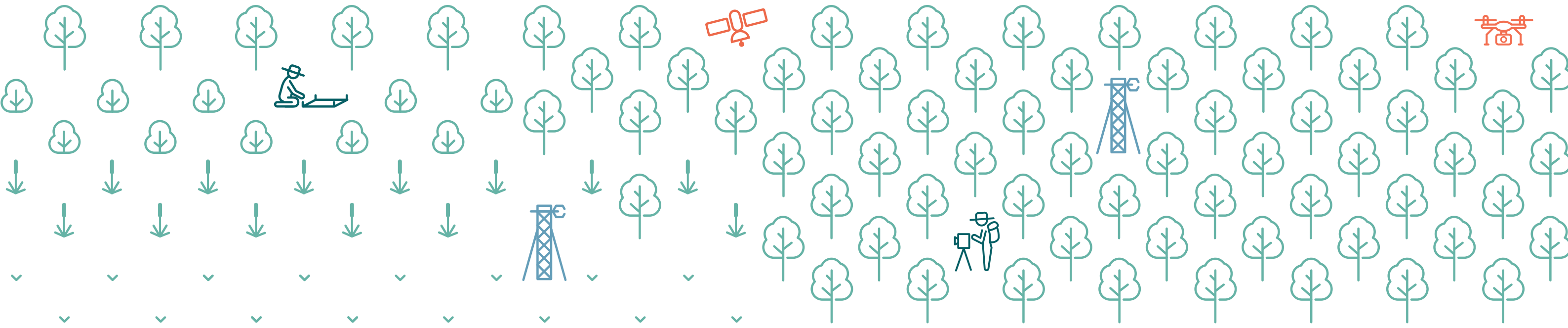

TERN SCIENCE SYMPOSIUM

5-6 July 2021 ONLINE

Proceedings

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Contents

Introduction

The TERN Science Symposium 2021 was conceived as a forum for sharing both transdisciplinary and traditional approaches to ecosystem science research, technological development, data system innovation, collaboration and action. It sought participation from all who have a passion for ecosystem science - to provide an opportunity to share information across domains and develop new collaborations.

Achieving national and global goals around biodiversity, responsible ecosystem stewardship, remediation of damage to ecosystems and quality of life through ecosystem resilience will entail embracing cross-disciplinary, cross-jurisdictional and cross-cultural discussion and collaboration.

The inaugural TERN Biennial Symposium in 2021 set themes that have resonance and urgency for the planet: **Climate impact on ecosystems, Ecosystem biodiversity, Soils and ecosystem function, Data and models for ecosystem management and decision-making, The role of ecosystem data in Australia's society**

It was a great pleasure to receive abstracts, within these themes, that filled a two-day online event. TERN is pleased to present this document as a record of the symposium, in the hope that in future years we may be able to hold the Symposium as a face-to-face meeting.

TERN thanks everyone most sincerely for the time and effort that went into taking part. The recorded presentations and discussions can be viewed via the TERN website.

Special thanks

The Symposium talks were grouped into eight sessions over four days, and we were delighted to enlist the assistance of a number of TERN luminaries to be moderators of the sessions. Our deepest appreciation and thanks go to the following people.

Dr Helen Cleugh

Session One: *Climate Impact on Ecosystems*

Dr Helen Cleugh is an atmospheric scientist with over 30 years' experience combining research discovery, delivery and leadership. She completed her PhD at the University of British Columbia in Canada and then was a Lecturer at Macquarie University in Sydney in 1987 before moving to CSIRO as a Research Scientist in 1994. She is currently a Post Retirement Fellow with CSIRO.

Helen's research expertise lies in quantifying how carbon and water fluxes are mediated by vegetation and the effect this has on carbon uptake and soil water availability, carbon and water resource management, environmental outcomes, and climate. Her research has provided data, information and knowledge for decision and policymakers in government as well as resource managers, urban planners and the agriculture sector. It also served as a platform for her leadership in building research infrastructure and data supporting ecosystem science via NCRIS TERN and its OzFlux Facility, which she led from 2010 to 2014 (www.ozflux.org.au and www.tern.org. au), and the successful NCRIS funding of the ACCESS NRI in 2020.

Helen was the inaugural Director of CSIRO's Climate Science Centre until 2020, and a senior leader of climate and atmospheric research for over a decade including Co-Chair of the Australian Climate Change Science Programme (www.cawcr.gov. au/projects/climatechange/), a 27-year research program delivered jointly with the Bureau of Meteorology and Australian government. This was replaced by the Earth

Systems and Climate Change Hub (http://nespclimate.com.au), which Helen led from its inception in 2015. Helen was elected as a Fellow of the Australian Academy of Technology and Engineering (ATSE) in 2019 and a Fellow of the Australian Meteorological Society (AMOS) in 2020. She has been a member of the World Climate Research Programme's Joint Scientific Committee since 2015 and is currently the Vice Chair (https://www.wcrp-climate.org).

Dr Tim Wardlaw

Session Two: *Ecosystem Biodiversity*

Tim has a research career in applied forest ecology and forest health management spanning almost 40 years. He has been the author, or co-author of more the 100 papers in scientific journals and book chapters. For the first 20 years of his career, Tim was Forestry Tasmania's forest pathologist where he worked on a wide range of diseases affecting native forests and plantations, including Phythophthora root rot, fungal leaf diseases, wood decay and crown diebacks. From 2001, Tim managed the Ecosystem Services group within Forestry Tasmania, which undertook applied research in conservation biology and forest health management. Since 2009, Tim has managed the Warra Long-Term Ecological Research site and was instrumental in getting Warra included in the Terrestrial Ecosystem Research Network that led to the establishment of a flux tower and saw it included in the TERN Supersite network. Tim is currently based at the University of Tasmania as an Honorary Research Associate within Plant Science where he maintains the role of Principal Investigator of Warra.

Dr Ross Wilkinson

Session Three: *Good Data and Models for Good Science and Management*

Ross Wilkinson was the executive director of the NCRIS-enabled Australian National Data Service, helping to make data more valuable for researchers, institutions and the nation, from 2009-2018. His research career commenced with his PhD in mathematics at Monash University before researching in computer science at La Trobe University, RMIT and at CSIRO. Some of his areas of research have been document retrieval effectiveness, structured documents retrieval, and most recently on technologies that support people to interact with their information environments. He has published over 90 research papers, has served on many program committees and was a program co-chair for both SIGIR'96 and SIGIR'98. He was a Council Member of the Research Data Alliance from its inception until 2019 and helped form the Australian Research Data Commons. The latter contributes to making Australia's research data more valuable and enabling Australia's researchers to more effectively use and re-use research data, wherever it comes from, and in partnership with researchers around the world.

Professor Glenda Wardle

Session Four: *Methods*

Glenda Wardle is a Professor of Ecology and Evolution in the School of Life and Environmental Sciences at the University of Sydney, co-lead of the Desert Ecology Research Group and a member of the Sydney Institute of Agriculture and the Citizen Science Node of the Charles Perkins Centre. Glenda's leadership roles include, Chair of the Ecosystem Science Council of Australia, TERN NSW ambassador, Biodiversity theme lead for ARC Centre for Data Analytics for Resources and Environments (DARE) and WWF Governor. Glenda's research spans long-term field studies, to mathematical models that integrate knowledge on how populations, species and ecological interactions change in relation to ecological drivers such as unpredictable rainfall, changing climates, grazing and fire. Glenda is motivated by using ecological and evolutionary knowledge to provide solutions for the challenges we face in living healthy lives and keeping the planet and its biodiversity intact for future generations.

Adjunct Professor Mike Grundy

Session Five: *Soils and Ecosystem Function*

Mike Grundy has a long-standing personal research interest in spatial soil science and its application to agricultural and forest production, environmental protection and systems approaches to complex problems. Mike is an Adjunct Professor at the Sydney Institute of Agriculture, University of Sydney and TERN's Specialist Advisor. He is a Fellow and Honorary Life Member of the Australian Institute of Agricultural Science and Technology and a Board Member of the International Soil Conservation Organisation. Before retiring from CSIRO in 2020, Mike was co-lead of the Landscapes platform of TERN and Research Director - Soil and Landscapes at CSIRO. In the latter role, he and his team helped to address the key emerging issues in the productive and sustained management of Australia's soils and landscapes and developing tools to observe and predict trends across agricultural and forestry landscapes and to understand the interconnection with the wider economy and environment. Mike recently co-chaired the Organising Committee of the World Soils Congress and continues to collaborate with international bodies on soil related matters.

Professor Graciela Metternicht

Session Six: *The Role of Ecosystem Data in Australia's Society*

Graciela Metternicht is a Professor of Environmental Geography at the Earth Science and Sustainability Research Centre of the University of New South Wales. She is an environmental geographer who works at the interface of science and policy for sustainable development. With over two decades of experience in applied research, training and as an adviser on environmental management, her skills range from development of tools and approaches to map and monitor land degradation processes and for land use change, to operationalisation of socioecological frameworks for sustainable land management. She currently advises on matters of land degradation for the UN Global Environment Facility and chairs the National Committee for Geographical Sciences of the Australian Academy of Sciences. Graciela's teaching and research training extends to undergraduate and postgraduate programs in Earth and Environmental Sciences.

Dr Kelsey Druken

Session Seven: *Good Data and Models for Good Science and Management*

Kelsey Druken is the Data Collections Manager at National Computing Infrastructure (NCI). She and her team focus on making FAIR (Findable, Accessible, Interoperable, Reusable) national reference datasets available in high-performance compute and data environments at NCI for the Australian research community.

Day 1:

Opening keynote

Dr Hugh Possingham FAA

Prof Hugh Possingham is Queensland's Chief Scientist. He is also TERN's Advisory Board Chair and played a pivotal role in the establishment of TERN.

Hugh's research interests are in conservation research, operations research and ecology. His scientific career started at the University of Adelaide where he completed his Bachelor's degree with Honours in Applied Mathematics in 1984, followed in 1987 by a doctorate in Ecological Modelling as a Rhodes Scholar at Oxford University. Hugh was elected as a Fellow of the Australian Academy of Science in 2005. In 2016, he was elected a Foreign Associate of the US National Academy of Sciences.

Hugh was Director of the Australian Research Council Centre of Excellence for Environmental Decisions, as well as the Australian Government's Threatened Species Recovery Hub hosted at the University of Queensland. In 2016 he became the Chief Scientist at The Nature Conservancy, a global conservation organisation with 400 scientists and 4000 staff, that has protected more than 40 million hectares of land and thousands of kilometres of rivers worldwide.

With his combination of expertise in mathematics and ecology, Hugh has undertaken conservation initiatives that integrate spatial planning and economic factors, leading work on problems to secure the world's biological diversity: efficient nature reserve design, habitat reconstruction, monitoring, optimal management of populations for conservation, cost-effective conservation actions for threatened species, pest control and population harvesting, survey methods for detecting bird decline, bird conservation ecology, environmental accounting and metapopulation dynamics.

TERN - looking back, looking forward

Australia punches above its weight in the environmental sciences. By any sort of demonstrable quantitative assessment, per capita or per GDP, we rank number one in the world in terms of the quantity and quality of research outputs. This seems to be unrecognised by our governments.

We're lucky to be in a country that spans environments from rainforest to desert; from coral reef to subantarctic island. One of our advantages is having almost every ecosystem in the world in one country. this means we are used to tackling a wide diversity of interesting environmental management problems.

Historically we are very good at spatial modelling, remote sensing and species distribution modelling. However much of our spatial modelling ignores change through time, and this is why TERN was so sorely needed.

We've been really poor at thinking about change through time – an area where the North Americans and Europeans are way ahead of us. If you don't collect data through time, it's impossible to see if anything is changing. Indeed, it's impossible to work out whether any management or policy we implement is having an impact.

TERN has a unique role, in collecting spatial time series data that informs us about the state of our nation and the consequences of management and policy. At the time NCRIS was conceived the federal government was asking "what are the biggest questions in the environmental sciences?"

TERN adopted a bottom-up approach to determining these key questions in the terrestrial ecosystem space, engaging with a huge number of people and many conversations around the two or three big questions in Australian environmental science.

Establishing a synthesis centre (ACEAS), based on a US model, the National Centre for Ecological Analysis and Synthesis, was essential in getting us to focus and collaborate.

If we're going to succeed in the future, we need to refine the business case for continuing to gather data above and beyond the benefits of advancing basic science and training many talented research students. There will always be disagreement about what TERN should or shouldn't be monitoring, and maybe we need to think beyond just interesting scientific questions.

An emerging area of application is providing the science to underpin carbon and biodiversity markets, other markets for ecosystem services, and environmental sustainability. Every organisation, private or public, on earth will soon want to be able to prove they are "nature positive".

We all need to develop more explicit stories about how our data is likely to inform actions on the ground or policies. What are the many real and quantifiable values (economic, social and environmental) of long-term spatially explicit environmental data?

Session One: **Climate Impact on Ecosystems**

Landscape level assessment of tree drought mortality in forest ecosystems of the Strathbogie Ranges in Australia

Prof Stefan K Arndt, Wagner B, Baker P, Nitschke C

Prof Stefan K Arndt

Stefan Arndt is Professor of Physiological and Ecosystem Ecology at the University of Melbourne. His research centres around the question of how plants and entire ecosystems cope with changes in environmental conditions and with climate extremes like drought or heat stress. He investigates plant performance under environmental stress which enables predictions of which plant species will be best suited to survive and thrive in a future climate in forests, revegetation projects or urban areas.

A very dry autumn in 2019 led to patchy tree canopy collapse in the Strathbogie Ranges, 100 km north of Melbourne in Victoria. Large patches of eucalypt forest showed signs of tree drought mortality, but it was not clear if this apparent tree mortality: 1) was widespread or only a local occurrence; 2) was related to harsher weather conditions in certain locations; and 3) impacted some eucalypt species more than others. We used a combination of remote sensing data, gridded climate information and ground-based plot assessments to investigate these questions. Using Landsat images from one year before and shortly after the drought event we calculated the plot difference Normalized Burn Ratio (dNBR) for the entire Strathbogie Ranges. This index is used to detect bushfire impact in forests, but was able to detect the drought canopy collapse accurately. However, while the method was slightly too sensitive, it accurately predicted all areas with a high degree of drought canopy collapse. Overall the drought canopy collapse was not widespread and was detected in six local areas. Gridded climate analysis revealed that rainfall or temperature in summer and autumn of 2019 was unlikely to have caused the canopy collapse on its own. Shallow soils and occurrence of rocky outcrops reduced soil water availability to trees in the impacted areas. Plot-based inventories confirmed that tree canopy collapse occurred in all five eucalypt species that are common in the region and there was no difference in the drought vulnerability among species.

The role of rainfall amount and intensity in driving tree growth across semi-arid and tropical Australia

Dr Alison O'Donnell

Alison is a Research Fellow based in the School of Biological Sciences at the University of Western Australia. She is an ecologist who has become fascinated by tree rings and the information they contain since being introduced to the world of dendrochronology during her PhD research. She's particularly interested in using tree rings to answer questions about the interactions between climate and ecosystems and the history of droughts, floods and fires in Australia.

Understanding how tree growth responds to changes in the amount, frequency and intensity of rain events is critical to predicting how climate change will impact on forests and woodlands in the future. We used five tree-ring records of the native Australian conifer *Callitris columellaris* that span a large climatic gradient from the tropical north to the semi-arid south of Australia to investigate how inter-annual and spatial variation in the delivery of rainfall (the amount, intensity and frequency of rain events) influences tree growth. We found that tree growth is strongly and linearly related to rainfall amount in semi-arid biomes and most strongly related to the amount of rain from heavy (>75th percentile) rain events or the number of extreme (>90th percentile) rain days. In contrast, growth in the tropics is non-linearly related to rainfall amount; growth is less responsive to changes in rainfall amount at the higher end of the rainfall range than at the lower end. Our findings indicate that predicted future declines in rainfall are likely to have proportional negative impacts on tree growth in semi-arid biomes, while in the tropics, projected increases in the inter-annual variability of rainfall are likely to have greater impacts on long-term growth rates than changes in the mean amount of rainfall. Our findings also indicate that projected increases in the intensity of extreme rain events are likely to have contrasting impacts on tree growth in different biomes, with greater and positive impacts on growth in semi-arid biomes and potentially negative impacts on growth in tropical biomes of Australia. Our results highlight how contrasting growth responses of a widespread species across a hydroclimatic gradient can inform understanding of potential sensitivity of different biomes to climatic variability and change.

Stress, recovery and resilience to climate extremes in Australian ecosystems and agricultural landscapes

Dr Jamie Cleverly

Jamie Cleverly obtained their PhD in ecology (plant physiological ecology and community ecology), soil science and statistics at the University of Nevada Las Vegas. Currently, Jamie is a Senior Research Fellow at the University of Technology Sydney, the PI for TERN 's Alice Mulga SuperSite in central Australia, TERN Science Partnerships Liaison, and associate director of OzFlux. Jamie's research interests include the land-atmosphere exchange of carbon and water, and ecosystem ecology more generally, ecohydrology, ecophysiology, meteorology, climate, statistics and agronomy.

Australia experiences its fair share of droughts and flooding rains, heatwaves and bushfires. Our natural ecosystems are largely resilient to climate extremes, in which those ecosystems that show the capacity to survive stress often demonstrate an extraordinary capacity to recover with vigour to the return of favourable conditions. Bringing this understanding of ecosystem resilience to climate extremes is of great value going forward for agricultural ecosystems, where institutional knowledge over generations of farming has brought close coupling between crop productivity and water use. This presentation will explore some of the key factors that will enable the prediction and forecasting of ecological responses to climate variability, both in Australia and abroad.

Tapping into the physiological responses to mistletoe infection during heat and drought stress

Dr Anne Griebel

Anne is a forest ecologist interested in unravelling the effects of disturbances and a warmer and drier climate on ecosystem function. She is particularly interested in studying tree health and the trade-offs between carbon sequestration and water loss in Australia's eucalypt forests. For predominantly experimental research projects, she utilises observations from micro-meteorological stations and from terrestrial and airborne remote sensing, and complements these with a suite of ground-based sensor networks and satellite observations.

Mistletoes are emerging as important co-contributors to tree mortality across terrestrial ecosystems, particularly when infected trees are stressed by water limitations during drought. In Australia, mistletoe distributions are expanding in temperate woodlands, while their hosts experienced unprecedented heat and drought stress in recent years. To investigate whether the excessive water use of mistletoes increased the probability of xylem embolisms, we monitored transpiration of infected and uninfected branches from two eucalypt species over two summers at the Cumberland Plain Supersite and used hydraulic vulnerability curves to estimate percent loss in conductivity for each species. We further coupled intensive observations of mistletoe population dynamics with measurements of host tree stem growth, canopy turnover and stand structure to monitor how mistletoe infection alters above-ground biomass distribution during and after a three-year drought. We show that daily transpiration increased up to five-fold for infected branches, resulting in an increase of up to 11% loss in conductivity. Moreover, severe mistletoe infection reduced live standing biomass and canopy volume, and a mistletoe-to-host leaf area ratio above 60% significantly reduced basal area growth. Yet, concurrent increases in basal area and the thickening of canopy volume indicate that host trees recover rapidly, after the three-year drought combined with record summer heat nearly extinguished the mistletoe population. The potential devastating effect of mistletoe infection on host survival has distracted from the challenges that mistletoe populations are facing when increasing drought and heat stress threaten their survival in healthy populations.

The water-use efficiency response of eucalypts to rainfall is modulated by soil phosphorus across Australia

Assoc Prof Lucas Cernusak

Lucas Cernusak is an Associate Professor in the Ecology and Zoology group at James Cook University, Cairns. His main research interest is to understand the environmental and biological controls on carbon dioxide and water vapour exchange between leaves and the atmosphere. He is also interested in improving the interpretation of stable isotope signals in plant organic material, in order to better understand how leaf gas exchange has responded to global climate change through time and how it varies across ecological gradients.

Ecological theory predicts that along a resource availability gradient, genotypes and species that use that resource more efficiently should be selected for as its availability decreases. Strong rainfall gradients from near the coast to the arid interior of Australia provide an opportunity to test this prediction with respect to plant water-use efficiency, the rate of photosynthesis for a given amount of water loss to the atmosphere. A number of such transect studies have been performed, examining leaf stable carbon-isotope ratios as a proxy for time-integrated, intrinsic water-use efficiency. Interestingly, different transects in Australia have shown widely varying responses of carbon-isotope ratio to rainfall, with relatively strong responses observed in south-eastern Australia, and much more muted responses observed in northern Australia and south-western Australia. We considered two hypotheses that might provide insight into these observed geographic differences: rainfall seasonality - if rainfall is highly concentrated seasonally, such as in northern and south-western Australia, expected responses to annual rainfall might be damped; and soil phosphorus concentration - very low soil phosphorus in Australian soils of some regions might favour high transpiration as a mechanism to accumulate phosphorus at root surfaces, thereby lessening the carbon-isotope ratio response to decreasing rainfall. To test which explanation is more likely, we sampled leaf carbon isotope ratios along a rainfall gradient in north-eastern Australia, which has high rainfall seasonality combined with relatively high soil phosphorus, a combination not found in the previously sampled transects. We found a strong response of leaf carbon-isotope ratio to decreasing rainfall, comparable to the south-eastern transects. Of the two considered hypotheses, our results indicate that soil phosphorus modulates the water-use efficiency response of eucalypts to rainfall among regions of Australia, not whether the distribution of rainfall within the year is highly seasonal.

Developing best practice Himawari data products for enhanced sub-daily monitoring and climate impact studies of Australia’s ecosystems

Prof Alfredo Huete

Alfredo Huete is a geospatial ecologist using advanced remote sensing tools to monitor vegetation health and function in the face of climate change, land-use and other major disturbance events. A Distinguished Professor in the Faculty of Science at UTS, Alfredo leads the Ecosystem Dynamics Health and Resilience research program and his work involves the use of ground, tower and satellite measurements to analyse ecosystem responses and resilience to climate forcings and extreme events.

From July 2015 onwards the Advanced Himawari Imager (AHI), located on the Japanese Meteorological Agency’s suite of operational geostationary satellites, acquires data every 10 minutes for the entire Asia-Pacific hemisphere. Data is in 16 bands (from the visible, near infrared and thermal infrared with spatial resolutions from 0.5 km to 2 km depending on the band). AHI provides unparalleled high-temporal imagery for Australian researchers to better understand how our ecosystems function by tracking important sub-daily and daily processes over multiple years. Tracking land-surface processes requires that cloud masking, atmospheric correction and sun-target observer angular dependency correction have all been implemented to produce accurate Level 1 AHI products of: (a) reflectance; (b) albedo; (c) surface solar irradiance (total partitioned into the direct and diffuse components); and (d) land surface temperature. These Level 1 products are then linked with biophysical models / analytical frameworks to monitor Level 2 sub-daily / daily processes including: (i) phenological processes; (ii) actual evapotranspiration (AET) and sensible heat fluxes; (iii) ecosystem stress / ecosystem resilience; (iv) Gross Primary Productivity (GPP); (v) resource use efficiencies, both Light Use Efficiency (LUE) and Water Use Efficiency (WUE); and (vi) photosynthetic capacity (Pc). Enhancing our biophysical understanding of these processes means we are better placed to predict how ecosystems will respond to simultaneous stressors such as climate change (warming, drying, extreme events) and other disturbance regimes. These processes govern Australia's ecosystems and heavily influence the biodiversity and other ecosystem services (e.g., water, food, carbon) they provide. Our TERN Landscapes project recently commenced and this presentation outlines progress in developing Level 1 products and plans to derive advanced Level 2 ecosystem understanding.

Demonstrating post-fire changes in vegetation and soil using TERN Surveillance monitoring: a case study from the Kangaroo Island bushfires

Tamara Potter

Tamara has been working with TERN since June 2019 as part of the TERN Ecosystem Surveillance field team. Tamara has a background in ecology completing a Bachelor of Advanced Science at the University of Sydney and an honours project looking at the diet of the Lesser Hairy-footed Dunnart in the Simpson Desert. She has an adventurous nature as well as relevant field skills, knowledge and experience and is passionate about monitoring and conserving Australian flora and fauna.

Bushfires have been a feature of the Australian landscape for millions of years and play a vital role in influencing the dynamics of ecological communities. Fires can alter both the abiotic properties of an ecosystem, such as the physical aspects of soil, micro-climate and hydrology, as well as the biotic components, like vegetation structure and species composition. With fire intensity and frequency increasing in recent decades, the importance of monitoring and detecting fire-related changes within soil and vegetation communities is becoming more imperative. In the past, monitoring the impacts of fire has been challenging, often ad-hoc, small-scale, and specific. TERN's Ecosystem Surveillance platform has been implementing nationwide soil and vegetation data collection and sampling over the past 10 years, following standardised survey methods. Using Kangaroo Island and the 2019/2020 summer bushfires as a case study, we demonstrate the benefit of these methods in identifying and monitoring change in vegetation structure and composition, and soil characteristics in response to fire.

Assessment of flux tower energy and water balance variables over Australian climate zones: implications for modelling

Thomas Van Niel

Tom's primary research interests are in spatial and temporal modelling of the environment. Recently he has concentrated on studying the interactions between the water and heat balances, focusing particularly on understanding and modelling the spatial and temporal dynamics of evaporation over all of Australia.

Climate determines the general spatial patterns and timing of the dynamics of energy and water fluxes. The TERN flux tower network has expanded to the point where it now covers the major climate zones of Australia, with some Supersites collecting data for decades. This allows for an opportunity to better understand the influence of Australia's climate on the interactions between energy and water balance variables. We performed an assessment of the interaction between flux tower observed energy balance components of available energy, latent heat flux, and sensible heat flux with precipitation and soil moisture dynamics of the top 10 cm of the soil profile for the major Köppen-Geiger climate zones across Australia (tropical, arid, and temperate). Results were placed in the context of popular evaporation modelling theory. This study found that climate determined the primary driver of water and energy flux and highly impacted even the very basic interpretation of the interaction between evaporation and soil water dynamics. A potential framework for identifying this interaction is introduced and implications for modelling evaporation from remote sensing are put forward.

Session Two: **Ecosystem Biodiversity**

Biodiversity and biogeography of wood decay fungi within the TERN Australian Field Observatory SuperSites

Dr Jeff Powell

Jeff is an ARC Future Fellow at Western Sydney University's Hawkesbury Institute for the Environment, where he has been studying interactions among plants, fungi and soils since 2011. Before that he did his PhD at the University of Guelph in Canada, where he studied the effects of genetically modified crops on soil ecosystems and turned an impressive number of non-significant results into a thesis. In between he was a postdoc at the Freie Universitaet Berlin, where he managed to stay productive despite the city's fantastic beer gardens.

Fungi are key agents of wood decomposition, returning carbon to the atmosphere. While biotic interactions such as competition among fungi are suggested to impact wood decay, these biotic interactions are rarely documented in the field. In addition, the effects of decomposer fauna on fungi are rarely considered even though their activities are likely to reduce colonisation limitations (by placing wood in contact with soil microbes) and modify chemical characteristics that influence microbial succession. Here, we identified fungi colonising blocks of *Pinus radiata* placed on the soil surface at thirteen TERN SuperSites and exposed (or not) to termites and other macro-invertebrates. Blocks were collected again after 12 to 24 months, with multiple harvests at some sites, and fungal communities characterised using high-throughput DNA sequencing. Hierarchical modelling was used to identify environmental variables and decay attributes associated with selection and residual biotic interactions among fungi. Decomposition, termite-associated damage and temperature were the most important variables identified. Fungal composition was also linked to the degree that baits exhibited damage caused by fungi. Exposure time, precipitation, aridity, forest cover and elevation were only weakly linked to fungal composition. Increased termite damage was more frequently associated with a reduced frequency of fungal species, although exceptions were observed. After accounting for these variables, we found evidence for relatively few negative co-occurrences among fungal species (4% of pairs). Positive co-occurrences were more frequently observed (10% of pairs). These results highlight the roles that climate and biotic interactions play during community assembly for wood decay fungi. The frequencies of positive and negative co-occurrences suggest a greater importance for facilitation compared to competition in this system, which we have also observed in other systems. The relatively high frequency of negative interactions between termite activity and fungi is surprising and suggests research is needed to understand this process.

Celebrating 10 Years of TERN Ecosystem Surveillance across Australia

Emrys Leitch

Emrys has a passion for arid flora and has worked extensively in the arid and semi-arid zone across Australia. Emrys is interested in understanding how landscape processes including fire, grazing and invasive species affect vegetation communities. Emrys has a broad range of skills and experience and is a firm believer in the intuitive responses that come from on-ground experience and from working closely with local land managers.

In the last 10 years, TERN has set up more than 800 soil and vegetation monitoring plots across Australia. These plots now span all of the major terrestrial biomes across the country. The success of the program has enabled a wide range of research and land management projects and collaborations across numerous disciplines. The logistics of running such a program across an entire continent has also presented challenges. In this presentation we will highlight our successes, discuss some of the challenges faced in the rollout, and look ahead to an exciting future for the TERN Ecosystem Surveillance monitoring network.

Applying conservation reserve design strategies to define ecosystem monitoring priorities

Dr Irene Martin-Fores

Irene is a postdoctoral researcher who holds a PhD in Ecology and Environment from the Complutense University of Madrid. Her field of expertise has been mainly focused on invasion ecology and plant community ecology. Irene has worked in a variety of scientific teams and institutions, which has allowed her to develop a multidisciplinary background and collaborative network that spans also forest ecology, functional ecology, biodiversity metrics, biogeography patterns and distribution of plant species, spatial modelling, monitoring infrastructure, conservation strategies, global change biology and socioecological systems. Irene has experience in teaching, has taken part in several international projects, participated in policy briefs and was recently selected by the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES) as an expert for invasive alien species assessments.

In an era of unprecedented ecological upheaval, accurately monitoring ecosystem change at large spatial scales and over long-time frames is essential to effective environmental management and conservation. However, economic limitations often preclude revisiting entire monitoring networks at a high enough frequency to accurately detect ecological changes. Thus, a prioritisation strategy is needed to select a subset of sites that meets the principles of complementarity and representativeness of the whole ecological reality. We applied two well-known approaches for conservation design, the 'minimum set' and the 'maximal coverage' problems, to develop a strategic monitoring prioritisation procedure that compares potential monitoring sites using a suite of alpha and beta biodiversity metrics. To accomplish this, we created an R function that performs biodiversity metric comparisons and site prioritisation on a plot-by-plot basis. We tested our procedures using data from 774 vegetation plots provided by TERN AusPlots. We selected 250 plots and 80% of the total species recorded for the maximal coverage and minimum set problems, respectively. We compared the results of each approach in terms of ecological complementarity (species accumulation) and the spatial and environmental representativeness of the plots selected by the different biodiversity metrics. We repeated the selection process for clusters of plots to incorporate logistic constraints for field expeditions. We found that prioritisation based on species turnover (i.e. most dissimilar plots in terms of species composition but ignoring species richness) maximised ecological complementarity and spatial representativeness, while providing high environmental coverage. Species richness was an unreliable metric for spatial representation, whereas corrected weighted endemism failed to capture ecological and environmental variation. Range-rarity-richness was a more balanced metric in terms of complementarity and representativeness. Our results inform monitoring design and conservation priorities, which should consider changes in the turnover component of the beta diversity instead of being based on univariate metrics.

Advances in drone remote sensing for ecosystem monitoring

Prof Arko Lucieer

Arko Lucieer is a Professor in Remote Sensing at The University of Tasmania, Australia. He leads the TerraLuma research group, focusing on the development and application of drones, sensor integration, and image processing techniques for environmental, agricultural, and high-precision aerial mapping applications. Arko teaches remote sensing and GIS at the undergraduate and graduate levels. He obtained his PhD degree in 2004 from the International Institute for Geo-Information Science and Earth Observation (ITC) and Utrecht University in The Netherlands. His current focus is on remote sensing of vegetation and biodiversity with the use of sophisticated drone sensors to better understand the structure, distribution, and functioning of vegetation, and to bridge the observational scale gap between field samples and satellite observations.

Knowledge of vegetation structure and condition are critical to evaluate ecosystem health and quantify the resilience of ecosystems to the pressures of climate change and extreme events. To provide a synoptic assessment of natural ecosystems at landscape scale, drone-based remote sensing provides a unique opportunity to collect ultrahigh-resolution imagery advancing our ability to map vegetation composition and structure. This TERN sub-project aims to advance drone dat+D19a collection and processing techniques. We are developing new protocols for data collection and processing of raw sensor data to produce analysis-ready data products, such as RGB and multispectral orthomosaics and 3D point clouds. In doing so, this project will advance our ability to monitor environmental resilience of natural ecosystems. In this presentation, we will give an update on the current drone technology, sensors, and accurate positioning. In addition, we will provide an overview of the use of drone remote sensing for assessment of biodiversity.

Investigating fire responses in endangered ecological communities of the Cumberland Plain in northwest Sydney

Dr Alison Hewitt

Dr Alison Hewitt completed a PhD in botany and plant ecology at Western Sydney University. Her research on reproductive biology and ecology of the Melaleuca genus demonstrated genetic and environmental factors critical to species survival. She has studied Australian native plant responses to shade and temperature as well as disturbance effects on vegetation in Western Sydney and the Blue Mountains. Alison's interests also include plant-animal interactions, Eucalyptus, threatened species and flora survey methodology. Alison teaches Botany with Western Sydney University and is currently a postdoctoral fellow in Bushfire Recovery there.

Over 200 years of extensive land clearance on the Cumberland Plain of Western Sydney has resulted in highly fragmented ecosystems that are now under added threat from accelerating climate change and altered fire regimes. This project is assessing impacts and monitoring recovery from fire in two threatened ecological communities of the Cumberland Plain: Castlereagh Scribbly Gum Woodland and Cooks River/Castlereagh Ironbark Forest. Detailed fire histories of the area have been compiled and vegetation structure and floristic composition are being quantified in fragments with differing times since fire, using a combination of remote sensing (airborne LiDAR) and on-ground biodiversity surveys. We hypothesise that relationships between biodiversity (e.g., species richness, tree hollows) and ecosystem structure (e.g., canopy height and heterogeneity) will emerge in response to fire and other disturbances. This project will inform management of these endangered ecological communities by evaluating the risk of invasive species encroachment and short and long term vegetation dynamics and recovery following fire. The project is being led by Western Sydney University in partnership with stakeholders Deerubbin Local Aboriginal Land Council, Greater Sydney Local Land Services, University of NSW, Department of Planning, Industry and Environment, Cumberland Land Conservancy and the NSW National Parks and Wildlife Service. All raw LiDAR and plot level data will be archived and made accessible via the Cumberland Plain Terrestrial Ecosystem Research Network (TERN) data portal, which is managed by Western Sydney University personnel (Pendall and Boer).

Extending biodiversity monitoring across space and time through citizen science

Dr Katie Irvine, Sally O'Neill, Rosalie Lawrence, Robert Lawrence, Tom Saleeba, Andrew Tokmakoff, Greg Guerin, Ben Sparrow

Dr Katie Irvine

Katie has a love for science communication and citizen science, having worked on the Wild Orchid Watch project from 2018 - 2020, and now as TERN Outreach Officer. Her background is in rainforest ecology and marine ecotourism, with a PhD in Earth and Environmental Science from James Cook University. Katie has experience working with community groups and volunteers to deliver a variety of citizen science projects for research institutions, government and private business, and is vice-chair of the South Australian chapter of the Australian Citizen Science Association.

Over the past three years we created and implemented a TERN-allied national citizen science project called Wild Orchid Watch (WOW). We learned valuable lessons through this process, from achieving greater temporal and spatial coverage in biodiversity monitoring to best practice when inviting community members to participate in project design and data collection. Citizen science projects which are planned and implemented with community involvement and training can meet the needs of both the community participants and researchers. We found that citizen science biodiversity monitoring can provide more than just species identification, date and location; users input a range of ecological monitoring data for far-reaching research and conservation outcomes. Appropriate use of technology is key. Apps have changed the game for community-scientist collaboration, but the complexity of designing custom technology and the potential pitfalls associated with setting up a citizen science project should not be underestimated. Nevertheless, well-designed and resourced citizen science projects can provide a range of beneficial outcomes for community members and scientists. We are now applying the knowledge and experience gained through the process of creating WOW to a new TERN pilot citizen science project. We look forward to sharing the details and initial results.

Session Three: **Good Data and Models for Good Science and Management**

Australian land surface phenology product from MODIS & VIIRS satellite data

Dr Qiaoyun Xie

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Land surface phenology (LSP), the study of seasonal dynamics of vegetated land surfaces from remote sensing imagery, reflects response of ecosystems to climate change. Phenological shifts have substantial impacts on ecosystem function, biodiversity, and carbon budgets at multiple scales. The global Moderate Resolution Imaging Spectroradiometer (MODIS) Land Cover Dynamics Product MCD12Q2 was developed to characterise the LSP of global ecosystems, but it failed to provide well-defined spatial pattern of LSP for most areas in Australia, which may be related to climatic variability causing high LSP variability. In contribution to AusCover/Terrestrial Ecosystem Research Network (TERN), we developed the Australian LSP Product to suit highly variable Australian conditions. This product includes two sets of national maps of phenological metrics, produced using MODIS Enhanced Vegetation Index (EVI) data from 2002 to 2019, and Visible Infrared Imaging Radiometer Suite (VIIRS) EVI data from 2012 to 2019, respectively. The product provides eight phenological metrics at 500 m resolution of up to two seasons each year, including the first and second minimum point, start, peak, end, length, and amplitude of the season. Integrated EVI under the curve between the start and end of the season time was calculated as a proxy of productivity. An example of peak of growing season is shown in the figure. We evaluated our product by comparing it with the MCD12Q2 product, and against the phenological metrics extracted from eddy covariance gross primary production data. From quantifying ecosystem resilience to climate change, bushfire fuel accumulation, to informing agricultural management decisions and crop yields, the product's list of real-world applications is enormous.

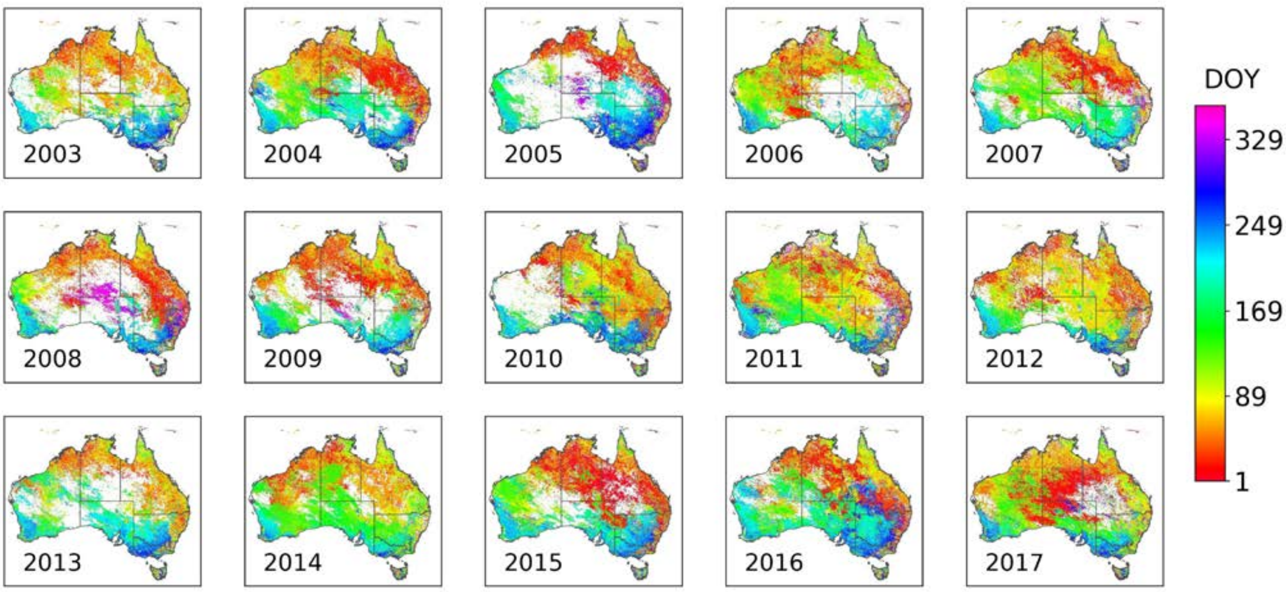

Figure. *Peak of the growing season for the first growing season captured by our product from 2003 to 2017. DOY represents day of year, with DOY equals 1 being 1st January.*

Developing a multi-decade, operational, Australia-wide, monthly, 30m actual evapotranspiration dataset: Part 1 Calibration of multiple Earth observation sensors

Dr Juan Guerschman

Dr Juan Pablo Guerschman is a senior Research Scientist with CSIRO Land and Water. He joined CSIRO in 2005, after receiving a PhD in Agricultural Sciences from the University of Buenos Aires, Argentina. In his first years in CSIRO as a postdoc his research focused on the calibration and application of a regional carbon cycle model, and the integration of remote sensing and ground-based observations through model-data assimilation for the analysis of carbon dynamics of tropical savannas. From 2007 onwards, he has been a project researcher and then research scientist with the model-data integration team of the Environmental Earth Observation Program. He has played a leading role in developing and evaluating methods to use satellite observations in hydrological and land management applications. Between 2009 and 2012, he led a part of the research portfolio of the Water Information Research & Development Alliance between the Bureau of Meteorology and CSIRO Water for a Healthy Country Flagship, around remote sensing of land cover and landscape water and using this to inform the Australian Water Resources and Assessment System. Juan has also been actively involved in developing algorithms for estimating vegetation cover from remotely sensed data across rangelands and croplands and applying these estimates to deliver timely information for better management of these environments.

Actual evapotranspiration (ETa) is the phase change of liquid water to its gaseous state, linking the energy-carbon- and water-D14 balances. It is an essential dataset for environmental monitoring to, as examples, assess: (i) the catchment/landscape water balance; (ii) water use efficiency; (iii) irrigation compliance; and (iv) the water regimes of groundwater dependent ecosystems and other biodiversity hotspots. In a TERN Landscapes project we calibrated the CMRSET (CSIRO MODIS Reflectance based Scaling EvapoTranspiration) model across the continent using five remotely sensed data products with temporal frequencies ranging from daily (MODIS, VIIRS) to multi-days (Landsat and Sentinel-2) and spatial resolutions from 500 meters (MODIS, VIIRS), 30 meters (Landsat) to 20 meters (Sentinel-2). CMRSET was calibrated using daily latent heat observations from the 29 TERN OzFlux sites, representing a wide variety of land covers and climates. The calibrated CMRSET model was able to estimate daily ETa observed at the OzFlux towers with a Relative Root Mean Squared Error (rRMSE) / coefficient of determination (R2) ranging between 0.16 / 0.96 (Sentinel-2) to 0.27 / 0.92 (VIIRS). Additionally, to check its utility for catchment water balance modelling, we compared the performance of CMRSET to long-term (5 years or more) differences between mean annual precipitation and ETa with measured streamflow at 638 unimpaired catchments across Australia. This comparison yielded a RMSE of 0.47 mm/d (rRMSE of 0.24) and a R^2 of 0.76, demonstrating that the data are suitable for catchment water balance studies. With MODIS soon ceasing operation (2022), calibrating CMRSET with VIIRS, Landsat and Sentinel-2 (all operational, not research, Earth observation platforms) means that ETa can be routinely calculated for all of Australia from 2000 to 2040.

Developing a multi-decade, operational, Australia-wide, monthly, 30m actual evapotranspiration dataset

Jamie Vleeshouwer

Jamie is a software engineer at CSIRO with 18 years of experience in developing data products, creating web applications, remote sensing, database design and developing interoperable web services. Lately he has been creating evapotranspiration datasets using MODIS, Landsat and VIIRS sensors for: monitoring irrigation compliance; monitoring the landscape water balance; and understanding the water regimes of biodiversity hotspots.

Actual evapotranspiration (ETa), the phase change of liquid water to a gas, is needed across Australia at high spatial resolution (e.g., 30m) and high temporal frequency (e.g., monthly) for environmental monitoring. Key uses of such gridded ETa data include: (i) monitoring the catchment/landscape water balance; (ii) tracking water use efficiency; (iii) monitoring irrigation compliance; and (iv) understanding the water regimes of ground-water dependent ecosystems and other biodiversity hotspots. We used the calibrated CMRSET (CSIRO MODIS Reflectance based Scaling EvapoTranspiration) coefficients produced in a TERN Landscapes project with time-series Landsat and VIIRS satellite Earth observation data within Google Earth Engine to track ETa across Australia from 2000 onwards. Landsat has high resolution (30 m) yet low frequency (16-days) contrasting VIIRS having low resolution (375 m) and high frequency (daily). Synchronous cloud cover over parts of the Australian continent with Landsat observations means there are places / times when no Landsat observations are available for a month. To infill such Landsat-cloud gaps we use VIIRSLandsat blending, augmented by linear interpolation as required, to generate a continuous (gap-free) ETa gridded dataset at high spatial resolution (e.g., 30 m) and high temporal frequency (e.g., monthly). This dataset qualifies for the 'big data' tag being 42 Tb from 2000 to current, growing by 4 Tb each year. As such making these data available to a range of users, some of whom want access to the monthly series of gridded data for specific locations to those who prefer summaries for either areas of interest that are user-defined (e.g., clicking on a map) or pre-defined (e.g., an IBRA region, National Park, or surface water catchment) raises a series of challenges.

Building a near real time continental soil moisture prediction using a Data-Model Fusion Approach system for Australia

Matthew Stenson

Matt Stenson is a Team Leader in the Environmental Informatics research group. Matt spent 8 years working with the Queensland Department of Natural Resources as a hydrogeologist and spatial modeller. It was here he developed a strong interest in information management and software development. Matthew Joined CSIRO in 2004 and worked on dryland salinity, catchment and spatial modelling as well as software development. It was during this time that Matthew became interested in the challenges associated with information supply chains and information infrastructures. Matthew also has research interests in data governance, web-based modelling services, provenance and the semantic web. Matthew has been heavily involved in large complex projects such as the Bioregional Assessments Program through his leadership of the Information management team. This team was core to the success of information and transparency management within the program and was recognised for their outstanding and innovative solutions. Over the last several years Matthew has coordinated the Terrestrial Ecosystems Research Network (TERN) Landscapes Platform. TERN Landscapes complements and completes the national land observatory with continent-wide, temporally dynamic information infrastructure. Drawing from other TERN Platforms (Surveillance and Processes) and with connections across relevant R&D providers, Landscapes provides the continental component of the TERN Observatory – in space and time. Landscapes enables the integration of TERN datasets (and other relevant data sources) with satellite data, observed ecosystem dynamics, biodiversity and productivity modelling tools for use in monitoring of ecosystem condition and change and state of environment reporting.

Soil moisture is a critical driver in ecological function and landscape condition through water availability to plants within the unsaturated zone. Additionally, it is a key component in controlling how quickly runoff may occur in a particular landscape due to rainfall and is an important variable in managed landscapes for the initiation of planting, irrigation and application of fertilisers such as nitrates. Traditionally soil moisture is measured using point-based sensors either via electrical resistance or neutron absorption, and while these data are useful at a paddock scale, the ability to interpolate to larger areas is limited. Typically, in order to estimate soil moisture over large areas, for example continental scales, physically based modelling is required to upscale relevant point scale measurements, but modelling is often unable to adequately capture and represent all of the physical processes involved due to inadequate parameterisation and low quality forcing data. Recently satellite products that estimate soil moisture at a global scale have become available and while these products have a continental coverage, and often a daily timestep, their spatial resolution is too coarse for appropriately scaled management decisions, and importantly they fail to capture important local processes. The SMIPS soil moisture system developed through TERN, takes a data model fusion path to produce daily estimates of volumetric soil moisture by combining the local physical representation of modelling with the spatial coverage in terms of national digital soil information and the temporal consistency of satellite-based products, to produce a "best-of-both-worlds" continental scale soil moisture product.

Detecting and correcting data errors in time series observations from geographically remote monitoring stations

Ashley Sommer

Ashley is a software engineer working in the Environmental Informatics group in CSIRO Land and Water. Ashley has been with CSIRO for 5 years, and has experience in creating high performance data storage, management and delivery systems.

Across Australia there are thousands of environmental monitoring stations continually collecting observations for use in research, academic, and commercial applications. The remoteness of these stations makes it difficult for the collected data to make their way into the hands of those who need to use it. Various methods are employed to send the data from the remote stations to the end user, the most common being commercial communications satellite providers. The data are usually received into a destination database, and directly used for applications such as trend analysis, fitting scientific models, training machine learning algorithms, and making agronomic decisions. How confident can we be that the received data are error-free? Data errors can and do occur, and fall into 3 broad categories; invalid observations, missing records, and duplicated records. Invalid observations can take the form of corrupted data, out-of-range values, and unpopulated fields. These are generally easy to detect using simple heuristics at the time of receipt and either flagged or discarded. However missing or duplicated observations present a greater problem. Missing records take the form of timesteps skipped by the station's datalogger, records observed by the station but not sent, and records sent but not received, and present as gaps in the timeseries. Duplicated data can be caused by records sent more than once from the station and/or records processed more than once in the database. When duplicated records have slightly different timestamps, it becomes difficult to detect. When missing or duplicated records exist, this lowers the quality of the dataset and adversely affects the data applications, particularly on accumulated values such as rainfall that aggregate their values over time. This presentation looks at various methods we're implementing in TERN Landscapes to detect and correct invalid, missing, and duplicated records in the TERN supported COSMOZ Soil Moisture Network.

Towards harmonisation and integration of ecology data

Dr Siddeswara Guru, Edmond Chuc, Javier Sanchez Gonzalez, Habacuc Flores, Tina Parkhurst, Jenny Mahuika, Anusuriya Devaraju

Dr Siddeswara Guru

There is a significant amount of data collected in ecology to monitor the environment by measuring biodiversity and ecological process at a certain point in time and space. Plot-based monitoring is used to survey vegetation and ecosystem processes that use repeatable methods and procedures. Repeated measurements of the same observed properties would enable us to decide on on-going environmental and resource management practices.

Generally, data collections are project-based, collected for a specific purpose and use the same monitoring methodologies at different plots covering more extensive geographical locations. These datasets are of considerable significance if they are integrated with other similar projects or programs. The handling and integration of ecology data is complex and challenging. Some of the challenges faced during data integration include uncertainty of source data management and capture, and harmonising different data terminologies and methodologies.

We will describe the development of Plot-X, the standard to represent and exchange plot-based survey data. Plot-X provides an information model with an aim to integrate ecological field survey data. The information model represents domain concepts such as ecology plots, plot visits, several domain features associated with plots and observations related to the domain features. We will showcase the system developed to represent and integrate ecology data that will enable users to query data at individual observation level.

ausplotsR – rapid access to vegetation plot data across environments

Dr Greg Guerin

Greg is a terrestrial plant ecologist with experience in community ecology, macroecology and ecosystem monitoring. He has described new plant species, mapped centres of plant biodiversity, and modelled the impacts of climate change on Australian ecosystems. As the 'Analysis and Synthesis Lead' for TERN Ecosystem Surveillance, Greg provides analytical support for effective field monitoring of the Australian environment and develops open-source software for extraction, analysis and visualisation of national ecosystem monitoring data from TERN AusPlots sites.

TERN Ausplots is a plot-based ecosystem surveillance monitoring method and dataset for Australia. Key vegetation and soil parameters and samples have been systematically collected across a national network of plots to enable continental comparisons and tracking of long term change. The dataset records a series of survey modules, which can be accessed through ausplotsR, including site information; full vouchered vascular plant inventory; ground and vegetation cover from point-intercepts; tree basal area; vegetation structural summary; and soils, including barcodes of physical samples. Environmental coverage Plots were originally stratified across the rangelands using cluster analyses to group similar bioregions. The scope was broadened to all terrestrial ecosystems, and subsequent site selection comprised gap-filling and opportunistic sampling. Gap-filling was optimised using iterations of targeted field campaigns and generalised dissimilarity models which predicted the most ecologically different target sites. 99.995% of Australia is now predicted to share some ecological similarity to at least one plot, despite remaining gaps such as the north-west deserts, wet tropics and tall eucalypt forest (sampled by TERN Ausplots Forests). Accessing data ausplotsR is a TERN R package that allows users to immediately obtain up-to-date Ausplots data, pre-process the data to facilitate rapid export or analysis, and apply built-in calculations and graphical applications to explore the dataset. AusplotsR has served over ten thousand requests for data to more than 440 users, comprising 5,000,000 sites of data and 1.2 billion total records. Since publication on CRAN in November 2020, the package has been downloaded over 3,000 times. Acknowledgements: We thank TERN (https://www.tern.org.au) supported by the Australian Government through NCRIS. For more information, see https://CRAN.Rproject. org/package=ausplotsR, https://github.com/ternaustralia/ausplotsR.

Standardising environmental monitoring protocols and data systems for improved decision-making (1st set of protocols)

Julia Bignall, Mark Laws, Kimberly McCallum, Sally O'Neill and Ben Sparrow

Julia Bignall

Julia joined TERN in February 2021 to develop survey protocols for the Commonwealth Department of Agriculture, Water and the Environment's (DAWE) Digital Environmental Assessment Program (DEAP) and Regional Land Partnerships (RLP) Program. Julia is an ecologist with experience working in consultancy and state government, giving her a well-rounded perspective on environmental assessment processes. She is passionate about improving systems to streamline and standardise the collection and dissemination of ecological data, to support environmental outcomes and accountability.

Conservation and restoration programs and environmental impact assessment decision-makers need access to consistent, comparable data across programs, jurisdictions and ecosystem types to understand change and effectively inform natural resource management (NRM) and conservation decision-making. TERN is working with the Department of Agriculture, Water and the Environment (DAWE) to co-design standardised ecological monitoring protocols and a data exchange system. The new protocols build on TERN's data aggregation systems and well-tested field survey protocols. TERN has produced a set of modular methods implemented at over 700 monitoring plots Australia-wide since 2012. A modular approach to the protocols will efficiently enable individual projects to collect information that is relevant to their project, whilst not requiring the collection of information beyond the scope of their project needs. This project will ensure service providers and ecologists collecting field data have ready access to comprehensive instructions for a suite of standardised monitoring protocols, be able to use web-based applications in the field to record data and have access to web-based portals for data curation. The standardised monitoring protocols will be used to support future DAWE NRM programs that benefit the environment, farms, and communities. In addition, the protocols will be available for use by other environmental land managers and environmental consultants. This presentation explores the first set of (draft) protocols delivered to DAWE in May 2021, including Plot Selection and Layout, Plot Description, Photopoints, Floristics, Plant Tissue Vouchering, Cover, Vegetation Mapping and Opportunistic Observations.

Standardising environmental monitoring protocols and data systems for improved decision-making (2nd set of protocols)

Mark Laws, Kimberly McCallum, Julia Bignall, Sally O'Neill and Ben Sparrow

Mark Laws

Mark joined TERN in November 2020 to develop standardised ecological field survey protocols for the Department of Agriculture, Water and the Environment's Regional Lands Partnerships Program and the Biodiversity Data Repository Program. Mark is as a passionate ecologist with a keen professional and personal interest in the conservation of Australian flora, fauna, and ecosystems. He is skilled in project management, planning and leading field surveys, flora and fauna assessment and monitoring, data collection, management and analysis, and the preparation of concise and comprehensive scientific reports and management plans.

Conservation and restoration programs and environmental impact assessment decision-makers need access to consistent, comparable data across programs, jurisdictions and ecosystem types to understand change and effectively inform natural resource management (NRM) and conservation decision-making. TERN is working with the Department of Agriculture, Water and the Environment (DAWE) to co-design standardised ecological monitoring protocols and a data exchange system. The new protocols build on TERN's data aggregation systems and well-tested field survey protocols. TERN has produced a set of modular methods implemented at over 700 monitoring plots Australia-wide since 2012. A modular approach to the protocols will efficiently enable individual projects to collect information that is relevant to their project, whilst not requiring the collection of information beyond the scope of their project needs. This project will ensure service providers and ecologists collecting field data have ready access to comprehensive instructions for a suite of standardised monitoring protocols, be able to use web-based applications in the field to record data and have access to web-based portals for data curation. The standardised monitoring protocols will be used to support future DAWE NRM programs that benefit the environment, farms, and communities. In addition, the protocols will be available for use by other environmental land managers and environmental consultants. This presentation explores the second set of (draft) protocols to be delivered to DAWE in November 2021, including Condition, Coarse Woody Debris, Recruitment, Basal Area, Soils, Fire, Vertebrate Fauna, Invertebrate Fauna, Targeted Surveys, Camera Traps and Interventions.

The value of standardised field survey methods for researchers

Dr Kimberly McCallum

Kimberly McCallum[1,2], Mark Laws[1,2], Julia Bignall[1,2], Sally O'Neill[1,2] and Ben Sparrow[1,2]

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Abstract

Reliable and high-quality ecological data is required by researchers to undertake meaningful analysis. When data is collected in a well-defined and standardised way, researchers can be confident in how the data was collected and can evaluate if it is appropriate for use in the context of their research. Standardising field survey methods can also facilitate more efficient planning and completion of field surveys and allow analysis to occur not only at the project level, but across sites as well as over time. Standardised methods for vegetation and soil surveys have been developed and widely implemented by the Terrestrial Ecosystem Research Network (TERN) and this data is freely available for researchers. TERN is currently working with the Commonwealth Department of Agriculture, Water and the Environment (DAWE) to develop a suite of new standardised field methods, which can be used nationally and have the potential for a range of research applications.

This paper provides a short summary of standardised methods and associated protocols, how standardised methods and data can be utilised by researchers, TERN's contribution to standardised field surveys in Australia and the potential research applications of these standardised methods.

Standardised Methods and Protocols

Standardised methods ensure that the same data are collected in the same way within and across projects and between observers. Documenting standardised methods (e.g. protocols, technical guides) facilitates knowledge transfer, ensures that procedures can be replicated and makes reproducing methods developed by others more efficient (Tay 2021). In ecology, standardised methods can range from those applicable across the country (e.g. The National Committee on Soil and Terrain 2009; White et al. 2012a; Cleary et al. 2015), to those developed for a particular state or system (e.g. DENR 2011; Eyre et al. 2015) or an activity or taxa (e.g. Atyeo and Thackway 2009; Auld 2009; DPIE 2020).

The value of standardised field methods are maximised when they are scientifically robust but also practical, with a focus on well-defined, precise, quantitative and repeatable measures (Sparrow et al. 2020a). Good protocols contain enough detailed information that they can be carried out by a range of users and include other supporting information such as how long procedure should take, preferred equipment or consumables, any preparation required and potential issues that may be encountered (Tay 2021). Quality protocols should also include step-by-step guidelines, well-defined terminology, version control and information about any updates, details on survey design and effort, strengths or limitations of the methods, and how they were developed and when they should be used to ensure methods can be easily replicated and are implemented appropriately (White et al. 2012a; Eyre et al. 2015; Tay 2021).

Applications for Researchers

Researchers can benefit from standardised methods in a number of ways, including increased availability of high-quality datasets, greater confidence in the data collected by others, potential for larger scale spatial or temporal analysis and more efficient field data collection because the need to design surveys from scratch is reduced (Sparrow et al. 2020a; Sparrow et al. 2020b). Researchers can better understand of the quality of the available data as they know how it was collected and any limitations of the methods used, which allows well informed decisions to be made about which datasets are appropriate for the research being undertaken (Sparrow et al. 2020a).

When ecological field data is collected in a standardised way, direct comparisons over large spatial and temporal scales are possible, and this facilitates a range of analysis, including large-scale or long-term biodiversity assessments, evaluation of land management activities and climate change, as well indicating when and where to implement conservation projects (White et al. 2012a; Capon et al. 2020; Sparrow et al. 2020a).

The Terrestrial Ecosystem Research Network

TERN was established to overcome the lack of standardised field survey methods available for ecological monitoring in Australia, with vegetation and soil survey methods now developed and widely implemented. All data are collected following well-defined, precise and standardised field protocols, where visual estimates are minimised in favour of quantitative measures, data are collected directly into an app and physical samples are also collected, which minimises any error associated with measurement method or observer variation (Guerin et al. 2017; Sparrow et al. 2020a). The TERN protocols are written as fully repeatable, step-by-step instructional guides, which means that any semi-experienced ecologist should be able to work through the protocols with no error (O'Neill et al. 2020). A modular approach is used, so the methods undertaken can be tailored to the system under study (Table 1).

The data collected by TERN is freely available to researchers and plot data is available across Australia (Figure 1), with the majority of data collected using the rangelands protocol (White et al. 2012a). The data collected by TERN has wide-ranging applications (see Table 1 and www.tern.org.au/research-publications), including assessing the distribution and dynamics of soils and vegetation across Australia, validating remote sensing, improving knowledge of carbon dynamics and climate change, and genetic analysis (White et al. 2012b; Sparrow et al. 2020a).

Standardising Methods for the Department of Agriculture, Water and the Environment

TERN is currently working with DAWE to standardise field data collection, data curation and data availability across natural resource management programs (Regional Lands Partnership [RLP]) and environmental impact assessments (Digital Environmental Assessment Program [DEAP]). The approach will focus on collecting quantitative data, rather than qualitative or descriptive measures, to ensure that baseline pre-intervention (or pre-development) data is comparable to any following post-intervention measures and consistent data is collected across projects. Data will be stored in a central biodiversity data repository, which will allow end-users to interrogate the data and also facilitates data re-use and sharing between users (Capon et al. 2020; O'Neill et al. 2020).

Table 1. *Modules in the AusPlots rangelands (R), forests (F) and woodlands (W) protocols, adapted from Sparrow et al. 2020a with additional information from Wood et al. 2015 and Sparrow et al. 2016.*

Module	Protocol	Time (min)	Application	R	F	W
Plot layout	Accurate layout using DGPS; installation of permanent markers	30	Accurate relocation, remote sensing validation	✓	✓	✓
Vegetation						
Photo-panoramas	Collection of 360° photographs from three points	20	Computer vision analysis, point clouds and measures of basal area	✓		✓
Vouchering	Collection of vascular plant samples	60-120	Taxonomy, spatial/temporal analysis of presence-absence	✓	✓	✓
Tissue samples	Collection of single tissue samples from vascular plants	30-60	Genetic/isotopic analysis	✓	✓	✓
Point-intercept	Collection of species, height, phenology, growth-form, senescence at 1,010 points	180-360	Change in relative abundance, cover and structure, remote sensing validation	✓		✓
Basal area	Collection by species using basal wedge at nine points	20	Convertible to biomass	✓		
Structural summary	Recording of three dominant species in each of the three strata (upper, mid, ground)	5	Community descriptions	✓		✓
Leaf Area Index	Collection of at least 50 evenly spaced readings with the LiCor LAI 2200 LAI meter.	20	Ecophysiological modelling; remote sensing validation	✓		
Large tree survey	Collection of species ID, trunk diameter and location for trees DBH >10 cm.	180-1200	Community composition, monitoring changes in tree growth, basal area growth, mortality and recruitment		✓	✓
Small tree survey and sapling/seedling counts	Collection of species ID, tree status and diameter, count of tree seedlings or saplings along belt transects	180-300	Community composition, tree diversity, changes in stand growth and biomass, mortality and recruitment, ecosystem structure			✓
Tree height survey	Collection of tree height data across DBH range	180-360	Biomass, site productivity		✓	
Coarse woody debris	Collection of CWD number and size along 5 transects	120-180	Ecosystem function, habitat			✓
Canopy photography	Canopy photos at 16 internal points using fisheye lens.	60	Change in canopy cover, remote sensing validation		✓	
Soils and Landscapes						
Plot description	Record location, substrate, microtopography, erosion/disturbance	10	Assessment of characteristics/impact of disturbance	✓	✓	✓
Soil pit characteristics	Collection of soil samples/data at 10 cm increments or identifiable horizons to 1 m	60-120	Characterisation and classification, correlate with vegetation	✓	✓	✓
Sub-site characterisation	Collection of nine samples in differing microhabitats at 0-10, 10-20 and 20-30 cm	60-90	Soil variability across plot	✓	✓	✓
Bulk density	Collection of three measures at the soil pit at 0-10, 10-20 and 20-30 cm	60	Conversion to volumetric measures	✓	✓	✓
Soil metagenomics	Collection of nine samples	30	Identify biota	✓	✓	✓
Fuel loads	Record understorey and litter biomass	240-360	Assessment of fuel height, shrub biomass, woody fuel counts.		✓	
Litterfall traps	Installation of litterfall traps	60	Litterfall mass and moisture content		✓	
Dataloggers	Installation of temperature and humidity dataloggers	60	Annual climate variation		✓	
Decomposition	Installation of litter decomposition bags	60	Decomposition rate – determine moisture content and biomass loss		✓	

The protocols being developed draw on the methods established by TERN and a range of other resources, and include plot layout and description, floristics, plant vouchering, cover, basal area, vegetation mapping, fauna (vertebrate, invertebrate), condition (including coarse woody debris, fire, recruitment), photo-points and camera traps, opportunistic observations, soils, targeted surveys and interventions (for more information see symposium presentations by M. Laws and J. Bignall). The protocols follow a modular approach to enable users to focus on collecting information relevant to their project (O'Neill et al. 2020).

Any future data collected as part of the DAWE projects, in combination with the TERN datasets will contribute to a network of ecological data across Australia (Figure 1; the location of current RLP project locations is shown to give an indication of potential spread of sites across Australia, but standardised data is not currently available for these locations). There is the potential for this network to be harnessed by researchers to undertake studies into vegetation and soils, invertebrate and vertebrate fauna, condition, fire, recruitment, coarse woody debris and natural resource management interventions.

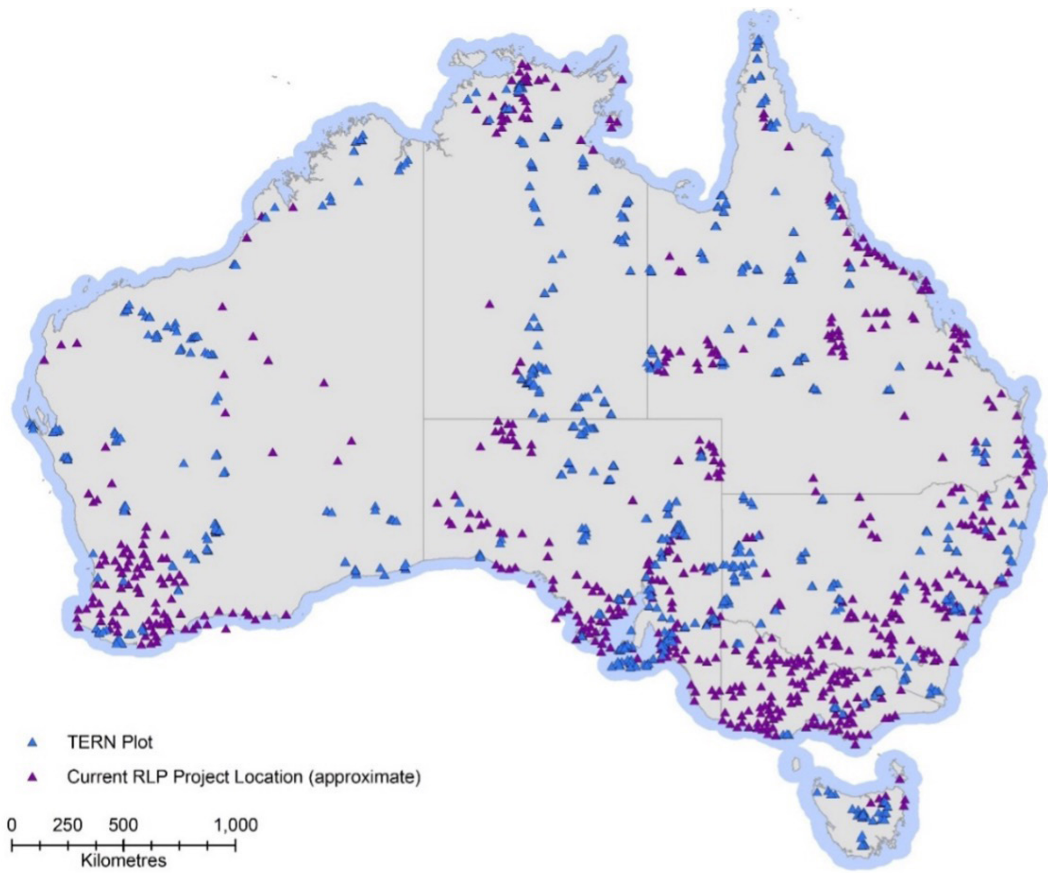

Figure 1. *Location of TERN plots and the approximate location of current RLP project sites (adapted from Capon et al. 2020). Standardised data not currently available for RLP sites. Data source: GeoScience Australia.*

Summary and Conclusions

Standardised methods have a range of benefits for researchers, including access to high quality data, greater analysis opportunities and more efficient field planning and data collection. Standardised vegetation and soil data are currently available from the TERN network and this is set to expand to a range of other measures including fauna, condition and interventions as the DAWE protocols become operational. The methods used by TERN, and the new DAWE protocols, will allow data to be collected in a precise, objective manner, which means that any researchers using the data or samples, can be confident in how it was collected and can easily evaluate if it is suitable for inclusion in their research.

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How can objective, standardised data collection increase the efficiency of assessments under the EPBC act?

Bethany Cox

Bethany is a Bachelor of Science (Honours) student at the University of Adelaide majoring in Science Policy.

Ecosystem monitoring is essential for assessing the efficacy of environmental action which reflects the legislation relating to the management of our natural resources. Absence of consistent, authoritative data that considers cumulative impacts spatially and temporally, creates an inability to understand the successes and failures of environmental management practices such as those highlighted in the recent independent review of the Environment Protection and Biodiversity Conservation Act 1999 (Samuel, 2020). Ecosystem monitoring is particularly relevant to the evaluation of both federal and state legislation. Policy changes are informed by the collection, analysis and reporting on the state of the environment across Australia (Jackson et al, 2016). Presently, there is no national supply chain for environmental monitoring information, with monitoring often fragmented between states, organisations and individuals. A lack of coordination, an absence of data sharing and no minimum requirements for data collection has led to inadequate data capture; preventing informed decision-making. I will discuss how the standardisation and streamlining of quantitative measures using clearly defined data systems will improve access to quality data from which to make informed decisions.

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Day Two

Keynote **Prof Stuart Phinn**

Effective Transition from Research to Operations for Government and Industry: The Essential Roles of Collaborative Research Infrastructure

Prof Stuart Phinn

Prof Stuart Phinn's research interests are in measuring and monitoring environmental changes using earth observation data and publishing/sharing ecosystem data. He received his PhD from the University of California – Santa Barbara/San Diego State University in 1997. Stuart is the Chair of the Committee that produced Australian Earth Observation Community Plan – 2026, he is also a professor of Geography at the University of Queensland where he teaches remote sensing and directs the Remote Sensing Research Centre, which includes programs to support government agencies across Australia (Joint Remote Sensing Research Program) and enabling coordination across all government, industry and research groups collecting and using EO data (Earth Observation Australia). The majority of Stuart's work uses images collected from satellite and aircraft, in combination with field measurements, to map and monitor the Earth's environments and how they are changing over time. A growing part of this work now focuses on national coordination of Earth observation activities and the collection, publishing and sharing of ecosystem data. Stuart was the founding director of TERN and its Associate Science Director, 2009-2015

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I would like to acknowledge the traditional custodians of the lands and waters across Australia on which we work and meet today, and pay my respects to their elders past and present. I extend that respect to Aboriginal and Torres Strait Islander peoples here today. I specifically acknowledge the traditional custodians of the Quandamooka, Turrbal and Jagera lands and waters where I live, work and teach. I offer my respect to their elders past, present and emerging as we work towards a just, equitable and reconciled Australia, one where we recognise and build our shared knowledge and experiences.

Introduction

How do we go from doing research to making things work in an operational context? In this keynote address I discuss two essential messages that relate to the use of collaborative research infrastructure.

1. *National collaborative research infrastructure is an essential component of a developed society's ability to conduct research, and translate it for use in government, industry, defence, and the general community.*
2. *Australia needs to revise its research: workforce, professional expectations, administration, funding and translational programs….*

   …as cornerstones of education and research programs supporting our society (and its economy etc)

There are six things to cover today.

1. Broaden the context of research so that we're all on the same page.
2. What does it mean – going from research to operational? It's something we see and hear a lot about in the media, and with directives from the Commonwealth government. While new to some, for others it's been the backbone of our work for a very long time.
3. Translating research to operation. Translational research activity isn't about just commercial activities. It's a whole range of different research.
4. Collaborative research infrastructure and how that's used,
5. A brief example, and then
6. Finish with some key messages to move forward

Research – a biased view of "Earth Observation" Research

My biases all flavour some of the points I make in relation to research infrastructure, so try and take them into account. Much of what I do, with the groups that I am lucky to work with, involves making field measurements in a wide range of different environments to understand what is there and how it is changing. And that is done through research centres. We get images from satellites, aircraft and drones, and collecting those and delivering them in a format that we can use is a collaborative activity with government agencies through research programs like the Joint Remote Sensing Research Program. We spend vast amounts of time working in open access software, as well as proprietary software, building techniques that integrate the field measurements and image data sets into information which people can make decisions on, and all of this work is done across multiple discipline areas. We publish our data sets, our methods and our work, it gets validated and is used for a range of different applications.

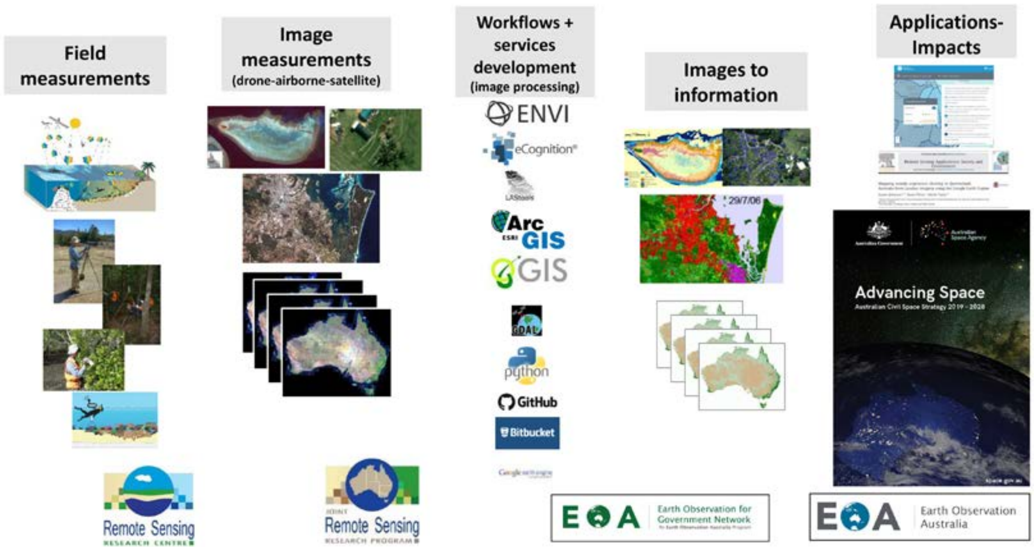

Figure 1: *Stuart's biased view of EO Research*

I have a deep interest in linking what we do to government applications and translating it for use –also coordinating communities across Australia that work in Earth observation so they can do research, so they can translate it into work, whether it's in government and industry, and also so that they can work with our Commonwealth and state and territories to have national approaches in some areas. In this case we do have a space agency and a space strategy - one of its major pillars is Earth observation. So, the approach I take there underpins a lot of what I talk about today.

Research – who does it and where does it happen?

Research is not something specific to universities. Government agencies, defence agencies, start-up industries, established industries, universities, research institutions, NGOs, community groups and individuals all do research in one form or another. It's a hang up people in universities need to get over really quickly, that they're the only ones that do research and know how to do it.

The good thing about the research we do across Australia, that's supported by research infrastructure, is it's across all these different environments and it fits into a range of government, industry, defence, community activities.

Our research is something that's done in a range of different areas. It is worth noting however, going back to the start, that one of the areas where we can improve

Figure 2 *Research activities supported by national research infrastructure in Australia*

on this is including indigenous knowledge systems and management. That is, other ways of collecting information, understanding the environment and managing the environment. We're starting to do this in a range of different activities across Australia, and it is something we definitely need more of within our research infrastructure capabilities and other program areas as part of what we're actively doing.

Research to Operational

This is terminology that we've heard a lot in the media. Ministers for education and other people talk about commercialising research, making it have impact. If you consider the review that's underway on the NCRIS road map at the moment, there is considerable focus on how things become commercial. So what does research to operational actually mean? Most of us know what research is, but what is something that's operational and how do you get to that point?

For methods and approaches to be operational, it's very context dependent, often dictated by the organisation you're working in, whether a government agency, defence, industry, the community, or other. There is not a one-off definition of what operationalising or translating research actually means and it's important to recognize that. Professor Bronwyn Harch, the DVC Research at University of Queensland suggests that if we are to look at the range of different approaches across a range of different sciences and different ways of gathering knowledge and information and communicating and using it, there are four stages.

1. Discovery type research where you're trying to work things out.
2. Applying it, whether in a physical context of managing an environment or a social context and showing that it works.
3. Demonstrating that it works, perhaps by going from one case study to a much larger scale and then
4. Seeing the research being deployed where it is actually being used, whether it's in government, different industries, communities – for a range of activities.

When we look at the research spectrum – and what we do in universities now, in particular, this is probably a strand that we'll see a lot more of in the future. We need to look at how research infrastructure fits in there and how we set up and manage it in that context, along with our research programs, and also the way that we reward people needs to look at those programs as well.

Here is some context around "operational" from an Earth Observation point of view, taking satellite images and turning it into useful information. The four dot points below come from a workshop with a range of state, territory and Commonwealth agencies in 2019. We asked people what was operational for them in terms of being able to access information from satellite image data sets, not the pictures or the images, but measurements. And these four points were essential, particularly in government agencies, to make sure it was usable.

1. Accessible all the time – 24/7, 365 days per year
2. It must be reproducible and replicable with publicly available documentation
3. It has to be verified and validated, with evidence and meta-data that can be checked and
4. Fit for use.

Source: Earth Observation for Government Network and Geoscience Australia (2019) Transitioning Australian Research to Operational Earth Observation Products Prioritisation Workshop. Canberra 6 -7 August 2019. Report https://www.eoa.org.au/eogn-resources

If you look at those requirements for operational, much of the testing to figure those things out, particularly in the applied and demonstrated context, can come from research infrastructure. We do see that in TERN, IMOS, AuScope and the Australian Plant Phenomics Facility, where people are doing those things. But I want to go a bit broader than Earth observation.

"Translating" research activities

A paper by Ramirez-Andreotta et al (2014), had a useful diagram (Figure 3) that relates to environmental monitoring, management etc. The diagram depicts environmental research translation in terms of understanding what's there and how it's changing. To achieve that you need multi- and trans-disciplinary teams and research infrastructure as part of it, working together, having the right administrative and organisational environments, funding and other activities to do that well, and I think we're not there yet.

There must be willingness to share and transfer information and data effectively, and that makes it essential to have effective intellectual property management and rewards for sharing. Once you're pushing things out, you go to public participation and communicating it further. The critical point is that research, translation, research infrastructure is a key part of it, but so are all the things that sit around and enable it.

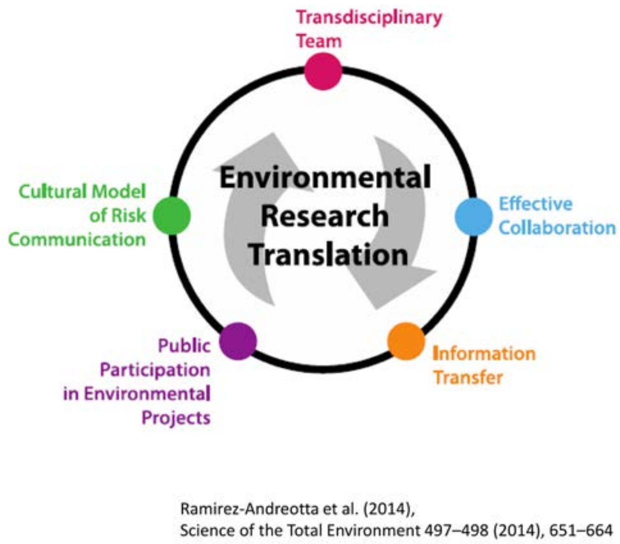

Figure 3 *Translating research activities*

One of the key points in doing this talk, (and keynotes are meant to make you think) is that for translational work to be effective, there needs to be coordinated state and national funding to universities, research groups, as well as industry and government that are doing the research as well as using it, so that those translational activities are done deliberately. It's not just an add on, it's not stuck on like a communication or a data publication plan, it's a core part of the work.

The second part relates to people and, particularly, the way that the academic system works in Australia. Our PhD training system in many major universities is not focused on this type of translation. It's quite dysfunctional, and in some cases, arguably, too hierarchical. It's archaic and focuses on individuals and individual rewards, not doing things together and translating work. We have to get away from impact factors. While we must publish our work and get it validated, the be all and end all is not an index in some specific journal. If we continue to go down that track we are lost. We need to have suitable legal and employment processes for keeping people in place to do this and suitable intellectual property. Australian Research Council and Co-operative Research Centre agreements don't really allow translation to occur between universities and industry and government effectively. The CRC model in particular keeps the IP within the CRC and you don't get a lot of small and medium companies interacting with them. So, if we're going to do translation we need to change things.

Figure 4 shows the progression in stages when people talk about technology readiness levels and research translation. Towards the end it becomes very commercially, engineering or technology focused.

I think the point we can move to (Figure 5) is a similar diagram, from the US National Science Foundation. On the X axis are the different stages of work starting from basic research or discovery then applied research, demonstration, deployment and commercialisation.

If you replace commercialisation with deployment across a range of areas, you've got a familiar sequence there.

Figure 4 *Technology Readiness Levels*

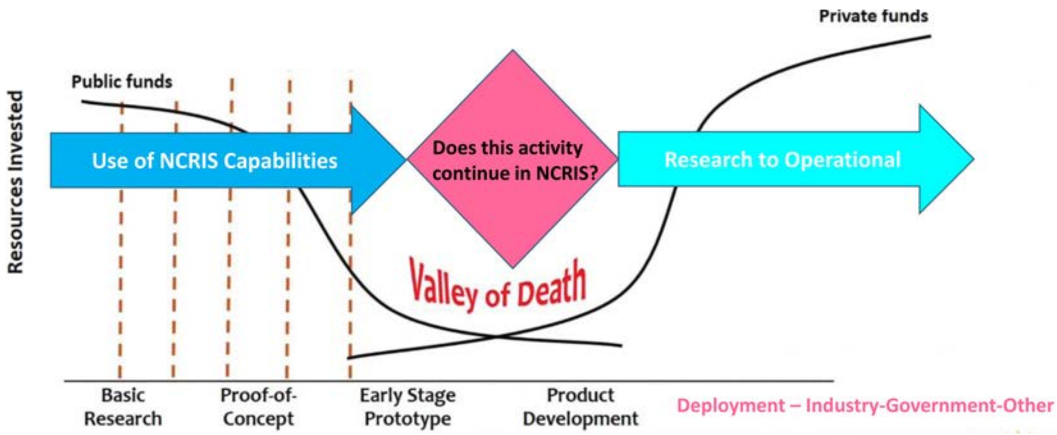

***Figure 5** Valley of Death in Research Translation*

The top of the graph does reflect what goes on in Australia to a certain degree, in that our public funds are very much at this end, on the research side, and then we get to the end, something works, and this is characteristic of NCRIS facilities.

This is a challenge – if something looks promising, then the question is what do we actually do with it? And then where does it go? Our NCRIS capabilities are used heavily in basic research, in universities, governments and other groups, and it proves that things work, but we get to a point where we don't have good decision-making abilities in place to decide what to do next? Does it get handed to a government agency to continue? Is it not working so it stops, or does it continue into private industry or otherwise?

Some NCRIS facilities do this, but it's something that TERN really needs to give more serious consideration, so that it doesn't get stuck in that valley of death. And I do want to point out again that if we look at the research funding environment in Australia, there's plenty of funding on the research side, research translation, sort of, but not really, research to operational activities - yes, we do, but I think the IP is not necessarily suitable for building industry and also working with government and other areas. We need to think carefully about where NCRIS facilities and TERN sit in supporting that process.

Collaborative Research Infrastucture

Collaborative research infrastructure does play a key role in translation. Figure 6, from the 2016 NCRIS roadmap, shows research infrastructure as central to industry, universities, research institutions, with some sort of magic stuff happening in the middle, resulting in food security, improved health, longevity and wellbeing. The arrow in the middle really needs some serious consideration. We haven't addressed it yet, particularly if we're going to do things like focus on farming and other applications and improve the Australian environment, economy and our future. We're good at building things, but to translate them, we need to pay some serious attention across the whole research context, and particularly within our research infrastructure facilities. They need to be integral to and used by government and industry and a range of different groups. Our NCRIS resource is really rich; it addresses a number of really critical areas that support society, government and industry. Some of these areas work really well with industry and some of them don't necessarily.

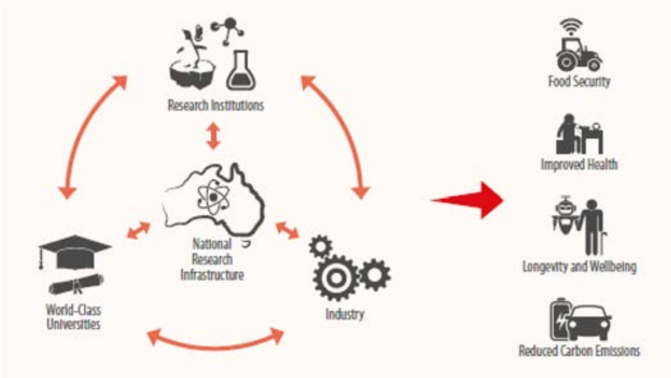

***Figure 6** From 2016 National Research Infrastructure Roadmap*

IMOS stands out as a bit of a role model among NCRIS projects. IMOS has established a New Technology Proving facility which enables people to go from development of ideas, piloting them, ie, essentially testing and demonstrating and then getting them operational and actually being used. They have a process for transitioning work in terms of submitting proposals and progressing them through the different levels starting from an idea to making something operational, in an IMOS context and then they support the whole process. That may be something that TERN could consider in future.

Example – Translating "tested" to "operational"

Now a quick example of going from tested to operational in an earth observation context. Vegetation cover is something states and territories were initially doing separately. TERN set itself the challenge of figuring out how to build this nationally. What TERN enabled us to do across the collaborative research infrastructure was to look at a range of different environments, a range of different field data sets and image processing approaches. How do we put them together to deliver an approach that works in these different areas to begin with? We brought in the image data sets, got them all corrected, the dots on the map are state and territory data sites which were shared, and the sort of TERN data sharing agreements that let us build a model between field measurements on the x axis and image predictions on the Y axis. It is not perfect, but it's a starting point, and then apply that to the image data set so we could estimate things nationally with no borders. That is a quick example of how things could work in this area.

That approach is being extended, particularly through the Digital Earth Australia program, which delivers a range of different products through national collaboration - much of which is enabled through collaborative research infrastructure. It is important to bring the ground-based measurements together with all of this data to make it work, and I know this is an Earth observation bias, but there is a wide range of other things you could use this for.

How do we go forwards – key message #2

To conclude we come back to the second key message, and that is the need to revise programs to be more effective at different stages of research, building a more supportive research environment that trains people to work in these areas, that maintains high quality science, but enables it to be used in a range of different application areas.

We need NCRIS facilities to have these transitional activities and to work in these different areas. We can look at programs elsewhere that are doing this, so we don't reinvent the wheel, figure out what works and what doesn't. We do need to look at how we coordinate state, territory and national funding in this context. Universities, research institutions need to seriously look at their professional processes around rewarding progress, how they build PhDs and delivering a more supportive, effective and diverse, professionally ready environment. Universities also need to revise their legal and employment processes to support the point above. And we need to have suitable intellectual property agreements that enable research to be shared and built up on commercially or not commercially as required and then suitable legislation, funding and taxes for industry, government and NGOs to engage with all of this.

There is a review going on right now. Hopefully it will take some of these points into account and quite carefully look at how we integrate indigenous approaches and indigenous management across the country into these areas. And we should look overseas at these things. This is not something brand new, but Australia is seriously lagging in getting on with it.

I acknowledge TERN and NCRIS and everybody there that has contributed to this.

Session Five: **Soils and Ecosystem Function**

Enabling soil data reuse for ecosystem management and decision making: A standards-based approach

Dr Megan Wong

Megan is a Research Associate in eResearch (PhD - Soil Ecology) with a background in science and education. Her research interest is enabling sustainable information management and knowledge transfer, and its application to environmental management. Current work focuses on helping ensure agricultural and natural resource management data, information and knowledge is globally available to researchers, government agencies, municipalities and the public, with a focus on making data understandable by both humans and machines (semantic interoperability).

Soil data forms an important part of monitoring, evaluating, reporting, and improving land use and management. However, discovering, accessing, and using soil data of varying quality, vintages and from multiple sources presents significant challenges for Farming Systems and Catchment Management Groups. Custodians store widely variable content (e.g. chemical, physical, biological) in multiple formats and structures (such as databases, pdfs and excel tables) with poorly documented content meaning. Visualising Australasia's Soils (VAS) enables soil data custodians to re-discover and access their legacy soil data in a standard format (using Observations and Measurements patterns) and standard content (using Controlled Vocabularies such as http://registry.it.csiro.au/def/soil). VAS allows data discovery, visualization, analysis and download via a web portal (https://data.soilcrc.com.au). The portal uses Application Programming Interface (API) endpoints that, subject to data-owner access permissions, provide JSON-LD contexts for observations (based on the observed property, procedure used or feature of interest), sites (such as plots, pits, paddocks), specimens and soil features (layers, horizons, profiles, bodies) using the W3C Semantic Sensor Network (SSN) ontology. Describing and delivering data in this standard way makes the data more findable, accessible, interoperable and re-usable (FAIR). VAS allows re-use of potentially lost legacy data for monitoring, reporting, benchmarking, tooling, modelling and machine learning. The data is more amenable to harmonisation and integration across space and time, for example by the procedure used or project. VAS faced considerable challenges in converting, understanding, and uploading the data providers' historical data due to the broad range of data variables/elements, formats, structures, and quality of the holdings. Future work is required to improve this process by developing custodian-based data capture mechanisms to make their data discoverable and accessible through VAS. Further refining user functionality and ease of use will help meet the monitoring, reporting, and benchmarking soil data use cases.

Spatially explicit estimates of brown and blue carbon stocks in Australia's terrestrial and coastal marine biomes

Dr Lewis Walden

Lewis' PhD research focussed on the impact of disturbance (drought and wildfire) on forest structure and carbon sequestration. Lewis' interests are broad but are underpinned by an interest in measuring, mapping and monitoring systems at a landscape scale, particularly in relation to management and disturbance.

Quantifying soil organic carbon storage across terrestrial and marine ecosystems is critical for determining current and future climate change mitigation potential of Australian soils. Organic carbon stored in soils is important in global climate change mitigation efforts. Current estimates of organic carbon stocks in Australia are derived separately for terrestrial, coastal, and tidal systems. Here, we collated and harmonised measurements of the 0–30 cm soil organic carbon stocks from Australia's diverse terrestrial and coastal ecosystems and modelled the stocks simultaneously. For the modelling, we used a regression trees algorithm and an exhaustive set of 20 spatially explicit predictors that represent climatic, soil, vegetation, terrain and oceanographic variables. The advantage of the algorithm is that it partitions the data into different regions with similar environmental characteristics, and then derives different local models for each of those partitions. We found that the model grouped regions according to their mean carbon density. For example, forested regions with large mean stocks were grouped, regions in the coastal habitats were separate from terrestrial systems, and the rangelands of inland Australia were also grouped. Native habitats (forests, tidal marshes and mangroves) have the largest mean soil organic carbon density and may be the most vulnerable to carbon loss with climate change and land management. Soils with smaller mean carbon density typically occur in the semi-arid and arid regions of the country and cover much larger extents. Our results suggest the need for the development of regional strategies for climate change mitigation via the protection, conservation, and restoration of terrestrial and marine ecosystems in Australia. The consistently derived estimates of the terrestrial and marine stocks might help to support Australia's National Carbon Accounting System, guide the formulation of policy around carbon offset schemes, improve Australia's carbon balances.

Updating Australia's digital soil mapping products: Soil texture case study

Dr Brendan Malone

Brendan's research focus is in using quantitative methods to precisely understand how soils function and change— spatially, and through time. Such methods are far from developed but believe some combination of mechanistic and statistical modelling is required to do this.

This research contribution presents new efforts to update the soil texture maps for Australia (Version 1 was delivered in 2015) which is part of the broader program to update and improve the country's soil information infrastructure. Not only is there new data on hand and a slightly different spatial modelling approach, the main distinguishing enhancement to what we will refer to as Version 2 products is the merging of field descriptions of soil texture with the traditional laboratory analysed data. We propose a fit-for-purpose algorithm to convert categorical soil texture data into quantitative measures. We also propose custom methodology to deal with the associated uncertainties of these conversions and how these can be propagated in any sort of spatial modelling. We first describe our efforts to re-calibrate the soil texture class centroids that were first determined by Minasny et al. (2007). Then we describe our approach for using these centroids and their uncertainties for generating plausible soil texture fractions for all qualitative soil profile texture descriptions contained in Australian soil databases. The next phase of the research details the renewed efforts to update the Version 1 soil texture products, that incorporates both data types and modification to the spatial modelling approach, which is more rigorous in terms of treatment of compositional data. Version 2 products are statistically more accurate than Version 1 products based on independent validation. Version 2 products were also compared to recently released Version 2 World Soil Grids products. These new products will enhance our abilities to characterises key soil functions such as soil water storage and transport and the cycling of soil carbon.

Filling the ecosystem monitoring gaps in TERN: making Western Australian SuperSites more super

Dr Caitlin Moore

Caitlin Moore is interested in research that brings together measurement and modelling techniques to observe and predict ecosystem processes over time and space. She established her foundations in this field during her PhD in the School of Earth, Atmosphere & Environment at Monash University, where she quantified tropical savanna productivity and phenology using the eddy covariance technique and phenocams. Caitlin expanded her skills through her Postdoctoral Researcher appointment at the University of Illinois Urbana-Champaign in the USA. There she worked within the Center for Advanced Bioenergy and Bioproducts Innovation (CABBI) on quantifying the sustainability of bioenergy crops grown in the United States, and on the Water Efficient Sorghum Technologies (WEST) project to build knowledge about agricultural systems and how to measure them in a high-throughput way. She also collaborated on projects aimed at improving food security, such as the Realizing Increased Photosynthetic Efficiency (RIPE) project. As a Research Fellow at the University of Western Australia, Caitlin is combining her interests in native and agricultural ecosystem processes by working towards improving our understanding of how these systems in Australia respond to climate variability over time and space.

Australia's terrestrial ecosystem observation capacity, supported by TERN, provides critical measurements of ecosystem health, and how ecosystems respond to climate variability and change. In the Ecosystem Processes platform of TERN's Observatory, eddy covariance towers record fluxes of carbon, water and energy between the ecosystem and atmosphere. Combined with a suite of measurements periodically collected to inform on plant structure and biodiversity, these towers form a core part of what defines a SuperSite. However, gaps exist within the SuperSite framework that need to be addressed to more completely capture changes in ecosystems over time. These include the need for better stress detection systems that link with ecosystem productivity, reducing temporal gaps in plant structural measurements, increasing biodiversity monitoring over spatial gradients, improving understanding of how sunlight moves through the plant canopy, and enabling better scaling from sites to region using remote sensing and modelling. This presentation details recent activities to improve ecosystem monitoring in Western Australia (WA), facilitated through a co-investment in TERN from the WA state government. New instrumentation has been installed to address measurement gaps at WA's three TERN SuperSites – a Wandoo woodland at Boyagin Reserve, the Salmon gums of the Great Western Woodlands, and the coastal banksia heath of Gingin. These ecosystems are unique to WA and are identified as sentinel systems for environmental change. The new instrumentation includes fixed terrestrial laser scanners to capture daily changes in vegetation structure, hyperspectral sensors to calculate vegetation indices and measure sun-induced chlorophyll fluorescence (SIF), and quantum sensor nodes to record variability of photosynthetically active radiation scattering and absorption through the canopy. These measurements will improve our understanding of vegetation stress and structural change as climate variability increases, provide synergies across the Landscapes and Ecosystem Surveillance platforms in TERN's Observatory, and allow for greater integration with novel satellite technologies.

Litterfall dynamics: developing a national dataset of daily fall rates and associated algorithms

Dr Alison Specht and John Carter

Litter fall (leaves, twigs, bark and flowers and fruits) is an important component of the total nutrient, energy and carbon budget of the plant community, but the spatial and temporal availability of the data is too sparse to interpolate at a continental level without associated measurements. The litter pool in grasslands, savannas and forests strongly influences the water balance by control of soil evaporation and is a major source of fuel for fires. Despite many individual studies the inter annual and seasonal dynamics of litter input to this pool is poorly quantified for use in daily timestep models running at a continental scale. This paper discusses an approach to fill this gap. Data have been acquired for more than 50 sites around Australia. Where possible, data were converted to daily rates (kg/ha/day/litter) for each collection interval. These data were further normalised to litter fall per unit foliage projective cover (FPC). The AussieGRASS model was used to extract daily climate data, e.g. rainfall, temperature, solar radiation and a number of other predictor variables such as soil water index and transpiration at each collection site. These data were then averaged across sites and times. This data set provides information to check annual models of litter fall, develop a simple model of litter fall seasonality, and more importantly provide a data set (and its statistics) for calibrating and validating other and more complex litter fall models. We shall discuss the challenges to incorporate these data in our national accounting, including (a) the availability and quality of data, (b) the variable lag phase between climatic conditions and leaf fall (in particular), and (c) the effect of fire and other extreme events. We shall also discuss the relevance of this work, and value in improving data quality and quantity.

Reducing Australia's greenhouse gas emissions through soil management

Prof Peter Grace

Peter Grace is currently Professor of Global Change at Queensland University of Technology (QUT) in Brisbane. He holds Professorial positions at Michigan State University and the Earth Institute of Columbia University (New York). He specializes in reducing greenhouse gases from agricultural systems. He has lived and worked throughout Australia, North and South America, Africa and South Asia. Peter coordinated the National Agricultural Nitrous Oxide Research Program under the Carbon Farming Futures initiative from 2008-16.

A small annual increase in soil organic carbon (SOC) over Australia's agricultural landscapes could potentially offset Australia's greenhouse gas emissions from all sources. The lack of long-term field trial data on the impact of innovative practices (e.g. adaptive management grazing and legume species) to increase productivity and SOC is a major constraint to reducing Australia's greenhouse gas budget. An additional constraint is the high cost of verifying small changes in SOC in landscapes with inherent variability in soil and plant production. This has placed greater emphasis on the acquisition of high temporal resolution, spatially integrated greenhouse gas flux data from "benchmark" monitoring sites throughout the agricultural sector. These benchmark sites provide the comprehensive calibration and validation data for simulation models to predict changes in SOC in response to management over time. The carbon dioxide flux data at benchmark sites underpins the rapid identification of carbon sequestration trajectories i.e. whether the management practice is actually storing carbon in this environment, without having to wait many years (to decades) for a significant result. The same benchmark sites can used to collect the non-carbon dioxide emissions data required for full cost C accounting (i.e. nitrous oxide from urine and manure and methane from livestock) and testing novel methods for reducing the cost of SOC assessment. TERN is ideally positioned to provide these benchmark sites in collaboration with industry.

Soil carbon isotopic proxies for determining the photosynthetic pathway of floral communities: A method inter-comparison

Rachel Atkins

Rachel Atkins is a current PhD student at The University of Adelaide. Her research focuses on the palaeoenvironmental reconstruction of Robertson Cave, Naracoorte, using plant macrofossils and stable carbon isotopic analysis.

The ability to accurately estimate changes in C_3 and C_4 vegetation cover across ancient landscapes will help us to determine how plants that use different photosynthetic pathways responded to climate change in the distant past. This knowledge enables us to make predictions about the influence of future climate change on today's floral communities. The carbon stable isotope values ($\delta^{13}C$) of soil organic matter (SOM) and long chain n-alkanes are commonly used for determining the proportion of C_3 and C_4 vegetation cover in palaeoenvironmental reconstruction. However, the relative accuracy of these two methods has not been rigorously tested. Therefore, we compared the C_4 cover estimates derived from both SOM and soil n-alkane $\delta^{13}C$ with modern ground vegetation surveys to evaluate the comparative accuracy of each method and determine if they can be used interchangeably for palaeoenvironmental reconstruction. Surface soil samples were collected from 20 TERN plots along a North to South transect through central Australia. We found soil organic matter- and n-alkane-derived estimates of proportional C_4 cover were positively correlated with the C_4 cover estimates calculated using vegetation survey data. The C_4 estimates derived for each method also produced similar trends with climate; as the climate became warmer, the abundance of C_4 cover increased. These results demonstrate that either isotopic approach can be used to reconstruct palaeovegetation without concern for variance associated with a particular method.

Carbon and water exchange in a plantation during initial years of growth

Marcela De Freitas Silva

Marcela commenced a PhD at Monash University in the Department of Civil Engineering in June 2018. Her project addresses the management of commercial plantations in Australia, specifically focusing on increasing plantation productivity in terms of water use and carbon allocation. This project entails complex numerical modelling, experimental data collection and data analysis. Marcella obtained her bachelor's degree in environmental engineering (honours) from the Federal University of Paraiba, where she developed the interest in research within the water resources field.

Eucalyptus globulus (blue gum) represents 51.7% of all plantation trees for hardwood production in Australia, and the largest planted areas are in South Australia and Victoria. Blue gum stands grow in a range of different environments with distinct climates and water availability; thus, they are extensively planted for large scale commercial plantations. Especially in semi-arid regions, the expansion of *E. globulus* plantations concerns governments because of their high water use. Factors including population growth and limited precipitation rates result in pressure for regulating water allocation for commercial plantation activity. Water accounting models for plantation establishments have been developed in South Australia over an 11-years management cycle. The models are based on limited experimental evidence on mature plantations, with insufficient information regarding the water use and growth of stands in the early years after establishment. Thus, management practices are difficult to be defined over the entire management cycle. This study aims to quantify the water use and carbon assimilation in a blue gum plantation in the first few years after establishment. Energy and carbon fluxes above the tree canopy during the first 3 years after planting were measured in a plantation in southwestern Victoria, Australia. The results reveal that dynamics of evapotranspiration and carbon flux resulted in increases in water use efficiency (WUE) over time. During the first two years, understory transpiration and soil evaporation had a major impact in the total evapotranspiration (ET) and net ecosystem exchange (NEE) of the site. After that period, trees grew enough to dominate the contributions to NEE, with the plantation becoming a more consistent carbon sink during the entire year, while maintaining ET at similar levels to the first two years.

Session Six: **The Role of Ecosystem Data in Australia's Society**

An Online Portal for Accessible OzFlux Data

Hoang Long Nguyen

The presentation is made by student representatives from the UWA Masters of Professional Engineering Environmental Engineering Design Class. These students have worked for 12 months to design and create a data visualization platform as part of their required training as Environmental Engineers.

TERN's Gingin OzFlux Supersite has been working with our Masters class of Environmental Engineering Design students at UWA, to develop a data-exploration platform. The aim of the platform is to help stakeholders, including the general public, to explore and learn from the data collected at Gingin. The platform is available online. The platform is focused on the topic of groundwater recharge from the Banksia woodland to the water supply aquifers below. This topic was identified as a priority by numerous stakeholders. The online platform introduces the Gingin site and allows users to engage with the data in a variety of ways. For example, users could interact with a guided "storyboard" that explains the recharge process and its variability. Alternatively, they could explore user-driven "dashboards" which allow self-guided manipulation of environmental datasets. Building the platform required overcoming several technical challenges: analysing the OzFlux data from Gingin to understand the recharge process; visually representing the important parts of this story; and developing a workflow to update the data access, analysis, visualisation and web-hosting. The workflow could be easily adapted to focus on different topics and sites. Our class hopes it might inspire other TERN and/or OzFlux sites to build their own outreach platforms, and we're happy to share templates, videos explaining how to use the specialised tools we relied on, and code.

The TERN SoilDataFederator

Ross Searle

Ross Searle is a Senior Experimental Scientist at the CSIRO.

Soil is a critical component of all ecosystems. Knowledge and understanding of its function and properties is vitally important in ecosystem management. Australia is fortunate to have a large amount of soil profile data observations and measurements publicly available. However, this data is collected and managed by a broad range of custodians across the country. These custodians collect the data for their own specific business purposes and manage it in a disparate range of data systems. Until now, individuals wanting to bring this data together in a unified way had to source data from each of the individual custodians on a case by case basis. A challenging process for most ecologists. At a conceptual level, there is a broad spectrum of approaches through which data unification can be achieved, from the creation of a centralised data warehouse through to the case by case collation of datasets. The "SoilDataFederator" is a federation approach to data unification, where data is made available and managed by custodians but is federated on the fly to into a consistent form. The SoilDataFederator is a web application programming Interface (API) implemented in the R programming language and the code is publicly available. The API is used to query data over the internet via a standardised set of URLs with standardised parameters. Data can be returned in a range of formats but always in a standard form optimised for delivering data on a per attribute basis. The SoilDataFederator manages a catalogue of available datasets and a series of associated "backend" modules which query the individual data systems and transform the data on the fly to the standard form. The SoilDataFederator significantly eases access to soil data and enhances our ability to use this data for understanding and managing ecosystems.

The detection of socio-economic impacts of protected area creation

Dr Alison Specht

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Abstract

This paper discusses a project aimed at detecting whether protected areas (PAs) influence the socio-economic well-being of adjacent communities. The Belmont Forum funded PARSEC project is using satellite images and deep learning algorithms to predict socio-economic conditions. In this paper we show our on-going work for the selection of PAs, development of methodology using deep learning to detect socio-economic indicators from remote sources, facilitation in data management and the approach used to handle a complex inter-disciplinary and trans-national team. We note the challenges in selecting case studies with examples from Australia, Brazil, Japan and the USA, and meshing remote sensed data with census data. We discuss the advantages of good data management for the individual and for the project and some simple steps to make this easy.

1 Introduction

The impact of global changes on the world's ecosystems, as well as the repercussions for human societies, is a major concern for the research and policy agenda. Protected areas (PAs) can contribute directly or indirectly to socioeconomic outcomes such as food security and development opportunities for nearby human communities in this uncertain future.

This topic is being addressed through the Belmont Forum-funded PARSEC project (www.parsecproject.org), with funding partners from France, the USA, Brazil, Japan, and associates in Australia and the UK. The method we are using is based on recent research on how satellite images and deep learning can be used to predict socioeconomic conditions (Jean et al., 2016; Yeh et al., 2020).

As a desired outcome from this project, the Belmont Forum expects not only a good scientific product but also a workflow and outputs that are transparent, open, and reproducible (i.e. it is FAIR, Wilkinson et al., 2016). To this end, the PARSEC project has two components, a team of synthesis scientists (the synthesis strand) and a team of data scientists (the data strand). The synthesis strand is working on the subject of this paper, while the data strand is developing tools to support active international collaboration and good data management practices. These two strands are designed to learn from each other: by the end of the project the domain scientists should be better equipped to practice good data management, and the data scientists better able to speak with and respond to researcher priorities. In this paper we discuss some initial successes and challenges using examples from Australia, Brazil, Japan and the USA.

2 Methods

2.1 Towards the detection of socio-economic indicators

The synthesis strand is essentially a working group of the FRB-CESAB, the French synthesis centre, and led by David Mouillot of the University of Montpellier. This strand is engaged with the core business of detecting the socio-economic effects of the protected areas. The work can be summarised in two steps: (i) to identify areas with PAs for which satellite images before and after their establishment exist; and (ii) to use novel techniques of deep learning and artificial intelligence to model the socioeconomic outcomes of the effects of creation of those protected areas on their settlements.

2.1.1 Site Selection

The primary concern for the synthesis strand to date has been site selection. We are prioritising protected areas (PAs) that are listed globally in the IUCN World Database of Protected Areas (WDPA, https://www.protectedplanet.net/), and we need PAs that will allow us to obtain satellite images before and after their establishment, ideally those PAs established after 1990 and before 2015. The PAs selected will have adjacent, small towns nearby that are relatively unaffected by strong influences like big cities and mining activity. For validation, 'mirror' or reference sites are also being selected (Figure 1). We have stratified the selection according to ecoregions using Olson, et al. (2001) for the terrestrial sites, and Spalding, et al. (2007) for the marine.

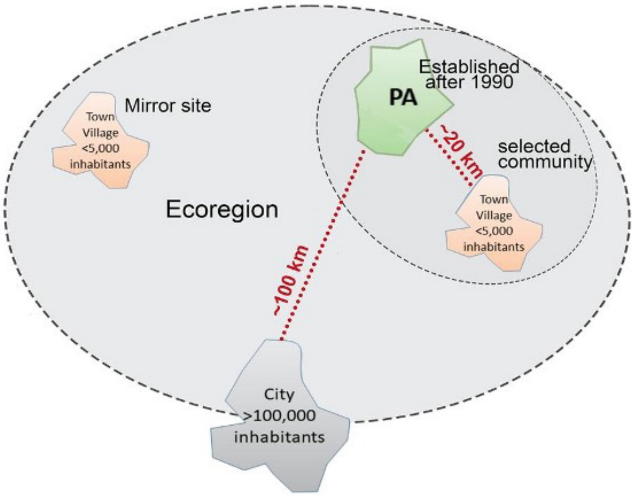

Figure 1: *PARSEC criteria for site selection.*

2.1.2 Satellite Data Availability

To conduct a time-series analysis for change detection using remote means, satellite images are preferably required a few times before the creation of a protected area, and several times after its creation. Reference sites also need to have such a time series. Effects may not be seen for some time after the 'impact'.

For a global project such as this, the availability of images is variable across space and time. Some countries have better coverage than others, and of course changes in satellites over time affects the quality of the images available. Some images are expensive, and this project does not have a large budget for acquiring them. Image type determines their spatial resolution, from 1m2 for some modern satellite images (often only commercially obtainable) to 70m2 resolution for old Landsat MSS images.

As an example for this paper, we have chosen a marine protected area in Jurien Bay, Western Australia, and the small town next to it (Figure 2). This PA was created between 2003 and 2005 (depending on source). In the satellite image before its creation (1985), the little village can clearly be observed. Over time the small town has clearly grown, but whether its growth is due to the creation of the PA, and whether the economic circumstances of the people living there have changed, is the question to be determined.

In many situations there are a lack of signals from the satellite image that are socioeconomically meaningful. One of the inspirations for this project was successful in finding that in East Africa (Jean, et al., 2016), and a few others have shown some success including Yeh, et al. (2020), and Ayush, et al. (2021).

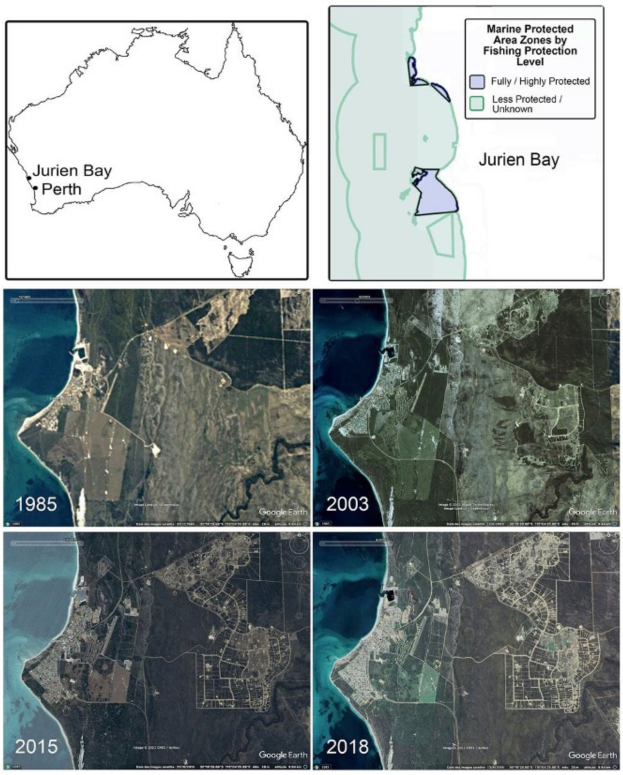

Figure 2: *Satellite data before and after the creation of the marine protected area in Jurien Bay, Western Australia.*

2.1.3 Workflow

Census data from each country and international (harmonised) sources will be spatially aggregated and interpreted through satellite imagery using visually detectable socioeconomic indicators. Using a deep learning model the team aims to develop predicted socioeconomic indicators that may well be used for decision support (Figure 3). Moreover, within the deep learning methodology the satellite images that belong to a selected site will be split for training, test and validation, which are used for the deep learning model.

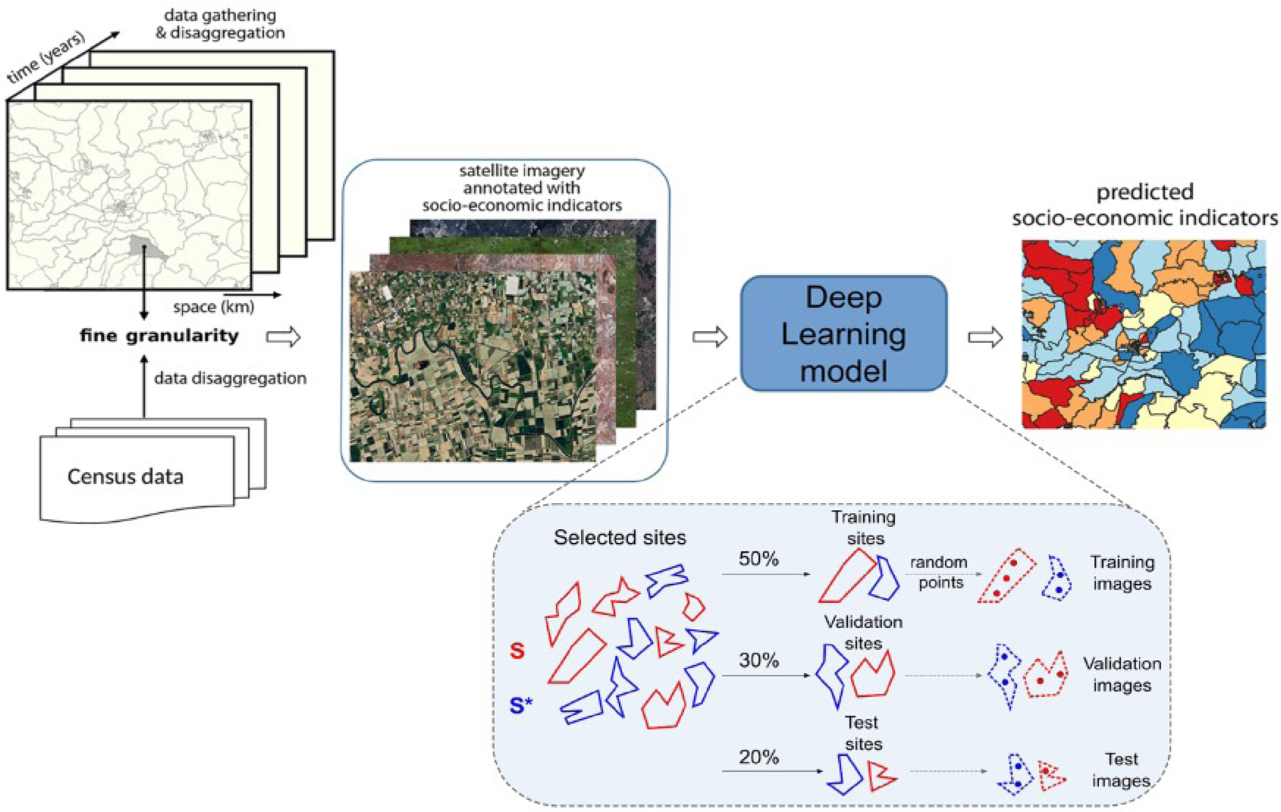

Figure 3: The proposed workflow. First, the dataset preparation, where the remote sensing image data and census data are acquired and aggregated into the image-labelled dataset. Second, neural network architecture will be used to train these data. Third, the configuration of experiments is set up using data sets split for training, validation and testing. The sites selected (S: sites (villages and towns) near to PAs and S: the mirror sites without PAs) are used for validation of the experiments in order to analyse the effect. Diagram based on Machicao, et al., 2020.*

2.2 Towards optimising data management and developing tools for researchers

The data scientists, led by Shelley Stall of the American Geophysical Union, are working in parallel with the research team. They are guided by the Belmont Forum's Data and Digital Object Management Plan (DDOMP: https://bit.ly/3yPsQIl) and Bishop et al., (2020). The Belmont Forum requires its funded projects to ensure they are open and reproducible, and the data strand aims to be an exemplar. This strand is charged with anticipating and responding to the data management needs of the synthesis strand and engaging actively with the wider research community. This includes the digital logistics of communication through to delivery of resultant data in a CoreTrustSeal registered repository (Lin et al., 2020). It also requires the actions taken in the project to be re-traceable and reportable at any time.

Communication and feedback from the wider community is achieved via conference participation (e.g. the Research Data Alliance, CoData, ESIP, the European, Japanese and American Geophysical Unions), round table discussions and training workshops as well as refereed articles. The engagement of a range of members from both strands in these activities is an important component of the sociological health of the whole team.

3 Results

3.1 Selected PAs

The first task has been to identify areas with PAs for which we could obtain satellite images before and after their establishment, and these are illustrated for four countries, the USA, Australia, Brazil, and Japan (Figure 4). As mentioned before, our main source for suitable protected areas is the WDPA, but we validate them with national information (e.g. Ministério do Meio Ambiente in Brazil, and CAPAD in Australia). In the USA there are many protected areas, but most of them, especially on the east coast, were established before 1990, so they were immediately excluded. On the west coast, there are suitable PAs, but villages that are not affected by other influences are hard to find. In Australia many parks were created in the 1990s, which is very promising, and in a draft selection last year in Western Australia we were able to identify some potential sites, but again adjacent settlements and the absence of disturbance factors become really significant in many cases. The same is true in Brazil, where most of the suitable parks are in relatively isolated regions (in the north west), and we have the same challenge.

In Japan, the filtering criteria were adjusted due to the small distance between cities. Despite this, the PAs that fell within the project's temporal and spatial envelope were those found on the Ogasawara Islands (Figure 4), so a different approach is being explored for Japan. The selection of suitable PAs remains a challenge and we have learned a lot during this process, not just about the choice of parks themselves.

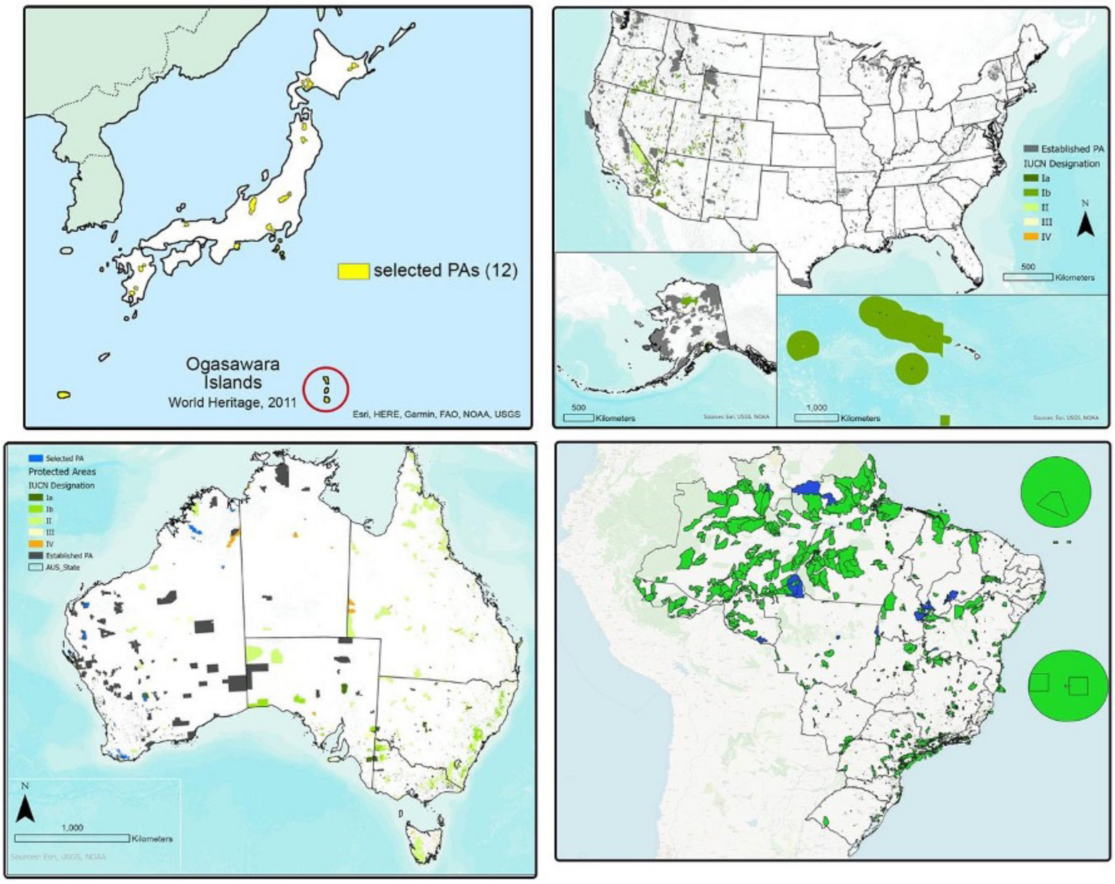

__Figure 4:__ Maps from Australia, Brazil and the USA showing protected areas that fall within our criteria (green) and selected PAs for Western Australia and Brazil (blue). For Japan a range of potential PAs are shown in yellow, but only the PA on the Ogasawara Islands (highlighted) falls within the project criteria.

3.2 Test of remote sensing of socio-economic parameters

In an experiment to test the use of machine learning to discover indices of socio-economic well-being from remote sources we took Google Street View (GSV) images as our 'remote' source using an approach developed by Suel et al. (2019) in a very comprehensive case of use of GSV for the city of London.

As described more fully in Machicao et al. (subm.), we aimed to evaluate the prediction of income indicators using street view images, through a case study conducted in the area Vale do Ribeira, located in the southeast of Brazil. This area is a semi-rural area with a large proportion occupied by protected areas. We collected 2010 census data from the Brazilian Institute of Geography and Statistics (IBGE) and Google Street View imagery of 30 regions within the Vale do Ribeira for our images. As the images returned from GSV are panoramic, we requested four picture orientations (0°, 90°, 180° and 270°) to cover the image view completely. The computation for the analysis involved extraction by a pre-trained convolutional neural network (CNN) whose goal is to classify the images to detect socio-economic indices (Figure 5).

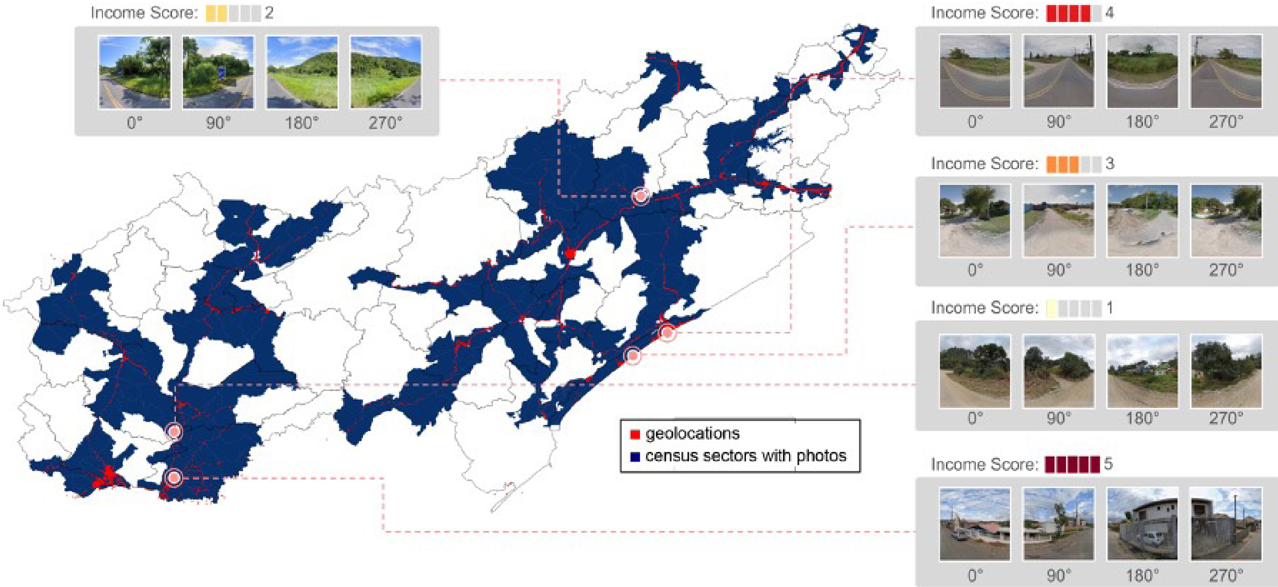

Figure 5: *Deep Learning method applied to the prediction of a socioeconomic (income) indicator on the Vale do Ribeira (southeast of Brazil) using Google Street view images. The census areas without colour are mostly occupied by sparsely settled rural or protected areas. Source: (Machicao subm.)*

The observed income score was compared spatially with the predicted values from the census (Figure 6). The best performance (80%) was obtained for the higher income region of the predicted cases, while it decreased uniformly for other regions. The result was inherently biased by the number of images in GSV, as the higher income regions had more available images (had more visible infrastructure) than lower income areas.

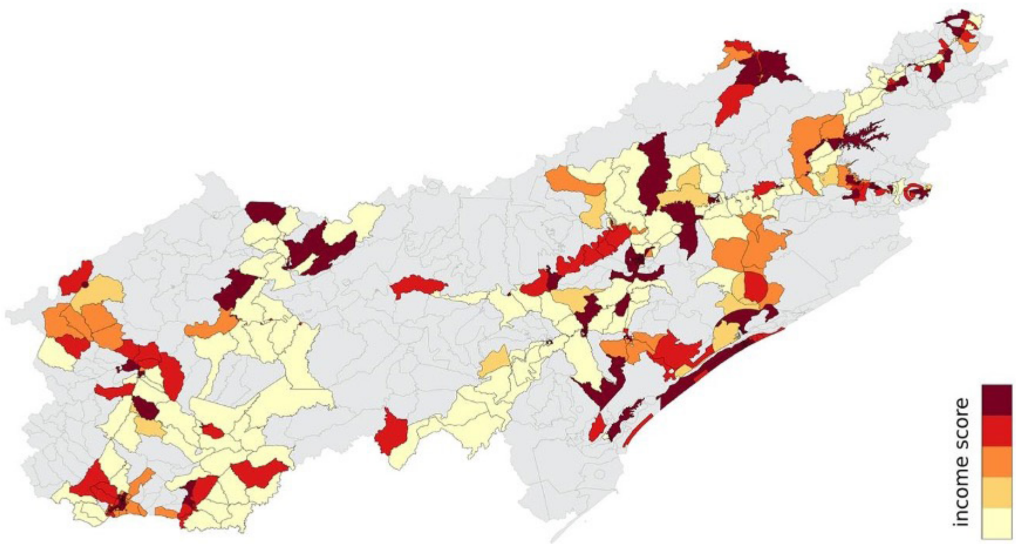

Figure 6: *Results of the prediction of income level using GSV images on the Vale do Ribeira. This plot shows the performance of the trained network to predict income score. The colour scale runs from 1 to 5, with 1 representing the lowest income and 5 representing the highest. Source: (Machicao subm.)*

3.3 Data management practices

The data strand has established a common set of resources for the transnational and transdisciplinary team. This starts with support for effective group function.

Communication tools used are primarily email and Slack (the latter less well used by the members), with regular zoom meetings held within country teams, strands, between the postdocs in the project (Brazil and France) and around particular sub-projects. Twice a year the whole group meets and given this project has mainly existed in the time of Covid19, this has, with one exception, been remote. Additional opportunities have been grasped at conferences with regular co-located meetings, for example, at RDA Plenaries since the start of the project.

Google Drive is being used for document sharing (including meeting notes) and as a temporary repository for data files. Google Drive is connected to a dedicated space on Open Science Framework (OSF, https://osf.io/), which in turn is integrated with Amazon Web Service (AWS, https://aws.amazon.com/). Software development with GitHub works well and is commonly used by the developers, with jupyter notebooks and R Markdown some of the most popular forms of recording code and versioning. As recommended, we have identified a repository for final data storage, the Environmental Data Initiative (EDI, https://environmentaldatainitiative.org/), which has become a partner in the project. We have a project library on Zotero for our bibliographic records. We have our own community on Zenodo to publish workshop materials, presentations, short reports, and software (https://bit.ly/2U1iCpj). Zenodo provides a digital object identifier (with versioning capability) and citation for each object published there. More details about this organisation can be found in Stall (2021).

Another big contribution of the data strand has been listening to the synthesis science team and getting them to think about a process during their workflow that would facilitate their data management goals and open-access practice. This has evolved into a simple checklist for the researcher which can be applied to any research team, not just PARSEC (Stall et al., 2021). Everyone on the team has their ORCID profile, ensuring links to CrossRef and DataCite are activated. Every quarter the team member reviews their ORCID profile to check that it is updated. Every week the datasets created and used are ideally recorded using spreadsheets provided on Google Drive, and any workflow or provenance details added. Monthly we update conference presentations and posters in a spreadsheet on Google Drive (cross-checking with Zenodo), and each team member is charged with ensuring data sets, images and software used are preserved and the publications that referred to them are recorded.

4 Discussion

We have presented some of the challenges and preliminary results for the PARSEC project, a project involving forty people from different disciplines, countries, languages and cultural backgrounds. Having two components, the data strand and the synthesis strand, has been useful to divide the goals and organize the knowledge flow.

The selection of protected areas with the criteria we require to address the core project question has proved challenging. Part of the reason for the project was to test the generality of the approach of Jean et al. (2016), and it was expected that there would be different situations in each country. Adjustments for variation in population density, from high (Japan) to low (some parts of Brazil and Australia) and conflicting land-use activities remain to be solved.

Blending census information with remote imagery, however, looks promising, assuming a good series of repeated images can be obtained. The experiment with Google Street View (GSV) was a direct attempt to test this, and it highlighted some useful limitations for which we need to plan. These include repeatability of the method. In the case of GSV the attractiveness of its ubiquitous nature throughout the world is offset by, even for one extraction event, the high temporal variability in the images, anywhere between 2011 and 2019 for the Vale do Ribeira study, while the census data were available for 2010 only. We continue to conduct small experiments that will be useful for choosing the best data management and the appropriate configuration for deep learning architecture.

The work of the data strand aims to ensure transparency across the team and encourage and support group work practices. Following the tasks outlined in the checklist has greatly eased the onerous reporting process for Belmont and the country funders (all of which have additional separate annual reporting requirements). The regular attention to recording activity ensures appropriate credit for data providers as well as team members when publishing their data, code or articles of any sort. The data strand has had many outputs which have largely been stimulated by the fortnightly meetings and high activity (conferences, presentations posters) in the data science community.

The desired outcome is not only to have a good science project, but also to have a workflow and a product that is transparent, open and reproducible.

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Where citizen science meets the built environment: the schools weather and air quality (SWAQ) network

Dr Melissa Hart

Melissa Hart is interested in the impact of cities on climate and climate on cities. With more than half of the world's population living in cities (close to 90% of us in Australia!), city dwellers experience a double whammy of climate impacts - global climate change due to increased greenhouse gas emissions AND local impacts from the urban heat island effect. Melissa works to understand these impacts and explore solutions that will make our cities more liveable and sustainable.

Sydney's population is predicted to grow by 30% within twenty years, most of which is slated for the semi-rural fringes. The resulting urbanisation will adversely impact temperature and air quality in these areas of rapid population growth. Both temperature and air quality can vary greatly within cities themselves due to spatial variability in land-use, surface characteristics, pollutant emissions, transport infrastructure and the geography of the city. Therefore it is imperative to have high density meteorological and air quality observations across a city. This presentation will discuss the development of a citizen science project, SWAQ (schools weather and air quality), that has placed meteorology and air quality sensors in schools across Sydney. The sites complement existing networks in order to target regions lacking monitoring sites e.g., urban growth areas on the rural fringe. Students analyse this research quality data in science and maths curriculum-aligned classroom activities. The data will also be freely available online to researchers.

Session Seven: **Good Data and Models for Good Science and Management**

TERN observatory synergies for scaling carbon pool and flux observations with remotely sensed data: Current activities and next steps

Dr William Woodgate

Will commenced his ARC DECRA fellowship (DE190101182) in 2019 at the University of Queensland. The research proposes to bridge scales with remotely sensed dynamic plant productivity. Previously Will held the position of Research Scientist at CSIRO, after commencing as a Postdoctoral Research Fellow in 2015. Will is the Principal Investigator of the TERN-OzFlux Tumbarumba research site. Now in its 20th year it is one of Australia's longest continuously running flux tower sites and rated equal second globally for verification of environmental satellite products by the Austrian Bureau of Meteorology (ZAMG) representing a European consortium of research organisations.

This presentation highlights synergies between all three TERN observatories for scaling carbon pool and flux estimates in Australian ecosystems. A new TERN Landscapes project facilitates the systematic collection of Terrestrial Laser Scanning (TLS) datasets at core TERN Ecosystem Processes sites, with the overarching objective to develop the first comprehensive 3D digital twins, i.e., genuine 3D abstractions, of a representative selection of Australia's diverse forest types. These 3D representations are intended to serve a broad suite of purposes across a range of research domains. When complemented by state-of-the-art 3D radiative transfer modelling (RTM), various forest structure and biomass retrieval methods at canopy to continental scales can be quantitatively assessed using RTM simulated Earth observation (EO) signals (e.g., air-/space-borne LiDAR and optical imagery). This is especially important for Australia's unique vegetation structure (i.e., highly clumped, vertically inclined leaves). The framework will allow for any type of active or passive LiDAR or optical sensor to be simulated, which includes current instruments, e.g., NASA's space-borne LiDAR GEDI, or be used to model and predict the performance of future planned sensors. In addition, these realistic 3D models will assist in parameterising the new wave of Earth System models with increasing canopy structure complexity. Another application of TLS-based 3D forest abstractions is to investigate structural attributes at unprecedented levels of detail, such as tree morphology and phylogeny. Such data is highly complementary to traditional plot-based inventories provided by the TERN Ecosystem Surveillance. Lastly, possible synergies with new proximal hyperspectral sensing systems co-located at flux towers will be discussed. These proximal systems fill an existing spatiotemporal gap (sub-daily and sub-plot resolution) between early generation sun-induced fluorescence (SIF) space missions and hyperspectral satellites, thus facilitating the next wave of research into remote measurement methods of canopy productivity, phenology, and other biophysical attributes (leaf chlorophyll, nitrogen content, LAI etc.).

The NEON Ecological Forecasting Challenge: Using forecasting challenges to leverage observational networks and advance prediction in ecology

Dr Quinn Thomas

R. Quinn Thomas is an associate professor in the College of Natural Resources and Environment at Virginia Tech in Blacksburg, Virginia, USA. He is the lead of the U.S. National Science Foundation-funded Ecological Forecasting Initiative Research Coordination Network (EFI-RCN). The EFI-RCN is hosting the NEON Ecological Forecasting Challenge has a means to grow the field of ecological forecasting.

Forecasting challenges, in concert with increased data availability from sensors and observational networks, can improve our predictive understanding of ecological dynamics by providing a focal point for developing forecasts using a diversity of approaches. To this end, the Ecological Forecasting Initiative Research Coordination Network is hosting the National Ecological Observatory Network (NEON) Ecological Forecasting Challenge. As continental-scale observatory, NEON has standardized measurements across 81 sites that include terrestrial and aquatic ecosystems. Leveraging these standardized measurements, the Challenge provides protocols, standards, and cyberinfrastructure for submitting forecasts for multiple time-series datasets before NEON collects the data. The Challenge has five themes that engage the community in forecasting populations (ticks), communities (beetle abundance and diversity), and ecosystems (plant phenology, lake/stream temperature and dissolved oxygen, and terrestrial carbon and water fluxes) and has been running since January 2021. This talk provides an overview of the Challenge along with lessons learned that can be applied to observations from TERN. It also highlights how such challenges can advance our synthetic understanding of predictability across different ecological system and scales while formalizing best practices that maximize forecast utility for society.

Plants down under: defining and mapping the photosynthetic pathway of plants across Australia

Dr Samantha Munroe

Samantha is an ecologist based at the University of Adelaide with the Terrestrial Ecosystem Research Network (TERN). At TERN, she designs innovative strategies, tools, and software to help produce world-class ecosystem monitoring programs and data.

As the climate in Australia changes, plants using different photosynthetic pathways (i.e. C3, C4, CAM) must adapt to these new climate conditions, 'migrate' to new habitats, or disappear entirely. However, our ability to monitor and respond to these changes is hindered by a lack of data on the pathways of different species, as well as their distribution and cover in distinct plant communities. This urgent problem drove the creation of a new data set that lists the photosynthetic pathway of > 2400 Australian species recorded across TERN's entire national plot network. This photosynthesis pathway data set was created by first listing every unique species recorded during field surveys conducted by TERN's Ecosystem Surveillance platform. This list was then compared to over 30 peer-reviewed resources investigating the photosynthetic pathway of plants to assign ~ 2000 species to their correct pathway. To determine the pathway of > 400 species not previously assessed, we used vegetation samples collected at TERN surveillance plots and performed carbon stable isotope analysis (δ13C). This analysis measures the ratio of heavy to light carbon (13C/12C) in plant tissue, which demarks plants as using either C3 or C4 photosynthesis. In addition to information on individual species, these data can be used in conjunction with TERN surveys to study the occurrence and abundance of pathways across the continent. We have developed convenient code for the R environment which enables scientists to quickly and easily calculate % C4 and C3 cover at TERN plots. These data and techniques have already been used to relate C4 cover in different taxa to changes in climate and local factors. These freely available data and tools have numerous other valuable applications, including investigating fractional productivity and carbon exchange or the impacts of global warming on vegetation abundance.

Using TERN products to predict habitat condition nationally

Dr Kristen Williams

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Abstract

The Commonwealth Scientific and Industrial Research Organisation (CSIRO) and the Australian Government Department of Agriculture, Water and the Environment (DAWE) have been collaborating on the development of a National Habitat Condition Assessment System (HCAS) since 2015. The overarching framework for the method was published in an international scientific journal (Harwood et al., 2016) and has since been incrementally improved

through two trial implementations: HCAS version 2.0 (Williams et al., 2020) and HCAS version 2.1 (Harwood et al., 2021b; Williams et al., 2021). HCAS was developed to address the need for nationally consistent, landscape-wide, site level estimates of habitat condition to inform the conservation of Australia's wildlife and natural heritage. The approach developed by CSIRO and DAWE aims to predict the quality of (mainly terrestrial) habitats in terms of the capacity of an area to provide the structures and functions necessary for the persistence of all species naturally expected to occur there, as if it were in an intact reference state.

The production of HCAS has been enabled by TERN products which support two of the three sets of inputs:

- remotely sensed data on seasonal variation in vegetation attributes such as such as green cover, yellow cover and litter, and bare ground, and
- environmental information about soils, climate, surface water and landforms.

The third set of input data are 'reference sites': locations in natural areas that are the least modified examples of their type (e.g. AusPlots locations - Guerin et al., 2021; Guerin et al., 2020). These are needed to train the model.

Here we: (i) present the results of HCAS version 2.1; and (ii) discuss how further development of TERN products can contribute to improve all three data inputs and, thereby, the accuracy of national habitat condition predictions.

Acknowledgment of Indigenous Australians

The Ancestors of Australia's First Nation's peoples came to this land probably more than 65,000 years ago (Clarkson et al., 2017; Rasmussen et al., 2011). Over many generations they founded a culture of land management that enabled them and Australia's native species to thrive (Bowman, 1998). The ecological legacy of tens of thousands of years of this oldest living culture is still evident in the supporting structure and function of habitats and in the composition of species that make up our ecosystems today. These ecological legacies, as they were perceived when Europeans settled the land in the last 250 years (e.g. pre-1750 Major Vegetation Groups for Australia - DAWE, 2020a), are what Western science generally uses today as the conceptual 'reference' for comprehending and measuring the quality or condition of habitats for Australia's indigenous flora and fauna (e.g. Eyre et al., 2011; Eyre et al., 2017).

Introduction

The Habitat Condition Assessment System (HCAS) is a national framework and method (Harwood et al., 2016), made possible by multiple decades of satellite remote sensing (e.g. Hill and Guerschman, 2020) and the generally accepted concept of measuring ecosystem condition as the departure from reference levels (e.g as defined for use in ecosystem accounts, Committee of Experts on Environmental-Economic Accounting, 2021). It was developed to enable nationally-consistent monitoring of the present-day capacity of a site to support the native species once occurring there naturally. As well as providing information in its own right, a proxy measure of habitat condition enables understanding and reporting on ecosystem status by integrating with a surrogate measure for biodiversity in a number of different ways (e.g. as a continuous measure or vegetation mapping classes), as outlined in Ferrier and Drielsma (2010). Work on HCAS was initiated by CSIRO as a multidisciplinary partnership between remote sensing and biodiversity scientists (Donohue et al., 2013). The subsequent partnership with the Australian Government Department of Agriculture, Water and the Environment, initiated in 2015, enabled the method to be further developed for their operational applications (Williams et al., 2020). The current version, HCAS 2.1, has further advanced the technical method (Williams et al., 2021) and publication will be accompanied by the data package for general use (Harwood et al., 2021b). Further development of HCAS is expected through a broadened collaboration with relevant State and Territory government agency scientists, and ecosystem research infrastructure administered through the Terrestrial Ecosystem Research Network (TERN)[i]. Therefore, this account of HCAS focusses on how TERN products have been used in HCAS and opportunities for future development in TERN products to improve the accuracy of habitat condition predictions nationally.

Basic processing workflow of HCAS

In this paper we first describe HCAS in the most basic way to focus on the data inputs, which is the key area where TERN has an enabling role.

The science challenge addressed by HCAS is how to use remote sensing and reference site data to map native vegetation condition (as habitat for biodiversity) across all sites, nationally, including those for which there is no field data. To do this, HCAS uses three primary input datasets which are integrated to estimate habitat condition (Figure 1).

i https://www.tern.org.au

1. *Environmental abiotic data* are variables depicting spatial patterns in Australia's soils, landforms and climates and that influence the reference character of native vegetation at any location. These include disturbance regimes (agents of spatial pattern formation in ecosystems that play out on various space and time scales, e.g. Battisti et al., 2016) such as the seasonal timing, intensity, and frequency of weather extremes and fires that would normally be associated with that environment. Examples of environmental variables include soil depth and fertility, landscape topography, and the long-term seasonal averages, variability and extremes of wind, sunlight, precipitation, air temperature and humidity (e.g. 30-year averages).

2. *Remotely sensed biotic data* are biophysical variables that characterise spatial patterns in the structure, function and composition of native vegetation and other managed ecosystems over a given period of time (e.g. multiple decades). The vast expanse of Australia necessitates the use of satellite imagery (or remote sensing) for biophysical monitoring. From the remote sensing signal, many of the bulk characteristics of vegetation and bare ground are directly observed or indirectly inferred, such as surface brightness, green leaf cover and vegetation seasonality (such as changes in leaf cover and litter throughout the year).

3. *Locations of sites in reference condition* are places where contemporary ecosystems are known, or assumed from multiple lines of evidence, to be the least modified examples of their type and therefore close to being in reference condition. Reference condition is generally defined as a level of condition against which the past, present or future condition of an ecosystem can be evaluated (Maes et al., 2020). HCAS uses the concept of dynamic benchmarks in the definition of reference sites (McNellie et al., 2020), which allows for different ecosystem expressions at different stages of biomass recovery in response to natural disturbances such as storms, floods, drought, fire and Indigenous cultural land management (Richards et al., 2020).

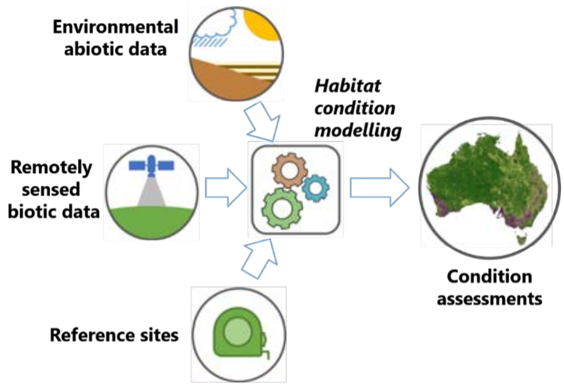


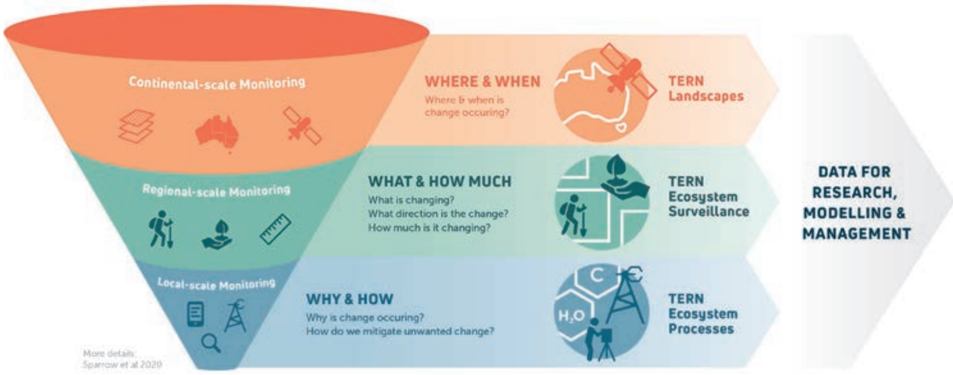
Figure 1 *Basic processing workflow of HCAS inputs and outputs.*

The HCAS approach provides a continuous measure of habitat condition, from completely removed native vegetation (scores 0.0) to entirely intact (scores 1.0), as the first step toward a more process-oriented approach to environmental decision making. An overarching operational principle of HCAS, in addition to being applied nationally, is continual refinement, as remote sensing, other data inputs, and computing technologies advance along with scientific methods for modelling and predicting ecosystem condition.

What TERN provides

As Australia's national ecosystem research infrastructure, TERN bridges the transition between innovative, maturing science and its implementation into operational routines by developing and establishing protocols that are scientifically rigorous and well-tested, and further supports their adoption into practice (through guidelines, workflows and training). The multiple scales of TERN ecosystem monitoring, shown in Figure 2 (Sparrow et al., 2020), demonstrate the various types of measurement that are fundamentally needed to inform an integrated assessment product like HCAS.

The remainder of this paper focusses in greater detail on how data inputs are used in HCAS, and how they are



supported by TERN's ecosystem monitoring function and products.

Figure 2 *The multiple scales of TERN ecosystem monitoring (Sparrow et al., 2020).*

A more detailed description of the HCAS processing workflow

An expanded view of the main workflow components of the HCAS modelling framework is shown in Figure 3. These components are described in detail in Williams et al. (2021) and are the 'cogs and wheels' shown in the basic processing workflow (Figure 1, above). These components are:

1. A model of the reference ecosystems depicted by the stages shown as 'reference vegetation modelling' and 'predicted vegetation signal' and associated inputs in Figure 3.
2. A process for estimating the departure from reference, depicted by the stages shown as 'observed vegetation signal' and 'vegetation benchmarking' and associated inputs in Figure 3.
3. A process for calibrating the predicted habitat condition scores, depicted by the stages shown as 'observed site condition' and 'calibration' in Figure 3, resulting in the output.

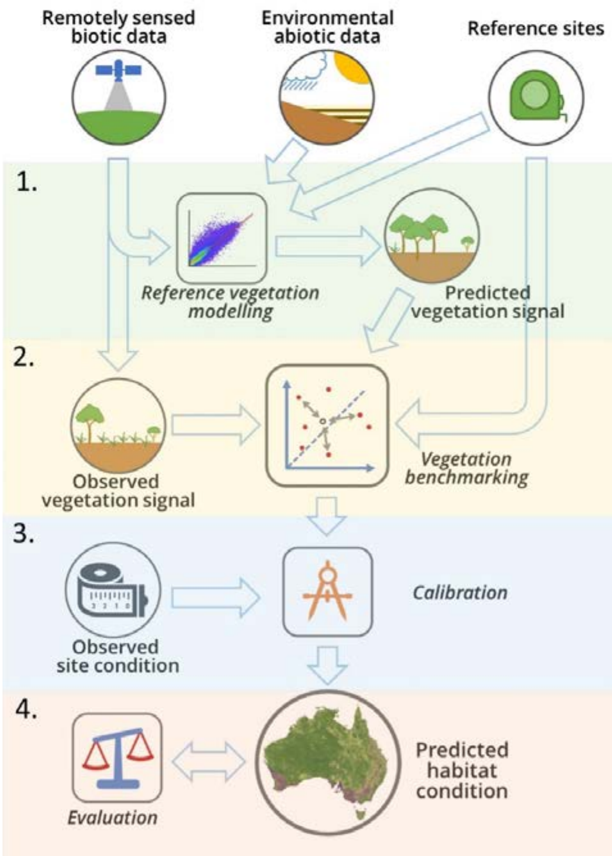


Figure 3 *The main workflow components of HCAS (Williams et al., 2021). A simple graphical explanation of the mechanics involved in the vegetation benchmarking process is provided by Lehmann et al. (2021). Colour coded and numbered swim lines are cross-referenced in the text.*

As a general description of Figure 3, the reference sites, remote sensing variables, and environmental variables are used to model and spatially predict reference vegetation patterns nationally in a way that retains the continuous variability (i.e. without needing to classify into particular vegetation types). The resulting predicted reference and observed patterns of vegetation from the remote sensing data at reference sites are then used to characterise the benchmarks and are inputs to the process of measuring the departure from reference for every terrestrial location in Australia. The resulting condition index is then compared with observed site condition data (or proxies for that) to calibrate and convert the index to a score between 0.0 and 1.0. The calibrated condition score is then qualitatively compared with other datasets such as vegetation clearing, land use, land management, fire frequency and so forth to evaluate its performance against a general expectation of what the condition should be. This form of evaluation substitutes for more conventional model 'validation' in the current implementation of HCAS version 2.1 (Williams et al., 2021), and informs an assessment of limitations and areas for improvement. In this respect, available observed site condition data constitute a fourth important source of data used in the HCAS framework; and other biophysical monitoring datasets for evaluation, a fifth.

The following sections describe in further detail how each of the three main data inputs are used and reflect on the current and future potential role of TERN data in supporting an improved HCAS. We start with reference sites, the use of which is a key point of difference between the HCAS approach and conventional approaches to remote sensing assessment of land cover. We then discuss calibration data where TERN has already made a significant contribution and has good potential to progress. Finally, we discuss the remote sensing and environmental datasets which are both core capabilities of TERN and their associated networks.

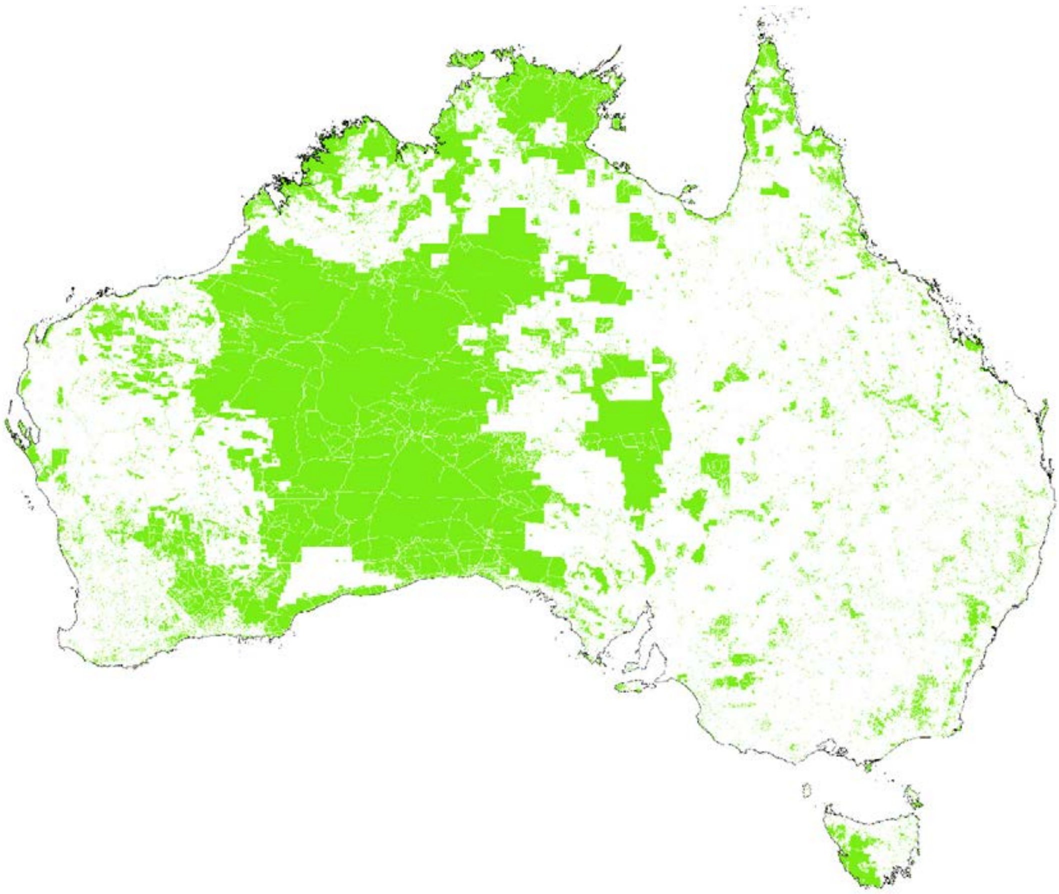
Reference condition sites for model training

In component 1 of the generalised workflow (Figure 3), HCAS first uses the location of reference sites (a representative sample of those shown in Figure 4) to model the remote sensing characteristics of ecosystem exemplars as a function of environment. Here the reference sites are used to derive a model which fits patterns of variability in the environmental data to that of the remote sensing data. Advanced statistical regression methods are used, as described in Williams et al. (2021), to accommodate the multi-dimensional spaces of the environmental and remote sensing data.

In component 2 of the generalised workflow (Figure 3), HCAS uses the same sample of reference sites to calculate 'departure from reference' for all locations across the continent. Each location's predicted vegetation signal, which is based on the model of reference condition from component 1, is compared to its observed vegetation signal. Multiple comparisons with similar 'nearby' reference sites are used, as described in Williams et al. (2021).

The multi-year variability in the remote sensing signal of reference sites is characterised by summary statistics so that they operate like dynamic benchmarks for estimating habitat condition. In this way HCAS aims to account for natural variability in the way ecosystems recover from disturbances such as climatic extremes and fires within the range they have adapted to. Over the time span of a condition assessment (i.e. 2001-2018 as used in HCAS version 2.1), we assume that reference locations are maintained in one or more natural states; that is, they have not been compromised by human activities that degrade ecosystem integrity.

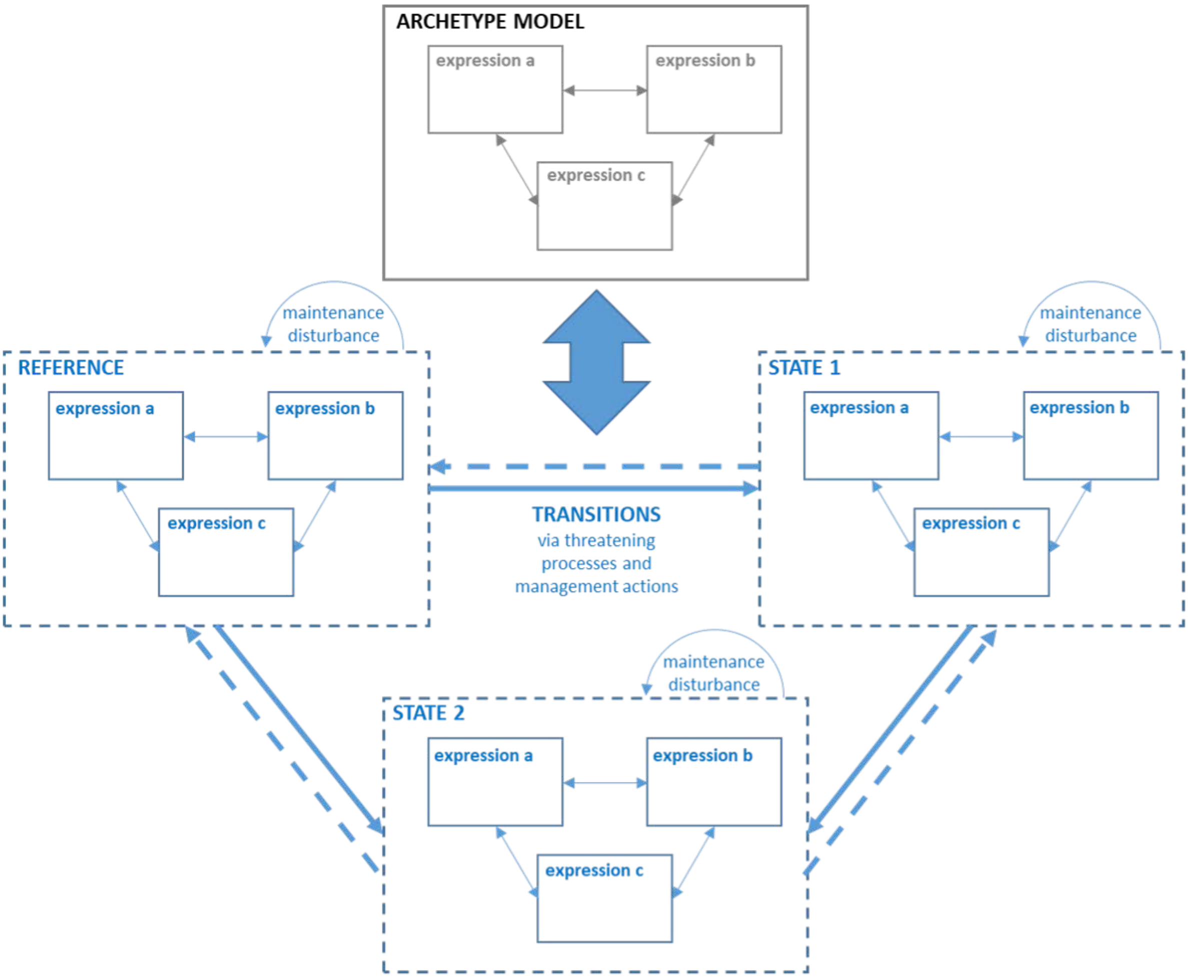
The validity of reference sites to train the HCAS model is crucial. In HCAS version 2.1, reference sites are identified using multiple lines of evidence from mapping of relatively natural areas, and by excluding settlements and other known converted areas (e.g. related infrastructure networks such as transport routes), as shown in Figure 4. There is potential to significantly improve how we identify, verify and routinely update a dataset of contemporary reference locations to ensure the HCAS appropriately trains the reference vegetation model and correctly benchmarks



deviation from reference condition.

Figure 4 *The inferred location of reference sites across continental Australia (shown in green) determined from multiple lines of evidence that is presently used as the source of training data in HCAS (Williams et al., 2020; Williams et al., 2021). Projection: GDA94 Geographics.*

Verifying reference locations, requires an agreed conceptual understanding of the dynamics of ecosystem reference states and how these might transition to alternate states with reduced condition. The Australian Ecosystem Models Framework (Figure 5) (Richards et al., 2020) provides a template for communicating this knowledge, which can inform a method for inferring and validating reference locations. This is another example of where TERN can help, for example, in developing routine methods using high resolution remote sensing to identify where relatively intact



reference sites persist in contemporary landscapes (e.g. like the Queensland ground cover disturbance index[ii]) that are suitable to use as condition benchmarks.

Figure 5 *A schematic showing the framework for conceptualising dynamic ecosystem states and transitions developed by the Australian Ecosystem Models Framework project, https://research.csiro.au/biodiversity-knowledge/projects/models-framework/ (Richards et al., 2020). Here, archetype models are a conceptual representation of a dynamic reference state. These models describe the characteristics and drivers of ecosystems in reference condition, using ecosystem expressions to delineate changes in structure, function and composition of an ecosystem reference along pathways defined by endogenous disturbance and biomass recovery processes. Archetype models are used as templates in the description of locally-specific and quantifiable state and transition models (shown in blue), which include both reference and modified ecosystem states. Transitions between states in state and transition models may be driven by 'exogenous disturbances': new or modified existing disturbances to which ecosystem are not adapted. These may be threatening processes (leading to a degradation in ecosystem condition) or management actions designed to improve ecosystem condition (dashed arrows). Separately, maintenance disturbances are those required to maintain an ecosystem in a particular state, such as low intensity grazing by cattle.*

Observed ecosystem condition sites for model calibration and validation

Once we have an estimate of the departure from reference condition (workflow component 2 in Figure 3), ideally we would use observed condition sites to calibrate this between 0.0 and 1.0 and validate the result (workflow component 3). The initial estimate of the departure from reference condition is limited by the availability of remote sensing data required to fully characterise habitat condition, that encompass indicators of native vegetation structure, function

ii https://www.data.qld.gov.au/dataset/queensland-ground-cover-disturbance-index and composition. This limitation can be addressed to some extent by calibrating the initial estimates (departure from reference) to approximate the scaling that would be expected from field observations of habitat condition. In the absence of suitable data for calibration, HCAS uses a non-linear scaling based on qualified subjective decisions. Calibration is an important step that requires stakeholder consultation and access to available relevant data and information. Again, TERN can make, and already has made, an important contribution in this respect, as outlined below.

A national protocol for measuring habitat condition

Several States and Territories have established field methods for assessing condition, but Australia lacks a national protocol that would enable disparate data to be harmonised and to standardise future data collection. To address this limitation, TERN in partnership with a predecessor of the Australian Government Department of Agriculture, Water and the Environment, ran a series of workshops in 2014[iii] that brought together State and Territory agency scientists and other researchers to discuss a common conceptual framework and methodology for measuring habitat condition in the field (Thurgate et al., 2014a; 2014b). A draft national protocol was developed as a discussion starter (Wundke et al., 2015). As can be seen from Figure 6, this is a relatively complex social and technical process.

Several years on, it is heartening to know that through the Australian government's Regional Land Partnerships[iv] (part of the National Landcare Program) there is renewed interest in establishing a national condition protocol, and a series of supporting modules for field survey standards[v] are under development by TERN's Ecosystem Surveillance platform (such as measuring important condition indicators like recruitment and coarse woody debris) (Australian Government and TERN, 2021).

There is also a need to develop a protocol for rapid expert site condition assessments, to supplement formal data collection methods. In partnership with the Arthur Rylah Institute in Victoria and the Atlas of Living Australia, CSIRO recently piloted a method to collect and calibrate expert knowledge as a precursor to developing a future citizen science platform (moderated by experts and artificial intelligence) (Pirzl et al., 2019) (Figure 7). This work was founded on the belief that career practitioners in field ecology are crucial repositories of knowledge about Australia's native ecosystems, and that there is value in harnessing and integrating that expert understanding. This pilot further acknowledged the inherent subjectivity in an expert's assessments and therefore the approach also included a method for cross-calibrating each expert's

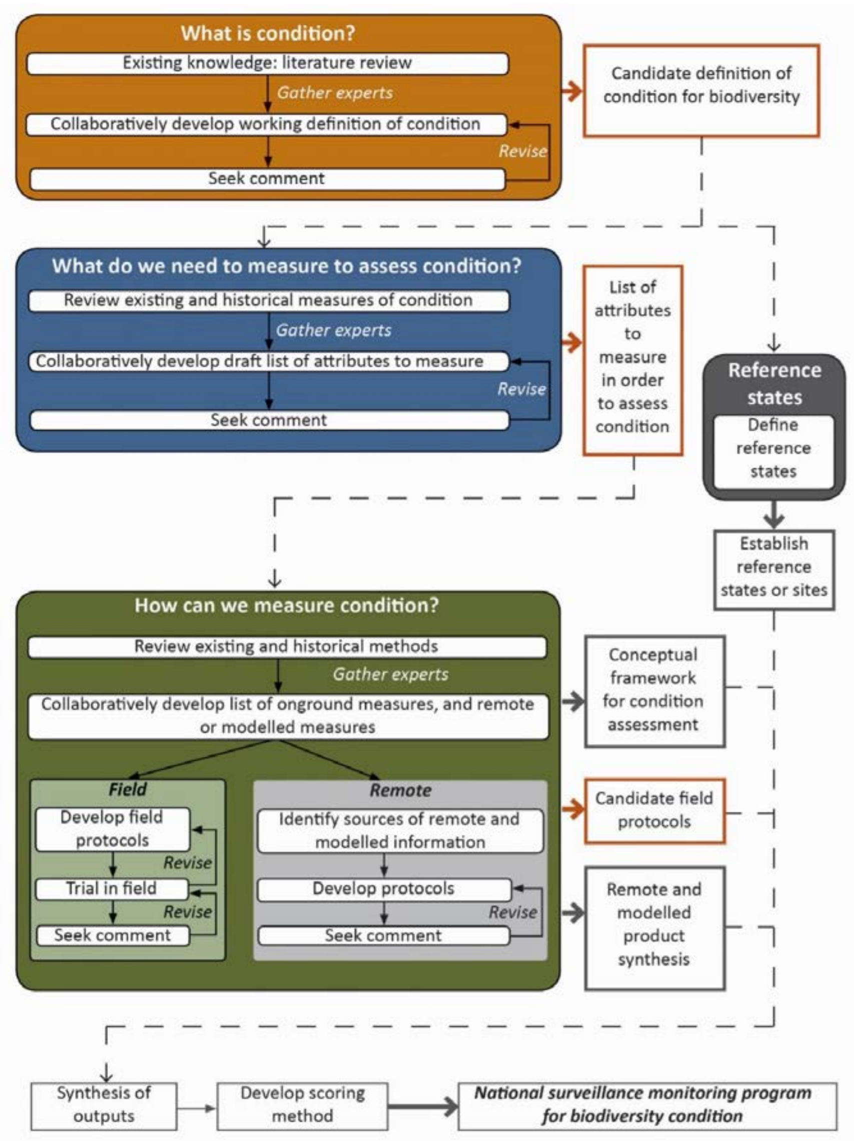
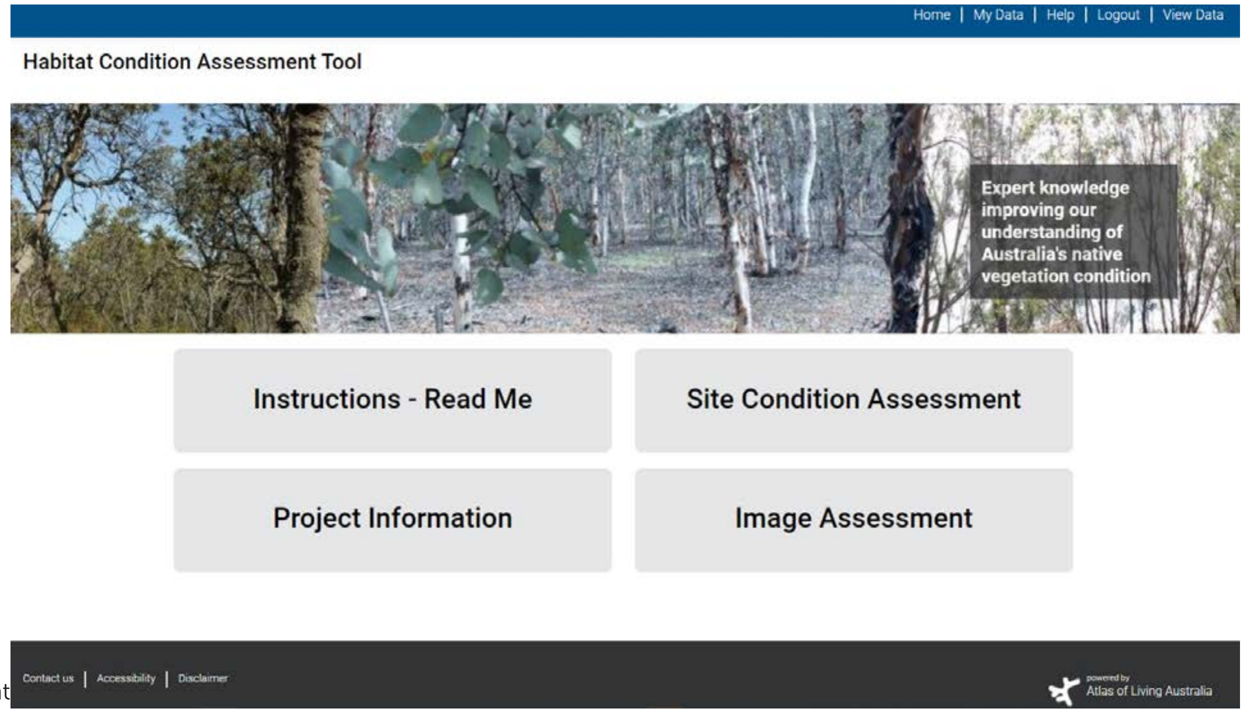


Figure 6 *Overview of the process used to develop the condition protocols outlined in the draft AusPlots manual (Wundke et al., 2015), toward a national framework and consistent method for assessing the condition of habitats for biodiversity continent-wide. Source: Wundke et al. (2015).*

iii http://www.ausplots.org/ecosystem-surveillance
iv http://www.gov.au/regional-land-partnerships
v https://www.tern.org.au/news-standards-assist-conservation-decision-making



int once that has been established, and ultimately integrate a rapid assessment approach with an expert-moderated citizen science platform.

Figure 7 *Habitat Condition Assessment Tool (HCAT) home page, https://biocollect.ala.org.au/hcat (access requires registration)*

Remote sensing of vegetation characteristics

HCAS requires relatively cloud free remote sensing variables that have some meaning in terms of vegetation characteristics, and ideally capture the full range of indicators related to habitat structure, function and composition. To meet these requirements, including capturing the within- and between-year vegetation dynamics and phenology driven by seasonally varying weather, HCAS presently uses satellite remote sensing products derived from MODIS (Williams et al., 2020). Using MODIS products restricts the application to 250m pixels, and in future, we are hopeful that relevant blended fractional cover products between MODIS, Landsat, Sentinel-2 and VIIRS[vi] (e.g. Chen et al., 2020) will provide the capacity for finer scale condition assessments (e.g. Love et al., 2020). It is important to note that HCAS requires relatively long time series of remote sensing data (i.e. at least 10 years) in order to properly distinguish the dynamics of response to natural regimes of disturbance from those modified by human intervention, such as clearing or thinning of vegetation cover for production uses.

For example, a new blended product developed by TERN – monthly, high-resolution (30 m) actual evapotranspiration for Australia (McVicar et al., 2020), will both add value to HCAS as an ecosystem function variable, and foreshadows capacity for finer scale assessments. However, as HCAS requires long time series of remote sensing, such blended products will only become useful for this purpose if extended to the legacy remote sensing data, as far back as possible (e.g. to encompass the entire MODIS time series), as well as continuing to be developed into the future. One off applications or only forward-focussed applications would not fulfil the requirement for rigorously monitoring habitat condition.

TERN produces a lot of remote sensing products (e.g. Scarth et al., 2017) and an opportunity exists to determine their utility for the current and future requirements of HCAS. In particular, it would be useful to have blended products for fractional cover (to make the most of the historical time series) (Hill and Guerschman, 2020), and other operational remote sensing variables such as actual evapotranspiration (McVicar et al., 2020) and height structure (Liao et al., 2020; Scarth et al., 2019) to improve the downstream HCAS product. Products such as burnt areas and fire severity are also important for change in condition attribution (e.g. DAWE, 2020b).

vi https://earthdata.nasa.gov/earth-observation-data/near-real-time/download-nrt-data/viirs-nrt

Environmental variables influencing reference vegetation characteristics

HCAS uses a wide range of environmental variables known to influence the remote sensing characteristics of reference vegetation (through growth and development). These include variability in climates, soils, landforms and hydrology – that is, the long-term averages, seasonal variability, and disturbance regimes including extreme events that characterise Australia's environments. A statistical model is used to fit the relationship between the remote sensing variables and the environmental variables (with judicious variable selection to minimise multicollinearity). The type, resolution and quality of these variables can all influence how well they perform as predictors of the reference vegetation characteristics.

TERN developed the soil and landscape grid of Australia that is used in HCAS (Grundy et al., 2015; Grundy et al., 2020; Viscarra Rossel et al., 2015) and TERN is continuing to improve digital soil attribute models (e.g. Malone and Searle, 2020), with plans to derive soil attributes using reference sites from relatively natural areas (i.e. that are not confounded by contemporary land use and management practices). Soil attributes are used in HCAS to predict the satellite remotely sensed reference characteristics of ecosystems, extrapolated from reference sites to continent-wide. Therefore, the ideal digital models of soil attributes for use in HCAS are those derived using soil site data from relatively natural areas, and that minimise use of remote sensing as an input, which may confound the prediction with contemporary land use patterns.

To comprehensively predict the reference vegetation characteristics from remote sensing, we also need to include variation in long-term climate variables (Williams et al., 2012) and surface hydrology (Mueller et al., 2016). As for remote sensing, an opportunity exists to look at how TERN's work on environmental variables (including climate) could more closely align with the current and future requirements of HCAS, which is closely aligned with the general requirements for correlative predictive modelling of species distributions and vegetation classes. We suggest this is an aspect of the soil and landscape grid that TERN could expand upon in future.

Conclusion

The habitat condition assessment system (HCAS) version 2.1 will be the first published data from this new approach,

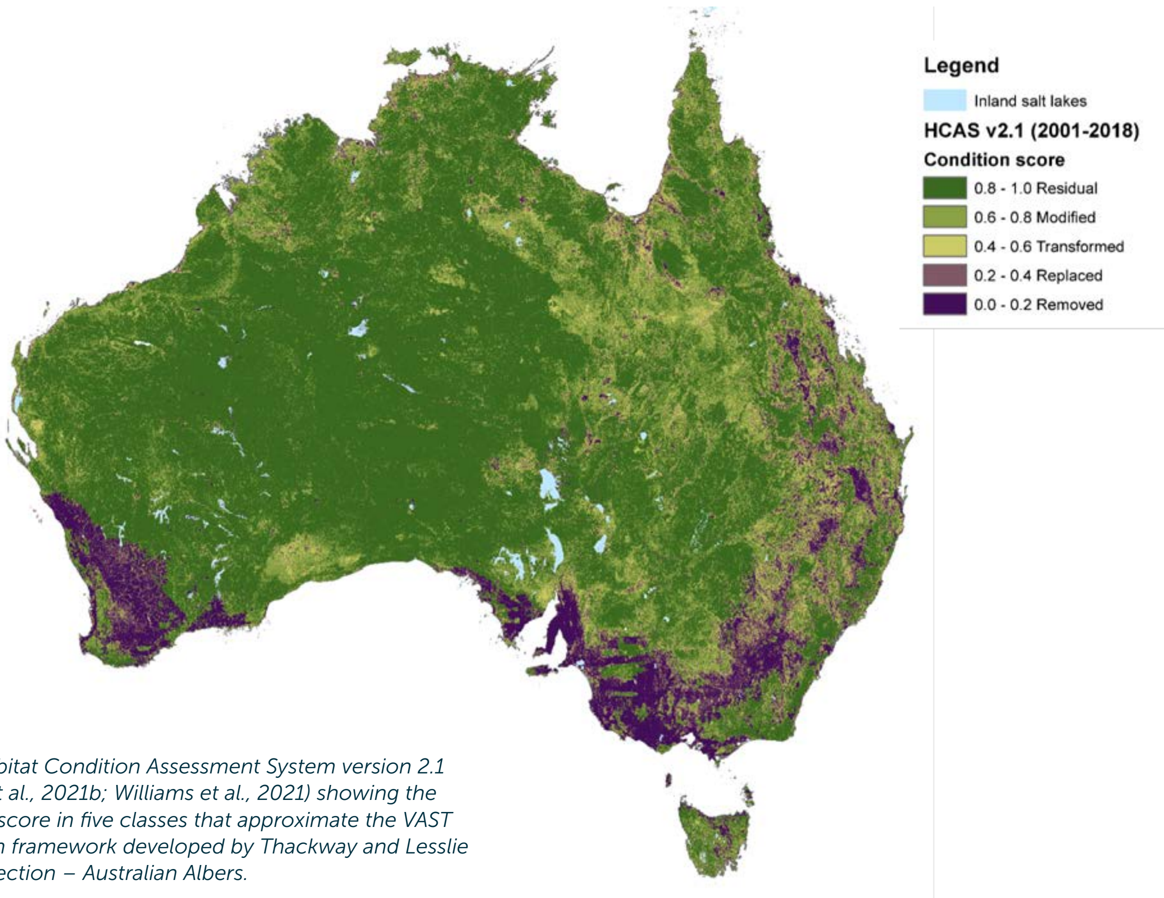


Figure 8 *Habitat Condition Assessment System version 2.1 (Harwood et al., 2021b; Williams et al., 2021) showing the continuous score in five classes that approximate the VAST classification framework developed by Thackway and Lesslie (2006). Projection – Australian Albers.*

initiated by CSIRO in 2012. The result for the assessment period 2001-2018 is shown in Figure 8, in 5 classes that approximate the interpretation provided by the vegetation assets, states and transitions framework (Thackway and Lesslie, 2006). Technical details about how the HCAS version 2.1 data product (Harwood et al., 2021b) was developed are provided in Williams et al. (2021).

HCAS version 2.1 to date has been used in the development of a pilot ecosystem account (Harwood et al., 2021a), in summary reporting for the 2021 National State of the Environment report (due for public release in early 2022), and is being assessed by the Department of Agriculture, Water and the Environment for use in a range of internal applications. HCAS is also being considered by EcoCommons[vii] for integration with the species distribution modelling workflow.

The HCAS method has been under development and involved considerable research and testing over nearly 10 years. It is now ready to be operationalised to provide regular updates of condition assessments, and ultimately evolve toward a more 'real time' dynamic system. However, advancing HCAS further requires collaboration with research infrastructures such as TERN and partnerships with State and Territory agency scientists engaged in vegetation extent and condition assessment.

Peer review

This paper was internally reviewed within CSIRO by two independent peers. The authors thank Mr Matt Stenson and Dr Glenn Newnham for their comments that helped improve this final version.

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Paratoo: next-generation field data collection infrastructure

Dr Andrew Tokmakoff

In the early-mid 2010s, TERN Ecosystem Surveillance developed the AuScribe App and associated backend ingestion and curation tools; the system has been in production and under active maintenance since 2014. AuScribe's key function is to ensure correctness and completeness of data collected in the field according to the AusPlots Rangelands field data collection protocol. This reduces the need for elaborate and time-consuming curation activities, thereby offering the team efficiency and productivity gains. This solution has been working well and remains in service. However, the underlying technology base for the system is starting to show its age, and we are now engineering a next-generation system that offers: Improved adaptability of the User-Interface over devices (UIs that scale from desktop to mobile, in a single code-base); More accessible web-based technologies (as opposed to native App development, which makes staffing simpler); Containerised backend systems (to allow for simple and repeatable system migration); A generic design which allows for the addition of Field Data Collection to existing systems (which have their own project and user management systems already in-place). In this talk, we will outline the design and technology-choices we have made for "Paratoo", our next-generation field data collection system, offering a technical glimpse of what's currently under active development.

An inclusive approach to develop community capability for environmental conservation in Lake Biwa (Japan)

Assoc Prof Yasuhisa Kondo

Yasuhisa Kondo is an Associate Professor at the Research Institute for Humanity and Nature (RIHN), where he coordinated a joint research project titled "Information asymmetry reduction in open team science for socio-environmental cases" in 2018–20, and a member of the Science Council of Japan. He is interested in theorising open science with and for society.

In the south basin of Lake Biwa, Shiga, Japan, overgrown aquatic weeds impede cruising boats and cause unpleasant odours and undesirable waste when washed ashore. To address this socioecological problem, the local government implemented a public program to remove overgrown weeds and compost them ashore to conserve the lake environment, while coastal inhabitants and occasional volunteers remove weeds from the beaches to maintain the quality of the living environment. However, these effects are limited because of disjointed social networks. The author's team worked as external action researchers to facilitate developing community capability to jointly address this problem by sharing academic knowledge with local actors and empowering them with an inclusive, adaptive, and abductive intent. In practice, the team held multi-actor workshops with local inhabitants, governmental agents, business people, social entrepreneurs, and research experts to unearth the best solution. The workshops resulted in developing an e-point system, called Biwa Point, to promote and acknowledge voluntary environmental conservation activities, including beach cleaning. A non-profit organisation was launched to implement and manage the Biwa Point system. This process was characterised by the dynamic organisation of actors of interest and their initiative to make decisions. This action research also raised ethical issues, such as the publication of inconvenient truths, undesired interpretation by the researchers, and social constraints in research methods.

Bushfire data commons

Dr Adrian Burton and Dr Sheida Hadavi

Sheida Hadavi is the program manager of Translation Research Data Commons program of the Australian Research Data Commons (ARDC). She is a data scientist whose work is focused on establishing data infrastructure to enhance research and operations. Sheida has a PhD in data analytics in transport and a M.Sc. in Computer science from University of Brussels.

The Australian Research Data Commons (ARDC) is a NCRIS facility, providing Australian researchers with competitive advantage through data. The Translational Research Data Challenges program is a new national-scale 'flagship' initiative providing innovative and high-impact digital infrastructure solutions to real-world problems. In response to the acute demand, the first societal problem is 'Disaster Resilience and Risk Reduction', with an initial focus on the impact area of 'Bushfires'. The Bushfire data challenges program aims to improve bushfire management by supporting research and development with pathways to advancing operational planning and response. Collaborating with partners from governments and research institutions, the projects address societal problems by removing barriers to the access, analysis and curation of data. The research and development infrastructure is expected to dovetail by design with existing and emerging initiatives from the mature organisations such as TERN, DAWE, GA and CSIRO. The bushfire data infrastructure has three aspects: 1) Aggregated data content; 2) A framework for aggregating data, establishing a systematic approach towards data sharing and storage, and 3) A platform to provide access, visualisations and modelling tools. ARDC runs two phases of the bushfire data challenges: 1) modelling bushfire behaviour, with data content on fire history, and fuel and 2) modelling impact, with data content on built infrastructure, health, air quality and environment. As part of this program, TERN leads the work stream on 'Aggregating and harmonising fuel data on a national scale'. This project aligns with TERN's national leadership in biomass, and in partnership with DAWE, they would provide a national scale fuel data layer including content, structure and moisture. State agencies and researchers are the other partners and beneficiaries in this project. In this initiative TERN and the ecosystems science community will address questions of national significance with national scale data infrastructure through joined-up efforts with other leading national players.

Robust scalable data management for EcoImages

Siddeswara Guru, Wilma Karsdorp, Gerhard Weis, Mosheh Eliyahu, Habacuc Flores, Daniel Sheath, Jenny Mahuika

Wilma Karsdorp

Wilma Karsdorp is a senior software engineer working for TERN. She develops innovative solutions to some of the challenging ecosystem data management problems. She builds systems to make TERN's ecological data discoverable and accessible for the wider community.

Advancement in technology has enabled ecosystem science researchers to sense the environment through audio, video and sound. The use of technology has enhanced the frequency of data capture and expanded the spatial extent of data collection. However, effective on-time end-to-end management of sensed data is paramount to leveraging data value and derived knowledge. TERN observing platforms use imaging technologies to detect the environment in different sites across Australia. The images collected are from photopoints, phenocameras, camera traps and cameras to estimate LAI. Effective management of these images is essential to enabling long-term usability and studying changes in the environment. We will present a web-based TERN Ecoimage platform specifically designed to implement end-to-end data management, including standardised data on-boarding, processing, discovery and access of different image types collected at TERN Ecosystem sites. The platform enables users to search images based on where, when, and kinds of images collected, download them and mint DOI for their image collection for further reuse.

Enabling FAIR flux data in TERN

Anusuriya Devaraju, Peter Isaac, Cacilia Ewenz, Ian McHugh, Jenny Mahuika, Gerhard Weis, Edmond Chuc, Mirko Karan, Siddeswara Guru

Dr Anusuriya Devaraju

Anusuriya Devaraju is a Senior Data Innovation Manager at Terrestrial Ecosystem Research Network (TERN), University of Queensland, Australia. Her interests lie at the intersection of Computer Science and Earth & Environmental Science (EES), primarily FAIR research data, semantic enablement of environmental data, and linking research assets (e.g., data, specimen, instrument). She has conceptualized and led several practical solutions in Earth and Environmental Sciences, which have resulted in an enhanced data management and discovery, e.g., at TERENO, CSIRO Mineral Resources, and PANGAEA.

Systematic management of scientific data, from collection to publication, requires standardized processing, quality control, curation, and long-term storage. TERN research infrastructure is committed to the continuous provision and long-term preservation of data generated from its observing platforms. Eddy covariance datasets (i.e., measures of energy, carbon and water exchange between the atmosphere and ecosystems) generated from the TERN Ecosystem Processes (EP) flux monitoring sites and the associated sites of the OzFlux network are critical assets to help researchers understand the impact of climate change on ecosystems across Australia. In the spirit of the FAIR (Findable, Accessible, Interoperable, and Reusable) data principles, the TERN Data Services and Analytics (DSA) and EP are working together to streamline data management practices to publish time-series flux data. This talk will provide an overview of the implementation and the progress made using the agreed-upon practices for managing flux data. The practices focus on data processing and curation workflows, data and metadata standardization, controlled vocabularies to describe associated data artefacts, the strategy applied for publishing time-series data using persistent identifiers and efforts to comply with the FAIR principles. The proposed approach will contribute to a sustainable, scalable flux data management in TERN, and we believe the practical experiences can offer valuable information to other research infrastructures managing time-series sensor data. Finally, the talk will offer insights into how this work may contribute to building collaborations across inter-continental micrometeorological flux observation programs.

Session Eight: **Open Forum**

Assessing resilience of terrestrial ecosystems in Australia across scales

Prof Lance Gunderson

Lance Gunderson is Professor and Chair, Department of Environmental Sciences at Emory University in Atlanta, Georgia. He is a founding Board member of the Resilience Alliance. His scholarly work has addressed the application of ecological understanding to the policy and practice of managing natural resources.

Many social ecological systems are characterized by discontinuous structures and processes across spatial-temporal scales, in a theoretical framework called panarchy. A panarchy is dynamic hierarchy, with spatial and temporal changes occurring across levels. It has been applied to explain cross-scale vegetation changes over time scales of years to centuries at spatial scales from stands to bioregions. Such panarchies have been described for south-eastern US forests, US midwestern landscape vegetation changes and managed forests in Sweden. Ecological resilience is related to the distributions of functions within and across scales of a panarchy. We propose a joint research pilot project to assess the interaction between panarchies and cross-scale resilience of monitored ecosystems across Australia. We propose to use data from the Terrestrial Ecosystem Research Network, to analyze status and trends of collected environmental data and use those data to assess the resilience of terrestrial plant and animal communities to long-term environmental changes, such as ongoing global climate change. A variety of approaches, including discontinuity analysis, timeseries modeling, spatial analysis and early warning indicators will be used to identify key indicators and proved quantitative estimates of resilience across scales.

Supersites and superorganisms: recurring themes in 85 years of ecosystem science

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The word ecosystem arose out of a dispute between two schools of thought amongst ecology’s twentieth century pioneers. Should communities of plants and animals be seen as naturally ordered superorganisms, or loose collections of species and their environment intelligible through the application of reductionist science? Arthur Tansley coined the term in 1935 in support of the latter view. Tansley never carried out ecosystem studies, and until Ray Lindeman published his attempt to track the flow of energy through a North American lake 7 years later, no one in the English speaking world was quite sure what ecosystem science might look like. Large multidisciplinary studies of terrestrial ecosystems received a major boost with the International Biological Program (IBP) in the 1970s, particularly in North America where research was stimulated by increases in science funding and questions about the biological effects of nuclear radiation. The IBP concept was extended in the USA through the Long Term Ecological Research network (1980-present). The superorganism concept resurfaced in popular culture in 1979 as the Gaia hypothesis. Rejected in its strong form by the scientific community on evolutionary grounds, Gaia has since been invoked in the peer reviewed literature to describe proposed mechanisms of self-regulation. This paper reflects on three recurring themes in the history of ecosystem science: the influence of politics and national interests, the tension between continuity and flexibility, and the elusive nature of general principles.

Keywords ecosystem science, history, Long Term Ecological Research, themes, principles

Introduction

Ecologist Arthur Tansley introduced the word ecosystem in a paper published in 1935 with the intention of killing off an idea that he believed was likely to damage ecology's reputation as an emerging science. That idea was the superorganism, a concept that gained prominence through the work of American ecologist Frederick Clements who in his conceptualisation of plant succession attempted to formalise the ancient idea that communities of plants and animals acted as organisms in their own right with their own structure, order and regulation.

To Tansley this was too close to vitalism, the belief in a life force beyond the realm of the physical word. Tansley's definition of an ecosystem, organisms interacting with their non-living environment, was intended to firmly locate communities of plants and animals as material objects in a physical continuum from galaxies to atoms.

As president of the world's first ecological society, Tansley was determined to have the new discipline of ecology taken seriously as a science. His 1935 article was a response to a series of papers by South African ecologist John Phillips who was influenced by Clements and Jan Smuts, South African soldier, politician and philosopher. Smuts had coined the word holism in a book published between two periods serving as South African Prime Minister (Smuts 1926), holism being the name Smuts gave to the universal creative process responsible for the evolution of matter into life and ultimately into mind (Brush 1984).

This reach into abstract, untestable theory that verged on the mystical was too much for Tansley and he was determined to bring ecology back down to Earth by establishing ecosystems as material entities *"...the basic units of nature on the face of the Earth"* that were understandable through the application of reductionist science (Tansley 1935)

1. Politics and the national interest

Sixty years before Arthur Tansley coined the term ecosystem, ecosystem science was alive and well in Germany and later in Russia as a result of periods of nation building. The unification of Germany and development of a national rail network led to concerns about exploitation of natural resources and in one case Karl Mobius, Professor of Zoology at Kiel, was commissioned to carry out a study of the shellfish industry on the Baltic coast. In his report published in 1877 Mobius coined the term *biocenosis* from the Greek for life and sharing or commons to describe organisms and their physical environment (Golley 1993).

Following the 1917 Russian Revolution, ecologists were dispatched to study forests, grassland and steppe to improve the productivity of Soviet agriculture and forestry. Adopting Mobius' concept of biocenosis, Vladimir Stanchinskii carried out energy analyses of steppe communities decades before ecologists conducted similar studies elsewhere. This came to an abrupt ending at the All-Union Zoology Congress in 1930 where suggestions by ecologists that there were biological limits to productivity were denounced by party officials. Stanchinskii and his colleagues lost their funding and their university positions and ecosystem ecology was stopped in its tracks (Golley 1993).

In the United States, understanding the biological impacts of nuclear radiation became the impetus for large scale ecosystem science in the 1950s and 60s funded by the Atomic Energy Commission and the Office of Naval Research (Golley 1993). The next major effort in ecosystem science was the International Biological Program (IBP) with its goal of 'Understanding productivity as a basis for human well-being' (Worthington (1965).

However the IBP was not universally welcomed. Population and community ecologists criticised its emphasis on energy analysis and trophic dynamics on several grounds. First because the role of individual species was lost in aggregated trophic levels, meaning that insights into phenology, adaptation, diversity, competition, predation, commensalism and mutualism were obscured behind wiring diagrams and the second law of thermodynamics. Second because the role of functional redundancy was overlooked in the search for measures of energy efficiency. And third because time was absent given that the analyses represented snapshots of a particular moment.

Levins and Lewontin (1980) singled out the trophic dynamic modelling approach to ecosystem ecology for criticism on the grounds that *"...much of the effort goes into problems of estimation, generously supported and singularly unproductive"*. This approach to ecosystem research is the subject of the second episode in a three part documentary series on the rise of the computer (Curtis 2011; Viner 2011). Taking its title directly from Tansley's 1935 paper, the episode on ecology presents the energetics approach to ecosystem modelling as overly optimistic and falling well short of expectations.

In the meantime, the Hubbard Brook experiment, established in 1955 by the United States Department of Agriculture's Forest Service and not part of the IBP, was demonstrating the progress that could be made in understanding ecosystem processes by a small team working in well-defined watersheds using mass balance techniques to study the input and output of water and nutrients.

The Long Term Ecological Research (LTER) program funded by the National Science Foundation (NSF) followed the IBP in the USA that set out to 1) Initiate the collection of comparative data at a network of sites representing the major biotic regions of North America and 2) Evaluate the scientific, technical and managerial problems of such long term research (NSF 1980). Including the word problem in its second goal suggests that the NSF recognised there were lessons to be learned from the IBP.

The lesson from this early phase of ecosystem ecology is that politics always has and always will influence ecosystem science as it is conducted at the scale at which human order most dramatically confronts natural process. The rest of this paper focuses on the LTER network.

2. The tension between continuity and flexibility

The comparison of the research themes of the IBP and the LTER in Table 1 indicates that the LTER set out with more emphasis on basic science than the IBP and less ambitious expectations of immediate application of science to management, conservation and human well-being. It also shows the remarkable continuity of research themes of the LTER to date with five core themes remaining essentially the same over its 40 year life with the addition of two social research themes in 1997 when urban sites joined the network.

Table 1. *Research themes of the International Biological Programme and the Long Term Ecological Research network in 1980 and 2019.*

IBP	LTER 1980	LTER 2019
1. Productivity of terrestrial communities	1. Pattern and control of primary productivity	1. Primary production
2. Production processes	2. Dynamics of populations of organisms selected to represent trophic structure	2. Population studies
3. Conservation of terrestrial communities	3. Pattern and control of organic matter accumulation in surface payers and sediments	3. Movement of organic matter
4. Productivity of freshwater communities	4. Patterns of organic inputs and movements of nutrients through soils, groundwater and surface waters	4. Movement of inorganic matter
5. Productivity of marine communities	5. Patterns and Frequencies of disturbances	5. Disturbance patterns
6. Human adaptability		6. Land use and land cover change
7. Use and management of biological resources		7. Human-environment interactions

Source: *IBP Worthington (1965); NSF (1980); LTER (2019)*

The biomes represented amongst the current LTER sites shown in Table 2 illustrates both continuity and flexibility. Continuity is evident from the fact that 14 of the current 27 sites are in their fourth decade, four are in their third, five in their second and four in their first with only six sites terminated over the 40 year life of the program to date.

Flexibility is also apparent with eight coastal and marine sites added to the network since 2000 coinciding with increasing concern over sea level rise and ocean acidification.

Table 2. Distribution of LTER sites by biome showing the decade in which they were established

Biome	Forest	Mixed	Grassland	Tundra	Freshwater	Coastal	Urban	Marine
1980s	*****	***	**	**	*	*		
1990s					*	*	*	*
2000s						****		*
2020s						*	*	**
Current total	5	3	2	2	2	7	2	4
Terminated	1		1		2	1	1	

Source: *Groffman et al. (2019)*

In terms of the flexibility of the program, a recent study of the LTER network highlighted changes in the expectations of the funding body between 1980 and 2018 (Jones and Nelson 2021). In 1980, collaboration between sites was a condition of funding but by 2012, criteria for new funding and re-funding proposals indicated that collaboration was 'encouraged' rather than mandated. New criteria have been progressively added, requiring funding and re-funding proposals to include reference to conceptual frameworks (1997), greater integration (2002) and supporting theory (2012). Jones and Nelson (2021) also found that the most common reasons given for probation and termination of sites have been lack of integration and lack of conceptual frameworks, and that changes in the character and composition of the program have coincided with staff turnover within the funding bodies program officers.

3. The elusive nature of general principles

The importance of continuity in ecological research is underlined by a set of five papers featuring case studies of 25 of the current 27 LTER sites published to coincide with the 40 year review of the LTER program (Bahlai et al. 2021; Rastetter et al. 2021; Iwaniec et al. 2021; Zinnert et al. 2021; Cowles et al. 2021). The examples from five of the case studies in Table 3 illustrate the length of continuous observation that has been required to identify trends in ecosystem processes at individual sites, let alone generalisations about those ecosystem types in general.

Table 3. Length of continuous observation required to detect trends in ecosystem processes

Years	Ecosystem process	LTER site	reference
40	Ca^{++} depletion due to acid rain	Hubbard Brook	Cowles et al. (2021)
46	trend in surface air temperature	Arctic	Rastetter et al. (2021)
60	trend in sea surface temperature	California Coast	Rastetter et al. (2021)
65	trend in krill populations	California Coast	Rastetter et al. (2021)
70	trend in understorey air temperature	Andrews Forest	Cowles et al. (2021)
80	change in forest structure	Coweeta	Rastetter et al. (2021)

Note: *monitoring at some sites commenced prior to establishment of the LTER network*

A clue as to why generalisations about ecosystem processes across sites and biomes has proven to be elusive may be found in a recent survey of 1,200 mainly US ecologists (Kuebbing et al. 2018). While 80% of survey respondents believed multi-site studies are necessary to contribute to theory in ecology and evolution, Gaiser et al. (2020) found that less than 20% of LTER publications on the topic of response to disturbance used data from more than one site. In addition, Knapp et al. (2012) found that of 239 controlled experiments across the LTER network, less than 30% involved manipulation of more than one variable. Meanwhile the two most pressing questions identified in the survey by Kuebbing et al. (2018), understanding system stability and resilience in the face of climate change and whether the speed of adaptation is fast enough to allow for evolution, arguably require not just multi-site studies but multi-site, multi-variate studies.

Just prior to each of the last three decadal reviews of the LTER network by the NSF, participating researchers have published summaries of major findings from LTER sites as sets of papers grouped under common themes (Table 4). Two features of the themes chosen to summarise these findings stand out. First, the inclusion of social research themes in the set of papers published in 2012 and second, a longer term trend towards the use of resilience, thresholds and multiple stable states as concepts for interpreting long term observations.

Table 4. *Themes of participants' reviews coinciding with NSF decadal reviews of LTER research*

2003 LTER (2003) BioScience 53(1): 46-98	2012 LTER (2012) BioScience 62(4): 342-404	2021 LTER (2021) Ecosphere 12(5)
• Biodiversity and ecosystem services • Mechanistic models • Disturbance • Variability in time and space • Land use legacies	• Role of long term experiments • Human influence on ecosystem processes • Scenario studies • LTER in a human dominated world • Environmental stewardship	• State change • Connectivity • Resilience • Time lags • Cascading effects

While it is possible to glean generalisations about ecosystem function from the published literature, for example, the pre-conditions for resilience (rapid turnover of populations biomass and nutrients, biotic control of fluxes, high species richness at ecosystem interfaces and negative feedback in biotic interactions, Turner et al. 2003) or the claim that species richness can only be used to predict productivity in reconstructed ecosystems (Robertson et al. 2012), there is a risk that such a search could end up becoming a rhetorical tennis match given that it is likely to return equally confident contradictory views. What might be more useful is to ask, 'Which themes have recurred in ecosystem science over the last 40 years?' and 'What is their relationship to one another?'

One way to view the relationship between the recurring themes shown in Table 4 is illustrated in Figure 1. Here, themes are grouped into four different categories of ecosystem processes; top down biotic control, bottom up resource control, disturbance regimes, and ecosystem response in the form of resistance, adaption and state change. Our view of this continuous interplay of internal and external fluctuating forces depends on the lens we chose to look through; observation, reconstruction, simulation or experiment. What we see also depends on the size of the window, how long we watch, what happened before we arrived, and our expectations – the assumptions, conceptual frameworks and hypotheses that precede enquiry.

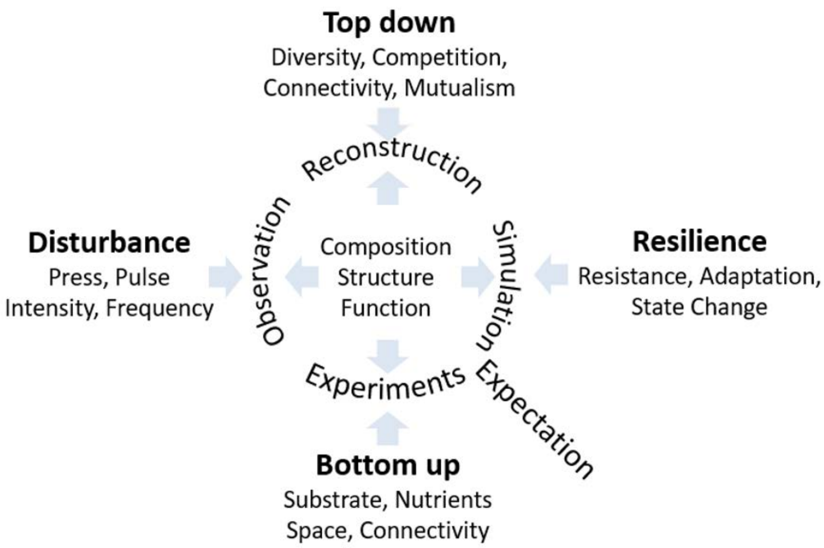

Figure 1. *The relationship between recurring themes in published reviews of the LTER network with the magnifying glass representing four methods of inquiry and research expectations in the form of conceptual models and hypotheses.*

Conclusion

1. Politics and the national interest will always be a major influence as the ecosystem is the most appropriate scale to study interactions between natural process and human order
2. Managing the tension between continuity and flexibility has been the outstanding achievement of the LTER network
3. General principles of ecosystems are likely to remain elusive until expectations are clearly spelled out in the form of conceptual frameworks and hypotheses, and there is greater emphasis on multi-site, multi-variate studies

Postscript: Back to the superorganism, the concept that motivated Arthur Tansley to coin the term ecosystem: did Tansley's paper kill off the idea that ecosystems are self-regulating entities in their own right, a concept that he believed threatened the credibility of ecology as an emerging science? In a word, no. It took the discovery of DNA and the modern evolutionary synthesis to seriously challenge the concept of the superorganism in the eyes of most scientists. But then in 1969 James Lovelock revived the superorganism concept when he published the first outline of the Gaia hypothesis (Lovelock and Giffin 1969) and followed up with a series of books for the general reader. While the concept of Gaia has been rejected by most scientists, first on the grounds that it is an untestable hypothesis (Kirchner 1989), and second because ecosystems and planets cannot evolve through natural selection as natural selection requires variation between individuals within a population, whereas each ecosystem and the Earth are effectively populations consisting of a single unique individual. That has not stopped earth system scientists from proposing the concept of sequential selection, a theoretical alternative to natural selection for the evolution of planetary self-regulation (Lenton et al. 2018), and so the debate that gave birth to the word ecosystem carries on.

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A DNA barcode library for all named Australian species

Dr Oliver Berry

A unifying theme in Olly's research is the use of DNA and "genomics" to provide scientific insights that support environmental management. Over the past 15 years Olly has researched such diverse topics as the ecology of fox control, change in marine food-webs, the evolution of bizarre subterranean creatures, the relationship between farming and biodiversity and more. Olly's work has provided several important technical innovations in applied ecological research, has been featured in university textbooks, and informed government policy.

Australia's environment is unique and valuable. But its size, complexity and high biodiversity mean that it is often expensive and difficult to gather the information we need to manage it effectively. In the past few years environmental monitoring has been revolutionised by a new technique called "eDNA" (environmental DNA). With eDNA analysis, scientists purify DNA from an environmental sample like water or soil and identify species present from their unique "DNA barcodes". This happens without needing to see the animal or plant to know it is present. It works because all organisms shed tiny invisible pieces of DNA into the environment constantly and because every species has a unique DNA sequence. eDNA is a very effective way to map the distributions of all types of organisms, especially in water. Worldwide, governments, industry and even citizen scientists are adopting eDNA because of its high accuracy, its uniquely universal approach that can be applied across the tree of life, and because it is a safe and simple way to sample. However, something is holding eDNA back. To identify a species with eDNA we need to know its unique DNA barcode. Yet, we only know the DNA barcodes for a small fraction of species. This means that when eDNA monitoring is conducted lots of species are not identified because their DNA sequence can't be correctly assigned. Without a full library of DNA barcodes we can't make the most of eDNA's amazing potential to cost-effectively provide the best information on the environment. CSIRO has created the technology to complete Australia's DNA barcode library. The platform can generate DNA barcodes for any type of organism, from microbes to birds. We propose to achieve this significant goal in partnership with a consortium of end-users, biodiversity and biosecurity experts, state and federal governments and philanthropic organisations.