decisions in the face of deepening uncertainty and increasingly inexact (even entirely absent) information and within multi-sector governance structures.

Despite Australia's world-leading plans and capabilities, disaster trends challenge us and can overwhelm our collective ability to cope. As the nation's disaster risk grows, the capacity of households, communities, industry and governments to be resilient to disasters diminishes. Disasters shine a light on existing and systemic problems. They illuminate the stresses, dependencies and challenges that were already there and create new ones. To reduce systemic disaster risk, we need to understand the points at which risk is created, managed and transferred. To do this we need better decision-ready data, information and guidance, scaled and contextualised for a future that is increasingly uncertain. The challenges demand we go *beyond business as usual* and co-design new approaches to better prepare and coordinate existing efforts and investments. We need to do more than change at the margins.

As the stakes get higher and experiences become more challenging, we need to help people understand the holistic nature of systemic risk. The stability of our systems can no longer be taken for granted. Stressors are accumulating, leading to tipping points, and demand is growing to address financial impacts of a changing climate. Knowledge, models, tools and standards are becoming insufficient for the challenges of the future. Modelling is critical to harness knowledge across time, space and disciplines. Decision processes are not geared towards climate and disaster risks. Market, regulatory and policy incentives need to align. We need to learn how to navigate a rapidly changing world. The momentum and need for predictive modelling are growing for short- and long-term operational decisions.

Beth Brunoro

'We in government make decisions that have real impacts today as well as profound ramifications for the future. While investing in straight environmental research is still very important, the complexity of cross cutting policy issues increasingly requires prediction science capable of integrating social, economic and environmental analysis at different temporal and spatial scales.' Beth Brunoro, Department of the Environment and Energy.

Environmental prediction and empowering end-users

It is important that sound science, information and research continues to guide the functions and responsibilities of government. The need for prediction science is a constant across a range of spatial and temporal scales, from making 'every day' optimisation decisions to achieve operational outcomes, to crafting policy advice and interventions with long time horizons.

We (in government) need timely and fit for purpose access to science advice. While investing in straight environmental research is still very important, the complexity of cross cutting policy issues like climate change increasingly requires prediction science capable of integrating social, economic and environmental analysis at different temporal and spatial scales. Climate projections alone won't provide all we need.

The contestability and transparency of the evidence base is an ongoing pressure and needs elevated focus. It is essential that, as we develop new predictive science capabilities, the underpinning assumptions and scenarios embedded in these capabilities are able to be openly analysed, communicated and discussed. There are a range of plausible futures when seeking to understand dynamic systems and policy domains; prediction systems that enable open dialogue on the pros and cons of taking particular decisions or policy avenues are what is needed to meet today's complex challenges.

Key messages

We need to consider the adaptive learning paradigm around the decision-making system. A national prediction capability needs to learn from the predictions that have been given (and gotten it wrong). There is no certainty, it doesn't exist. It is about understanding choices and knowing trade-offs. Choice is an explicit part of what prediction delivers. We need to build the capacity of decision makers to understand what choices they have in front of them.

Data doesn't change minds as much as story telling. Those who can engender trust and use the information cleverly to weave a narrative around it get better results. Start with those people who are making big decisions and explore how they make those decisions with or without the information they need. Critical infrastructure operators are connected to how we live our lives and society. Help people with the immediate operational issues and reduce intervals between events that have cascading effects on society and economic repercussions. Poorly informed decisions have long lasting impacts.

Predictive models and capabilities are more than a database platform. It also includes the people who translate this information to decision-ready intelligence. People in complex roles have extraordinary capabilities but uncertainty affects their decision making. There are domains with perfect predictive models and despite this, well-informed decisions aren't happening. There are also users who want to be well informed. This motivation exists in the private sector investment community. In the short-term it is about pricing risk and about degrees of confidence that investments will be viable into the future.

1

Who needs prediction?

- Decision makers, planners, policy makers, regulators, resource managers.
- Essential services, insurance companies, industry, agriculture, investors, operators, businesses, financial sector, researchers, reporters.
- Future generations, global community, Australian public, politicians, government, national parks, environment.

2

What would prediction be used for?

Optimise well-being of population, animal life and vegetation under a range of possible futures. Save threatened species and prevent further habitat degradation, protect the long-term public good, disaster mitigation (especially climate change mitigation).

Learning about systems and change, exploring the limits of possibility, understand how ecosystems are changing and understand future uncertainties and risks. Understand change in climate and environment and resilience to future challenges. Inform choice and make better decisions, inform adaptive planning, design effective interventions, understand cumulative impacts of policy options.

Navigate to a safe, prosperous and sustainable future for all in a rapidly changing world. Plan for the future, reduce uncertainty around future states, work towards futures we want. Optimise investment, improve outcomes and reduce economic, social and environmental risk. Give credibility to decisions and provide a basis for action and learning. Support people who have complex roles.

3

What must a usable prediction capability provide?

Plausible scenarios that can be used to inform national debate about the future. Scenarios reveal consequences of current settings and illustrate potential outcomes to encourage people to think across a range of possibilities and understand multiple views. Insights catalyse prudent decisions on our use of environmental resources. Adapt as the world evolves, our understanding of it, and our aspirations.

A framework for transparent execution of scenarios: Findable, accessible, interoperable and reusable data and models. This includes:

- models that are robust and can be validated
- quantitative assessments that dynamically bridge domain areas
- acknowledgement of structural uncertainties and nonlinear change
- flexibility to point to the most critical need
- auditable trail of assumptions and limitations of the data and models used to generate predictions
- a user friendly, accessible ‘interface’ to engage a multitude of stakeholders
- enabling environment for collaboration, learning and adaptive decision making
- reliable predictions in a useable form for decision making
- reliable spatial-temporal trajectory of changes in a system
- information is trusted, timely, appropriate resolution and scale, fit for purpose and readily understood with measures of likelihood and uncertainty
- allows comparison of trade-offs between different adaptation paths.

2 Future and problem framing

Diverse approaches for exploring environmental futures, multidisciplinary perspectives on uncertainty and risk, and future ready problem-framing and objective setting.

Mark Stafford-Smith

'We need to reconcile the tension between knowledge, values and rules in order for decision making to move forward.' Mark Stafford-Smith, CSIRO.

Framing complex social-ecological futures

How can environmental prediction and modelling interface with societal processes of visioning futures? Scenario processes are often described as differentially exploring what is *likely to be*, what *could* be, or what *should be*. While being able to draw on some similar supporting information, these have profoundly different purposes, requiring different methods and forms of engagement. In particular, the role of stakeholders in relation to technical support differs critically.

- What is likely to be: 'problem focused' scenarios.
- What could be: 'actor-focused' scenarios. Interactions between domains. Ownership of problems and important interactions. How to 'war game' emergency or disaster plans.
- What ought to be: 'process-focused' scenarios. People may agree on lots of issues but need to deal with the differences in opinion.
- Opening up scenarios to more stakeholder input also highlights diverse values that cannot all be captured in conventional environmental modelling. In recent years the simple use of 'triple bottom line' to approximate this diversity has given way to a more sophisticated but complex framing such as that of the Sustainable Development Goals. This provides new opportunities with a mix of quantitative and qualitative approaches to think about how to manage conflicts in objectives, and at least then maximise synergies and identify key trade-offs in ways that can seek to take the heat out of polarised debates.

We need to reconcile the tension between knowledge, values and rules. Sustainable Development Goals have helped to set a framework for what we want. Our modelling usually doesn't report on distributional outcomes so it's hard to think about winners and losers. We need to make it clear that investing in the environment can help other areas of government. We need our environmental prediction platform to work at a scale that winners and losers can be identified so we can better understand future scenarios.

Gabriele Bammer

'Improved expertise is needed to deal with systems, values, contexts, unknowns and imperfection. Knowledge is like an island in an infinite ocean of unknowns. As we know more, both the island and the shoreline (our knowledge of what we know we don't know) grow.' Gabriele Bammer, ANU.

Disciplining interdisciplinarity and embracing unknowns

Effectively understanding and responding to complex societal and environmental problems requires more expansive ways of approaching problems and significant new expertise, not just tweaks to business as usual. Interdisciplinarity requires specific expertise to address problems with:

1. no clearly defined limits
2. contested definitions
3. unresolvable unknowns
4. real-world constraints on understanding and action, and
5. solutions that can only ever be partial and temporary.

This expertise needs to be codified so that it can be effectively shared, taught and built on. One way to achieve this is through a new discipline of Integration and Implementation Sciences (i2S), structured around three domains: synthesis of knowledge from disciplines and stakeholders, understanding and managing diverse unknowns and supporting policy and practice change.

Of these, understanding and managing diverse unknowns is least developed. Various taxonomies are starting to highlight different kinds of unknowns, for example known unknowns, unknown knowns and unknown unknowns, as well as differentiating what we are ignorant of from what we choose to ignore, or distinguishing error from vagueness. There's also growing interest in how to deal with unknowns that cannot be either reduced or ignored but must be accepted. The key issue is avoiding adverse unintended consequences and nasty surprises, especially those with major impacts.

Interdisciplinarity requires its own expertise – especially in dealing with systems, values, contexts, unknowns and imperfection, all of which help in understanding how far we can push predictive modelling.

Six ways to deal with unknowns include: reduce, banish, accept, exploit, surrender and deny. Considerable focus is on reducing or banishing unknowns and we need to improve capacity to accept unknowns, such as being flexible in dealing with surprises. There is ongoing work in building all the different areas of expertise discussed, but much of this effort is fragmented and it needs to be brought together to improve expertise for understanding and tackling complex problems.

Michael Dunlop

'It's not enough to discover current management is not working as change happens, we need to be working on new options in advance, so we are ready to transition to new methods.' Michael Dunlop, CSIRO.

Environmental prediction through the lens of transformational adaptation

There is a very real prospect that future environmental change will drive transformations in society. Future environmental change will be widespread, affecting every corner of the planet, all ecosystems and all sectors, and it has the potential to lead to impacts on society that are significant and necessitate responses that are markedly different from current practices.

Our approach to enabling adaptation to transformational environmental change can be used as a frame to help assess the needs for environmental prediction.

Key points about the approach:

1. It addresses adaptation as a governance problem, looking at the needs of decision makers at a societal level, as an alternative to analysis driven by an understanding of impacts.
2. It identifies different types of future information needs, for example those associated with anticipating:

- what successfully living with change might look like (the scope of a transformed system)
- the challenges for decision makers and society in getting there (transition to a new system)
- information that will help overcome barriers to transition (learning to do differently).

3. It highlights the complex nature of the interactions between knowledge and values and rules, and the benefit of viewing this as a co-evolutionary process rather than a knowledge transfer process.
4. It reveals the multiple different people, organisations, sectors, and so on, that require knowledge about the future in order for society to be able to transition.

Climate adaptation is about anticipating transformation. It involves understanding three things: implications of future change, understanding how to make different decisions, and designing actions to enable multi-level learning to overcome barriers (adaptation pathways). It is important to understand the decision context – values, knowledge, rules – in order to know how to make information useful.

Current climate adaptation approaches are going to become less effective and we will need new solutions. Climate adaptation needs to envision a large range of potential scenarios with the possibility of new problems emerging. Climate change will have impacts on diversity, but we can still have valuable protected areas that can be resilient and overcome the problems associated with climate change. We need to find barriers to action and bring together people working on different parts of the problem. We may discover current management is not working but needs to be working on new options in advance, so we are ready to transition to new methods. There is going to be change and we need a system for framing decisions.

Key messages

Environmental regulators are making decisions on very specific things, creating a demand for environmental prediction. But will environmental predictions increase certainty about the future? Or will predictions be questioned and increase uncertainty and fear in the broader community?

We need future scenarios that anyone can use to understand the future and to plan how they respond. Generic predictions could be enough to drive policy change if people understand them and they help identify things to focus on for more detail. In framing the future, it is critically important to understand objectives and motivation. Different styles of scenario development are needed for communicating.

We need to consider community values to support and enable action. We need to reconcile scale and complexity of modelling and decision making with the need for tailoring solutions. How can a 'prediction' system be flexible enough to allow people to explore different values? How can values be introduced? Predictions require trade-offs; how do we apply values-knowledge-rules? How do we identify unknowns and make them more of a known entity? Collective ownership will be required for predictive models to work. Who are we doing the modelling for? What is the context? Why are we doing it?

We need strategies for deciding next steps in the face of enormous uncertainty. We resist uncertainty but the solution isn't inflexible adherence to rules and models. People will gravitate towards messages of stability and certainty. By collecting more data about where we are now our environmental prediction will get better. If we don't know where we are now, we can't monitor change. We need to focus on learning and improving rather than achieving goals. We can learn as we go, multi-loop learning, asking: did it [an action] work as planned, was it the right thing to do, how do we decide what 'right' is? We cannot be paralysed by the unknowns; targeted intervention is key. Solutions are only temporary; understanding 'change' is important for decision making.

1

Uses for an environmental prediction capability

- Explore trajectories in non-stationarity systems influenced by biophysical change and human actions and interrogate predictions from the perspective of different values
- Help us to face up to unresolvable uncertainty and unknowns, to adapt to surprise, to go beyond diagnosis to designing interventions (e.g. where and how to place ourselves in the landscape)
- Identify and explore shared future pathways, identify pathways that are most acceptable to the greatest set of value systems, articulate and navigate trade-offs
- Meta-analysis of environmental systems to identify catastrophic outcomes.

2

Challenges to address in an environmental prediction capability

- Develop approaches for modelling environments that are changing faster than we can measure. Go beyond paralysis or resistance to uncertainty: seek partial, temporary solutions evolving within an adaptive learning process. Have humility about what we do and don't know. Help people engage with uncertainty and complexity. Provide guidance on when we have good enough knowledge to act.
- Enable science-to-policy brokering and tailoring, balance developing complex models at scale with tailoring for specific needs, be responsive to different contexts, help users identify their needs. Reframe away from "what is your problem?" to "what do you want to achieve?" so that knowledge supports action, not just diagnosis. Use multi-loop learning and adaptation processes.
- Develop collective ownership of predictive infrastructure to ensure relevance, trust and acceptance. Recognise the values that support authorising environments for action. Recognise and build interdisciplinary expertise, including ability to handle multiple perspectives and values.
- Reduce fragmentation across disciplines, and in planning and decision making. Integrate environmental, social and economic dimensions. Make links using frameworks such as the Sustainable Development Goals.
- Systematic analysis and interpretation at scale, drawing on multiple methods, both qualitative and quantitative, work across multiple scales. Evaluate predictive skill to support ongoing learning and revision.


Environmental Prediction Symposium

3 Information infrastructure for prediction science

Assessing the information infrastructure (technical, information and social) needs of prediction science, current capabilities and identifying solutions to fill gaps.

Building infrastructure is not easy. It requires a lot of thinking and investment in tools (hardware and software), information (semantics, context, access) and social architecture (controls, enablers, incentives). Different domains – climate, water, socioeconomic, biodiversity – all have different languages, implement things in different ways and operate with different conceptual models of the world.

Andre Zerger

'Barriers still exist to harnessing the full richness of data that exists in Australia.' Andre Zerger, CSIRO.

Connecting data infrastructure with prediction systems – opportunities and challenges

Environmental data infrastructures have reached a point of maturity in Australia where they can now operationally support a suite of environmental monitoring, reporting and prediction needs at a relatively low cost of entry for users (output-side). However, barriers still exist to harnessing the full richness of data that exists in Australia that will be necessary to deliver integrated prediction systems (input-side). These include:

1. Interoperability "burden" – is the burden on the data provider or the system. In many examples, the interoperability responsibility is pushed to data providers.
2. Participant maturity – technical and social. A barrier to working with users of water and environmental data, particularly in government, is access to technology. Organisations need the ability to host data and APIs and web browsers. Participant access needs to be built into the design of a forecasting system.
3. Effective social architecture – soft enablers for supporting data infrastructure including governance, agreements, access to participants.

Sarah Richmond

'The challenge remains to bring these data together and expose them to methods and tools to analyse the interaction between biodiversity and the environment.' Sarah Richmond, Griffith University.

ecocloud: connecting an ecosystem of infrastructure for environmental research and decision-making

Access to good quality ecological and biodiversity data alongside analysis tools is critical to synthesising our understanding of the natural world and making forward projections into novel conditions. Recent technologies have enabled consistent and continuous collection of ecological data at high resolutions across large spatial scales, and there are a number of initiatives and institutions collecting this data. The challenge remains, however, to bring these data together and expose them to methods and tools to analyse the interaction between biodiversity and the environment. These challenges are mostly associated with the accessibility, visibility and interoperability of data hosted in disparate places, and the technical capacity, computation and analysis needs of those interpreting the data.

ecocloud is an online environment that works the way ecologists do. It consists of two virtual laboratories, *ecocloud Platform* and the Biodiversity and Climate Change Virtual Laboratory (BCCVL), that provide specialist data visualisation and analytical tools and workflows for transparent and repeatable analytics. It also includes an innovative training and skills development program, EcoEd, to help drive a skilled workforce of students, researchers, government practitioners and industry professionals.

When building infrastructure think about sustainability first and foremost. Understanding and predicting change is complex and requires a lot of data and participation by diverse organisations. *ecocloud* is a large collaborative effort, involving many institutions and comprising core infrastructure, external services and data connections, a microservice toolbox and a platform / application layer.

Matt Paget

'The challenge is not technical but about bringing people and domain knowledge along together.' Matt Paget, CSIRO.

Terrestrial Environment Research Network (TERN)

- Interoperability: NCRIS facilities are 70% along pathway for interoperability. Work required to be more machine readable, identify fit for purpose, introduce uncertainty as metric or data layer.
- People to data: Trend is for data to go into centralised services and data repositories. Take work to data rather than data to work. Approximately 30% of our work happens on cloud and repositories.
- Commercial compute: Commercial providers able to support compute and analytics. Efficiency, diversity, redundancy. Our target should be to use those resources in most efficient manner. We need to get better at trust and security, adapt and adopt, costs and market.

As we bring data into repositories, people need to figure out data management, infrastructure and standards. APIs become a user interface for working across platforms. The challenge is not technical but about bringing people and domain knowledge along together. We need to learn from others – bring community together, set standards together, standardise and aggregate, community-oriented data structure. Ask the user – how do they want to interact, which data and how do you want to use it?

Adrian Burton

'If we want to predict environmental futures, what reference datasets do we invest in?' Adrian Burton, Australian Research Data Commons.

Australian Research Data Commons is a good data system that works well. Data services include storage and computing services using a nationally coherent system, capacity, coordination, software and platforms, people and policy. It is globally unique and has referenceable identifiers.

NCRIS – transforming digital infrastructure to support leading edge research and innovation. A set of ingredients for working with information infrastructure; technology in storage and compute; content, data and analysis; partnering with the environmental prediction community. Includes services for discovery of data assets, national identifier service (unique globally referenceable identifiers), terminology, data.

Transformational national reference collections – Investing in partnerships for really big datasets that can't be operated by a single organisation. What are the big reference datasets we need for environmental prediction? If we want to predict environmental futures, what reference datasets do we invest in?

Software and platforms – Joint assets to be re-used among different discipline communities; nationally significant modelling assets.

People and policy – Building expertise, culture of how to work at scale, new literacies required, policies of organisations and funders and government agencies. Bringing together key players to build capacity at scale in data and analysis; need to build data assets and analysis platforms at a scale not done before.

Simon Hodson

'What are the challenges?' Simon Hodson, Co-data.

The remit of the Committee on Data of the International Science Council (Co-data) covers all areas of research, for example, Future Earth, urban health and wellbeing. Relevant to challenges of data integration and interoperability, data policies and advancing data science, specifications, data training and education.

1

What are the key challenges in achieving a national research and/or operational capability for environmental prediction and why are they not already being addressed?

- Need a value proposition for the community – fragmented governance, no shared vision about what prediction is, operating environment is diffuse, amorphous and complex. Changing policies and rules undermine predictions. What changes will be made as a result of predictions?
- Scenarios for alternative futures – reducing multitude of possibilities to a consistent, accepted and manageable set of shared socio-economic pathways at Australian scales. Temper expectations and communicate uncertainties and probabilities: what's likely, what could be, what should be.
- Lack of processes and incentives to share data or agree on common protocols – constraints include leveraging of IP, sensitivity, commercial, privacy, risk considerations, legal, etc. Short funding cycles – don't gain the benefits of sharing data, models, digital assets.
- Knowing that capability exists – ease of access, discoverability, ease of use and being allowed to use it. Knowing and testing capabilities and limits.
- Acceptance and trust in predictive models – lack of trust in others using data appropriately, releasing data perceived as a threat, lack of trust in models, may expose sub-standard data.
- Accountability – know why we are doing it, understand the consequences of wrong predictions. Make the tools to arrive at the point that the end-user needs.
- Data needs expertise to be of value – environmental data is local, purpose specific and does not necessarily scale. Need to retain more informative data and context to help scale data.
- Standards – transferability, interoperability, processes, automated metadata generation, modelling frameworks, approaches, languages and interfaces.
- Lack of infrastructure – many organisations don't have the technical capability to share or store data, computational expertise, skills and capacity.
- Information architecture is different across scientific cultural backgrounds. Need scientific acceptance of tools that increase access to modelling capability.
- Projection vs prediction and Forecasting vs. decision support. Forecasting futures required acknowledgement of past change and non-equilibrium dynamics. Challenges of model/data fusion.

2

Most infrastructure aimed at understanding past or current state. Does prediction introduce new challenges?

- Good infrastructure for data curation but not the same skill set as needed for modelled data. Models need to be maintained as well as input datasets so they can be reproduced and stand up to scrutiny – provenance, transparency, data formats, algorithms, accuracy of data changes and so on.
- Lack of investment in infrastructure foundations – there are costs in pulling data together and managing it. Most funding is about solving problems not building a baseline capacity.
- Uncertainty – highlighting what we don't know affects credibility of scientific community. Challenges with modelling non-stationarity. Scientists need to outline implications of predictions and demonstrate evidence base – convincing others that model outputs are reasonable.
- Scenario planning – recommended for climate change because of the level and nature of uncertainty beyond what can be represented probabilistically. Modelled data will be specific to a scenario. How to articulate outputs and make them available but ensure they are used responsibly.
- How do we manage use and uptake and interpretation of outputs knowing that relationships and knowledge from past data may not apply well to the future?

4 Modelling for prediction science

Understanding the current modelling capabilities of environmental prediction science both within and across domains.

Steven Lade

'Understanding environmental shifts also means being able to understand human systems. Sometimes the product is not so useful as the process taken to get there.' Steven Lade, Stockholm Resilience Centre.

Modelling complex systems – Regime shifts and resilience in social-ecological systems

My research deals with two phenomena that make environmental prediction difficult: (1) Ecosystems are subject to regime shifts: nonlinear shifts in ecosystem state that are large, sudden and difficult to reverse; (2) Understanding human behaviour is crucial for managing ecosystems. People behave in complicated ways, that can be difficult to predict, and can display nonlinear dynamical patterns such as traps. While these uncertainties can render prediction difficult or impossible, all is not lost. Modelling can still be used to explore and understand the mechanisms that govern human-environment dynamics and anticipate what kinds of future dynamics are possible.

We are all modellers; we build models to project how much of a resource might be available in the future, to understand unexpected events, to explore scenarios and to communicate. To understand environmental shifts, we also need to understand human systems. We use models to explore a system's dynamics and how those dynamics depend not only on external drivers but on the changing structure of the system itself.

Nonlinearity and complex social-ecological coupling. Regime shifts are hard to predict, with little or no warning and are the result of complex feedbacks, often unknown historically. They are difficult to reverse.

To properly understand ecosystems, the coupled social-ecological system needs to be modelled. Human behaviour is affected by many drivers on multiple scales, it is not rational and is context-dependent.

Carmel Pollino

'It is crucial to understand the purpose before you start modelling – which includes lots of stakeholder engagement.' Carmel Pollino, CSIRO.

Linking environmental modelling and prediction to decision making: water and basin management

Murray-Darling Basin is a good example of using predictive modelling to inform decision making. Crucial to understand purpose and that requires extensive stakeholder engagement. Environmental prediction informs many questions. What are we targeting environmental water for? Why do we need a sustainable diversion limit? What are the likely outcomes of different scenarios? How do we influence decisions?

The first challenge is synthesising existing knowledge. The second challenge is linking robust science with policy – scaling information to the right context, adding ecological complexity into water modelling, allowing for built infrastructure, governance arrangements and policies. We can't consider outcomes in isolation, but we need to consider whole ecological systems, across physical scales and trophic representations. Framing and co-design takes time but is definitely worth the effort. Understanding the policy and science environment, taking in the perspectives of a range of users, is really important, along with shared capacity, tools, and technologies.

Andrew Rendall

'The frontier of knowledge – pushing it out makes it clearer what we don't know, so the frontier of ignorance is actually really important.' Andrew Rendall, CSIRO.

Integration science and modelling (ISAM): At the frontier of integrated modelling capabilities

CSIRO's Integration Science and Modelling (ISAM) is on the frontier of integrated modelling capabilities worldwide and can quantitatively address a wide variety of topics across multiple dimensions. This capability builds upon the deep domain expertise across CSIRO using applied scenario science, sophisticated computational frameworks and macroeconomic models. ISAM underpins the on-going Australian National Outlook (ANO) series that highlights the strengths of scenario-based modelling. Starting with the ground-breaking achievements of the first ANO (2015), ISAM continues to be a global benchmark for high-impact and scientifically rigorous integration capabilities.

Core models of ISAM are economic models and other models are integrated with it. ANO2 explored how to make Australia better, more prosperous, and was not focused on environmental outcomes. It used climate change and biodiversity for spatially explicit land use trade-offs models. ANO3 seeks to understand climate change in a more robust and thorough way. ANO3 will start from Productivity Commission question on the environmental impact of population patterns in Australia.

This requires modelling across many dimensions, not just economics: co-development of storylines, qualitative scenarios, quantitative investigation, integrated modelling, interpretation and reporting, co-development of knowledge, practices and tools. ISAM is a capability that is already in place – hardware, software, people, constantly being developed and aligned with domain-specific models. It is scientifically rigorous, well cited and published, has impact and addresses big questions.

1

Where has environmental modelling had the biggest impact on decision making?

- Bureau of Meteorology weather forecast and extreme weather event forecasting, hazard forecasting, flood and storm modelling, fire regime and fire weather warnings.
- Montreal Protocol-Ozone hole, Ozone modelling, IPCC, Climate Earth System Modelling, Climate change forecast, earth system modelling, acid rain modelling.
- Fisheries system model for harvesting regulations, biosecurity impact pests, resource allocation sustainability and livelihood, Murray-Darling Basin water resources.
- WorldClim and BioClim, IUCN red list of ecosystems, Millennium ecosystem assessment, ecosystem services models.

2

What are the sectors where Environmental Prediction could have a bigger impact, but currently are not?

- Politics, general public, community planning, cross-sectoral integration, population forecast, population pressures and impacts, epidemiology, health and wellbeing.
- Government including economics and treasury, local government, national security, border security, industry regulation, resource allocation.
- Urban planning, land use planning, natural resource management, coastal zone and water resources management, drought management, sustainable cities, emergency management, biosecurity, disaster risk reduction, major infrastructure investment.
- Conservation planning and biodiversity conservation, ecosystem change, climate change and adaptation, Great-Barrier Reef, social-ecological resilience, global primary productivity prediction, air and water quality, run off, cumulative impact assessment, remediation, decommissioning mines.
- Food production, food security shocks, fisheries and agriculture, forecast yields, forecast outbreaks of pathogens, international markets and trade, sustainable minerals industry, aviation, blue economy sectors, insurance, banking and finance including exposure to climate risks, tourism.
- Climate change modelling as a key driver of action. Whole range of models, rigorous process etc. Counterfactual; what if there were no modelling? There would be general discussions that things are changing. We would be walking into bigger disaster than we know.
- Human health and how environmental prediction can impact on planning in the health sector. Environmental change and epidemiology, cause and effect, economics. Impacts on respiratory effects e.g. extreme weather events, air and water quality, communicable diseases, zoonotic diseases. Health models need to be integrated with environmental models.
- Results need to be usable. Australian National Outlook a good platform for feeding information into dialogues. Intergenerational report – multi-sector, published by treasury. Not just developing one model, but a series of models, ensembles etc to build trust.

5 From prediction science to application

Building a knowledge base for decision makers and practitioners to support more future-focused decision-making relies on new science to understand how to link science and application. These include: co-design and co-production of research; the quality of process as well as outcomes; strategic decision-making processes that consider multiple criteria and better address uncertainty; and ways to bridge organisational cultures. It addresses the characteristics of science for impact in the environmental prediction domain.

We need to bring together the 'science', 'policy' and 'practice' if we're going to be more future focused. We need to nurture future-focused decisions that integrate biophysical and social dimensions. There is a perceived need to adjust our orientation to be more deliberately focused on informing decisions on a different and environmentally-sustainable future. We need to be inclusive of all futures. What does science need to do to harness that future context? It involves NEPS and the latest iteration of ANO. But if we just progress those approaches without considering future-focused environmental science and what it needs to be, we risk ad hoc fragmented approaches and fail to learn together.

One thing that is important about this bigger picture is understanding multiple knowledge types. It includes how decision makers want to interface, people from a policy or practice background, futures and problem framing, infrastructure, modelling and the science of how you stitch together those worlds. These are areas of science that need to dovetail and work together to be more future focused.

Louise Freebairn

'Need to be agile and adaptive to meet the needs of the policy makers. Communicating complexity and uncertainty. We can see model uncertainty but makes policy makers nervous.' Louise Freebairn, ACT Health.

Co-producing knowledge using participatory modelling for complex, policy questions

Systems science methods such as dynamic simulation modelling are increasingly being used to address public health policy questions, as they consider the complexity, context and dynamic nature of system-wide behaviours. Co-production of knowledge and involving policy decision makers in the model development process is an important, but often not explicitly considered, component of project design and implementation. Key implementation strategies for operationalising interdisciplinary, participatory modelling approaches for the Australian Prevention Partnership Centre are discussed. The reported experiences of end-user decision makers, including senior public health policy makers and health service providers, who took part in participatory simulation modelling projects for applied health policy decision support (alcohol related harm, childhood obesity prevention, diabetes in pregnancy), and their perceptions of the value and efficacy of this approach are described. The 'co-production' aspect of the participatory approach was highly valued and considered to be an essential component of building understanding of the modelling process, and thus trust in the model and its outputs as a decision-support tool. The participatory aspect of simulation modelling was time and resource intensive and therefore most suited to high-priority, complex topics with contested options for intervening.

Changing a policy agenda is a challenge. Different disciplines have to collaborate together which means developing a shared language. Uncertainty in models makes policy makers nervous and communication needs to explain why the tools are still valuable in spite of uncertainty. In the health sector, we constantly need to keep marketing modelling as a valuable tool. Using action research methods to think about the process as well as the model. We need to be agile and adaptive to meet the needs of policy makers.

Building and using dynamic simulation models is experiencing exponential growth in the health context. When working with stakeholders who have had little engagement with these models, we have to educate as well as elicit input from them. The model architecture helps these activities (state charts, factors contributing to transitions between states, stocks & flows). The structure and logic then become familiar.

People need to make decisions on where to spend time and there is an opportunity cost for each engagement. People participated when discussing something that was a priority for them; participation increased when the approach came from a domain expert with respect and trust; some were frustrated by current epidemiology methods and curious about new technologies; others wanted to make a difference.

Establish effective partnerships. It is difficult to maintain energy and relationships and accommodate different views. We need key people there from the start, find a shared language, and respond to rapidly changing policy environments. We need to communicate complexity and uncertainty while still conveying the usefulness of the tool. Identify and include lead domain experts. We need transparency, use action research methods and reflective practice, and adjust practice to meet needs.

Russ Wise

'We need environmental projection capabilities that will enable dynamic adaptation pathways. Robust decision-making means having decision makers actively involved with processes of adaptive learning and decision making. Much of our research is going into the wrong things to inform decisions focused on holding on to things we can't hold on to'. Russ Wise, CSIRO.

Futures literacy and strategic decision-making under uncertainty

There are three broadly distinct types of decisions that consider future uncertainties associated with large, rapid and ongoing population, socio-economic, and environmental changes in quite different ways. Each of these decision types increasingly need to adopt iterative and adaptive approaches that consider cross scale influences (a scale above and below) and diverse knowledge types with the express purpose of learning more about the ongoing and increasingly unprecedented effects of global change.

1. Optimisation decisions in high-reliability environments tend to consider future uncertainties in cost-benefit analyses using probability distributions around a most-likely or largest-plausible change scenario.

2. Contingency planning / decision making in less controllable systems need to use exploratory scenario approaches to identify low regrets responses that perform satisfactorily across many possible future scenarios.
3. Transformative decision making requires ‘rigorous imagination’ that draws upon inspiration, legacy, chance, and mystery to explore and prepare for the potentiality of the present to undergo radical novel shifts or discontinuities.

The decision process we adopt and the way we use futures and scenarios depends on the knowledge we have to work with. We need environmental predictive capabilities that will enable dynamic adaptation pathways. We need to build capabilities in futures literacy and strategic and adaptive decision making under uncertainty.

Exploratory modelling and scenarios are a fundamental shift away from approaches that make assumptions first about how the system works. Instead, in situations of large and uncertain change, it is more appropriate to defer agreement on assumptions until decisions have been analysed under different assumptions, values and expectations. We iteratively revisit, check and change assumptions and objectives under broad sets of potential futures.

What if you have different stakeholders with different values and priorities that will call into question your current objectives? Dynamic adaptive pathways recognise different beliefs and values and fundamentally different options and pathways that emerge under different worldviews. We recognise these approaches should be done within processes with decision makers involved to discuss and negotiate shared strategies for moving forward.

Robustness comes with a trade-off; pursuing an objective may be inconsistent with high levels of change. Have some early triggers so that decision-makers don’t lock into a ‘high regret’ pathway. We must provide a more strategic way to engage in more difficult conversations and bring in new tools to support difficult conversations and more strategic change.

Steven Cork

‘High certainty and high control is where prediction reigns supreme. We need scenario thinking for decision making where there is low certainty and low control. What questions do we want to ask about the future – hopes, fears, values? Predictions don’t need to convince, but just get people thinking. Educate to accept uncertainty.’ Steve Cork, ANU.

Cultural challenges for thinking about the future

Humans deal with complexity and uncertainty largely by ignoring or denying them. We filter information to fit with our simplified mental models about how the world works and we fool ourselves that we can predict the future. Within societies and organisations, we tend to support leaders who reassure us they know what the future holds, yet there is overwhelming evidence that useful anticipation and preparation for future challenges and opportunities requires considering multiple plausible futures and continuously testing and modifying assumptions and expectations.

We need to be careful of our relationship with prediction. We can put too much effort into predicting what we think will happen and not enough into what is less likely to happen but still plausible. We need to have a balance between prediction and considering multiple possibilities.

High certainty and high control is where prediction reigns supreme. We need scenario thinking for decision making where there is low certainty and low control. People deal with uncertainty through denial (among other things) and we deal with complexity by forming mental models. Predictions don’t always need to lead to preparation but they need to get people to entertain possibilities so they at least consider them.

Organisations need to be open to change and open to dialogue. What do we want to ask about the future? Hopes, fears, values? What might affect that future, and which are most critical and uncertain? Reflect on whether we asked the right questions in the first place. Can’t have these conversations if you don’t have a culture that enters into dialogue; if you don’t have people in leadership who facilitate this. How do we create a culture in which this kind of thinking can happen? Educate to accept uncertainty.

1

What are the most important things to consider?

More highly dependent and most disconnected we've ever been. Prediction is relevant and needs to be packaged for decision makers – this means people will be much more interested in this than they are in the past-to-present time scales. Create trusted relationships with those who influence decisions or outcomes; empower and enable space for reconciling competing values and accommodate contested views. We need to communicate what we're doing with interested users. Unless predictions are used to develop possible future states, including winners and losers, they may not actually drive desired change.

Governance should include: the overall prediction system, mandate, ensure engagement & participation to achieve alignment of multiple communities, participation from all stakeholders, reveal and understand values tensions and trade-offs between stakeholders, understanding viewpoints across organisations and disciplines, accepting multiple competing objectives. Communicate mental models and values of contributors to the process. Build a trusted relationship through conversation with those that might influence decision and outcomes. Create a culture of adaptation and integration.

Constraints within government can limit adoption of prediction infrastructure – once established it can be successful. What are the benefits from investment in environmental prediction infrastructure? How do we get buy in to difference approaches? How does information infrastructure scale? What infrastructure do we want/need? What type of environmental prediction do we want? Over what time frame?

We need to frame problems depending on stakeholders. We are dealing with multiple competing objectives, values and motivations, fragmented leadership and a lack of capacity to influence decisions. The context is complex, uncertainty is difficult for users to deal with, there are competing domain areas, hard environmental constraints and limited resources. There is a strong need to engage users through participatory processes such as participatory modelling, story-telling, scenario narratives and visualisation.

Scenarios can be difficult to elicit from communities. How do we pull together human dimensions, risk and economic drivers at the system scale? How do we determine what is covered and what is not? We need to develop model literacy, so modellers and end-users understand model strengths and constraints. This take time, expertise and a structured process. We need to differentiate between safe operating space and thresholds. Modelling and response in place for those areas/events where we have known unknowns.

We need to consider enterprise infrastructure, governance across multiple groups, repurposing data, transparency, repeatability, provenance, privacy, security, interoperability, efficiency versus robustness, thresholds, constraints, trade-offs, safe boundary conditions and data standards.

There is complexity in information architecture design: scalability, thematic data sources, different user needs, variable user literacy and digital inequity, challenges of scale and co-design. We need sustainable information infrastructure: model objectives, whether the model is appropriate, trust in data and tools and outputs, ease of use, ease of testing and we need to retain more informative data and context.

We need to consider what sort of team we need. Where there is a lack of context setting it increases the need for social scientists. There are challenges to governing large, autonomous, networked communities. We need to view data and digital infrastructure and people with expertise as important assets.

2

What are the things that you would change to enhance impact?

Perpetuate a new narrative about what is required for effective prediction processes. Proactive collaboration is needed to understand needs, scope and identify users. We need to work with operational agencies and co-design with highest priority stakeholders. Setting defined goals and objectives, perhaps comes at the expense of "inclusiveness". It is important to understand each other, value leadership, increase user engagement, increase model literacy and understand the process of building a model.

Research institutions need to allow more time to build expertise and find common ground for infrastructure. We need to build trust in modelling and prediction science. This includes ensuring participation, conversations, continuity and overcoming structural impediments. Co-design with end users so as to build ongoing platform for dialogue.

Fostering openness to change and sharing information to help understand need for change. Be inclusive to the diversity of views, but also talking about the same thing. Reflective active learning; adjusting the course as we go. We won't ever have certainty, but we can have certainty of process for learning and adjusting.

3

If you think of someone who does that well, what is their main strength?

- Strategic vision and authenticity
- Ability to build trust and ability to influence people
- Collaboration and good communication
- Credibility and experience
- Resourcing
- Persistence
- Making complexity look simple
- Allocating time at the start to develop a shared understand of the problem

4

How will you know that you will be successful?

In the future we hope to have:

- new stories – we see the world in new ways. A culture of engaging with uncertainty has been established. We are having mature conversations about what we value and what is at risk of being lost. We can envision alternative futures and engage society to debate which of those we choose
- a national environmental prediction capability exists. People use prediction science as normal practice in decision making. People, organisations and governments are making different intentional choices which create a different pathway forward
- we have vibrant partnerships and we are meeting users' needs and we are able to identify everybody in the supply chain. Increased authorising environment
- recognise that success has many dimensions, it is never complete
- shared understanding of the problem at hand. Established culture that engages with uncertainty. Envisaged alternative futures and basis for society to debate which ones to choose
- capability is sustained and is used and maintained actively. People value the output, are willing to pay for it and engage with it
- it just works, you don't need to think about it.

6 Synthesis

The Symposium generated a goal for a national environmental prediction capability. We need people engaging across disciplines and different domain areas to realise that vision, and starting to work together in spaces that they are not comfortable in. This is a necessary part of the process.

Key challenges to getting operational capability?

- Why has this not already been addressed? Current infrastructure aimed at now or the past. Does looking to the future inject new challenges? Participant maturity and effective social architecture are pre-requisites to moving forward.
- The scale of the endeavour is huge, raising questions about who funds and delivers across all of the needs. There are multiple different information types and scales required, meaning information architecture is varied, discoverability is an issue and there are multiple levels of complexity – scales, disciplines, regions and nested, domains, global interconnections.
- The solutions require a degree of self-organising to make them feasible; build artificial intelligence into the system to find data etc. Support smart use; appropriate method, caveats, learning what is needed to get best result etc. Need data handling infrastructure.
- Use search engine optimisation and online marketing tools so that information is pushed to users, tailored for the user community, opt in to mechanisms for tracking and alerting to interests.
- Customisation is a big need, but there are challenges to making models relevant. Databases have to be tailored. Brokers are needed to translate information to match the actual need.
- Infrastructure comes with responsibilities. Risks in informing decision making, responsibility for how predictions are used, managing and communicating uncertainty? What if we get it wrong?

Challenges for implementing new approaches

- Build trust around longer forecasts. Co-design for maximum trust and learning. Increase the understanding of what is possible so more people can make use of it.
- If making predictions then we also need decision-making capacity to do something about them. How do we get alerts that resonate so people respond and also have predictions on timeframes that allow for preparation and/or response cycle?
- Commonalities in challenges are shared across population health and environmental sciences. Syndemics – multiple changes in multiple domains at multiple scales.
- Support those creating a culture of collaboration and embracing uncertainty. Address false certainty. Communicate complexity and uncertainty without overwhelming users.
- CSIRO and others have the capacity to lead interdisciplinary approaches due to many different disciplines working together effectively. Need expertise in working in an interdisciplinary way. Look for shared understanding across disciplines and sectors.
- Unwittingly we have engineered the world we live in, pushing beyond boundaries of our current models. True not just of technical models, but also our rules of thumb, mental models. Consider nonlinearity, regime shifts, different types of uncertainty and ambiguity.
- A future focus requires new approaches to decision making. We need to build future systems and models together. We need new computational capabilities, new integrative modelling, and to use them in adaptive modelling and scenario contexts.

Key messages

1. Environmental prediction capability is urgently needed to inform decision making, to support transformational leadership, to support leaders to be agile and responsive as the world changes faster than we can keep up and to support us to deal with increasingly uncertain futures.
2. Environmental Prediction could have an impact in diverse sectors including epidemiology, health and wellbeing, border security, natural resource management, sustainable cities, emergency management, biosecurity, infrastructure investment, biodiversity, climate change adaptation, social-ecological resilience, cumulative impact assessment, food security, fisheries and agriculture, international markets and trade, aviation, insurance, banking and finance, and tourism.
3. To understand environmental shifts, we need to understand the coupled social-ecological system. Human behaviour is affected by many drivers on multiple scales, it is not rational and is context-dependent. This requires co-development of knowledge, practices and tools and modelling across many dimensions – qualitative scenarios, quantitative investigation and integrated modelling.
4. We need environmental prediction more than ever before, tailored to the requirements of decision makers for short- and long-term operational decisions. Prediction science can enable policy uptake. Contestability and transparency of evidence base is critical.
5. A national prediction capability will help us learn, explore the limits of possibility, understand how ecosystems are changing and understand future uncertainties and risks. It will inform choice and better decisions, inform adaptive planning, effective interventions and understanding of cumulative impacts. It will give credibility to decisions and provide a basis for action and learning.
6. Environmental prediction needs to counter reluctance to embrace an uncertain future. Modelling has to contemplate unlikely occurrences and look at the full potentiality of possible futures. It can help people engage with uncertain and complexity.
7. We need new ways of knowing. Our knowledge, models, tools and standards are becoming insufficient for the challenges of the future. Modelling is critical to harness knowledge across time, space and disciplines. We need to learn how to navigate a rapidly changing world.
8. The flipside of knowledge is uncertainty and it's always going to be there. We need an understanding of choices and trade-offs. We can use predictive capability to build the capacity of decision makers to understand what choices they have in front of them and to learn and adapt.
9. We need to grapple with what we don't know. It is a risk to extrapolate beyond data, but we are moving faster than our datasets. We have uncertainty, specificity, nonlinearity, long time frames – we need to learn to work with uncertainty, complexity and with not having all of the answers.

10. There are communication challenges with modelling non-stationarity. Scientists need to outline the implications of predictions and demonstrate the evidence base, convincing others that model outputs are reasonable. We need to know how to articulate outputs and make them available and ensure they are used responsibly.

11. We need future scenarios that anyone can use to understand the future and to plan how they respond. Generic predictions could be enough to drive policy change if people understand them and they help identify things to focus on and provide guidance on when to act.

12. This is a collective effort. Focusing prediction science efforts to achieve impact and benefit for society requires an understanding of the diversity of actors and their needs, motivations and benefits. We must start with those who value predictive capacity.

13. The challenge is not technical but about bringing people and domain knowledge along together. We need: a shared vision, governance, incentives to work together, discoverability, knowing and testing capabilities and limits, acceptance and trust, accountability, standards and expertise. We already have data repositories. Commercial providers are able to support compute and analytics.

14. Building infrastructure requires thinking and investment in tools, information and social architecture. Different domains have different languages, they implement things in different ways and operate with different conceptual models of the world. We must consider infrastructure sustainability, the interoperability "burden", participant maturity and effective social architecture.

15. We have good infrastructure for data curation, but this is not the same skill set as needed for modelled data. Models need to be maintained so they can be reproduced and stand up to scrutiny, ensuring provenance, transparency, data formats, algorithms and accuracy of data.

16. Decision processes and the way we use scenarios depends on the knowledge we have to work with. We need environmental predictive capabilities that will enable dynamic adaptation pathways and build capabilities in futures literacy and strategic decision making under uncertainty. Dynamic adaptive pathways recognise different beliefs and values and fundamentally different options and pathways that emerge under different world views.

17. We need to be careful not to put too much effort into predicting what we think will happen and not enough into what is less likely to happen but is still plausible. We need to consider multiple possibilities and find a strategic way to engage in difficult conversations. We must develop tools to support difficult conversations and enable strategic change.

18. There are multiple information types and scales, and information architecture is varied. Discoverability is an issue and there are multiple levels of complexity. It requires a degree of self-organising, support for smart use, data handling infrastructure, search engine optimisation and social architecture to push information to users, tailored to their interests. New computational capabilities, integrative modelling, an adaptive modelling system, and scenarios are required.


Environmental Prediction Symposium

7 Appendix
Symposium attendees

Ms	Maryam	Ahmad	CSIRO
Mr	Cameron	Allen	The University of NSW
Dr	Sam	Andrew	CSIRO
Dr	Ken	Anthony	Australian Institute of Marine Science
Professor	Kate	Auty	Commissioner for Sustainability and the Environment
Professor	Gabriele	Bammer	The Australian National University
Dr	Simon	Barry	CSIRO Data61
Dr	Erin	Bohensky	CSIRO
Mr	Paul	Box	CSIRO
Dr	Elisabeth	Bui	CSIRO
Dr	Richard	Brinkman	Australian Institute of Marine Science
Ms	Beth	Brunoro	Department of the Environment and Energy
Dr	Adrian	Burton	Australian Research Data Commons
Dr	Iadine	Chades	CSIRO
Dr	Francis	Chiew	CSIRO
Ms	Jane	Coram	CSIRO
Dr	Steven	Cork	The Australian National University
Dr	Simon	Cox	CSIRO
Mr	Mark	Crosweller	National Resilience Taskforce, Department of Home Affairs
Ms	Fiona	Dickson	Department of the Environment and Energy
Dr	Veronica	Doerr	CSIRO
Dr	Michael	Dunlop	CSIRO
Ms	Cheryl	Durrant	Department of Defence
Ms	Jillian	Edwards	National Resilience Taskforce, Department of Home Affairs
Dr	Cameron	Fletcher	CSIRO
Ms	Louise	Freebairn	ACT Health
Dr	Beth	Fulton	CSIRO
Dr	Kylie	Galway	Department of the Environment and Energy
Mr	Chris	Gentle	Western Australian Biodiversity Science Institute
Dr	Aaron	Greenville	The University of Sydney
Dr	Nicky	Grigg	CSIRO
Dr	Juan	Guerschman	CSIRO
Dr	Siddeswara	Guru	Terrestrial Ecosystem Research Network
Dr	Steve	Hatfield-Dodds	Australian Bureau of Agricultural and Resource Economics and Sciences
Dr	Vanessa	Haverd	CSIRO
Dr	Melinda	Hillery	NSW Office of Environment and Heritage
Dr	Alastair	Hobday	CSIRO
Dr	Simon	Hodson	Committee on Data of the International Science Council
Dr	Chantal	Huijbers	Griffith University
Professor	Tony	Jakeman	The Australian National University

Dr	Mohan	Karunanithi	CSIRO
Dr	Steven	Lade	Stockholm Resilience Centre
Dr	Eric	Lawrey	Australian Institute of Marine Science
Dr	David	Lemon	CSIRO
Mr	Peter	Lyon	Department of the Environment and Energy
Dr	Tara	Martin	CSIRO
Mr	Warwick	McDonald	CSIRO
Dr	Ben	Macdonald	CSIRO
Dr	Tim	McVicar	CSIRO
Professor	Belinda	Medlyn	The University of Western Sydney
Dr	Karel	Mokany	CSIRO
Dr	Beryl	Morris	Terrestrial Ecosystem Research Network
Dr	Helen	Murphy	CSIRO
A/Prof	Emily	Nicholson	Deakin University
Dr	Deborah	O'Connell	CSIRO
Mr	Matt	Paget	CSIRO
Mr	Amit	Parashar	CSIRO
Dr	Dave	Penton	CSIRO
Dr	Katrina	Phillips	Department of the Environment and Energy
Dr	Rebecca	Pirzl	CSIRO
Dr	Carmel	Pollino	CSIRO
Dr	Suzanne	Prober	CSIRO
A/Prof	Sujatha	Raman	The Australian National University
Dr	Andrew	Rendall	CSIRO
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B&M | 19-00386