A STATISTICAL REVIEW OF TERRESTRIAL PLOT NETWORKS WITHIN TERN

December 2014

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Three Parks Savanna Fire Effects Plot Network, Kakadu National Park in April 2012. Researchers are walking to meet the chopper, which is approaching for landing in the background. Choppers are needed to access some plots which are not accessible by road and/or foot due to heavy rains in the preceding month.

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Executive Summary

In mid-2012, the last of the Terrestrial Ecosystem Research Network's (TERN's) field survey plot networks was initiated through the inception of the Long Term Ecological Research Network. This represented the final sub-facility-level component of TERNs infrastructure, which started in 2008. Under the umbrella of the overarching Multi-Scale Plot Network (MSPN) facility, the five terrestrial field survey plot sub-facilities were: AusPlots Rangelands, AusPlots Forests, the Long Term Ecological Research Network (LTERN), the Australian Supersite Network and the Australian Transect Network (ATN).

The five facilities were created, or brought together under the MSPN with a desire to incorporate field-based studies that provided scientific information at a range of spatial and information scales. This scale ranged from high, temporal information content at a low spatial coverage at the Supersites, through LTERN and ATN on-ground activities, to the greater geographic coverage obtained through cross-State data collection undertaken by the two AusPlots sub-facilities. In July 2013, the MSPN facility was formally dissolved and four standalone facilities were established: AusPlots, LTERN, the Australian SuperSite Network and the ATN. The AusPlots facility is composed of the original two sub-facilities, AusPlots Forests and AusPlots Rangelands. The table at the end of this Executive Summary groups the plot networks by several attributes.

This report provides an overview of the following three terrestrial plot facilities within TERN: AusPlots, LTERN, and the ATN. On-ground, plot-based activities undertaken as part of the Australian SuperSite Network are reviewed in a second document, *A statistical review of terrestrial plot networks within TERN—SuperSites*. For the three facilities above (excluding SuperSites), 17 field-based projects were subject to review. The review was undertaken primarily using an enquiry-based approach. Substantial consultation was needed to obtain sufficient insight into how the projects were designed as there was a distinct lack of informative documentation available on the study design of the component projects both at the inception, and throughout the review process. This was primarily because the review was undertaken through a demanding 'build-phase' of the Multi-Scale Plot Network within TERN.

A difficulty experienced with the review was understanding what constituted TERN-funded work. For new initiatives, like the AusPlots facility, this was a not a problem. But for the majority of the projects, existing, externally-funded work has been brought under the TERN umbrella to a greater or lesser extent. This made it unclear what was TERN infrastructure and intellectual property, and what was not. During the review, we attempted to avoid documenting and reviewing sub-projects that were neither funded by TERN, nor within the control of TERN facility Directors or facility scientists.

Cooperation and collaboration exist across some of the facilities. For example, AusPlots Rangelands and the ATN use the same field protocols for parts of their work. And Western Australian scientists from the ATN and SuperSites liaise and cooperate on the establishment of field survey sites to examine themes of common interest. There are other examples where researchers from one program have established survey plots and recorded vegetation measurements in proximity to study sites set up by researchers from other programs. The swapping of ideas between scientists from these sorts of associations may lead to new ideas and ways of pursuing ecological questions.

However, while the communication between scientists afforded through the TERN network is a valuable thing, it is clarifying to acknowledge that the programs collectively, what was known as the MSPN, do not represent a cohesive set of field survey plots that complement one another in some rich, integrated manner. Notwithstanding the motivations for assembling the MSPN originally, the field programs themselves—the activities collectively—are largely a set of independent field projects that have been established by different people, at different times, for different purposes. They all have value, whether they be descriptive, inventory-style activities or more structured studies that seek to understand the relationships between selected biodiversity responses and factors that influence or drive those responses. Correspondingly, to aid understanding in what the on-ground plot networks of TERN represent, this review considers the terrestrial plot networks of TERN as a collection of separate field-based activities.

The review seeks to clearly identify and document what the specific objective of each project was, and how the study was set up. This information is necessary to review the work in a statistical sense. Without a clear objective, or without sufficient information on what was undertaken as part of the study, it is difficult to evaluate the level of confidence that respective scientists should have in their research findings. The review makes the distinction between *Study Design* and *Measurement Protocols* because it makes discussion of the statistical aspects of each project clearer. Where there is interest in considering how field plots from different studies could complement one another with an integrated approach, it is critical to first understand how the individual component studies have been established.

There were two features that were common across the terrestrial plot studies that comprise TERN. First, as is often typical with ecological field studies in general, there was a lack of probability-based sampling in deciding where to locate survey plots in the field. That is, in all but a handful of projects, no element of randomisation (within constraints or strata or otherwise), was incorporated in survey site selection. This absence of randomisation in site selection introduces the potential for inadvertent bias. As a result, researchers should use caution when generalising their results beyond their surveyed plots. Selection bias and the idea of representativeness is discussed in the review.

Second, as is also common with ecological field studies, the majority are observational rather than manipulative (experimental). The contrast between observational and manipulative studies has implications for the type of conclusions that can be drawn from the projects. Observational studies can identify correlations and associations between different variables but do not provide clear evidence of cause-and-effect relationships. Often, researchers may have a clear conceptual model of how an ecosystem might function. However, with observational studies, the possibility of confounding remains between factors thought to influence the response of interest, and hidden (unknown) variables that may have more direct influence on the response. When communicating the results of studies, it is recommended that researchers, and TERN, keep these two issues in mind.

The idea of melding or integrating data from the different projects is a very challenging one. Differences in field measurement protocols raises issues of confounding between field project and protocols that are not easily resolved. The informal site selection process used in many of the studies, which to some degree reflects the respective researcher's original motivations, adds to the difficulties. Issues relating to combining project datasets are discussed in the report. The potential for integrated projects to provide reliable information is best assessed on a case-by-case basis with clear objectives understood by all participants.

It is recommended that TERN seeks to more clearly document the study design (site selection) and field measurement protocols for their infrastructure. For responsible re-use of data, users not familiar with the origins of the study infrastructure need to understand how field sites were established. Ecologists are often very good at describing the measurements they undertake in the field, but more care could be given to transparently describing how field survey sites, and any sub-plots within them, were selected. In this regard, it is not adequate to simply state that survey sites "are a representative sample" of the ecosystem of interest, as it is the method of site selection that is informative to end-users of the data. For example, was personal judgement used to select homogeneous areas of vegetation, were plots placed at systematic intervals from a random start point, or was some form of stratified random sampling used? A mix of informal and formal methodologies may be used in selecting sites in any one case that can't be described with a set phrase or label. However, what is most important for end users of the data, and other user-types of TERN infrastructure, is that whatever approach was used to establish the infrastructure, it is clearly and transparently described.

Table 1. Plot Network grouping by broad theme and type of study. Plot networks are grouped by broad study theme (e.g. Fauna), linkages or associations between plot networks, and whether the focus of the study is across a large geographic scale (Biome or Regional), examines specific disturbance issues, or investigates habitat or community dynamics. The three-group study focus classification may be a useful classification, but the classes are not mutually exclusive. For example, the LTERN Tropical Rainforest Plot Network may be regarded as fitting into all categories: it spans a large geographic area, plots are used to examine recovery from disturbance events, and the dynamics over time of rare and common species is an area of scientific interest.

Plot Network	Fauna	Flora	Soil	Hydrology	Climate change		Cross-TERN linkages	International linkages	Biome or Regional	Disturbance	Community dynamics
AusPlots											
Forests		y			y		y	y	y		y
Rangelands		y	y				y		y		
LTERN											
Connell Rainforest		y									y
Tropical Rainforest		y	y		y				y		y
Victorian Tall Eucalypt	y	y								y	
Victorian Alpine	y	y			y			y		y	y
Nanangroe Plantation	y	y								y	
Woodland Restoration	y	y								y	y
Jervis Bay Booderee	y	y								y	
Three Parks Savanna Fire-Effects	y	y					y			y	y
Desert Uplands	y	y								y	
Desert Ecology	y	y			y		y			y	y
Mallee Plot		y	y				y			y	y
Upland Heath Swamps		y	y							y	y
Australian Transect Network											
South Australian TREND		y	y		y		y		y		
Northern Territory NATT	y	y	y		y		y	y	y	y	y
Western Australian SWATT		y			y		y		y		

From Table 1, international and cross-TERN linkages for AusPlots include RAINFOR methodologies and associations with the TERN facilities SuperSites, Australian Transect Network and AusCover. International linkages within LTERN include the Victorian Alpine plot network's adaption of International Tundra Experiment (ITEX) methodologies in establishing the Australian Tundra Experiment. Cross-TERN linkages for the Three Parks Savanna Fire-Effects plot network include associations with SuperSites, OzFlux and AusCover. The Desert Ecology and Mallee LTERN plot networks have cross-TERN linkages with AusPlots Rangelands. The North Australian Tropical Transect (NATT) has international linkages through the United Nations International Geosphere-Biosphere Program (IGBP), and cross-TERN linkages of the broader Australian Transect Network include those with AusPlots Rangelands, SuperSites, AusCover and LTERN.

Purpose Statement

This report was commissioned as part of the Australian Government Education Investment Fund under a Collaborators Agreement between The University of Adelaide and The Australian National University in mid-2012.

The purpose of this document is to provide an overview of the strengths and weaknesses of the 17 field projects within the three TERN terrestrial plot networks: AusPlots; the Long Term Ecological Research Network (LTERN); and the Australian Transect Network (ATN). On-ground, plot-based activities within the SuperSites facility is documented in another report, *A statistical review of terrestrial plot networks within TERN—SuperSites.* This review sought to document the objectives and methodology for the field projects within each of the facilities and make recommendations where relevant. Projects were reviewed against the study objectives as described by principal investigators or facility leaders.

A critical examination of the collective ability of these projects to inform synthesis-based research question was beyond scope. However, we do provide some limited commentary on this important topic at the end of the report.

Report Structure

This report has three sections. Section 1 provides background and contextual information relevant to the review. Section 2 provides a review of each of the 17 projects. Section 3 provides additional comment on some relevant statistical aspects, including key considerations to inform any future aspirations to use these individual projects for synthesis initiatives.

SECTION 1: Context

This section of the report provides relevant contextual information.

Background

The Terrestrial Ecosystem Research Network, www.tern.org.au is a collection, storage and sharing infrastructure network for Australian ecosystem science. TERN was initiated in 2008 and has been funded primarily through the Australian Government National Collaborative Infrastructure Strategy (NCRIS) and the Education Investment Fund Super Science Initiative (EIF).

TERN is administered by The University of Queensland but the administration of the terrestrial plot-based components of TERN were outsourced to The University of Adelaide. These plot-based components were collectively known as the Multi-Scale Plot Network (MSPN) until mid-2013, and were administered by the MSPN facility at The University of Adelaide.

The MSPN was inclusive of five separate sub-facilities: AusPlots Forests, AusPlots Rangelands, the Australian Transects Network (ATN), the Australian SuperSite Network (ASN), and the Long Term Ecological Research Network (LTERN). LTERN was the last of the facilities to be established, and came into effect in mid-2012. In July 2013, the MSPN facility was formally dissolved and four standalone facilities were established within TERN (see following section).

This review was commenced in May 2012 after the recruitment of the lead author. However not all capabilities within TERN, that were subject to the review, were in place at this time (discussed further below).

In total, the review was inclusive of 22 field projects: five ASN projects (separate report), three ATN projects, two AusPlots projects, and 12 LTERN projects. Several of these projects, however, have multiple components.

Overview of terrestrial plot networks within TERN

The collective purpose of the terrestrial plot networks within TERN is to provide a scientific basis to understand environmental change across Australia and, in turn, to inform effective natural resource management. Four facilities within TERN are responsible for the delivery and management of these terrestrial plot networks. These are the:

(1) Ausplots facility which administers Ausplots Rangelands, which is a new continental network of surveillance monitoring plots in rangelands, and Ausplots Forests, which is a new large-scale network of surveillance monitoring plots in tall eucalypt forests;

(2) Long Term Ecological Research Network (LTERN), which is built on pre-existing long-term terrestrial ecology research plot networks;

(3) Australian Supersite Network (ASN), which is a series of new and established sites undertaking intensive ecosystem measurements; and

(4) Australian Transect Network (ATN), which is a network of new and established monitoring transects spanning environmental gradients.

In developing the original Multi-Scale Plot Network, there was a desire to incorporate field-based studies (infrastructure) that provided scientific information at a range of spatial and information scales. Broadly, this scale ranged from high (temporal) information content at a low spatial coverage (SuperSites), through LTERN and ATN on-ground infrastructure, to the high spatial coverage and comparatively lower information content obtained through AusPlots facility activities.

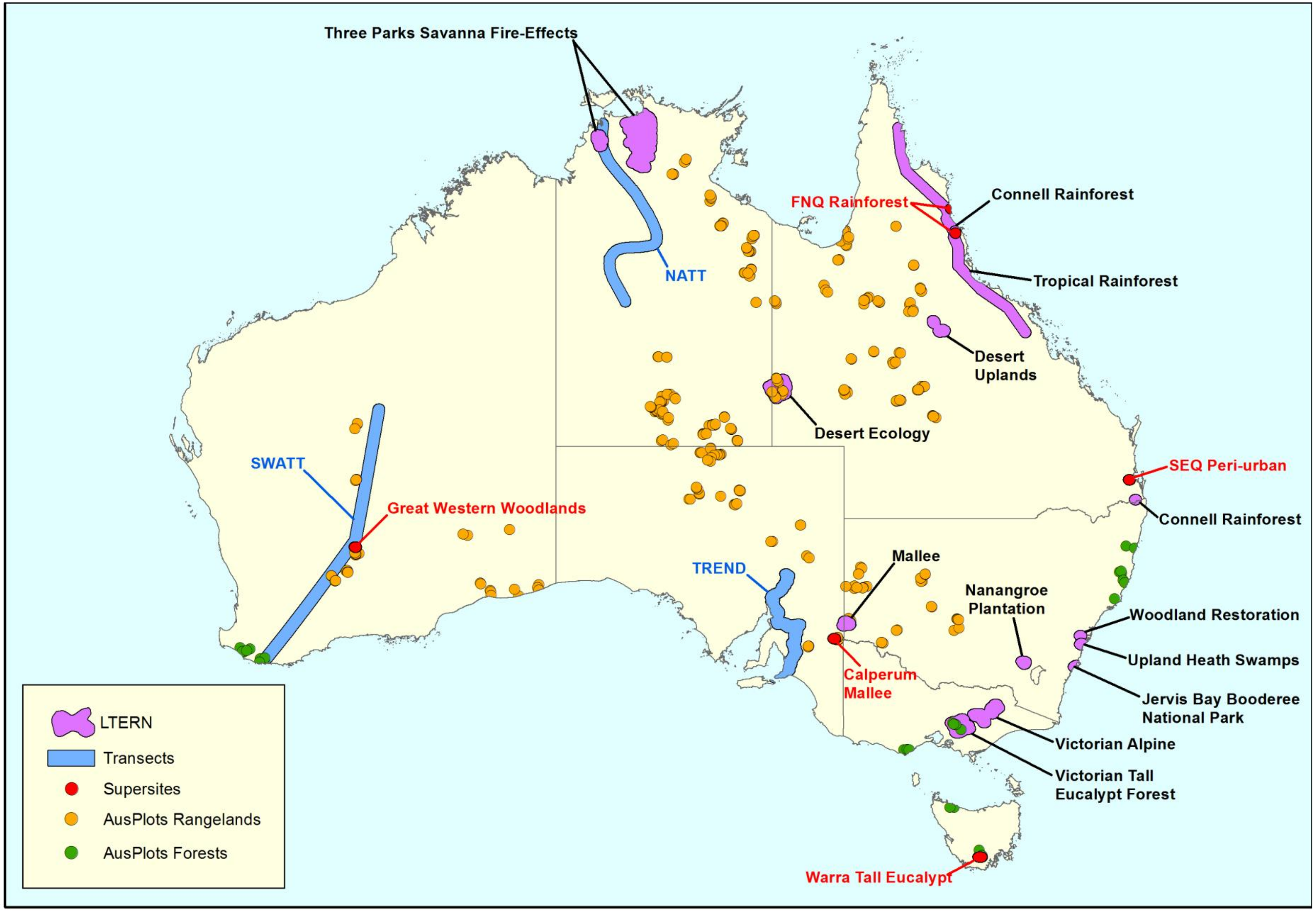

Figure 1: Spatial distribution of plot networks (i.e. the 22 projects which are the subject of this review) within TERN

Approach taken

An ‘in-house’ model was employed to complete this review. That is, a statistician was recruited through The Australian National University (ANU) to undertake the review within the EIF period (2011-2014) of TERN funding. The Long Term Ecological Research Network (LTERN) is administered by the ANU, and the statistician was based within the LTERN Office. In addition to undertaking the review, under the broad supervision and guidance of Professor Alan Welsh, the statistician provided statistical advice to TERN-related or TERN-linked activities; and provided input and feedback on a range of TERN-related plans, products, proposals or activities.

The review was primarily undertaken using an enquiry-based approach. When available, written material was reviewed. Substantial consultation was needed to obtain more than a superficial understanding of how the projects were designed and an enquiry-based approach was needed because there was a distinct lack of documentation on relevant aspects of study design available both at the inception of, and throughout the process of the review. This was largely due to the review being undertaken through a demanding ‘build-phase’ of TERN (see next section for further information).

The scientific activities that are undertaken by each of the four main facilities differed in the extent to which they were part of larger scientific programs. For example, all components of a field project were identified as TERN infrastructure in some cases, while in others, a sub-component may only have been identified for inclusion. This demarcation was sometimes difficult to identify while in other cases it was made explicit by the researchers. In this regard, it is important to understand that the review seeks to cover those parts of the scientific programs that are funded by TERN, and not necessarily the whole programs. Where the TERN-funded work is known to be a component of a larger program this is identified in the report. In addition, for the SuperSite facility, not all TERN-funded work was subject to the review. Hydrological measurements and flux tower activities, including associated tower-based instrumentation, was out of scope for the review as the focus was on activities undertaken on terrestrial, on-ground survey plots. Plot-based activities undertaken at the SuperSites are documented and reviewed in a separate, companion report, *A statistical review of terrestrial plot networks within TERN—SuperSites*.

Enquiry-based research

Information was obtained through a combination of meetings, telephone discussions, workshops, attendance at presentations, and looking at written material. A table of dates of consultations and requests for information from TERN scientists is provided at the end of this section.

Field Trips

Site visits to all project were not feasible within the time and budget constraints of the review. However, where feasible, face-to-face interviews with researchers were made as follows:

- July 2012 – a trip to Adelaide to meet with Transects and Ausplots Rangelands personnel 2012.
- July 2012 – a trip to Tasmania to meet with AusPlots Forests personnel.

- September 2012 – a trip to Sydney to meet with Desert Ecology Plot Network (LTERN) personnel.
- April 2013 – field work for the Three Parks Savanna Fire-Effects Plot Network. Phil Tennant and Alan Welsh participated in parts of this field work.
- October 2013 - a field trip to the Dune Mallee Woodlands of south western NSW to participate in the ongoing work on herbivore effects in relation to post-fire vegetation response undertaken by Professor David Keith.

Workshops

During the period of the review, a number of workshops were conducted across TERN and these were instrumental in seeking clarification from researchers about their projects. Workshops attended included:

- 28-29 August 2012 - A MSPN Methods Workshop held in Adelaide.
- 10-11 September 2013 - A MSPN planning and review workshop held in Brisbane.
- 28 November 2013 - participation in an LTERN and ASN data planning day in Brisbane.
- 26-28 May 2014 - a joint LTERN and ASN workshop on Stradbroke Island.

Semi-structured phone interviews

A large proportion of the material needed to undertake the review was acquired through semi-structured phone interviews followed by email correspondence. In all cases, multiple requests were needed with repeated follow up questions. Requests were made from project inception through to October 2014.

Data examination through linkages to data portal staff activities

For LTERN, information also was acquired through collaboration with data portal personnel who are charged with curating and publishing data collected within the facility. In particular, the statistician examined data structures and facilitated the development of metadata based on the outcomes of his research.

Table of dates of consultations and requests for information from TERN scientists excluding the report review period 14 November to 12 December 2014.

Plot Network	Consultations and requests for information.	Plot network contacts
AusPlots		
Forests	May and June 2012, March 2014	Sam Wood, David Bowman, Lynda Prior
Rangelands	May, July and August 2012, February 2013, March 2014.	Ben Sparrow, Jeff Foulkes, Nikki Thurgate
LTERN		
Connell Rainforest	August 2012 and June 2014.	Peter Green
Tropical	August 2012, May, September and	Dan Metcalfe, Matt Bradford

Plot Network	Consultations and requests for information.	Plot network contacts
Rainforest	October 2014.	
Victorian Tall Eucalypt	November 2012, October and November 2013, August 2014.	David Lindenmayer, David Blair, Ross Cunningham, Heather Keith
Victorian Alpine	August 2012, November 2013, February, August, September and October 2014.	Dick Williams, Michael Nash, Ary Hoffmann, John Morgan, Warwick Papst, James Camac
Nanangroe Plantation	August 2012, October and November 2013, June 2014.	David Lindenmayer, Sachiko Ellicott, Ross Cunningham
Woodland Restoration	August 2012, September and October 2013, August and October 2014.	David Keith, Renee Woodward, Katy Wilkins
Jervis Bay Booderee	April 2013, March, June and August 2014.	David Lindenmayer, Christopher Macgregor, Ross Cunningham
Three Parks Savanna Fire-Effects	August 2012, April, May and September 2013, June and August 2014.	Jeremy Russell-Smith, Cameron Yates, Andrew Edwards, Dominique Lynch, Graeme Gillespie, Alaric Fisher
Desert Uplands	August 2012, November and December 2013, February, May, June, July 2014.	Chris Pavey, Eric Vanderduys
Desert Ecology	August and July 2012, March 2014.	Glenda Wardle, Chris Dickman
Mallee Plot	August 2012, March and September 2013.	David Keith, Mark Tozer
Upland Heath Swamps	August 2012 and October 2014.	David Keith, Tanya Mason
Australian Transect Network		
South Australian TREND	June 2012, May, July, September, October, November 2013, June and September 2014.	Stefan Caddy-Retalic, Greg Guerin, Ian Fox
Northern Territory NATT	June and August 2012, March 2013, September 2014.	Stefan Caddy Retalic, Alan Andersen, Garry Cook, Israel Del Toro
Western Australian SWATT	June and July 2012.	Stefan Caddy Retalic, Stephen van Leeuwen

Review of written material

At inception, there was little or no documentation on the design principles of the initiatives within TERN which were the focus of the review. As capabilities matured, there was some documentation but this was not consistent. In particular, the approach adopted by LTERN to develop a Conceptual Design document became a valuable resource for the statistician and considerable time was spent assisting LTERN Office staff in the compilation of this significant document which was finalised in December 2013.

In many cases, researchers expected the statistician to read and obtain relevant information from published scientific publications. In many cases this was neither practical nor feasible as the information presented in the journal articles was not at the level needed to understand how the study was actually designed and implemented, nor which components were specifically TERN-funded. Nevertheless, in conjunction with speaking to scientists this was a significant source of information for the project. Written material that was consulted during the review is listed in the Appendix.

Report finalisation

Due to delays and resultant time pressures (see below), individual Prinicpal Investigators of each of the 17 projects were not given an extended opportunity to review their sections prior to the submission of this report. Following the submission of the report at the end of October, Principal Investigators were provided with the period from 14 November until 8 December to advise in writing of errors made by the authors in describing their studies. Information received up until 12 December on errors made was incorporated into a revised final report.

Report utilisation

This report is considered 'contract material' under the Collaborators Agreement between the University of Adelaide and ANU. It is therefore up to the University of Adelaide to decide how best to utilize this report and share its contents. Its dissemination to Principle Investigations, the TERN Executive Advisory Council, and the TERN Board is encouraged.

Difficulties

There were some difficulties in undertaking this review in a timely and comprehensive manner. To undertake the review, the networks within the MSPN needed to be established with identifiable structures and purpose. In the case of LTERN, which is the largest of the facilities within the MSPN, this was not achieved until late 2012 when it delivered its project plan to the MSPN facility[1].

Also, despite best endeavours in advance of contract finalisation (see footnote), there was difficulty in attracting a suitably qualified statistician to undertake the review. In total, three recruitment rounds were completed between late September 2011 and March 2012. The third attempt resulted in employment from 15 May, 2012.

Finally, the multifaceted demands on researchers and managers within the MSPN during the EIF establishment period, coupled with a lack of documentation, meant that there were repeated requests for information and subsequent delays.

[1] Project Plan delivery was on time and as scheduled in the Collaborators Agreement. However there were substantial delays in finalizing a Collaborators Agreement between the University of Adelaide and ANU, resulting in LTERN not officially starting until mid-2012.

SECTION 2: Individual project reviews

This section reports on the different projects reviewed, 17 in total. To understand, discuss and assess the way each of the field studies are being implemented, we sought to document several aspects of the individual projects as part of the review:

- Background to the project. Many of the projects have been running for some time. In some cases, project implementation has been staggered where additional field sites and/or methodologies have been incorporated over time. The background or history of the project provides context with respect to how the work is currently being implemented.
- Broad objectives and specific objectives. The objectives of a given study focus the interest on specific topics but generally do not provide the detail on how the work will be undertaken.
- Specific questions being addressed or proposed to meet the objectives. The questions that an ecologist investigates reflect the objectives of their project and are a critical aspect that influences how they design and undertake their studies. Without specific research questions it is hard to statistically evaluate a scientific study.
- Study design. Design aspects such as site selection, sampling schemes, and any use of stratification are significant components of scientific field studies. An important part of the review will be trying to understand how well scientific questions can be answered using the implemented study design. While analysis of field data is an important step, it is often aspects of study design that determine how well study objectives can be met.
- Measurement protocols. Measurement protocols differ from aspects of study design in that they relate to what is actually measured or recorded on the study sites, and how.
- How will the study's scientific questions be examined or answered using the data? The approach and implementation of data analysis is an important part of a study. We sought to document the approach to data analysis that the principal investigators had used, or were planning to use, where possible.
- Discussion. A discussion of the project's features and how they relate to meeting the objectives.

AusPlots

Reviews for AusPlots Forests and AusPlots Rangelands are covered in this section.

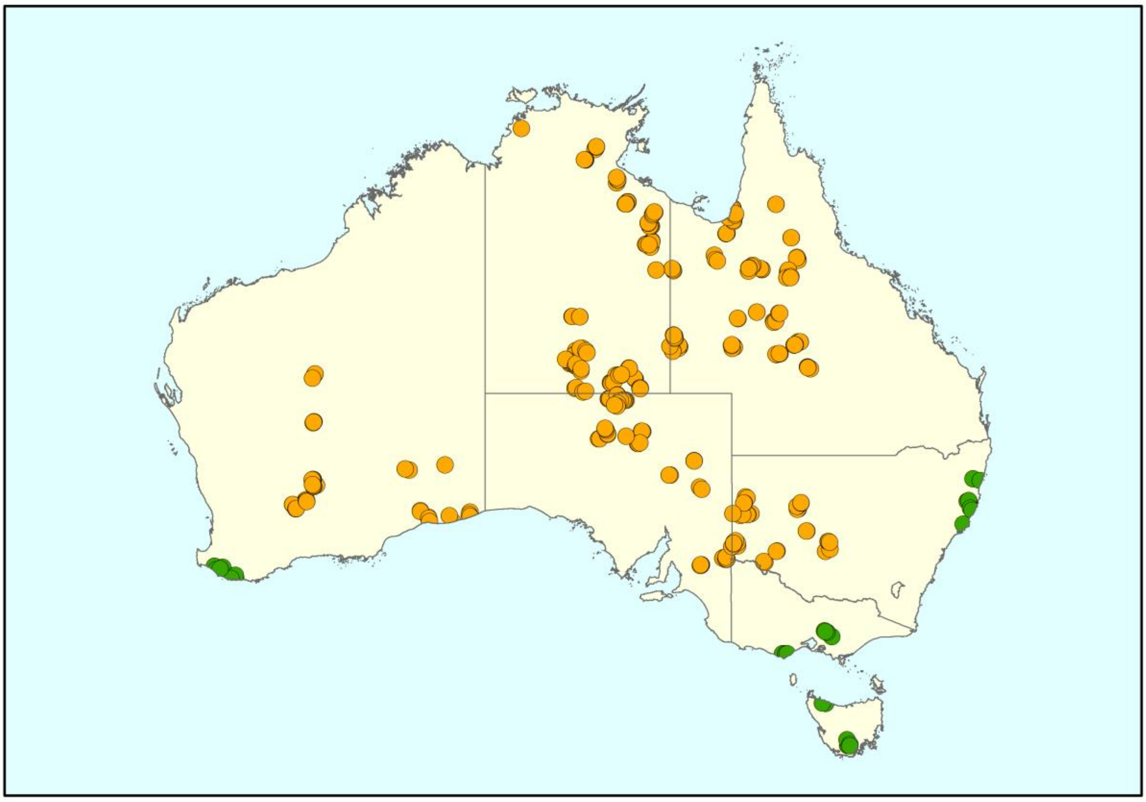

Figure 2: Spatial distribution of plots within the AusPlot network within TERN

AusPlots Forests

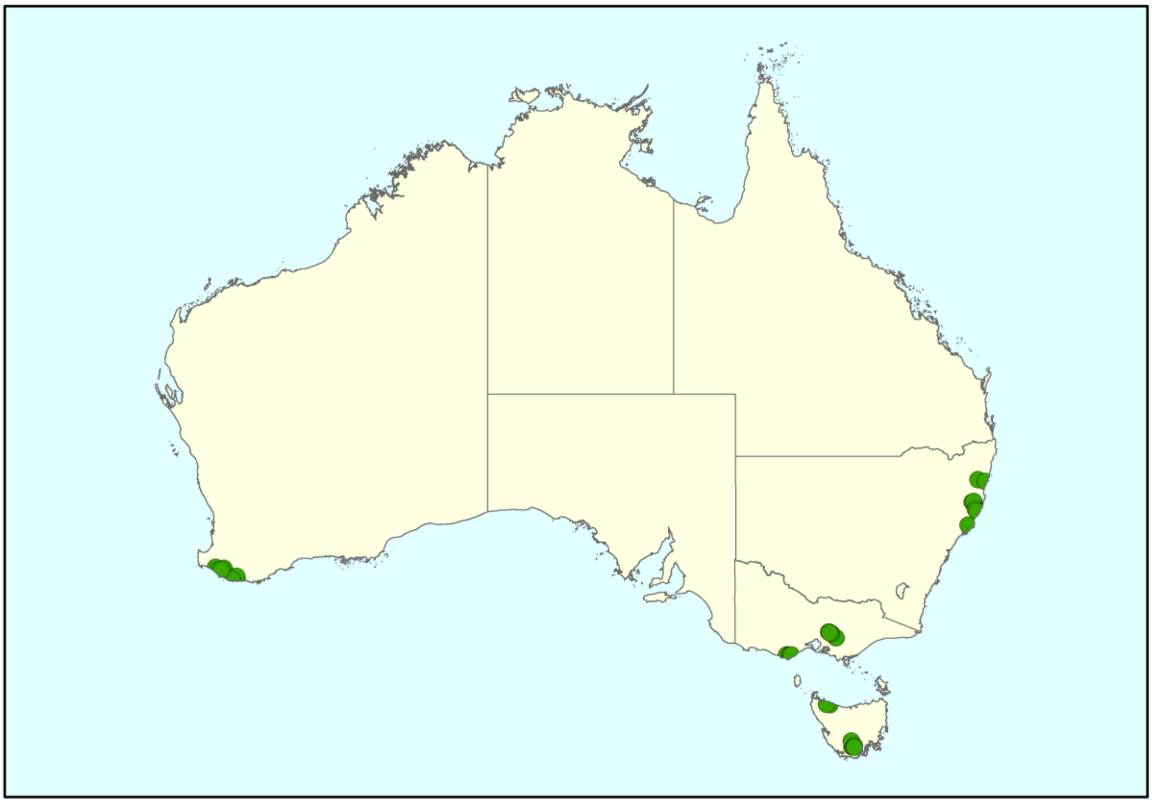

Figure 3: Spatial distribution of plots within the AusPlots Forest network within TERN

Background to the project

The Ausplots Forests program was initiated following collation and analysis of data from existing individual State-managed permanent forestry inventory plots from across Australia. Analysis of the permanent inventory plot data focused on examining the relationship between tree growth and precipitation, temperature, rainfall seasonality and other selected environmental variables (Prior *et al.* 2011). The present AusPlots Forests program aims to build on the knowledge obtained from the permanent inventory plots and extends field protocols to the measurement of all plot-based trees and includes observations on tree mortality and recruitment. Components of the field measurement protocols draw on methods used internationally including the RAINFOR collaboration.

Objectives

AusPlots Forests is a program undertaken in the tall eucalypt forests of five Australian states to examine relationships between tree growth, tree mortality, tree recruitment and a range of climatic variables including rainfall and temperature. Relationships will be examined both across the country, in the five States in which field work is being undertaken, and over time at each of the plot locations. Conclusions from the effects of rainfall and temperature will be used to explore the potential role that climate change may play in tree growth and forest dynamics.

Secondary objectives of the program are forest biogeographic ones and exploring the idea that the large forest eucalypt tree species evolved from rainforest tree species (Tng *et al*. 2012).

Research Questions

The researchers stressed that AusPlots Forests was an infrastructure program established for surveillance purposes and to be used by the scientific community. Hence, there are no distinct scientific hypothesis to be tested. However, a key research question to be examined using the program includes: *How are tree growth, mortality and recruitment influenced by rainfall, temperature and a selection of other biophysical variables?*

Study Design

Forty 1ha plots are planned to be established in the late regeneration/mature growth stage stands of tall eucalypt forest across Tasmania, Victoria, New South Wales, Queensland and Western Australia. A plot size of 1 ha was chosen as it was considered an appropriate size to effectively record forest stand dynamics including recruitment and mortality. In addition to selecting survey sites from older aged stands, only sites with a minimal history of past harvesting will be selected. Forest trees of different age grow at different rates and different intensities of previous logging affects forest stand dynamics.

Tall eucalypt forests span subtropical, warm temperate and cool temperate climates across Australia. There will be up to eight plots in each State. A small set of dominant canopy species, preferably two, will be chosen for each State to characterise the forest stands in which the work will be undertaken. Within each State, for these two (or more) canopy tree species, the geographic range with regard to mean annual temperature and mean annual rainfall will be identified and an effort made to distribute the survey sites, representing those canopy species, across that range. Some of the dominant canopy species have broad geographic distributions either within or across States allowing examination of responses across a range of rainfall and temperature values.

Prior to final site selection, field inspections will be needed to verify canopy species composition and the level of previous harvesting documented in logging history maps and records. There will be a preference for the sites to be located within reserves on public land to help maintain access for repeat measurements and observations in the future.

There are plans to locate some of the 40 1ha plots on top of the existing, smaller permanent inventory plots to take advantage of the observations recorded from the original plots. This matching of sites would only occur where the constraints of the existing design are met with regard to stand growth stage, dominant canopy species, minimal past harvesting, temperature and rainfall.

The same Ausplot Forests staff will be involved in all site selection in conjunction with State-based forestry agencies and a core team of field staff will travel and do the measurement and recording in each State. The survey sites are planned to be re-measured at a 5-10 year interval.

Measurement protocols

A core set of measurements and observations will be made at all 40 sites and a supplementary (optional) set of measurements will be undertaken if time and other resources permit. For logistical purposes, the 1ha plot is split into 25, 20m by 20m sub-plots. The core set of measurements and observations are: trees greater than 10cm in diameter tagged and diameter at breast height (1.3m) recorded; percentage canopy cover at 16 systematically placed points (internal sub-plot vertices); and height and form of 40 eucalypt individuals and 40 non-eucalypt individuals recorded across diameter classes. The core measurements and observations being undertaken have been selected to correspond with the RAINFOR forest mensuration procedures used internationally.

A supplementary (optional) set of measurements and observations include soil cores, recording seedlings and saplings (<10cm dbh) to examine recruitment processes and ground layer floristic measurements. Photographic work and observations on coarse woody debris are also being considered.

Analysis

It is anticipated by the researchers that regression and mixed models will be used to explore the relationship between the response of forest tree species (predominantly tree growth, mortality and recruitment) and key covariates including mean annual temperature and mean annual rainfall as well as other selected biophysical variables.

Discussion

Growth stage, historical harvesting intensity, dominant canopy species and the distribution of site characteristics with regard to temperature and rainfall have been constrained through the study design with the intention of making relationships between tree growth and climate and other environmental variables easier to interpret. In this regard, working with limited resources within a defined subset of the forestry estate is a sensible choice and reduces the risk of interpretation difficulties due to confounding with other factors that may influence the response of interest. The constrained set of survey sites limits the ability to draw study conclusions across the broader forestry estate. Within the strata that has been imposed, it was recommended that the researchers employ some element of randomisation when choosing sites to help minimise selection bias.

The researchers have a variety of options to expand or build on the program if additional resourcing becomes available. These options include incorporating: different disturbance histories or forest types, additional observations and measurements at existing sites (e.g. fauna), or additional sites within the existing study design constraints while maintaining present measurement protocols. The last option, corresponding to increasing the sample size of the current design, may be the most productive if the variability of the response variable of interest is high from the (anticipated) two individual canopy species plots per State.

Incorporating dominant canopy species into the study design allows examination of the growth responses of key canopy species. Tall eucalypt forest species may have different growth responses to climate variables like mean annual temperature (Prior *et al.* unpublished).

The 1ha plot size seems like a large area to measure every tree and this may present field challenges in implementing the planned measurement protocols across the survey sites. This potential problem is likely to be alleviated to some degree through the relatively modest, constrained study design.

Characterising climate, and consequently climate change, using the two variables (*viz*: mean annual temperature and mean annual rainfall) will have limitations. This is acknowledged by the researchers in previous work (Prior *et al.* 2011). A variety of climate attributes may need to be considered to more effectively characterise climate to help explore the consequences that a changing climate may have.

The researchers anticipate that a similar analysis approach may be used for the AusPlot Forests data as was used in Prior *et al.* (2011). The following remarks based on reading Prior *et al.* (2011) may be useful to the researchers:

- It is good that there is an effort to explore the representation of selected survey sites compared to the broader forest estate. However, this analysis does not really replace randomisation (within strata) because it focuses formally on locations when the whole distribution is of interest, on one variable at a time when joint distributions of variables are important, and on variables that have been measured when even variables not considered may be important.
- There are observations (data values) which seem to be spurious. These have been dealt with by setting formal exclusion criteria and then deleting the observations which meet them. This is reasonable as a first pass but the variability introduced by this process is not included in the inferences. Formal robust methods offer a way to more effectively include the relevant variability.
- It is not straightforward to do model diagnostics in the mixed model framework. However, it would be useful to see some model diagnostics to see how well the models fit the data. Some kind of R-squared is reported but it is not clear what this is or how meaningful it is.
- The linear mixed effects model for individual trees has a single random effect. This plot random effect is trying to capture both between-tree and within tree through time effects. It would be more usual to fit a random effect for plot and nested (within plots) random effects for each tree to more effectively partition the variability.
- It is more difficult to predict with mixed models so the prediction is done with regression using a restricted set of climate variables. These are obtained by downscaling from the A2 greenhouse gas emission scenario. The regression 95% confidence and prediction intervals are too narrow because they ignore many sources of uncertainty. Some of these are discussed in Prior *et al.* (2011) which is good. The effect of ignoring the dependence (captured by the random effect) should be mentioned. There is a question about whether it is worth reporting the optimistic regression intervals when so much uncertainty is not quantifiable.

In November 2014, researchers advised they had established 43 plots as part of the program, and that additional scientific papers had been published related to the work described in Prior *et al.* (2011) (Bowman *et al*. 2014, Prior and Bowman (2014a, 2014b).

Summary

The constrained study design focuses the AusPlots Forests project on examining aspects of tree growth in minimally-harvested, older forests with selected canopy species. Working at the 1ha plot size may be a substantial field workload considering the number of plots that are scheduled to be established. However, the researchers are confident that it is the most appropriate size to effectively record forest stand dynamics. When using downscaled climatic variables like mean annual temperature and mean annual rainfall to explore the potential effects of climate change, it is recommended both that: a) uncertainty is accommodated in any statistical modelling; and b) that it is acknowledged that measures like mean annual temperature function only as one attribute of climatic conditions.

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AusPlots Rangelands

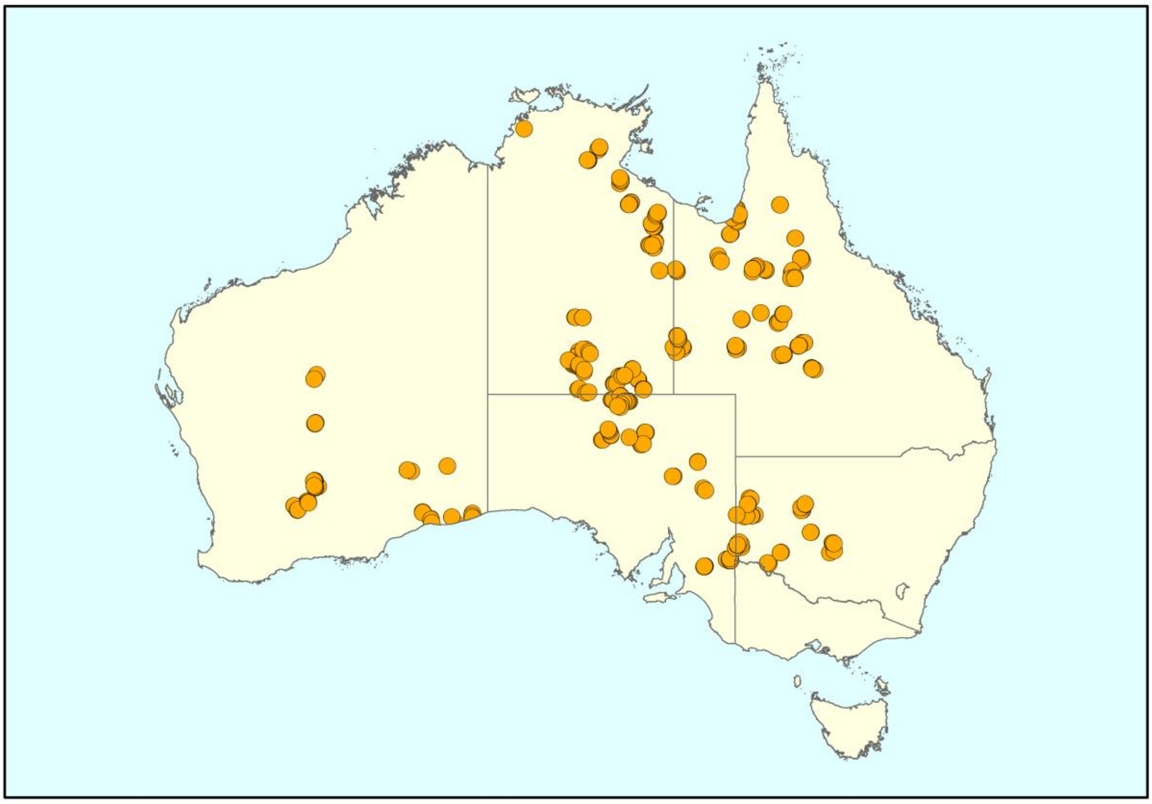

Figure 4: Spatial distribution of plots within the AusPlots Rangelands network within TERN

Background to the project

The AusPlots Rangeland project was initiated in 2008 through the National Collaborative Research Infrastructure Strategy (2008 – 2013) and continued to develop through the Education Investment Fund (2010-2014). Survey plots from the AusPlots Rangelands project have been established as `scientific infrastructure' to help the research community obtain environmental information on poorly surveyed regions of interior Australia. Broadly, Australia's rangelands corresponds to land that is not suited for intensive agriculture due to low, highly variable or seasonal rainfall, and/or low nutrient soils. The rangelands cover approximately 80% of the Australian continent. It is understood that much of the scientific plot-based work undertaken in the rangelands to date has been targeted toward pastoral land use and in many places occurs in areas subject to heavy grazing. Much of the existing work has occurred at the State government or regional level with different survey methods being used by different agencies. The Ausplots Rangelands project seeks to address the poorly surveyed status of the rangelands through establishing plots in examples of vegetation communities that are less affected by grazing, and in doing this, uses a consistent survey methodology across regional and state boundaries.

Objectives

The objective of AusPlots Rangelands is to "establish permanent plots throughout the Australian rangeland bioregions where baseline surveys of vegetation and soils will be conducted" (White *et al*. 2012, p.3). In conjunction with foundational surveys of vegetation and soils being undertaken, there is a significant inventory-type role associated with the project, with a range of plant and soil specimens being collected and stored for subsequent examination and analysis.

Research Questions

The researchers that established AusPlots Rangelands have stressed that it is an infrastructure program that was set up for the scientific community to use. Due to these origins, the researchers confirmed it has not been designed with any specific research or land management questions in mind. The researchers believe that the infrastructure—the establishment of a set of permanent monitoring plots with associated field survey methodology—will be useful to scientists interested in the rangelands environment.

Study Design

In 2012, the objective of the Ausplots Rangelands researchers was to establish several hundred permanent 1ha plots across the rangelands and collect data on vegetation and soils using a consistent field survey protocol that they had developed. A 1ha sized plot was chosen by the researchers as that was the size regarded as an accepted standard in rangeland environments in Australia and parts of South Africa. Over 340 plots have been established through the AusPlots Rangelands project to date, and more are planned. It is estimated by the end of 2015 (under NCRIS 2013 funding), there will be around 450 plots in place across the rangelands.

Information relating to the survey design of the Rangelands program is presented in White et al. (2012), and following consultation with researchers in August 2012, is summarised below. During the project design phase, 21 Bioregional Groups were identified in the rangelands through collapsing the existing IBRA bioregional classification using multivariate (cluster) analysis and the associated interpretation by scientists. Some of these 21 Bioregional Groups contain one IBRA bioregion, while others are composed of more than one IBRA bioregion. The above bioregional stratification was then used to geographically distribute the survey plots across the landscape into districts or regions that have not been frequently surveyed for biological resources. This process has meant that a range of ecosystems are included (represented) in the AusPlots Rangelands project.

Following the above bioregional stratification process, where some strata (Bioregional Groups) were represented by one IBRA bioregion, and other strata by more than one bioregion, decisions were then made on which IBRA bioregion within a stratum (Bioregional Group) should be surveyed. Here, the motivation was for one component bioregion to be surveyed well, rather than the plots to be spread across multiple bioregions within a stratum (Bioregional Group). The decision on which bioregion within the 21 strata to survey was made by the AusPlot Rangelands researchers in consultation with local jurisdictional managers. Factors influencing the decision included state agency priorities, the presence (or absence) of historically collected data, logistical considerations, and the likely ability to have continued access to sites.

Following the decision on which component bioregion within a stratum to survey, information was collated about the respective bioregion to identify areas of interest that could motivate site selection. Similar considerations made in deciding which bioregion to survey (above), were used also to help decide where in the selected bioregion plots should be placed. For example, there may be preferences for sites where (good quality) data has previously been collected, conservation reserves where access is secure, and areas that are important for local public land managers.

Additionally, representation of different land systems, which reflect geomorphological differences across the landscape, were considered when thinking about areas that were desirable to survey. Within each bioregion, both land systems that were common, as well as those that are less frequently encountered (e.g. sand plains, rocky outcrops) were identified as valuable components to incorporate in the survey program. The process of considering particular land systems, and examples of them, is undertaken in conjunction with State agencies. White *et al*. (2012) reports that IBRA sub-regions are used in the stratification process, but researchers confirmed that sub-regions were not formally used for further geographic division.

The researchers sought to make available among the field plots, contrasts between different levels of (grazing) disturbance. Part of the plot selection process involved allocating approximately 80% of the plots to least modified areas (>=10km from a water point), with the remaining 20% being placed in areas of 'intermediate levels of disturbance' (between 3-5km from water points). It is understood that the 80/20 disturbance regime split is made in the field and undertaken by State agency staff, who document the reasons why a plot was established at the location.

When deciding on potential locations for a plot, researchers also give consideration to the presence and availability of previously collected field data at the location. In this regard, a range of criteria are considered in deciding how useful the historic data is likely to be including the duration and frequency of historical collection, the specific factors or variables recorded, and accessibility to the data.

Largely, the States' previous or on-going pastoral monitoring programs are on degraded sites and the AusPlots Rangelands project seeks to address this imbalance by including minimally disturbed sites. In deciding on the specific location of the plot in the field, (following consideration of the desired attributes and constraints discussed above), judgement was used in placing the plot in a relatively homogeneous area of the one vegetation type, and of consistent slope and relief that was not interrupted by a stream or water course. There was some clustering of plots out of convenience to alleviate travel time in the field. For example, once a site was chosen at which to locate a plot, a further one or two plots also might be established in the same district.

From the commencement of the study, the researchers planned to establish 50-70 plots within a bioregion, and within that, five replicate plots of each vegetation community that they had chosen. Decisions regarding which vegetation communities to include are also made on a range of environmental, historic, logistical and administrative factors (see above).

It is understood from the researchers that any future decisions about how frequently to re-survey the plots after establishment will largely be determined by the frequency of heavy rainfall. This is because little change would be expected in the vegetation without these weather events.

Measurement protocols

The AusPlots Rangelands Survey Protocols Manual provides an illustrated description of the field measurement protocols used in the program (White *et al.* 2012). Only a brief summary is provided here.

The point-intercept method is used across the 1ha plot at 1010 points along 10, 100m transects where intercepts are recorded at 1m intervals to provide cover estimates of individual species, total vegetation cover, and cover of different substrates (bare soil, litter, rocks). Heights of canopy-intercepts are also taken during this exercise. Rapid estimates of basal area for each woody species >1.3m height are taken at 9 points throughout the 1ha plot using sweeps with a basal wedge.

A five minute vegetation structural summary is made by recording the three most dominant species in the upper, middle and lower strata. As part of the protocol, an estimate is made of the shortest distance `to a different vegetation community' from the centre of the plot. It is understood this latter estimate is made to help with remote sensing validation.

Voucher specimens are taken for each vascular plant species with a sub-sample of leaves taken for genetic profiling. Photo-panoramas are obtained from three photopoints located near the centre of the 1ha quadrat. Up to 120 photographs may be taken from a plot with researchers indicating that developing technology for 3D reconstruction from the photos provides opportunities for estimating basal area and biomass for the photographs.

Ancillary data gathered on behalf of other researchers includes leaf area index (AusCover) where conditions are suitable and equipment is available, and a variety of soil characteristics and samples (CSIRO). Some of the soil procedures require a soil scientist.

The researchers estimate that marking out the plot and recording the vegetation attributes, including the photographs, takes between 7-8 hours plus another 3 hours for the basic soil survey (or 6 hours if the full soil survey is undertaken by a soil scientist).

It is understood that State-based teams are used to establish and collect data from the plots. Conventionally, State teams will consist of a vegetation specialist, a soil specialist plus additional field crew. In some States field crews are employed 100% on AusPlots Rangelands, while in other States, working on the project represents a portion of their time.

Analysis

The Ausplots Rangelands permanent plots (infrastructure) have been set up for the science community to use. The researchers who established the project do not recommend any general or specific approach for analysing data collected from the plots. This is understandable as the project has not been developed with any explicit research questions in mind.

Discussion

The AusPlots Rangelands project undertakes inventory-style vegetation and soil survey in parts of the rangelands where previous work has either taken place infrequently, or been undertaken with a pastoral monitoring focus on smaller-sized plots. The geographical stratification used in the program—the identification of 21 strata (Bioregional Groups) in the rangelands derived from the existing IBRA bioregions—ensures that, to some extent, plots are distributed across a broad area and, as a result, examples of a variety of vegetation communities and land types have been included in the work.

The desire to establish field plots across multiple States has presented challenges for the researchers in at least two ways. First, with the need or desire for the different States to welcome and adopt the AusPlots Rangelands project, a substantial amount of energy has been invested by the researchers in liaising, collaborating and cooperating with State agencies over resourcing, the timing of surveys, and the location of the plots. Second, cross-State implementation of the AusPlots Rangelands project by necessity involves large distances being covered by field crews to survey bioregions within the 21-group geographical stratification. With limited time and other resources, this presents logistical and study design challenges for the researchers and their field teams.

While it is understood that vegetation structure information, herbarium specimens, genetic samples and a variety of soil measurements are potentially useful in furthering the biogeographical understanding of parts of the rangelands, it is unclear how specifically the data could and will be used by scientists to investigate patterns or relationships of interest. In the absence of specific scientific questions that the researchers are examining, it is difficult to think about how useful the study design is likely to be in pursuing the project objectives. However, some aspects of the design of the project do influence the confidence that scientists should have when using the AusPlots Rangelands infrastructure to draw conclusions about the rangelands environment.

AusPlots Rangelands uses a bioregional stratification to spread the plots geographically across the landscape. The division of the Rangelands into 21 Bioregional Groups and the subsequent selection of a 'survey bioregion' within each of these 21 groups ensures this geographical spread. Conventionally in scientific studies, variables used for stratification of a study area are those that are available for all parts of the target population and are used pre-survey to divide the population up into different groups or strata. Commonly, samples are then drawn from the strata using a type of sampling method. For the AusPlots Rangelands project it is understood stratification variables that were available in this sense are restricted to IBRA and land system classifications (White et al. 2012). However, while it is clear that Bioregional Groups (with IBRA boundries), were mapped and selected from, it is not clear whether land system was used in this pre-survey, desktop-sense or was alternatively pursued and identified in the field. Understandably, the demarcation between least modified areas versus intermediately disturbed areas was made in the field.

Working across State boundaries or different land use divisions, even within the one State, means that land is not used, described or managed in a consistent manner. For example, different schemes may be used for land degradation and vegetation classification, and weed and pest animal regulations and management may differ. While cooperation and collaboration with State agencies is clearly valuable, cross-State inconsistencies or dissimilarities makes implementing a formal survey sampling design difficult.

Commencing from the identification or demarcation of the rangelands themselves, which may be considered more or less well-defined by agricultural landuse and/or rainfall patterns, a series of constraints are imposed by the survey design of the AusPlots Rangelands program. These constraints are listed and discussed in White et al. 2012 and include factors like a preference for long term access, state agency priorities, the presence of previously collected data and logistical considerations.

These constraints narrow the rangelands down to a subset of the biome which satisfy a range of logistical, historic, political and environmental criteria. In this sense, the survey population or target region of interest, is reduced from the broader rangelands environment as a whole, to smaller possibly disjunct areas that collectively satisfy joint criteria (e.g. logistical issues like reasonable access that is likely to continue into the future). Implementing these constraints make working in remote locations, covering large distances, and the necessity of establishing plots across multiple State boundaries more achievable. These pragmatic decisions, do however, have consequences for what the broader population is to which results from subsequent survey samples can be generalised to.

For the AusPlots Rangelands project, the process of deciding which patch of ground to establish a survey plot on has elements of quota sampling. A decision is made by survey staff working in a district or region that a certain number of least modified sites (or intermediately disturbed sites), are required and these are then selected in the field while also considering joint representation of vegetation type and land system. Other factors like fire history and/or weed or pest animal management may also play a role in deciding in the field what combination of qualities are desirable to survey in that district. Quota sampling is a form of constrained convenience sampling where targeting of the desired qualities in the sample (e.g. least modified on a particular land system), restricts the convenience aspect to the sampling. Nonetheless, the consequence of applying a targeted, quota-type sampling approach, is that while sites with desired attributes are included in the sample, the subjective selection process means that bias may have inadvertently been introduced when choosing the survey sites. In common with many ecological studies, AusPlots Rangelands survey sites are not chosen using a probability-based sampling method (for example, like stratified random sampling). Using some element of randomisation to select sites is very useful because it removes the site selection bias that may inadvertently occur when subjectively deciding where to locate survey sites. The use of probability-based sampling provides the scientist with confidence in drawing conclusions from the plots surveyed to a broader area of interest.

The AusPlots Rangelands researchers acknowledge the variety of factors that have needed to be considered when deciding where plots should be placed. These factors include the presence or weight of scientific, environmental, and historic information, and logistical and political considerations. A mix of personal judgement and convenience sampling has been used in the AusPlots Rangelands project within the level of the 21-group strata, and consequently, the final site selection process lacks repeatability.

Summary

AusPlots Rangelands undertake vegetation and soil survey work in selected parts of the rangelands. The project has primarily focused on establishing plots in least modified areas to address an existing imbalance focused on pastoral monitoring in the rangelands. It is expected that the project will be most useful as a resource inventory study. There is publicly available documentation which describes the field protocols so that people can understand how data are being collected. It is understood that establishing the necessary relationships with state and regional agencies to implement the project across state borders has been a substantial task. However, the practicalities of needing to liaise and collaborate with a variety of land management agencies, the desire to ease logistical challenges in the field, and subjective methods of site selection has contributed to a targeted but informal method of plot selection within bioregions nominated for survey. Statistically, this informal approach lacks repeatability, introducing the potential for unknown bias in the selection of plot locations.

As a result, the dependability of drawing conclusions from the surveyed plots to the broader community or region is reduced. Randomisation within relevant ecological design variables (such as grazing practice, weed and pest animal occurrence, or fire regime characteristics), is lacking, introducing the potential for confounding in subsequent analyses of the data. For example, if scientists wish to use the infrastructure to report on relationships between what's measured at the plots (vegetation characteristics), and one or more of the above attributes, they cannot do this with confidence.

References

White, A., Sparrow, B., Leitch, E., Foulkes, J., Caddy-Retalic, S. (2012) Ausplots-Rangelands Survey Protocols Manual, Version 1.2.3.

Long Term Ecological Research Network

The 12 research projects described here are more thoroughly explained in the facility's Conceptual Design document[2]. Please refer to this report for further information, especially in relation to methodologies employed within these projects. Here succinct overviews are provided.

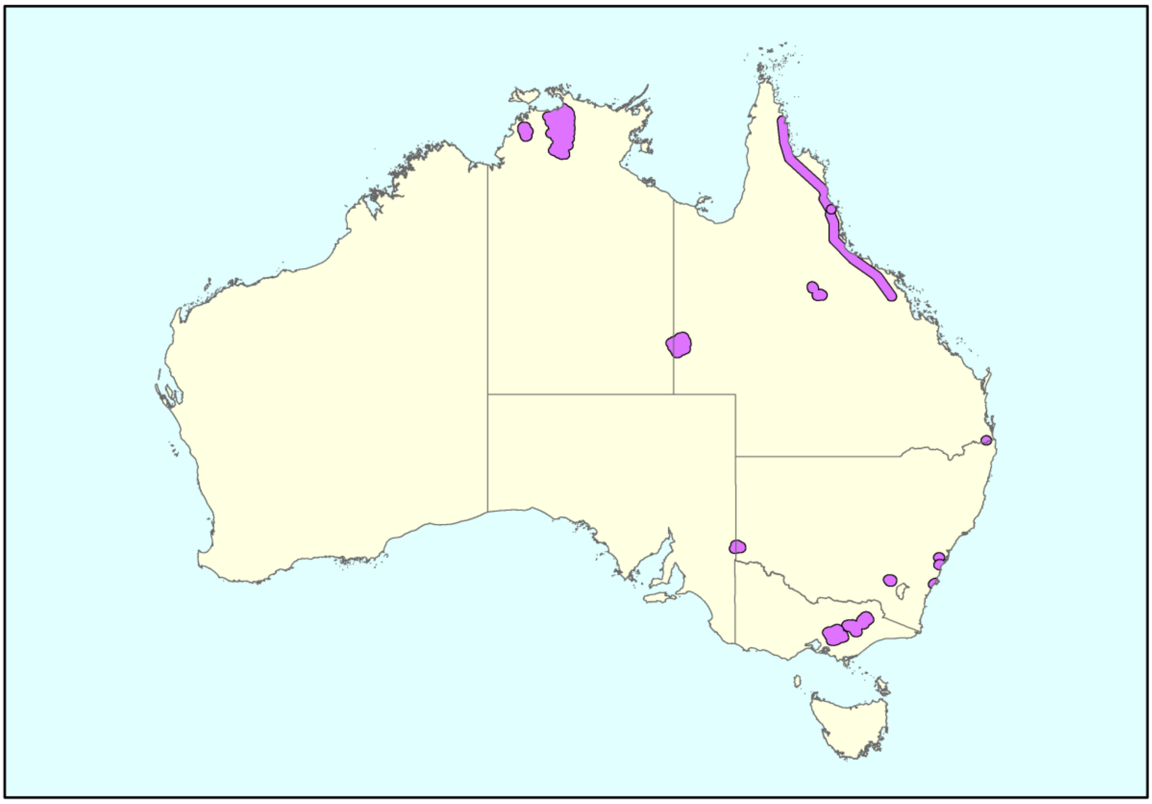

Figure 5: Spatial distribution of plot networks within the LTERN within TERN.
(Shading shows indicative locations of study areas.)

[2] Citation: Burns, E., Nolan, K. Tennant, P. *et al* (2013). Conceptual Design. A report on the design principles and field methodologies of the Long Term Ecological Research Network. This report was submitted to The University of Adelaide as contract material in December 2013.

Connell Rainforest Plot Network

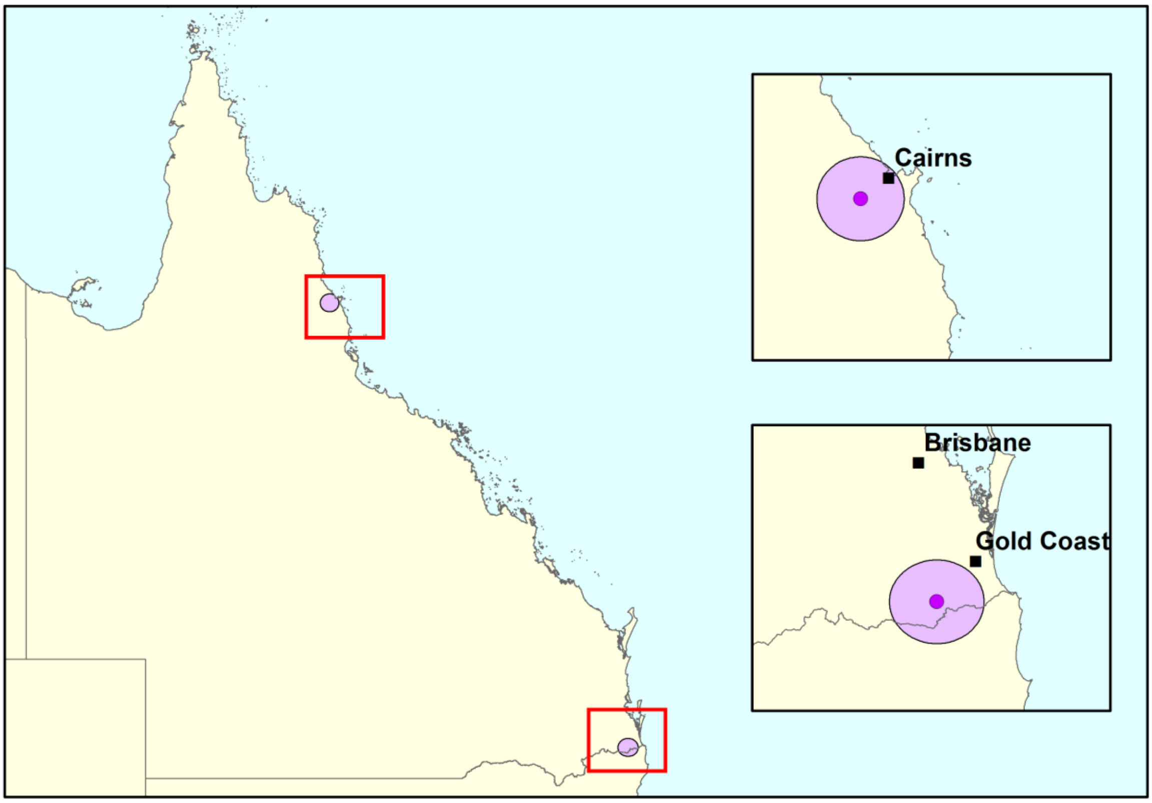

Figure 6: Connell Rainforest plots within LTERN
(Lighter shading in inset boxes serves to highlight the location of the plots and does not indicate an effective study area boundary.)

Background to the project

The two Connell rainforest plots were established in 1963 by North American ecologist Joseph Connell. The Davies Creek plot is located in tropical rainforest near Mareeba in Far North Queensland and the O'Reilly's plot is located in subtropical rainforest in Lamington National Park in south east Queensland. Joseph Connell's primary professional interest in being in Australia in the early 1960's was to work on coral reefs but he established the two rainforest plots to examine the demographic processes of births, deaths and growth in a high diversity terrestrial system. At the time the Connell plots were established, most other work undertaken in rainforest had a focus on timber production. Therefore field researchers typically made measurements in production-focused small-sized plots only on larger trees. In this respect, the Connell plots were not typical of the time: they used a larger plot size to record seedlings, and measurements were taken from small, medium and large trees. While numerous repeat measurements have been taken from both Connell plots, there was limited opportunity for Joseph Connell to direct specific, allocated funding toward re-measuring the two plots until the early 1990's.

Joseph Connell liaised with, and took advice from, two Australian rainforest ecologists in establishing the plots. The Davies Creek plot was overlain on an existing 0.4ha unharvested silvicultural control plot that was part of a larger set of Queensland Department of Forestry plots set up in the early 1950's. It was considered that co-location of the new plot with the existing plot could be beneficial in interpreting data from the new plot. While there were many Queensland Forestry plots subject to various silvicultural treatments, there were relatively few control plots for Joseph Connell to choose from which were not subject to (silvicultural) disturbance.

Objectives

The Connell plots were established to improve understanding of the mechanisms that maintain plant species diversity in complex, species-rich tropical and subtropical rainforests. This understanding is pursued through the collection of recruitment, growth and mortality (demographic) data on rainforest trees in unlogged forest.

Research Questions

1. How do long term demographic patterns (recruitment, growth and mortality) vary across life stages (seedlings and small, medium and large trees), within and between species?
2. Is this variation in demographic patterns correlated with plant functional traits?
3. Can interspecific variation in key demographic processes explain the maintenance of species diversity in these forests?
4. Can compensatory density and frequency-dependent recruitment, growth and mortality explain the maintenance of rare species in species-rich forests?

Study Design

One of the Connell plots is located in Davies Creek National Park (NP), and 1.68ha in size at approximately 850m elevation. The second Connell plot, located near O'Reilly's Guest House in Lamington NP, is 1.94ha in size at approximately 900m elevation.

The Davies Creek plot includes three rainforest types: complex mesophyll and notophyll vine forests in the gully and lower slopes to simple notophyll vine forests on the upper slope and ridge. The Lamington NP plot is described as complex notophyll vineforest on basalt and is an example of warm wet seasonal subtropical forest. Effects of human disturbance are considered by researchers as minimal with neither plot having been subject to industrial logging practices.

The location of the two plots were likely to have been chosen through a combination of convenience for access and botanical judgement on their suitability of being a typical example of tropical and subtropical rainforest.

Measurement protocols

Plots are irregular polygons and are formed at each of the two study locations from aggregated, contiguous, nested belt transects. The Davies Creek and O'Reilly's plots are composed of eight and nine transects, respectively. There are two elongated (along contour) 'sub-plots' at the O'Reilly's location separated by approximately 600m, but researchers have always treated the pair as one plot. The motivation behind the disaggregated plot is unclear. It may simply be the case that the desired-sized plot (>1ha), could not originally be established at the initial location due to proximity of artificially disturbed areas (access tracks). Therefore, a second nearby location was chosen to supplement the first. The alignment of the belt transects at Davies Creek has resulted in the plot being approximately square in shape. Measurement units most closely aligned with the imperial system continue to be used at the plots to map and measure trees (feet, tenths of feet, inches, tenths of inches).

The measurement of large (girth at breast height (gbh) ≥12.5 inches), medium (12.4 inches ≤gbh≥3.2 inches), and small (seedlings and stems; gbh ≤3.1 inches) trees is undertaken across three nested zones within a plot: Large trees are measured across the whole plot (across contiguous belt transects); medium trees are measured within 20 foot-wide belt transects centred on survey lines a chain (approx. 20.1m) apart; and small trees and seedlings are measured within 6-12 foot-wide strips centred within the belt transects. Large trees rooted outside the plot boundaries, but whose canopies extended over the plots, also have been monitored.

The locations of trees are mapped using a local coordinate system measured in feet and tenths of feet. The origin of the coordinate system is distance along a plot-specific survey line (x-coordinate) and perpendicular distance `above' (+) or `below' (-) the survey line to the tree location (y-coordinate). There is more than one survey line used in each plot and steel stakes have been established every 7.5 metres along the lines.

Field measurements are converted to SI Units for analyses and publication. Measurements are taken from the Connell plots every 1-6 years. Trees have been measured on varying schedules since the project began in 1963. Growth (girth in inches and height in feet) is recorded less frequently than mortality and recruitment. Medium and large trees have their girth (stem perimeter) at breast height (1.3m) measured in inches with a tape measure and small trees have their height measured in feet using a clinometer and measuring tape. Voucher specimens have been collected on an ad hoc basis over the duration of the study. Natural disturbance has been monitored at both Davies Creek and Lamington. The boundaries of gaps created by the death of large canopy trees have been recorded on hand-drawn maps over the duration of the study. These maps have not been digitized. A range of plant traits are being determined and recorded from the sites.

Analysis

Researchers calculate a suite of species diversity measures within each size-class. Regression analysis has been used to explore the relationships between rates of recruitment, growth and mortality, and tree species abundance using both number of individuals and basal area across the plots.

Discussion

The plots are different sizes and have different layouts. Appropriately, there has been no attempt to combine data from the two different plots and analysis is conducted from each location conditional on the respective methodology (plot configuration). Comparisons have then been drawn between results obtained from the plot in tropical rainforest (Davies Creek) against those obtained in subtropical rainforest (O'Reilly's). Logistically, for the counting and mapping of individuals, the elongated nature of the nested transects is regarded by the researchers as more efficient to work from than (equal-sided) quadrats. Recruitment rates are used for comparative purposes with other species rather than an absolute measure due to seedlings being systematically recorded on only a portion of the plots (internal narrow belt transects). A range of procedures are adopted to minimise measurement error: the staking of reference lines on the transects, the height specification of `girth at breast height' measurements when tree trunks are deformed (buttressed) and not undertaking height measurements on medium and tall trees due to the difficulty of measuring them accurately in the forest in a reasonable time.

The plots were established about 50 years ago to examine rainforest dynamics. At the time of their establishment, the decision to work on relatively large plot sizes and record measurements across a range of size classes (seedlings, saplings, medium and large trees) was considered innovative. The strength of the project is the duration of time over which it has systematically collected data on different size plants in plots up to about 2ha in area. Results are obtained from one plot in tropical rainforest and one plot in subtropical rainforest. It is interesting to consider how the results from these two sites differ and how characteristic they may be of each rainforest type. However, without replication within each region or vegetation type, caution should be used in interpreting the results as being typical or being seen as an `average response' from each rainforest community. Due to the informal way the location of the plots were likely to have been originally selected, caution should be used in generalising the results beyond the surveyed study sites to the respective districts or regions. It is uncertain how closely results from the plots correspond to broader demographic patterns in these forests. The researchers acknowledge the limitations of working with a single plot in each broad type of rainforest community, but believe that results from each plot are broadly applicable to the respective rainforest at the same elevation, on a similar type of soil.

Summary

The Connell rainforest plot network focuses substantial resources on two Queensland rainforest plots. The comparatively long duration over which measurements have been recorded from plants of different size classes provides an uncommon opportunity to explore the relationships between establishment, growth and mortality within and among different rainforest species. The use of only two plots and the subjective manner in which the study locations were originally chosen mean it is uncertain how typical the results are of the respective rainforest vegetation communities.

Tropical Rainforest Plot Network

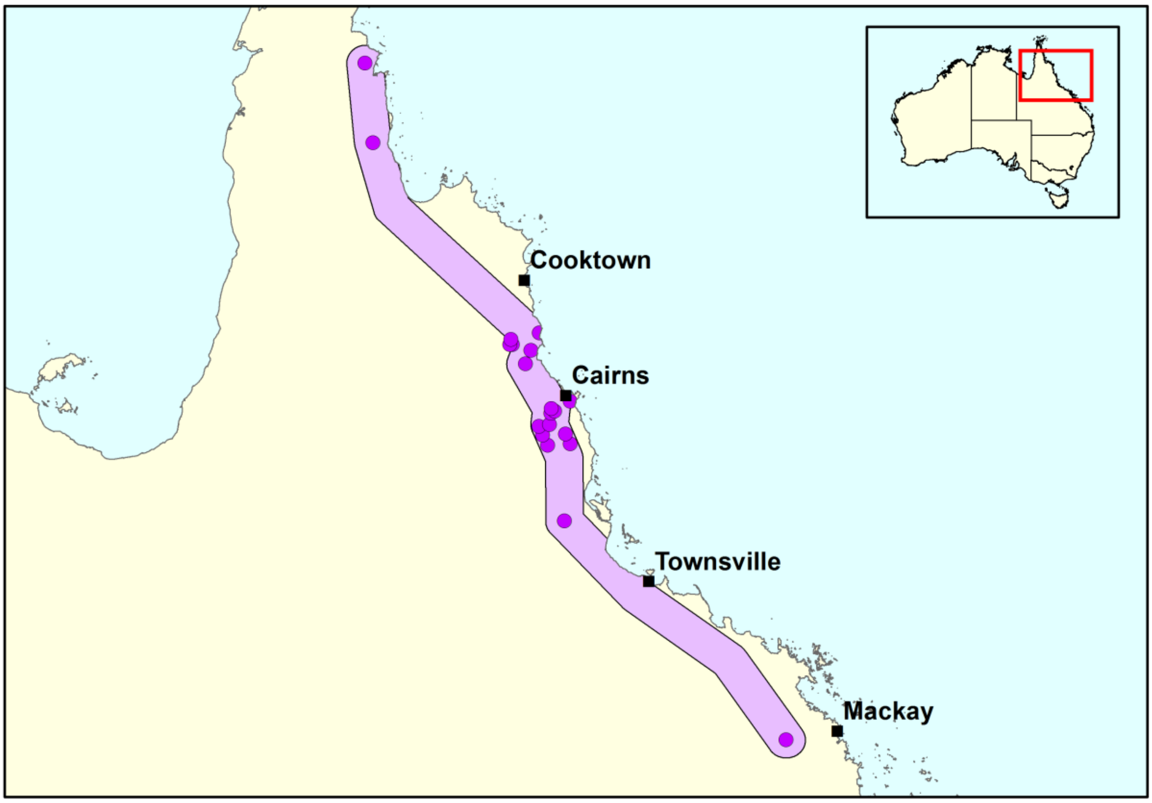

Figure 7: Tropical Rainforest plots within LTERN
(The lighter shading seeks to highlight the distribution of plots and does not indicate an effective study area.)

Background to the project

The field plots that comprise the Tropical Rainforest Plot Network were established between 1971 and 1980 to monitor the growth, mortality and recruitment of commercially important cabinet timber species. The plots were established to function as control-type plots to supplement silvicultural plots that were being used to investigate the effects of different thinning and ground cover disturbance regimes on the productivity of cabinet timber species. With the listing of the Wet Tropics of Queensland as World Heritage areas in 1988 and the subsequent cessation of commercial logging, monitoring of the silvicultural plots was discontinued. The control plots have been maintained by researchers to enhance their understanding of rainforest community dynamics under natural disturbance systems. There are 20, 0.5ha plots in the project that are located from near Mackay in the south to Iron Range National Park in the north, which is located about 100km east of Weipa on Cape York.

Objectives

The objective of the Tropical Rainforest Plot Network is to study plant growth rates, species turn-over, and the patterns of mortality and recruitment to help understand the impacts of, and recovery from, cyclones, disease and invasive weeds.

Research Questions

The research questions that the scientists are examining are:

1. How do forests recover from landscape-scale disturbance events such as cyclone and disease outbreaks?
2. What can we infer about the impacts of climate change on tree growth from studying altitudinal and latitudinal variation, and how does the composition of the canopy layer change with time--does the proportion of rare and common species remain stable over time?

Study Design

The locations of the 20 plots were chosen subjectively to complement existing silvicultural treatment plots. A key factor influencing their placement was locating the plots in stands that supported moderate to high densities of commercially important timber species. No formal stratification was used to select the survey sites and "the general position for each plot was determined by the vehicular access available at the time, by the progress of logging activities, and in consultation with staff of the Queensland Department of Forestry" (Graham 2006, p6). The 0.5ha plots were established with a 20m-wide buffer on all sides to protect the core plot from disturbance and within a site were subjectively positioned in order to be structurally and floristically similar to the surrounding mature forest.

The plots were established in old growth forest with minor disturbance from selective logging occurring on two of the plots. A minimum of four of the earliest established plots were targeted toward stands containing *Flindersia* spp. to improve ecological understanding of that group of species. The 20 plots cover a latitudinal range of approximately 1000km with mean annual rainfall ranging from 1400mm to >3000mm. Four of the plots are less than 200m in elevation, four between 200-700m, and 12 plots are above 700m elevation. It is understood that most of the sites are on soils of moderate or low-moderate soil fertility. When the study was initiated, unlogged forest on soils of high fertility was very uncommon. It is understood that two of the plots are located on soils of high or moderately high fertility. When establishing the plots, it is understood that areas affected by recent storm damage were avoided. Half of the plots were established between 1971 and 1975, with the remaining plots established between 1976 and 1980.

Measurement protocols

The 0.5ha plots in the Tropical Rainforest Plot Network measure 100m by 50m in dimension. The boundaries of all plots were surveyed with a compass and distance measurements were corrected for slope. The corners of each plot are marked with pegs. Each plot is divided into 16 sub-plots of 25m by 12.5m for logistical convenience of recording measurements in the field. A range of measurements has been completed at each plot. A vascular plant species list was compiled for each plot. At the time of establishment, diameter at breast height (dbh) lines were painted on all trees at 1.3m in height for all trees ≥10cm dbh and diameter measurements were taken on these stems. The position of all trees ≥10cm dbh were located on the plot with a local coordinate system with a consistent origin at one corner of the plot and were numbered using an alphanumeric code that corresponded to the number of stems within respective 25m by 12.5m subplots. On some plots, *Flindersia* spp. ≥10cm were mapped and measured due to the interest in those species. Following plot establishment, diameters were measured every two years until 1991, after which re-measurements occurred less frequently, typically every 3-4 years. Since commencement of the study, all individuals entering the ≥10cm dbh size class were identified, mapped and measured for both diameter and height.

At the time of plot establishment, in addition to the diameter of all trees ≥10cm dbh being measured, it is understood that visual estimates of the height of those trees were made by comparison with the calculated heights of a selection of trees on the plot. Calculated heights were made on a selection of trees using measuring tape and clinometer. Height estimates on the plots of trees ≥10cm dbh were made a second time in 1998 using either a clinometer or laser rangefinder.

An initial soil survey was undertaken on 19 of the plots and forest structural profiles were drawn to describe the forest structure. Throughout the project, notes have been made, and mapped where useful, on the extent and type of disturbances occurring on the plots (including disease). More detail on plot establishment can be found in Graham (2006).

Analysis

A range of analyses approaches has been used to explore the forest dynamics of the plots including tabulation, graphics and *t*-tests.

Discussion

Documentation of the site selection process for the Tropical Rainforest Plot Network describes it as being opportunistic with no formal stratification being used (Graham 2006). It is understood the location of the plots was targeted with regard to some criteria, and overall, there was a considerable degree of subjectiveness with regard to plot placement. Criterion informally used to establish the plots included: a necessity to have the plots placed in stands that supported reasonable densities of fine furniture timber tree species (as the plots were to function as controls for silvicultural trials on these species); a preference for areas that were least disturbed with respect to logging history and recent storm damage; and a desire to have reliable vehicular access to the plots. One forestry scientist from the then, Commonwealth Forest and Timber Bureau, was heavily involved in the site selection of all plots and worked closely with Queensland Department of Forestry staff in establishing the plots. With regard to the site selection criteria of reasonable densities of desirable timber species, it is understood that a lot of the species are very common in the forests so there was little need for researchers at the time to actively seek out restricted or uncommon stands of forest in which to select survey sites. In this respect, the researchers currently working on the study believe the plots characterise or typify broad areas of tropical rainforest. Researchers see the low representation of plots in areas of high soil fertility as a limitation of the dataset. While the constraint on soil fertility certainly restricts the breadth of any conclusions that may be drawn from the data, the representation of plots solely in forests of moderate or low-moderate soil fertility was unavoidable due to the lack of availability of unlogged, highly fertile sites.

The researchers feel confident that the 20 plots are broadly characteristic of tropical rainforest across the region (on soils of moderate or low-moderate soil fertility). However, the lack of randomisation in the site selection process means inadvertent bias may have been introduced when deciding where to locate the plots. This potential for bias, with regard to unknown factors that may influence the response of interest, means the statistical basis for generalising the results beyond the plots to the broader district or region of interest is not secure. The fact that the plots have a reasonable breadth across several known variables—elevation, latitude, mean annual rainfall—does not provide, in itself, a firm foundation for generalising conclusions drawn from the data. If plot placement was undertaken or directed in a non-randomised, but transparent, reproducible manner, there may be the potential for adjustments to be made at an analytical stage to help reduce the bias that may have been introduced during the site selection process. Here, there were a number of factors that contributed to the subjective decision on where the plots were placed and an analytical adjustment is unlikely to be effective. Consequently, use of the plot data to represent Australian rainforests (or a broad class within them), should be made with caution.

Previous researchers on the project (pre-TERN), have compiled a compendium about the plots including the biophysical attributes, information about establishment and measurement, and descriptions of known disturbance at the individual sites, including recording the presence of disease (*Phytophthora cinnamomi*, root rot fungus) (Graham 2006). This information has been used to examine the response of the vegetation on individual plots following disturbance from cyclones or mortality of individuals from disease. Information on plot establishment and measurement protocols has recently been comprehensively documented by Bradford *et al.* (2014). The data and site descriptions that have been recorded since the plots were first established, provide a resource to examine how examples of tropical rainforest may recover from disturbance events such as cyclones and disease outbreaks. While cyclone damage has been recorded across several plots, there is limited ability to determine the variability in disease recovery as it is understood only two of the 20 plots have had some tree patch death confirmed or attributed as due to *Phytophthora*. The point should also be made that as it is unknown what bias may have been introduced when originally selecting the plots, it is unclear how typical or characteristic the recovery response from individual plots is likely to be of the broader rainforest community

Summary

The Tropical Rainforest Plot Network provides data on growth, mortality and recruitment from examples of tropical rainforest going back to more than 40 years ago. The quality of the site measurement protocols and associated field descriptions within the plots provides a valuable resource for learning about examples of tropical rainforests. However, the lack of probability-based sampling for the initial site selection means the dependability of applying study conclusions across the broader region or tropical rainforest community is reduced.

References

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Victorian Tall Eucalypt Forest Plot Network

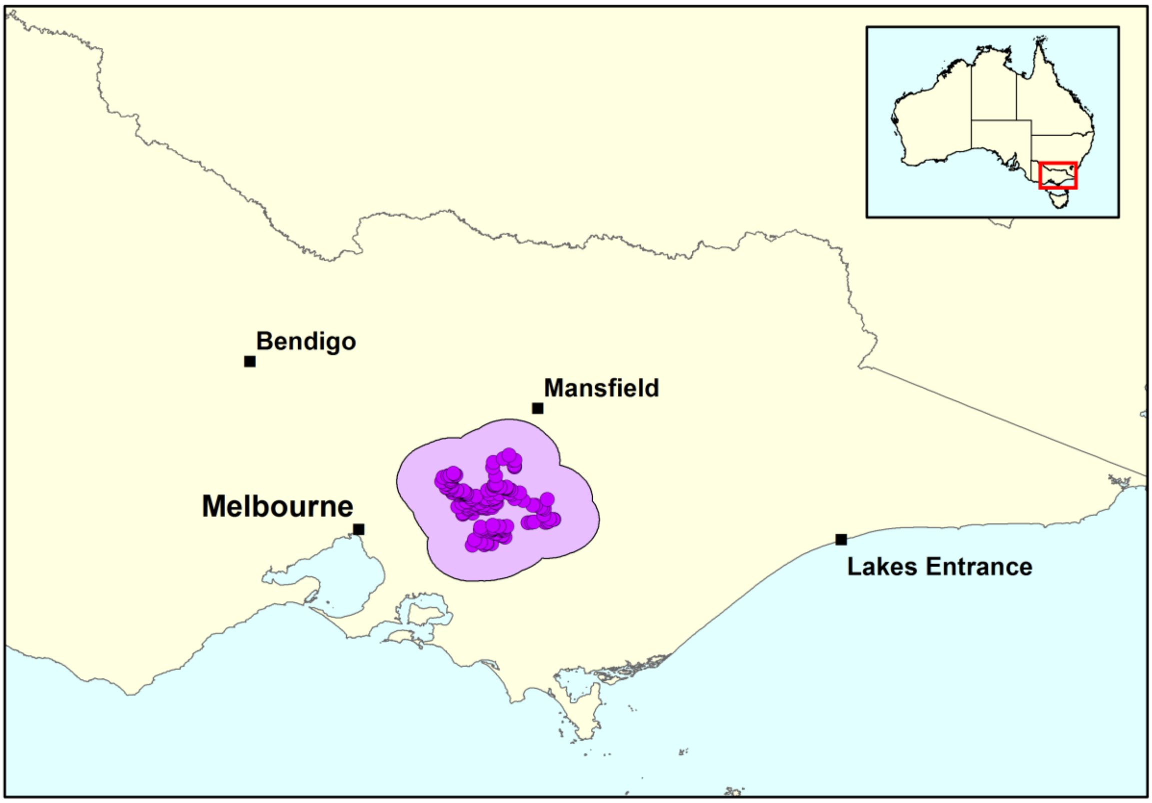

Figure 8: Victorian Tall Eucalypt Forest plots within LTERN.
The lighter shading seeks to highlight the distribution of plots and does not indicate an effective study area.

Background to the project

The Victorian Tall Eucalypt forest plot network extends over approximately 60km by 80km in the montane ash-type forests of the Central Highlands which lie approximately 120km north east of Melbourne. The work originated in 1983 to help understand the habitat requirements and effects of timber harvesting on Leadbeater's possum (*Gymnobelideus leadbeateri*). The breadth of the original work has expanded to include other fauna including their occurrence in response to the `Black Saturday' fires in 2009. Current work is focused on fire dynamics and the effects of fire and logging on vegetation, arboreal marsupials and birds.

Objectives

The broad objective of the program is to quantify the inter-relationships between human disturbance and natural disturbance, and changes in vegetation condition and biodiversity response.

Research Questions

The research questions that the scientists are examining are:

1. What are the relationships between vegetation condition and biodiversity?
2. Are relationships between vegetation condition and biodiversity consistent between vegetation types?

3. Is the reference concept (e.g. old growth forest) an appropriate benchmark for measured vegetation attributes in the context of biodiversity assessment?
4. How does natural disturbance and/or management intervention alter vegetation condition, and in turn, the response of biodiversity?
5. What is the relationship between vegetation condition and biomass carbon stocks?
6. What are the relationships between measures of biomass carbon stocks and various elements of old growth forests?

Study Design

In 1983-84, 32 3ha survey sites were established across eight geographic regions spanning the then known range of Leadbeater's possum. Collectively, sites were chosen to capture a range of both stand-age, and degree of *Eucalyptus* and *Acacia* spp. dominance. An effort was made to ensure that each 3ha site was structurally and floristically homogeneous, and located within 2km of a previous Leadbeater's possum record. In 1987-88, an additional 120 3ha sites were added across the original study area using stand-age and vegetation type to establish a stratified random survey. Vegetation type as a design variable refers to the dominant canopy species being either mountain ash (*Eucalyptus regnans*), alpine ash (*E. delegatensis*) or shining gum (*E. nitens*). The focus of the work up until this point had been on modelling the habitat requirements of Leadbeater's possum.

During 1997-1998, modifications were made to the study to include the ability to monitor the numbers of Leadbeater's possum across an expanded set of survey sites. A total of 161 sites had a 1ha plot established on them, where 140 sites were used from the existing 152 sites, with 21 additional 1ha sites set up to increase the representation of old growth and young regrowth forest stands. Of these 161 1ha plots, approximately half were available for timber harvesting operations and half located in excluded water catchment areas and National Park. Reflecting the stratified design developed in 1987, there were several forest age cohorts with a minimum of eight sites in each cohort with the stands of many sites having regrown from the extensive 1939 wildfires.

From 1997, a scheme for selecting a set of rotating, overlapping survey sites was trialed to estimate total numbers of selected arboreal mammal species across the population of 161 survey sites. In the rotating sample design, a subset of sites was surveyed each year with a site's inclusion being proportional to abundance of the previous survey count and potentially, covariates including vegetation type and number of hollow bearing trees. The motivation for the overlapping, partial survey approach was achieving useful estimates of species abundance across a population of sites at a reduced survey cost, while incurring a manageable loss in precision of the estimates. It is difficult for researchers to survey the full set of 161 sites in the same annual field-work season due to the very high level of resources that are needed. Following a full census of the 161 sites in 2009, an overlapping subset of 40-50 sites that are stratified on stand-age are presently selected for survey each year where approximately half are burned and half remain unburned from the 2009 wildfire (see below).

The 161 1ha plots remain the core set of field sites at which a variety of annual work is undertaken. In February 2009, `Black Saturday' wildfires burned parts of the study region. Researchers subsequently scored fire severity across the sites with more than half remaining unburnt, 30% experiencing a moderate fire, and approximately 15% being severely burnt.

Bird surveys have been completed at a subset of 87 survey sites in 2004, 2005, 2007 and then annually post-fire in the years 2009-13. The bird survey sites were chosen to cover a range of stand-ages, slopes and topographical aspects. Sites selected in 2004 for the bird surveys now reflect differences in burn severity from the subsequent 2009 wildfire. Carbon work has been done between 2010 and 2014 at a constrained set of 54 mountain ash sites stratified by three stand-age and three fire severity classes.

Measurement protocols

For the original work that commenced on arboreal marsupials, all hollow-bearing trees on the 200m by 150m 3ha site were mapped and given an ordinal 9-point score that reflected tree form or decay. Stagwatching at each hollow-bearing tree on a site was used to record arboreal marsupials as they left their nest in the evenings. From 1997, the 1ha-sized plots have been used for stagwatching. Each site is surveyed from dusk for approximately one hour using one volunteer/watcher per tree on a site. Volunteers participating in the survey are instructed by researchers on protocol prior to the surveys and stagwatching does not occur in heavy rain.

Vegetation floristics and structural data are collected within three 10m by 10m plots that are spaced 30m apart along the central 100m transect. All stems >2m tall within these plots are identified and allocated to an ordinal diameter class and an ordinal height class. Plant species are counted along a central 10m-wide belt transect, in addition to the three 10m by 10m plots. The frequency of seedlings in each of five height classes is scored in 1m by 1m plots placed in the middle of each of the 10m by 10m plots. Vegetation surveys were done less regularly before the February 2009 wildfire and either a full or partial survey (primarily burnt sites) has been done each year since 2009.

Bird surveys are undertaken in November/December using five minute point-interval counts conducted at each of the 0m, 50m and 100m positions along the central 100m long transect of the 1ha site. The surveys are conducted each year in November/December. The sites are surveyed by two different observers on two separate mornings with surveys commencing from dawn and being undertaken until mid-morning (depending on temperature). Counts of all the birds seen and heard during the five minute period and their estimated distance away are recorded.

A variety of standardised measurements are taken for the carbon work across the 1ha site including characteristics of coarse woody debris across two diameter size classes; height and girth and dead/alive status recorded for different size trees; bark thickness and litter depth and cover; and attributes of hollow-bearing trees.

Analysis

A variety of statistical modelling approaches are used to analyse (the longitudinal) data where the response may be non-Gaussian, geographically clustered and/or have a moderate-high frequency of zero counts.

Discussion

The selection of survey sites has used blocking to geographically distribute sites across an area of interest to forest managers, and the stratified random design uses variables that are of direct relevance to the relationships the researchers are interested in examining. The inclusion of probability-based sampling provides the researchers with a secure basis for drawing conclusions of ecological association beyond their study sites to other areas within the Central Highlands that share properties corresponding to the stratification levels that they have used. The researchers use the term *vegetation condition* to represent a number of floristic or structural properties depending on the focus of their work: the height of the canopy, the decay class of hollow-bearing trees or other elements influenced by timber harvesting and/or wildfire. In this regard, stand-age reflects disturbance history, and its use as a stratifying variable in the study provides the mechanism for examining the relationships between vegetation condition and arboreal mammals, birds or biomass carbon.

Stagwatching was adopted for surveying arboreal mammals as it was considered by the researchers to be the most reliable method in montane ash forests due to the dense vegetation commonly found in the ground layer and mid-storey layers. Stagwatching is labour-intensive requiring as many field staff or volunteers as there are hollow-bearing trees on a site. Notwithstanding support from dedicated groups of volunteers, the reliance of the survey technique on managing comparatively large groups of people can pose logistical challenges in completing scheduled field work. The current method of selecting an annual subset of stagwatching sites uses stand-age and 2009 wildfire occurrence to obtain a mix of sites with different attributes. Stratifying the survey sites in this manner permits continued examination of fauna (and elements of their habitat), against measures of natural and human disturbance. Should the focus of the work return to estimating population numbers of selected arboreal mammal species across the 161 sites, a statistically designed partial survey schedule that was first used from 1997 could be re-introduced. With the survey area for arboreal marsupials changing from a 3ha to a 1ha site from the 1997-1998 survey year, caution should be used when combining data before and after this time. It is understood that the field definition of a hollow-bearing tree also changed at this time.

A range of floristic and structural elements is measured on the 10m by 10m vegetation plots. Some thought should be given to how useful these measurements are in meeting project objectives and discontinuing those that aren't being used. The bird protocol allocates one of the two observers to survey all three point-interval count stations of a site on the one day. That is, one observer does all three counts one day, and the second observer does them all the next day. This method should be continued to avoid confounding observer effects with bird response from different stations. Resources are presently insufficient to re-measure biomass carbon at the sites. The researchers are interested in undertaking measurements of soil carbon in future and the stratified random survey design provides a sound basis on which to undertake the work.

Summary

The stratified random survey design of the Victorian Tall Eucalypt forest study provides an opportunity for the researchers to examine the relationships between aspects of biodiversity and various forms of disturbance across the Central Highlands, and have confidence that the associations they find apply beyond their study sites. Disturbance factors like logging or fire have not been at the discretion of researchers to allocate randomly across the study area, so cause-and-effect relationships cannot be clearly identified from this observational study. Modifications to the size of the field sites has occurred over the relatively long duration of the study. Working with changes to protocols like this does not necessarily present insurmountable difficulties, but thought is needed when drawing on data that spans the life of the project.

Victorian Alpine Plot Network

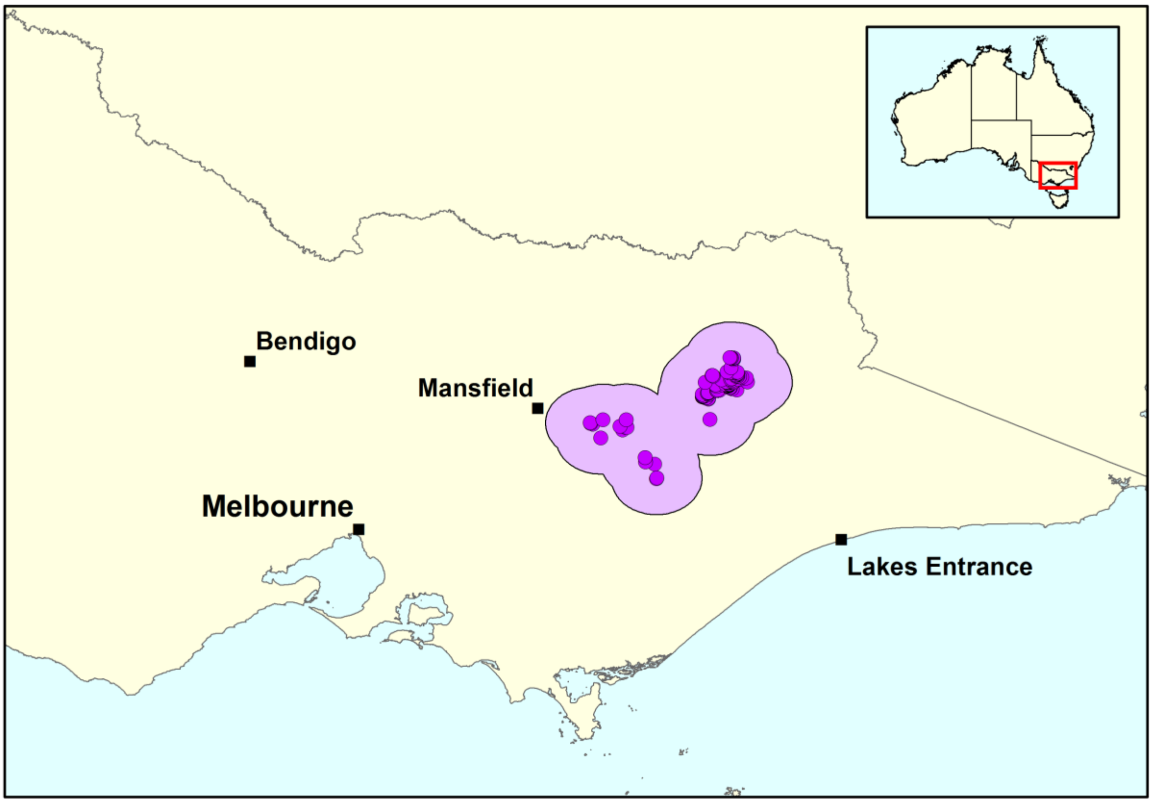

Figure 9: Victorian Alpine plots within LTERN
The lighter shading seeks to highlight the distribution of plots and does not indicate an effective study area.

Background to the project

The Victorian Alpine Plot Network is a group of six main sub-projects located in the high country of Victoria. There are: a) long-term, and b) post-fire vegetation monitoring sites, both of which document changes in plant community dynamics in relation to disturbance and land use; c) a set of sites associated with a long-term climate change experiment established using protocols of the International Climate Change Experiment (ITEX); d) recently established phenology transects that investigate plant responses across different taxa at a range of elevations; e) two studies that are examining changes in species diversity and the abundance of exotic, invasive plant species along roadsides across a range of elevations and on selected mountain summits; and f) a group of sites examining the distribution and populations dynamics of the Mountain pygmy possum *Burramys parvus*. The focus of this review is restricted to a) and b), the long-term and post-fire vegetation monitoring sites, and e) the alpine summit plots and the roadside transect study. The alpine summit plots study is being used to investigate mountain-top changes in species composition, and the roadside transect study is being used to investigate how roads may function as vectors for weed dispersal into the Victorian alps.

Objectives

The objectives of the Victorian Alpine Plot Network are to draw together a collection of on-ground studies to help examine the effects of human disturbance, fire, climate change, and invasive flora and fauna on biodiversity, soils and vegetation of the montane, sub-alpine and treeless alpine ecosystems.

Research Questions

The research questions that the scientists are examining with respect to projects a), b) and e) above, are:

1. What will the long-term changes be in the major vegetation types and faunal assemblages? And what will future changes likely be?
2. What are the likely long-term effects on the alpine biota of human disturbance, climate change, drought, fire and altered biotic interactions?
3. How is the invasion and expansion of non-native and native biota affecting treeless alpine ecosystems?
4. What effects do disturbances have on faunal and plant communities?

Study Design

(A)

The Victorian Alpine Plot Network's long-term vegetation monitoring plots are located on the Bogong High Plains and nearby Mt Bogong, and Holmes and Wellington Plains in the Gippsland alps. The earliest plots date back to several that were first surveyed in 1945 (Rocky Valley) and in 1947 (Pretty Valley). There are 83 long-term plots across the Bogong High Plains in grassland, snowpatch herbfield and wetland vegetation communities. Below is a summary of the establishment of these plots.

The Rocky Valley and Pretty Valley plots were set up to determine the effects on soils and vegetation of excluding free-ranging domestic cattle from the main plant communities of the Bogong High Plains: grasslands, heathlands, snowpatch herbfields and wetlands. Within an approximately 7ha area that had been fenced to exclude cattle, four plots (each approximately 500 square metres), were set up in each of open-heathland, closed-heathland, snowpatch herbfield and wetland vegetation. The 7ha area was selected due to it having typical or characteristic examples of the four vegetation communities. Four plots corresponding to each of the four vegetation types and having similar slopes and aspects as the fenced ungrazed plots, were established as grazed plots outside the fenced exclosure for comparison.

At the nearby Pretty Valley site, two grassland plots were established adjacent to each other, one fenced and the other unfenced. These two plots were established in an area of grassland that was chosen as being typical or characteristic of one of the most extensive grassland communities across the Bogong High Plains area. Within the grassland area, the plots were established adjacent to each other in an area of reasonably uniform vegetation, soil and slope. Each of the two adjacent plots measured about 30ft by 180ft (9.14m by 55m) and one plot was chosen at random to be fenced and have cattle grazing excluded. In 1979, it is understood an additional two grazed grassland sites were subjectively chosen to the south of the Pretty Valley plots near Cope Hut and Cope Creek. These two sites were originally selected to help in the monitoring of vegetation change in the Alpine National Park. Researchers have previously used these two sites to complement the one grazed grassland plot at Pretty Valley. From the late 1970's, additional monitoring sites have been established in four different vegetation communities on the Bogong High Plains, Holmes Plain and Wellington Plain. All sites were selected as being typical or representative of the respective vegetation community. That is, relative species abundance and structure were within a range that identifies each plant community. There are:

- 22 grassland sites, including those described above at Pretty Valley, Cope Hut and Cope Creek.
- 17 Heathland sites including the Rocky Valley plots and post-fire heathland sites on the Bogong High Plains and Wellington Plain.
- 34 snowpatch herbfield sites, with roughly half above the climatic treeline (alpine), with the other half below the climatic treeline (subalpine). The snowpatch sites are located in nine loose geographic clusters across the Bogong High Plains. At each chosen location, the actual area to be surveyed was determined by the areal extent of the snow cover that was retained well into the spring thaw.
- 10 wetland sites on the Bogong High Plains chosen with a focus on particular plant communities within each site. Three of the sites have been excluded from cattle grazing (since 1944, 1980 and 1991). Two sites are located above the treeline in the alpine zone, and eight are located in the sub-alpine zone.

(B)

Fires in January 2003 burnt approximately 400 000 ha within the Alpine National Park. Following the bushfires, 419 survey points were established along 17 transects to examine the pattern of burning across the Bogong High Plains in relation to previous grazing. Transects between 3-5km long, located along major ridges and valleys across the Bogong High Plains, were used to record various attributes at approximately 50, 200 or 500m intervals along the transects. With about half of the areas that were licensed for grazing having had most of their area burnt in the 2003 fires, the researchers used the widespread bushfire as an opportunity to examine the patterns of burning across both grazed and ungrazed areas of the Bogong High Plains. At the time of the 2003 fires, large areas in the south-west of the Plains had recently been grazed, whereas areas in the north-west had largely been ungrazed for 10 or more years. Nine transects were located in grazed regions and eight transects were located in ungrazed parts of the Bogong High Plains. The locations of the transects were chosen to obtain geographic coverage across the broad, fire-affected area and drew on the convenience of aligning the transects with existing tracks, snow-pole lines and walking trails.

In 2008, a subset of 80 heathland sites, stratified by presence of grazing was randomly chosen from the above 419 survey points to examine the heathland community more closely. The 80 sites were chosen from a pool of the original survey points where the extent of heathland at the survey point was at least 0.25ha and the survey point was at least 50m from wetland vegetation. Preliminary surveys were undertaken on foot to enumerate a pool of 150 heathland sites that met the above criteria. Forty open heathland and 40 closed heathland sites were randomly selected from the 150 available, stratified by previous grazing. A single 50m transect placed through the middle of the heathland patch used five, 2m by 3m quadrats to record measurements on vegetation composition. The researchers plan to resurvey the floristics of the 80 heathland sites at 10-year intervals.

In addition to the above surveys, earlier studies on post-fire regeneration have been undertaken following the 1998 'Caledonia Fires' when five sites across Holmes Plains and Wellington Plains were chosen as being typical or characteristic of extensive areas of Victorian subalpine high plains. A burnt (40ha) and an unburnt (2ha) grassland site were chosen at Homes Plains, and a burnt (2ha) grassland, burnt heathland (40ha) and unburnt grassland site at Wellington Plain. The number of transects used to record species composition at each site was proportional to the size of the area chosen as being a typical or characteristic example of that vegetation community.

(E)

Study 1

For the alpine summit project, five mountain summit survey sites were established in the Kosciuszko National Park in 2004, several in the Victorian Alpine National Park in 2006, and some additional Victorian sites more recently. In selecting the Victorian summits to be included in the study, the researchers chose all the ones they could get access to. It is unknown how the NSW summits were chosen because different researchers were involved. Currently, the alpine summit project comprises 14 summits, encompassing the geographic distribution of high alpine summits in the Australian Alps, with each summit to be surveyed every 5-years.

Study 2

For the roadside transect study, the aim is to determine how exotic (and native) species are distributed on mountain roadsides. The researchers also intend to contrast data from the roadside study with older archived vegetation data from across the region to investigate whether and to what extent roads help invasive plant species disperse and colonise new areas. Weed surveys have been undertaken informally along roadsides in the Alps for many years. The current project was established in 2012 to formalise the earlier investigations. Fixed-length permanent belt-transects have been placed systematically along the five roads which correspond to the major 2WD access roads into the Victorian high country. There are 20, 2m by 50m belt-transects that run parallel to the road in each of the five road sectors. Belt-transects are between 50-70m apart (being a fixed distance within each road sector). The five major roads and management tracks in the Victorian Alps that are part of the study are: 1) Mt Beauty to the Bogong High Plains; 2) Shannonvale to the Bogong High Plains; 3) Harrietville to Mt Hotham; 4) Dargo to the Dargo High Plains; and 5) Licola to The Howitt Plains.

Measurement protocols

(A)

For the long-term grassland monitoring sites established across the Bogong High Plains, vegetation data are collected using point-quadrats. Across the grassland sites, which range in area from approximately 0.5-1.0ha, a variable number of transects are used to survey each site, along which, records of species occurrence are taken at consistent intervals using point-quadrats with a 4mm pin diameter.

The Pretty Valley plots were surveyed annually from 1947 to 1951, then in 1954, 1957, 1958, and then every 3-13 years from 1966 to the present. The Rocky Valley plots were surveyed twice in the 1940's, 1950's and 1960's and then approximately once every decade after 1966. The other grassland sites on the Bogong High Plains have been surveyed at different temporal intensities since their establishment. For the long-term snowpatch monitoring sites, the area surveyed at each site was determined by the spatial extent of the snow cover that was retained well into the spring thaw. Across the chosen area, at least 15, 3m by 2m quadrats were used across upper, middle and lower elevational zones of the individual snowpatches to score a rank of cover-abundance. At least five, 3m by 2m quadrats were used in each of the three zones, upper, middle and lower, with the number of quadrats used dependent on snowpatch size. A range of site-level variables were recorded including slope, aspect, area and altitude. The snowpatch sites were first surveyed in 1993/1994 and most recently in in 2011/2012. For the long-term monitoring sites established in wetland vegetation, the cover abundance of each species was recorded along permanently-marked transects of contiguous 1m-square quadrats that spanned the wetland. Transects were between 20m-70m long and there were between 5-10 transects at each wetland site (depending on the size of the site). Ancillary variables were also recorded for each quadrat including including surface type (peat, gravel, sand, alpine humus soil, bare ground, rock), slope, aspect, and broad vegetation type. Vegetation measurements were first undertaken in 1995/1996 and surveys are scheduled every 5-10 years. To achieve more objective estimates of species composition, the point-quadrat method was introduced for grassland, wetlands and snowpatch communities from the 1980's. A 20cm interval is used for the point-interval distance.

(B)

For the 419 survey points recorded along the post-fire traverses undertaken on the Bogong High Plains after the 2003 bushfire, observations were taken along the transects at randomly selected intervals of either 50, 200 or 500m. The decision to survey the left or right-hand side of the transect (trail) was made randomly. At each survey point, the presence of burning, broad vegetation type, estimated pre-fire shrub cover, and at survey points in heathland (68% survey points), an estimate of fire severity was commonly recorded using minimum diameter of burnt twigs. For the fire severity measurement protocol, twig diameters were measured on five randomly selected branches within each of 10 randomly selected shrubs of a certain species depending whether the vegetation type was open or closed-heath. For each 2m by 5m quadrat in the subset of 80 sites taken from the initial 419 sites, rank cover-abundance was used to estimate the cover of each vascular plant, total shrub cover and bare ground. Researchers plan to resurvey the survey points and heathland sites every 10 years. Density and heights of shrub seedlings were measured at the 80 heathland sites in 2012.

(E, 1)

For the alpine summit study, four variable length permanent transects have been established that run downslope from the summit to a contour 5m in elevation below the summit. Transects run from the summit to the north (0 deg), south (180 deg), west (270 deg) and east (90 deg). Along each transect, line intercepts (to the nearest centimetre) are recorded for each of the main growth forms (grasses, forbs, shrubs), noting dominant species, as well as ground cover condition when vegetation is absent (bare ground, rock). For each transect, 20, 1m by 1m quadrats are randomly distributed from the summit to the contour 5m below, five quadrats on each slope/aspect. All species are recorded and assigned a percentage cover (<1%, 1%, 5%, then to the nearest 5% thereafter) by eye. Litter, rock and bare ground are also recorded. Across all aspects on the summit to the contour 5m below, a vascular plant species list is compiled. The surveys are scheduled for every 5-7 years.

(E, 2)

For the roadside transect study, in each of the 20 transects within each of the five road sectors, one belt transect (2m by 50m), is placed parallel to the roadside. The transect is positioned from the edge of the bitumen or gravel in an effort to survey parts of the roadside where plants may first establish. Each transect had its location recorded by GPS, and altitude, aspect, slope, tree cover and degree of disturbance (low, moderate, high) is recorded for each. Within each quadrat, all species were assigned a rank abundance score. The minimum re-survey period for the roadside transect study is five years.

Analysis

Regression and graphical approaches have been used to examine the relationships between species density and elevation for the Summit plots and the Roadside Transect Study. Various analyses have been used to examine data from the long-term monitoring plots including graphics, *t*-tests, linear models and generalised linear models. The presence of autocorrelation is routinely examined in analyses.

Discussion

The sites of the long-term monitoring work were chosen subjectively to represent typical or characteristic examples of the respective vegetation types: grassland, heathland, snowpatch herbfield and wetland communities. While the researchers are not going to intentionally select 'un-representative' areas to survey, subjectively choosing sites creates the possibility of inadvertent selection bias with respect to the primary survey sites and as a result reduces the dependability of generalising results beyond the surveyed sites to other regions of the Bogong High Plains. Within these subjectively chosen locations, transects were located randomly, or in some cases, systematically. Random or systematic placement of the transects stand to provide measurements that can more confidently be expected to represent the site that has been chosen for inclusion in the study, rather than if the transects were chosen subjectively to cover typical or characteristic patches within the broader chosen site. For the two (one grazed/ one ungrazed) Pretty Valley plots first surveyed in 1947, the choice of which plot to fence to exclude cattle was made randomly affording greater confidence that the difference in species composition between the two plots is due to grazing. However, researchers acknowledge the limitations of using only the original Pretty Valley and Rocky Valley sites in investigating the effects of grazing. The treatment for each of the grassland (Pretty Valley) and open heathland, closed heathland and sedge herbfield snowpatch plots (Rocky Valley) were not replicated, preventing an estimate of the variability in vegetation species response to grazing within each of the vegetation types at these sites.

For the 419 survey points measured after the 2003 bushfire on the Bogong High Plains, researchers primarily used ridge-based sections of tracks, trails and snow-pole lines as transects to record the presence of burning, vegetation composition, and in the case of heathland, estimated fire severity. The emphasis of this study was on comparing the pattern of burning between the typically grazed south-west region of the plains with the ungrazed north-east area of the Bogong High Plains. The transects were placed by researchers to obtain good geographic coverage of the plant communities and took advantage of convenient tracks and pathways to do this. With the emphasis of the study on comparing the burning of spatially separated grazed and ungrazed regions, it is important that geomorphological features that were used for the transects do not differ between the north east and south west areas of the High Plains in ways that may influence whether survey points located on the transects may or may not be burned in a bushfire. The researchers believe that there were no gross differences between the two regions in this regard, notwithstanding an elevational gradient that occurs from north to south with respect to where survey points were located. Prior to analysis, researchers checked for possible confounding between grazed and ungrazed areas with respect to average shrub cover and slope within the different vegetation communities and average transect length and distance between transects. The researchers report that there were no differences in the dominant species within the respective communities between grazed and ungrazed areas of the High Plains supporting the idea that there were no obvious differences between the two districts that might influence their susceptibility to burn in a bushfire. The researchers have used covariates like aspect, slope and pre-fire shrub-cover to accommodate any differences in these variables as part of their analyses. The non-manipulative nature of the study design, with observations recorded after bushfire and the geographic demarcation of the grazed and ungrazed sites to the south west and north east of the Bogong High Plains respectively, means the possibility of confounding between variables remains. That is, the south west region of the Bogong High Plains where recent grazing has predominated may have unknown attributes that influences the propensity of that region to burn more (or less) readily compared to the north east region. The researchers believe that the presence of confounding variables is unlikely and the two regions of the plains are comparable. Within each of the 17 walked transects used for the study, the interval between survey points was chosen randomly from three options: 50m, 200m or 500m. This protocol removed subjective choice of where next to record a measurement and avoided the introduction of inadvertent bias in deciding where to survey along a transect. The researchers found little evidence of spatial-correlation in successive survey points from examining variograms of the residuals from the best-fitting statistical models.

For the subset of 80 heathland sites, a stratified random approach was used in selecting a subset of the original 419 survey points to include 30 grazed and 10 ungrazed in each of the 40 open heathland and closed heathland vegetation types. A minimum size constraint of 0.25ha of heathland ensured that any of the subsequently randomly selected survey points would correspond to a large enough area of heathland vegetation to accommodate a 50m transect that was used for vegetation measurements. The random selection of sites provides a secure foundation on which to generalise results across the rest of the 150 heathland sites that were available for inclusion. The systematic placement of the 50m transect within each site evades inadvertently introducing bias when deciding where to record vegetation measurements.

When the mountain summit plot work was established, the original choice of the summits used was likely to have been based largely on convenience. Researchers say there are not many true alpine summits in Victoria and the surveying of the majority leaves less opportunity for selection bias than if a lower proportion of the total summits available were chosen out of convenience for survey. Upon each of the summits, the four transects are placed systematically using the four aspects: north, east, south and west. The five 1m by 1m plots that are used between the four transects (total of 20 plots on each the summit), are distributed randomly affording confidence in generalising the species composition results from the 1m-square plots across each summit.

In a similar way to the Summit plot surveys, the roadside transect study seeks to survey a large proportion of the high elevation alpine road options that were available. The five roads used in the study represent the major two-wheel drive access roads into the Victorian mountains. Two major access roads were not surveyed as they were considered too dangerous to work on as they were steep, with limited opportunity for a vehicle to pull over. With the inclusion of the major access roads into the Alps there is little reason to suspect that a biased selection of road transects are being used. Importantly, as the interest is in the role that these particular roads play, the value of having a sample of roads selected without bias in order to provide a secure basis for generalising, is not relevant. In addition to these road transects, it may be useful to set up altitudinal transects without roads to provide a more secure basis in understanding how roads contribute to the dispersal and establishment of invasive plant species. The researchers believe that the systematic placement of the 20 strip transects within each road segment is not aligned with any regular or cyclical pattern in the landscape and therefore the placement of the plots are not biased in this regard. Together, the five roads span an elevational range of 205m to 1848m, with all five road sectors covering the altitudes 726m to 1621m. Replication of roadside transects across some ranges in altitude allow an estimate of the variability of invasive plant abundance at these elevations.

Summary

The Victorian Alpine Plot Network brings together discrete projects that have been operating in the Victorian high country at different times and for different durations. The various sub-projects are composed of manipulative and passive observational studies. For the four sub-projects described here—the long-term monitoring plots, the post-fire regeneration surveys and the summit and roadside studies—the plots allow the researchers to explore the relationships of interest between vegetation composition and: aspect and elevation of mountain summits; the distribution of roads and management tracks; and disturbance from fire and grazing. Randomisation of plot locations or study sites is used for some components of these sub-projects providing greater confidence in generalising results in those circumstances.

Nanangroe Plantation Plot Network

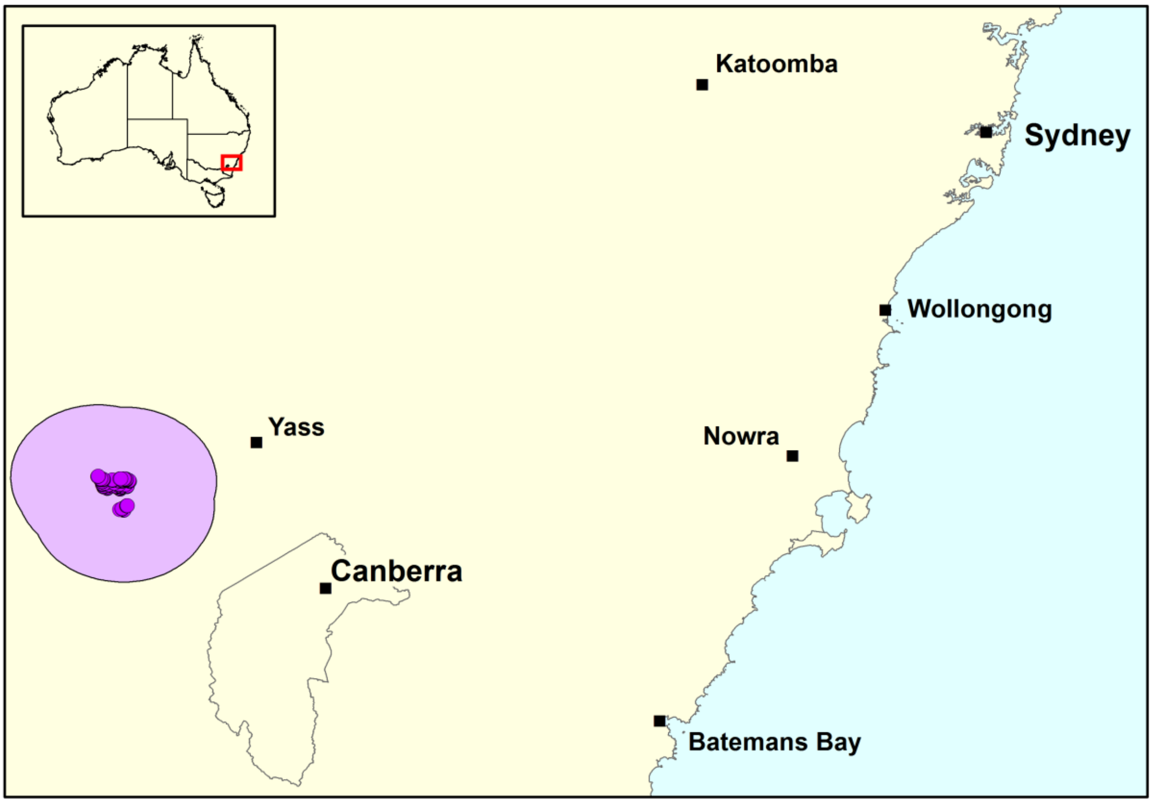

Figure 10: Nanangroe plots within LTERN
The lighter shading seeks to highlight the distribution of plots and does not indicate an effective study area.

Background to the project

The Nanangroe Plantation study is located about 70km north west of Canberra and covers an area approximately 18km by 16km. The study occurs in highly fragmented temperate eucalypt woodland surrounded by and/or adjacent to *Pinus radiata* plantations. The main landuse in the area is sheep and cattle grazing and plantation forestry. The current project grew out of an earlier forest fragmentation study in the nearby Tumut region that sought to examine the relationships between habitat isolation and fragmentation on forest birds and other groups of biota. The motivation for the current project, and the earlier one in the Tumut region, is to determine what effect increasing modification of the agricultural environment is likely to be having on aspects of biodiversity. The focus of the Nanangroe study is on examining the response of selected vertebrate fauna to the establishment of pine plantation on former grazing properties

Objectives

The key objective of the program is to quantify the impact of plantation expansion on biodiversity inhabiting remnant patches and eucalypt woodland.

Research Questions

The research question that the researchers are examining is: *What is the effect of changing landscape context on the biota in woodland patches?*

Study Design

In 1997, a set of native woodland sites were selected with approximately half located within areas subject to plantation establishment, and half within grazing lands surrounding the plantations. A stratified random survey design using woodland patch size and broad vegetation group was used to select 50 woodland patches from a total of 70 that were available from the plantation areas. Pines were planted adjacent to 19 and 31 of these patches in 1998 and 2000 respectively. A random selection of 56 woodland patches was selected on grazing properties next to the softwood plantations to help contrast the effects of plantation establishment. The characteristics of these grazing remnants were matched with the plantation remnants on the basis of the design variables; woodland patch size and broad vegetation type. Ten survey sites also were located within the recently planted *Pinus radiata* itself and a further ten sites within cleared paddocks. An additional five plantation remnants were added in 2000. Measurements at all 131 patches occur within a 100m by 200m, 2ha plot, within the remnant woodland patch. Survey effort is not proportional to the area of the patch. That is larger patches do not get more plots. It is understood the long-axis of the survey site was located to run through the centre of the patch and inset to avoid edge effects. Distances between woodland patches range from 300m to 4km.

Measurement protocols

Vegetation measurements are made every five years in three 20m by 20m plots placed equidistant along a central 200m transect in the 2ha survey site within the woodland patch. Numerous attributes are estimated including: number of trees (live/dead), tree stumps, tree hollows and mistletoe clumps; stand height; basal area; grass height; an ordinal regrowth index score and litter layer score (1-4); occurrence of dieback; and the scoring of cover using the six ordinal classes None, 0-20, 20-40, 40-60, 60-80 and 80-100% for the following attributes: exposed rock, weed cover, Blackberry, grass, native ground layer, shrubs, dominant trees and sub-dominant plants. The number of logs or coarse woody debris is also recorded in the following diameter classes: 10-20, 20-30, 30-40, 40-50 and >50 cm.

Bird surveys are undertaken in early November every 1-2 years using five minute point-interval counts conducted at each of the 0m, 100m and 200m positions along the central 200m-long transect of the 2ha site. The sites are surveyed by two different observers on two separate mornings with surveys commencing from dawn and being undertaken until mid-morning (depending on temperature). Counts of all the birds seen and heard during the five minute period and their estimated distance from the observer are recorded.

Frogs and reptiles are surveyed every two years using artificial substrates and active search methods. Artificial substrates comprise eight standard roofing tiles, eight half-size (cut-off) railway sleepers and four sheets of corrugated iron per site. A set of two sheets of corrugated iron placed on top of one another, four half-size railways sleepers and four roofing tiles are placed around a point at the 0m and 100m point of the 200m transect. These artificial substrates are inspected to record occupants with some of the animals hand-captured to identify the species. Active searching is done by turning over any rocks, logs or fallen bark at locations selected by the observer along the 200m transect. Several measurements including head width, head length, snout-vent length, total body length and body mass are also recorded.

Analysis

A variety of statistical modelling approaches are used to accommodate the longitudinal nature of the data, non-Gaussian responses and/or a moderate-high frequency of zero counts.

Discussion

A stratified random survey design has been used to investigate the effects of maturing softwood plantation on selected groups of biodiversity. The stratification that was used ensured coverage of survey sites was achieved across the patch size classes and vegetation types that existed across the study region. The project was designed as a comparative longitudinal study to examine the trajectory of the faunal response at the survey sites over time while accounting for other factors that might influence the response including woodland patch size, vegetation type, and the number of sides of pine that surround the remnant patch. A range of habitat structural elements are also measured at the site-level as potential covariates. The incorporation of sites both within and outside of the plantations allows the investigation of faunal patterns being associated with plantation maturation rather than being related to broader landscape effects like drought. The use of equal survey effort across woodland patches of different size is a resourceful approach for quantifying the trends from repeated measurements and avoids complications associated with sampling proportional-to-area3. It is 'resourceful' in that limited resources are distributed to maximise the number of independent study sites at the expense of increased survey effort within sites. The use of probability-based sampling provides the researchers with a secure basis for drawing conclusions of ecological association beyond their study sites to other areas within the Nanangroe region that share attributes corresponding to the stratification levels that they have used.

The area of the woodland patches used in the study range from 0.5ha to 28ha. Several of the woodland patches are less than 1ha making the reference to a standardised 2ha survey area confusing. In practice, all standardised measurements are taken using the framework of a central 200m transect, rather than survey effort being distributed evenly (or otherwise) across a 2ha area. However, the bird surveys use a 50m radius from the point-interval count stations and some patches are too small to accommodate the extent and 100m spacing of these stations. For those sites, researchers seek to count only birds that occur within the native woodland patch (rather than within the adjacent plantation as well), and where needed, the three count stations are placed closer than 100m apart. The consequences of this inconsistency in the bird measurement protocol is not severe, but levels of detectability may be different in these sites resulting in differences in measurement error. It is recommended that researchers include some measure of patch size or woodland extent in their statistical models to help account for this. For the standard design where bird count stations are 100m apart, the researchers do not regard the stations as being spatially independent within a site for their analyses.

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[3] Here, the focus is on monitoring selected fauna over time as the plantation matures rather than characterising the community of different size patches or estimating fauna density across those patches. The latter objectives may benefit from sampling proportional-to-area.

Some of the survey sites are within 300m of each other and responses from more mobile taxa like birds may lack spatial independence between sites. The researchers are aware of this and have explored spatial correlation in the data through the use of variograms. Depending on how strong and extensive spatial correlation is across the study area, options include randomly removing a closely adjacent site from the dataset or more challengingly, incorporating the spatial dependence structure in the analysis of the repeated measures data. Ignoring the spatial correlation, where it exists, can be expected to result in optimistic measures of precision for estimated parameter values.

The delineation of patch extent is somewhat arbitrary for some of the grazing-land remnants with indistinct boundaries between the bulk of trees and those on the perimeter and nearby. Researchers have explored the influence that the amount of retained native vegetation may have on the response of selected biodiversity by using measurements other than the calculated size of the woodland patch. These have included using the amount of native woody vegetation within a 250m, and a 500m radius of each site as covariates. Advantageously, to ease confounding, there is a reasonable degree of matching with these measures between the grazing `control' remnants and those patches in the plantations.

With respect to the research questions, the scientists use the term vegetation condition to refer to the transformation of agricultural land that the woodland remnants lie in, from cleared paddocks to maturing pine plantations. In this regard, vegetation condition is explicitly incoporated into the design of the study. A variety of vegetation structural attributes are estimated within the survey site. The value of using these plot-based habitat attributes to explain or predict faunal response is unclear and consideration should be given to how useful they are and discontinuing those that are not.

Summary

The Nanangroe plantation project was designed as a longitudinal study to examine the effects of softwood plantation establishment on selected native fauna in agricultural grazing land. The study uses a stratified random survey design to help isolate factors of interest and provide a secure basis for drawing conclusions of association found from the work beyond the survey sites. While the landscape intervention of interest, plantation establishment, was not allocated randomly to woodland patches, the use of the grazing remnants to help function as `controls' is a useful feature of the study that helps interpret the results. Some contraction or expansion has occurred in the extent of some of the native woodland patches since the study commenced 17 years ago in part because of natural regeneration of native eucalypt woodland trees. Researchers should continue to think of effective ways to measure and describe the extent of native woody vegetation across the study area so these changes can be incorporated meaningfully into analyses.

Woodland Restoration Plot Network

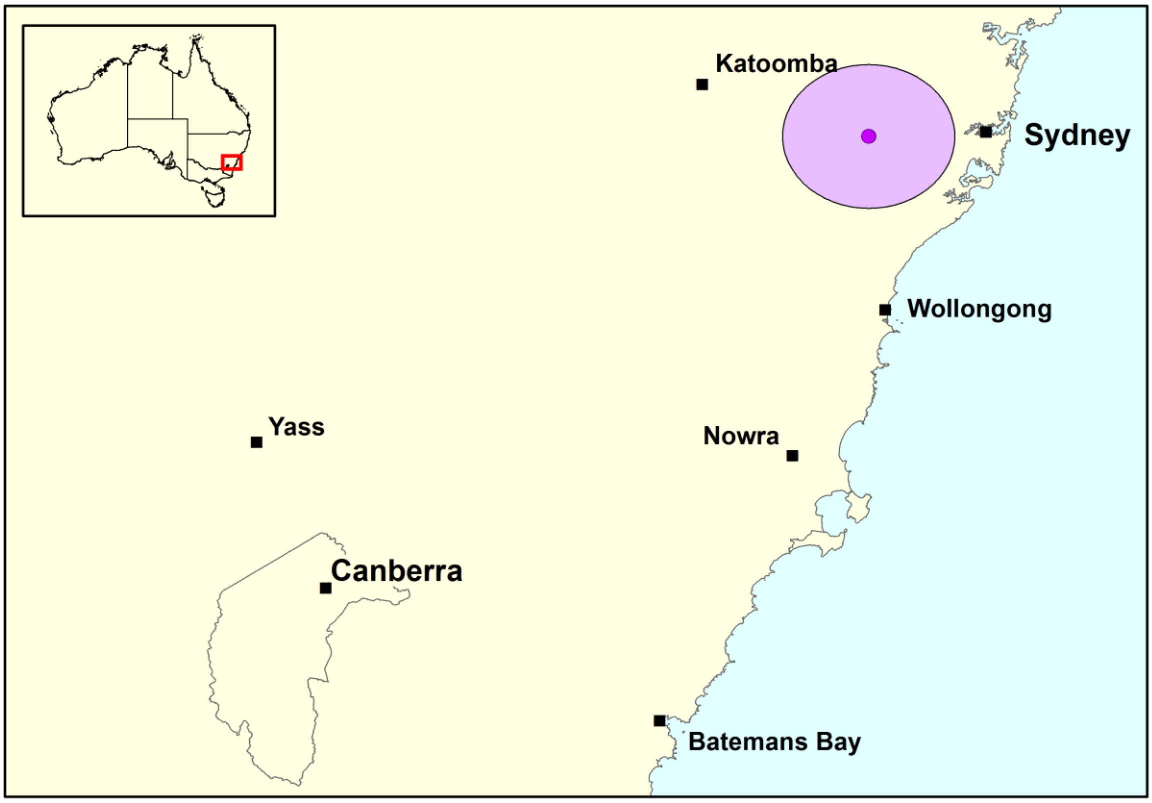

Figure 11: Woodland restoration plots within LTERN
The lighter shading seeks to highlight the distribution of plots and does not indicate an effective study area.

Background to the project

The Woodland Restoration Plot Network is located in the Western Sydney Regional Parklands which is situated approximately 30km west of the Sydney central business district. Within the Western Sydney Regional Parklands, the study is undertaken across areas of older native regrowth, restoration plantings of different ages and (semi) retired pasture. The older regrowth vegetation is referred to as 'remnant', but it is understood it is not true 'old growth' woodland, as almost all large trees were removed during more than a century of agricultural use. The study area is distributed across four adjoining locations or localities which now comprise the present, contemporary configuration of the Western Sydney Regional Parklands. Running from north to south these localities are known as: Prospect Reservoir, Sydney Parklands, Plough and Harrow, and Hoxton Park. Areas of pasture and restoration planting are located on old farming land that was historically grazed, fertilized and planted with exotic pasture grasses. These agricultural areas were acquired by State government agencies prior to 1990 with the first restoration planting projects occurring in 1992. The restoration plantings were implemented with the objective of re-establishing native vegetation particularly through the connection with existing areas of older native woodland regrowth. These older regrowth patches were the primary sources of seed for growing tubestock for the restoration planting. It is understood that there are no 'old growth' woodland remnants across the study area or anywhere in the Cumberland Plain region. The original restoration plantings took place from 1992 to 2002. The study seeks to examine the influence of different land use management practices—older age native regrowth, restoration plantings, and (semi) retired pasture—on vegetation structure and floristics and bird diversity

Objectives

The objectives of the Woodland Restoration Plot Network are to develop methods for evaluating the success of native woodland restoration on retired agricultural land and apply them to a major restoration project. The study aims to determine whether the composition and structure of restoration plantings undertaken between 1992 and 2002 are progressively becoming less similar to the retired pasture and more similar to the older woodland regrowth. Data collected from the study will help inform future restoration efforts.

Research Questions

The research questions that the scientists are examining are:

1. What is the pace and direction of temporal trajectories in woodland structural features and composition of plant, invertebrate and avian communities within restoration plantings?
2. What ecological traits differentiate native species that respond positively to restoration treatments and those fail to respond?
3. What site features enhance the chance of successful woodland restoration (i.e. rapid trajectories towards reference states)?
4. How do alternative management strategies influence the pace and direction of restoration trajectories?

Study Design

Restoration plantings, older regrowth woodland and retired pasture are distributed across an elongated, north-south orientated study area running from Prospect Reservoir in the north to Hoxton Park, 10-12km to the south. The study area is located adjacent to, and either side of, the M7 motorway. The four areas that make up the greater Western Sydney Regional Parklands—Prospect Reservoir, Sydney Parklands, Plough and Harrow, and Hoxton Park—largely adjoin each other, with some separation between Prospect Reservoir and the original Sydney Parklands estate (1-2km), and between Sydney Parklands, and Plough and Harrow to the south (approximately 1km). The restoration plantings that took place between 1992 and 2002 occur as a mosaic of discrete but largely adjacent patches of various shapes and sizes mostly within Sydney Parklands and Hoxton Park. The size of discrete restoration planting patches (planted in a particular year), appear to range from less than 1ha up to approximately 50ha or more. There are no restoration plantings or pasture at Prospect Reservoir in the north of the study area. Across the study area, the researchers have constrained their survey site locations to upper or mid-slope topographic positions on a north or north-east aspect. It is understood this feature focuses the restoration study on the shale hills woodland form of the Cumberland Plain Woodland community rather than shale plains woodland form.

Vegetation measurements have been made on four occasions: 2001, 2004, 2009, and 2012-13. In each of the scheduled survey years, locations (sites) for survey are selected from across the study area. These selected sites correspond to six management classes: retired pasture, older regrowth, and four age classes of restoration plantings. The age range of the four restoration-planting classes change each survey occasion with the maturing of the planted cohorts. In selecting survey locations, a geographic information system (GIS) is initially used to determine the distribution of restoration-planting age classes, topographic attributes and to help ensure that survey sites are located in a large enough area (minimum 40m by 40m), to implement the field measurement protocol. Using the GIS, survey locations are then distributed across the study area in a haphazard manner while drawing representation from the six management classes described above. Site selection is regarded as haphazard as while there is an effort to distribute the survey locations across the length and breadth of the study area in an informal, non-systematic way, there is no demonstrable element of randomisation used in the process. It is understood that within a survey season, placing multiple survey locations within the same discrete patch (of plantings, older regrowth, or retired pasture), was generally avoided. During the GIS-based approach, the selection of sites in a survey year was largely made without reference to where survey sites were placed in previous survey seasons. That is, there was little systematic effort made to avoid the locations of previous surveys or to place new sites in close proximity to previous survey efforts. GIS-based assessments were confirmed in the field to ensure that the vegetation present was the correct community, or corresponded to the expected (planned) restoration planting age. Once on-site in the general area of the selected survey location, a random position was chosen to establish a corner of the 32m by 32m quadrat used as part of the measurement protocols.

The number of survey sites that are selected from across the study area in any given survey year depends on the level of available resourcing. The proportional representation of the number of sites in each land use management treatment (i.e. retired pasture, plantings, older regrowth), remains approximately constant. Twenty-five sites were chosen for survey in 2001, 54 sites in 2004, 24 sites in 2009 and 30 sites in 2012-13. It is understood that surveys are scheduled every 3-5 years.

Beyond the control of the researchers, management agencies for the Parklands re-introduced grazing in the late 1990's to the southern, Hoxton Park locality of the study area. Grazing occurs periodically and has not been consistent or heavy. It is thought a key motivation for re-introducing grazing in this district was to reduce fine fuel levels to mitigate fire risk. It is understood the Hoxton Park district contains the more recently planted restoration areas (planted 1997-2002), areas of pasture, and a patch of older regrowth.

Measurement protocols

For vegetation composition, complete species lists are compiled in each of six nested square sub-quadrats. Sub-quadrat dimensions were successively doubled from 1m to 2m, 4m, 8m, 16m, and 32m. All six sub-quadrats have a common corner marked with a star picket. A frequency score was calculated for each species by counting the number of sub-quadrats in which it occurred. Planted and wild occurrences of the same species were recorded separately. In addition, a species list with Braun-Blanquet cover-abundance estimates (8-point scale) were recorded in a 20m by 20 m plot inserted within a nested configuration of subplots. Average height and cover of each vegetation stratum are visually estimated to record vegetation structure in the four quadrants of each 20m by 20m plot. Percentage cover of bare ground and leaf litter, and environmental variables including aspect, slope and soil texture are also recorded.

Ants are surveyed with 5 pitfall traps at each survey site. Four pitfall traps are placed at the corners of a 15m by 15m quadrat and one pitfall in the middle. All traps are established at least five days before opening to allow for animals to be somewhat habituated to the ground disturbance. Trapping sessions are conducted for 14 days.

Birds were surveyed from 2013 using the vegetation survey locations selected in that year. These same sites will be re-surveyed in future survey years. Point count stations are located within the centre of the 20m by 20m quadrats described above. After a one minute settling time, an observer surveys the area surrounding the point count station for a 20 minute period within 3.5 hours after sunrise. The species, method (visual or auditory), time (0-3mins, 3-5mins, 5-10mins, 10-15mins, 15-20mins), stratum (canopy; upper-understorey, mid-understorey, lower-understorey; ground), distance (<10m, 10–20m, 20–30m, >30m) and compass orientation from observer, and activity type, is recorded for the birds detected. Flyovers, juveniles and flushes are recorded separately. Each of the point count stations are surveyed a minimum of six times by two independent observers within a seasonal period. Sites within 500 m of each other are not surveyed during the same morning, and wherever possible, each station is surveyed at a different time on subsequent visits. The starting time, weather conditions (approximate temperature, wind strength, precipitation), presence of flowering or fruiting plants, and an estimate of ambient noise is also recorded. Surveys are not conducted on days of rain, high wind, or fog. Surveys are undertaken in Spring and Autumn.

Analysis

To date, researchers have used exploratory multivariate techniques to examine the relationship between land management practice and the distribution and abundance of vascular plant species.

Discussion

In evaluating the success of the restoration program, researchers are using the composition and structure of the areas of older regrowth as a benchmark. The key focus is in investigating whether the restoration plantings approach the composition and structure exhibited by the established areas of older regrowth. Through the development of Western Sydney Regional Parklands as an urban park, restoration, landscaping and other land management activities have been beyond the control of the researchers. In examining how effective the maturing restoration plantings are becoming by comparing them to vegetation within older regrowth patches, the researchers have needed to take advantage of the land-use configuration that is in place, and that continues to develop across the Parklands.

From the vegetation surveys that have been undertaken since 2001, researchers have recorded measurements from areas within restoration plantings that were of a revegetation age of 1-2 years, up to the most recent surveys where data has been recorded from plantings with a maximum revegetation age of 20 years. Measurements are not recorded from the same spot in successive field survey seasons. The same discrete patch of retired pasture, restoration planting or older regrowth, may or may not be represented among the survey sites chosen for successive surveys, but the specific, on-ground sites used for the current survey season are chosen afresh from across the study area each time the surveys are undertaken.

It may be expected that discrete patches within a land management treatment—for example, within plantings of a particular age—may differ from one another for a number of reasons. For example, two discrete patches of plantings that were both established in the year 2001 may have inherent differences due to historical patterns of land use or minor, but important differences in how or when the plantings were established. If this is the case, two measurements taken within the same discrete parcel can be expected to be more similar than measurements taken in each of two geographically separated patches that were both planted in 2001. In a similar way, two measurements recorded within the one older regrowth parcel may be expected to be more similar than two measurements taken in widely separated older regrowth patches. It is understood that researchers avoid surveying the same discrete land management treatment patch twice in the one survey year. However, elements of site dependence can be expected to remain over successive survey seasons. For example, measurements taken from two survey sites, 3 years apart within the one patch that was planted in 2001 can be expected to be more similar than if measurements were taken 3 years apart from two different patches that were both planted in 2001. The dependence that is likely to occur within some parts of the data would be useful to incorporate in the analysis to more appropriately quantify the uncertainty around estimates and to more clearly understand the treatment effects of interest. To ignore the 'membership' that survey sites have to patches (or to the broader four districts that make up the Parklands), is to assume there is some exchangeability among the observations which is not supported by the way the data have been collected. While ignoring this structure in the data may or may not lead to different conclusions, it is recommended that researchers recover patch membership when analyzing the results to help separate treatment effects from differences due to the patch or parcel of land.

Restoration plantings took place over a ten year period. Differences in rainfall or temperature at important stages of the restoration planting process may influence the growth and survivorship of the plantings into the future. It would be useful to account for these differences in the analysis or to keep them in mind when interpreting results. The transformation of the restoration plantings toward the desired state of the older regrowth patches may be heavily influenced by weather patterns operating over the study area or region for particular periods.

The restoration plantings that took place over a 10 year period were managed by a single authority (Greening Australia). It was discussed above that potential differences in restoration practices across the study area may lead to systematic differences among the plantings in addition to effects due to revegetation age. A consistent planting protocol from initial site preparation to post-planting management helps reduce potential confounding issues where different planting practices may be expected to influence growth or survivorship of the plantings.

The researchers are aware of features of their study that will add to the difficulty in interpreting their results. The southern section of the study area is more undulating, has the more recent restoration plantings and has been subject to some, predominantly, light grazing. North of this area in the original Sydney Parklands location, the land is flatter, restoration planting occurred earlier (1992-1995), and grazing has not been re-introduced. Potential confounding occurs between grazing, year of planting and potentially geomorphological attributes that may correspond to differences in land use or fire history between the locations.

Constraining the survey sites to the 'shale hills' form of the woodland community on north and north easterly aspects reduces the variability of responses due to differences in soils and aspect and reduces potential confounding between these attributes and the management treatments of interest compared to if surveys were conducted over a broader range of topographic positions. Correspondingly, study conclusions are restricted to the 'hills' form of the vegetation community.

Bird surveys are implemented in a standardised, systematic manner with the comparatively long survey period (20min), the consistent use of only two observers, and six visits per site per survey season, likely to help reduce measurement error in detecting bird species. Survey time within a day is rotated within a site helping to reduce possible confounding between survey time and the recording of bird species presence.

Summary

The Woodland Restoration Plot Network takes advantage of the woodland restoration activities that have been occurring at the Western Sydney Regional Parklands to examine how successful such activities can be in recreating a woodland community on the Cumberland Plain. Although gross differences between the land management treatment classes will be apparent, there will be some challenges involved in reliably identifying the trajectory from restored pasture through to older regrowth woodland.

Jervis Bay Booderee National Park Plot Network

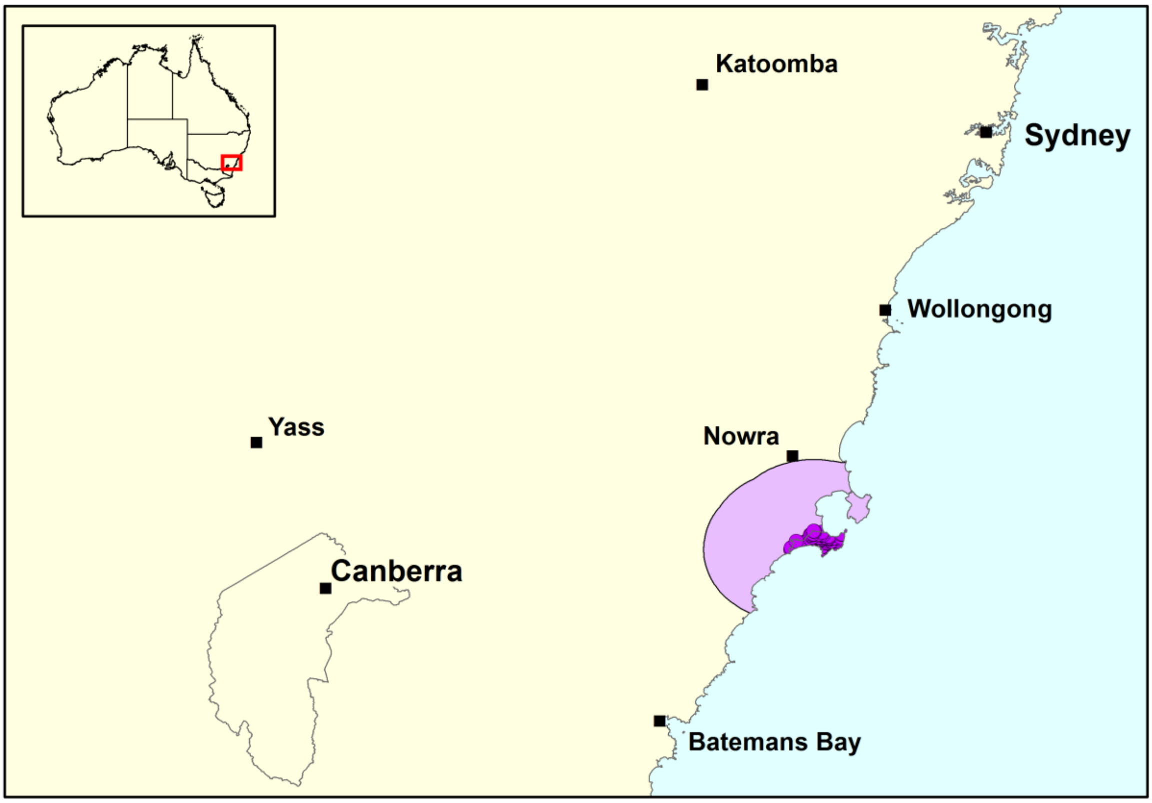

Figure 12: Jervis Bay Booderee National Park plots within LTERN
The lighter shading seeks to highlight the distribution of plots and does not indicate an effective study area.

Background to the project

The Jervis Bay Booderee National Park Plot Network is located primarily within the Booderee National Park. This is an approximately 6,500ha area which is co-managed by the Wreck Bay Aboriginal Community and Parks Australia. Booderee National Park is located 200km south of Sydney and 20 km south of the city of Nowra on the south coast of New South Wales. Work in the plot network commenced in 2002 and arose, in part, out of the desire to quantify the impacts of prescribed burning on selected biodiversity. Presently, the work is documenting the occurrence of birds, mammals, reptiles and plants in different vegetation types subject to fire and weed control, against a backdrop of pest animal control across the national park.

Objectives

The broad objective of the program is to quantify relationships between the occurrence of vertebrate fauna and fire, weed control, and changes in vegetation condition.

Research Questions

The research questions that the scientists are examining are:

1. What are the relationships between vegetation condition and biodiversity?
2. Are relationships between vegetation condition and biodiversity consistent across vegetation type?
3. How does natural disturbance (wildfire), and management intervention (prescribed burning and weed control) alter vegetation condition and, in turn, the response of biodiversity.

Study Design

A stratified random survey design was developed using 10 vegetation types and four fire history classes (40 strata) to select 110 polygons across Booderee National Park. Two categories of future prescribed burning were to be applied post-stratification to allocate prescribed fire treatments, however these did not proceed (see below for an explanation). Prior to selection, polygons less than 1.5ha were removed from the pool of areas as they were too small to contain the standard 100m transect used in the study without introducing edge effects from adjacent strata. Replication within strata was intentionally chosen to be higher for those combinations which were more common within the study area. A 100m permanently marked transect was established in the 110 selected polygons where transect length was chosen because of the heterogeneity of the vegetation within the Park—longer transects would have spanned two vegetation types and/or fire history classes in many areas.

A major wildfire in December 2003 burnt approximately 50% of Booderee National Park. Fifty-nine of the 110 permanent sites were burnt at varying levels of severity from the wildfire. These were located mainly in the east of the Park. As a result of the wildfire, park management suspended most plans to do any prescribed burning, and therefore a post-stratification allocation of burns did not proceed for this project.

Measurement protocols

Each of the 110 sites in the Jervis Bay Booderee National Park Plot Network consist of star picket markers set at 0 m, 20 m, 40 m, 60 m, 80 m and 100 m points along the transect. The co-ordinates of the first and last marker of each transect were recorded. Terrestrial mammals, reptiles, arboreal marsupials, and birds are surveyed on the 110 sites. Vegetation surveys also are conducted at the sites.

Ground-dwelling mammals are surveyed with the systematic placement of Elliott (10), small wire cage (4) and large wire cage (2) traps along the 100m transect. Trapping has been undertaken on at least three consecutive days, annually, since 2003.

Until December 2010, pitfall traps were systematically used to capture small reptiles and frogs. Each site was trapped annually in December. From 2010, sites are surveyed for reptiles and frogs using artificial substrates. Two sheets of corrugated iron, four roof tiles and four 'half length' railway sleepers have been placed at the 20 m and 80 m point of the transect. These transects are checked annually in August and again in December of each year.

Arboreal marsupials are counted using 20 minute transect-based spotlighting surveys every 1-2 years along the 100 m transect at each site. Counts are not undertaken in poor weather (rain, fog or high wind). Abundance of species observed or heard is recorded. Presence of frog species also are recorded. Spotlight surveys were conducted annually from 2003 until 2007, then every second year from 2008.

Birds surveys commenced in 2002 and are undertaken in late September each year using five minute point-interval counts conducted at the 20m mark and 80m mark of the 100m transect. All birds seen or heard are recorded and assigned to different distance classes. The sites are surveyed by two different observers on two consecutive mornings with surveys commencing from dawn and being undertaken until mid-morning (depending on temperature).

Vegetation condition measurements are recorded every three years using two, 20m by 20m plots located at the 20-40m and 60-80m points at each site. Within each of the 20m by 20m plots, ground cover is estimated in four 1m by 1m subplots. For the 2003 wildfire, the dominant fire severity (5 classes) of the survey sites was scored for the 100m transect. The area of burnt vegetation (by vegetation type) was estimated at the broader landscape-level within 200m and 500m radial distances around each site using aerial photographs and ground-based inspections.

Analysis

A variety of statistical modelling approaches are used to analyse data where the response may be non-Gaussian, geographically clustered and/or has a moderate-high frequency of zero counts. The ten classes of vegetation used in designing the project are commonly consolidated to a fewer number of broad vegetation groups for analyses. Spatial autocorrelation of model residuals is routinely assessed by researchers to examine spatial dependence between survey sites.

Discussion

The selection of 110, 100m survey transects using a stratified random survey design is a sound mechanism for the researchers to generalise the associations that they find from the study sites across the broader Booderee National Park. The original motivation for undertaking the work—to examine the effects of prescribed burning on selected fauna while accounting for differences in vegetation type and fire history—was derailed with the December 2003 wildfire which resulted in park management suspending most of their plans to do any prescribed burning. However, in lieu of undertaking the original study, the 2003 wildfire provided an opportunity for researchers to examine vegetation condition and the occurrence and abundance of fauna in areas of the Park that were both burnt and unburnt, while seeking to control for vegetation type and fire history that the original stratification sought to afford. In this regard, the project is well placed to examine the research questions of interest concerning the relationships between selected fauna, fire frequency and severity, and structural elements of vegetation (condition), within an observational study framework. However, the different fire regimes experienced by the different vegetation types at Booderee National Park present some challenges for the researchers when analysing data and trying to identify factors that are likely to be driving the responses. It is an inherent property of the vegetation communities at Booderee National Park that some vegetation types experience more fire than others, which directly influences the amount of time that has transpired since fire was last recorded in those vegetation types. In such cases, these close associations between variables can make it difficult to ascribe differences in fauna response confidently to one of either vegetation type or time since last burnt. The researchers have discussed additional confounding that may occur in the data. For example, because the 2003 wildfire burnt approximately from the centre of the park in an easterly and northerly direction, this introduces difficulty in isolating the effects of the 2003 wildfire from any east-west gradient in species distribution that may exist. These difficulties don't reflect deficiencies in the design of the project, but unavoidable properties of working in these vegetation communities. The researchers are cognizant of these issues and the limitations it introduces into some of their investigations.

The reptile surveys were changed from using pitfall trapping to artificial substrates due to the logistical difficulties in maintaining the former protocol. The researchers have explored analytical ways to calibrate the new methodology with the old.

Summary

The stratified random survey design of the Jervis Bay Booderee National Park Plot Network facilitates the examination of the relationships between fauna, vegetation type and fire regimes and provides a secure basis that associations recorded at the study sites apply across the National Park more broadly. By definition, wildfire disturbance has not been at the discretion of researchers to allocate randomly across the study area, so cause-and-effect relationships cannot be clearly identified from this observational study. Within the framework of a non-experimental study, the stratified design should give the researchers a sound foundation to examine the factors of interest, but challenges remain in identifying the effects most closely associated with response due to confounding of some variables.

Three Parks Savanna Fire-Effects Plot Network

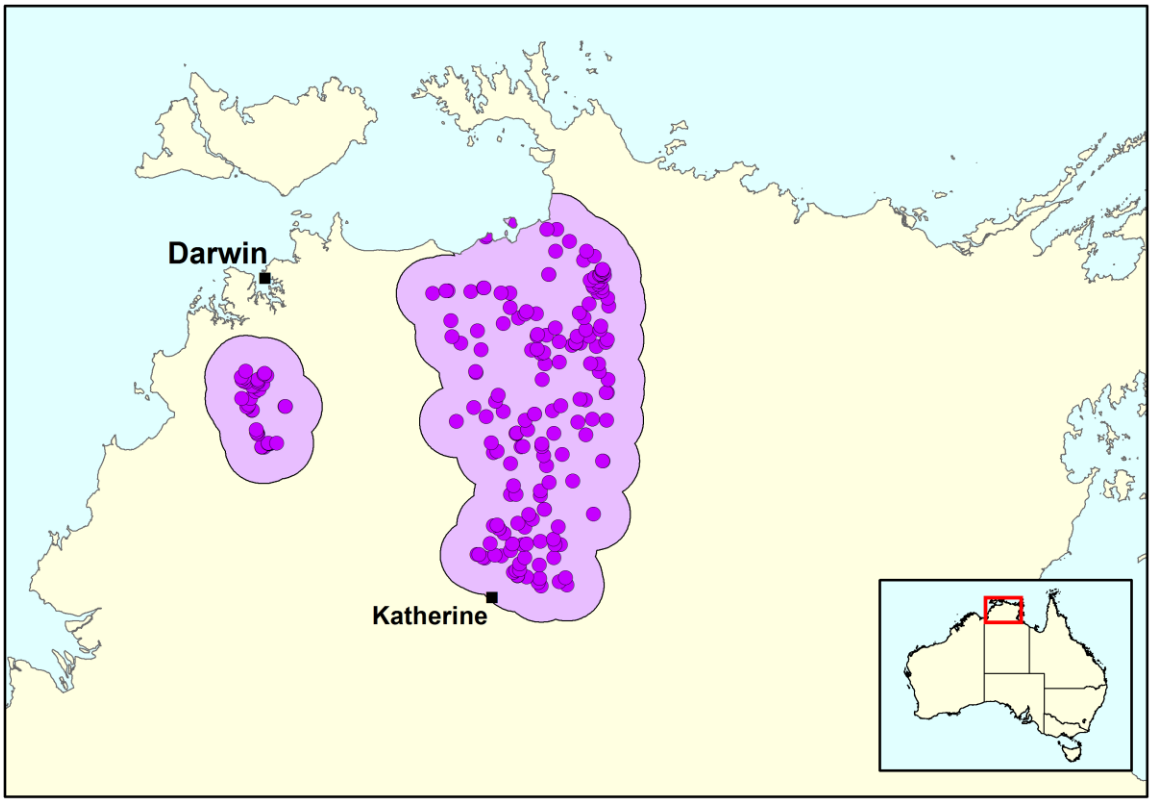

Figure 13: Three Parks Savanna Fire-Effects plots within LTERN
The lighter shading seeks to highlight the distribution of plots and does not indicate an effective study area.

Background to the project

The Three Parks Savanna Fire-Effects Plot Network occurs in Kakadu, Litchfield and Nitmiluk National Parks in the Northern Territory. The current program has evolved out of earlier experimentally-designed work at nearby Munmarlary (1973-1996) and Kapalga (1989-1995). Munmarlary examined effects of fire season and frequency in two different vegetation types (open-forest and woodland). Kapalga also looked at the effects of fire season and frequency but at a larger sub-catchment scale (15-20km2), compared to the hectare-sized plots of Munmarlary. While current plot network researchers believe these studies provided valuable information, they also thought they returned results of limited relevance to on-ground fire management due to the artificial nature of the experimental treatments. In addition, it is believed the rigour of the experimental studies and the associated management by the original researchers resulted in local conservation management staff and traditional owners feeling disengaged and excluded from activities occurring in their own park.

Consequently, the current plot network was established in 1994 with a primary aim to assist Parks management with the development of conservation-based fire management. From the outset, a major objective of the project has been to provide opportunities for the involvement and training of park staff and traditional owners. There are three key components to the plot network: a) fire mapping using satellite imagery; b) vegetation and fauna monitoring at permanent plots; and c) observations of fire occurrence and intensity at the permanent plots. This discussion focuses on the set of permanent monitoring plots.

Objectives

The overarching objective of the Three Parks Savanna Fire-Effects Plot Network is to better understand how to effectively manage imposed fire regimes on tropical savanna landscapes through understanding impacts of this disturbance on vegetation structure, plant species and vertebrate fauna.

Research Questions

The research questions that the scientists are examining are:

1. What are the effects of management-imposed fire regimes on the responses of the savanna matrix, flora and fauna species?
2. What are the effects of management-imposed fire regimes on vegetation and associated biomass dynamics?
3. What is the trajectory and status of biodiversity values on the three parks in response to ambient fire regimes?
4. What is the response of small-sized (ie non-tree) savanna woody species recruitment and growth dynamics to ambient fire regimes?

Study Design

There are 220, 40m by 20m plots distributed across three National Parks: 133 in Kakadu National Park, 41 in Litchfield National Park, and 46 in Nitmiluk National Park. The plots were established in 1994-1995 and it is understood the locations of the plots were chosen through a combination of personal judgment and convenience, and broadly, were selected with similar motivation within each of the three parks. The Chief Ranger for each of the five districts within Kakadu National Park, and the Chief Ranger for each of Litchfield and Nitmiluk chose the locations of the plots for their area of jurisdiction in consultation with their local staff. The broad motivation in deciding where to locate the plots was to select sites in locations of interest where the effect of ambient[4] fire conditions could be recorded over time. Sites of interest include those where particular species or groups of species are found, where ecotonal areas are present, or are examples of more intensively used areas like ranger stations and various visitor assets. Due to the differences in biophysical and cultural values between districts and National Parks, Chief Rangers had different specific interests with respect to monitoring (e.g. often different species or groups of species), although their general motivation could be regarded as being the same—to record some examples of values of interest to see what happens to them over time. The specific reason for selecting each of the plots has been recorded by the researchers: the species, groups of species or floristic community that was of interest, and a broad corresponding class of management applicable to the plot. For example, *regeneration monitoring* for examining jungle or jungle ecotones and *intensively managed* for high visitation areas

[4] Ambient referring to wildfire and burning undertaken by traditional owners.

like campgrounds. An additional consideration in placing the plots was to spread them out geographically across each of the districts/National Parks.

Vegetation attributes are recorded at the plots approximately every five years while fauna surveys are completed less regularly due to the added logistical difficulties and associated costs. It is understood fire occurrence and severity is presently scored annually.

Measurement protocols

Floristic and structural attributes are recorded on the 40m by 20m plots which are permanently marked with star pickets with their GPS location recorded. For survey visits, plots are delineated with measuring tapes run between the star picket markers. The 40m by 20m plot is systematically divided into sub-plots to measure different vegetation strata. Within the main plot, all trees >5cm diameter at breast height are tagged and measured. Within a central core strip measuring 40m by 10m, shrubs and juvenile trees are identified and counted in two height classes: 0.5-2m and >2m. Within two, 40m by 1m transects, shrubs and juvenile trees <0.5m are identified and counted, and within 40, 1m by 1m quadrats for herbaceous ground-layer species, ground cover is estimated by a botanist. The 2013 field surveys also included measures of woody debris and foliage percentage cover (FPC) to assist colleagues working on carbon-related studies. Woody debris was recorded in size classes with the logs recorded across the whole plot and coarse woody debris collected from within two, 40m by 1m transects, and weighed. A sub-sample of coarse woody debris is collected to dry and then calculate dry weights. FPC is measured for the upper strata using the step point method with a minimum of 200 points. Vegetation surveys are undertaken toward the end of the wet season before the fire season starts as for most plant species, this is the best time for identification as flowers and/or fruit still remain on the plants.

Fire severity is scored from plot photos using three ordinal classes of leaf-scorch height: low (<=2m); moderate (>2m, but scorched to mid-canopy only); and high (>2m, canopy scorched). Photographs to record fire incidence and severity are presently taken once per year due to limited resources and the one senior researcher does all the scoring from the photographs.

Fauna surveys are based on an existing protocol used in the Northern Territory. Ground-dwelling mammals are recorded across a 50m by 50m trapping area located immediately adjacent to the fixed 40m by 20m plot used for the vegetation survey. Twenty box-aluminium traps are placed around the perimeter with a larger cage placed in each corner of the 50m by 50m area. Three, 20litre pitfall buckets with drift fence are placed within the plot. Conventionally, traps are open for three nights and individuals are not marked. Two, 10 minute spotlight searches of the 50x50m area are completed during the typically, three day visit to the site. Opportunistic recording of animal sign also is made during the visit.

Bird surveys are completed in a search of un-extended duration (an 'instantaneous snapshot') of approximately five minutes or less within a 1ha plot that is centered on the 50m by 50m fauna site (and so partially overlaps the vegetation plot). The bird count does not use a timed search protocol, instead an observer moves across the 1ha site to record birds present, generally taking no longer than five minutes. Birds are recorded on 8 occasions over a 3-4 day period using the above method, ideally within 1-2 hours of dawn. All birds seen or heard within the plot are identified and counted. Birds entering the plot during the survey period are not counted. The two, 10 minute spotlight searches are also targeted toward birds. A relatively small number of observers are used in the project and have >10 years of experience in surveying birds in the region.

It is understood that annual fire mapping has been undertaken through remotely-sensed imagery and obtained through three scenes per year: early dry season (late May/early June), end of early burning season (late July/early Aug), and late in the dry season.

Analysis

Changes in the value of response variables have previously been calculated from the first survey to the last survey (two time points) for basal area, stem density for trees and shrubs and species richness (by structural form). Relationships between vegetation structure (e.g. change in stem density) and fire regime (frequency) have been explored using t-tests, regression analysis and generalised linear models. Explanatory variables have included modeled rainfall, location (i.e. which National Park), habitat, soil, topography, inundation, canopy height and several fire related variables including frequency (by season) and time since fire (by severity of burn). Fire severity has been examined using Spearman's rank correlations between fire severity classes and vegetation response variables. The total number of birds recorded across the 10 inspections per survey visit has been used as measure of abundance for each species. Differences in the abundance of terrestrial mammals and birds has been explored using Spearman's rank correlations between abundance measure and time of survey. Comparisons in abundance are not made between fauna species due to likely differences in detectability.

Discussion

The Three Parks Savanna Fire-Effects Plot Network commenced following earlier experimental work conducted in Kakadu National Park. While a lot was learned from these earlier studies, they were regarded by some as disappointing because the restricted set of experimental conditions did not mimic the complex, multifaceted natural conditions and outcomes closely enough to be useful to on-ground managers. Additionally, regional park managers and other local conservation staff were largely not involved in the design and implementation of the studies. As a result, a sense of involvement and participation was not engendered in the work, the results of which, stood to have an impact on conservation management of the park. This is a significant point as the subsequent (current) Three Parks Savanna Fire-Effects Plot Network project was initiated, developed and established primarily for involving and training the local park staff in conservation fire management. That is, to promote involvement and engagement of the local staff in the management of their park. A key component of park staff participating and taking ownership in the new project was for them to play a major role in deciding what to monitor and where to place the survey plots. These decisions on specific values to investigate, and deciding where to put plots, were decided on a district-by-district basis, with different staff deciding where to locate the plots in each of the five districts within Kakadu, and within Litchfield and Nitmiluk National Parks.

Within a district (or within each of Litchfield and Nitmiluk National Parks), the selection of plots using personal judgment (and not unlikely, some element of convenience), on the part of local staff doing the selection, means there is likely to be unknown bias associated with the placement of the plots. Typically, the problem is not one of being able to identify the value of interest that motivated the plot selection (e.g. heath species in sandstone), but rather the motivation for selecting that particular location for the value among a broader set of possible locations that also were available. This potential for bias means the statistical basis to generalise the results beyond the plots to the broader district of interest is not secure. In some ways, caution required in interpreting the district-wide results due to the site selection process is implicitly acknowledged by the researchers with the district-based ranger training camps they endeavour to run. At these camps, the results and patterns of the data over successive surveys are collated, transparently presented and discussed among park staff and scientists. For these discussions, the focus can often be on the trajectory or profile of plot by plot results over time and what factors may be influencing those trajectories. These training camps are an important part of the original motivation for initiating the Three Parks Fire-Effects Plot Network, and the opportunity for scientists and local staff to discuss the results together appears to be a particularly good way to strengthen the working relationships between Park staff and government/academic researchers. However, across districts, for drawing conclusions about the environment more broadly, the informal site selection process presents challenges for data modellers wishing to use data from the Three Parks Savanna Fire-Effects Plot Network together in the one analysis. The difficulty in dealing with the site selection bias introduced with the subjective nature of the decisions on where to locate the field plots is compounded across the three different National Parks by several groups undertaking this plot selection task. It is not unreasonable to expect that the unknown bias in selecting sites is likely to be different across districts and the other two Parks. In this regard, the most reliable use of the data in examining the effects of management-imposed fire regimes on selected biodiversity may be that undertaken on a district by district basis in close consultation with those involved in selecting the field study sites. Both within and across districts, information on the target species and the broad class of management for each plot has been recorded and tabulated. There is potential for this information to be used in an analytical way to try and help diminish the effect of unknown district-based bias inherent from the manner in which the survey plots were selected.

In examining the relationships between management-imposed fire regimes, the researchers are cognizant that the response of vegetation and fauna may depend on aspects other than fire that are not well understood. For example, densities or presence of feral predators are likely to influence the distribution and abundance of ground-dwelling mammals but systematic information is not available on the abundance of exotic carnivores. The researchers have an understanding of the reliability of the vegetation data that are collected from the 40m by 20m plots. The estimated heights of trees are regarded as less reliable than stem diameter measurements, and are not relied on for allometric analysis but rather used for qualitative structural descriptions.

For the bird surveys, the idea of taking as much time that is needed, but no more, to quickly determine what birds are present is understood, but it is uncertain how effectively this works in practice to ensure a consistent effort across the sites. Eight bird counts are completed during each survey visit and it is expected the repeat inspections per visit may, overall, help reduce the measurement error introduced from an expedient single inspection.

With regard to the dissatisfaction with earlier scientific studies at Kakadu, it is not desirable for science to try to operate in isolation from the indigenous community in the Savannas environment. The involvement of traditional owners could be expected to benefit several aspects of the scientific process: design, sustained and committed implementation, interpretation of results and their communication. This is easier said than done, however, and while indigenous involvement is a necessary aspect for successful ecological work in the Savannas, it can equally be said that principles of survey or experimental design are also a necessary component. Ideally, active participation by traditional owners in scientific field studies should occur within an appropriate framework of survey design that provides confidence in drawing conclusions from on-ground plots to the broader management area of interest.

Summary

The Three Parks Savanna Fire-Effects Plot Network spans Kakadu, Litchfield and Nitmiluk National Parks in the Northern Territory. The plot network was developed primarily as a training exercise and to encourage active involvement of indigenous staff in conservation management of the National Parks. This objective is most effectively implemented through the district-based focus of the Ranger Training Camps where the likely impacts of management-imposed fire regimes on selected flora and fauna species are discussed. However, the lack of probability-based sampling in site selection means the dependability of applying study conclusions across the Park and to the broader region is reduced.

Desert Uplands Plot Network

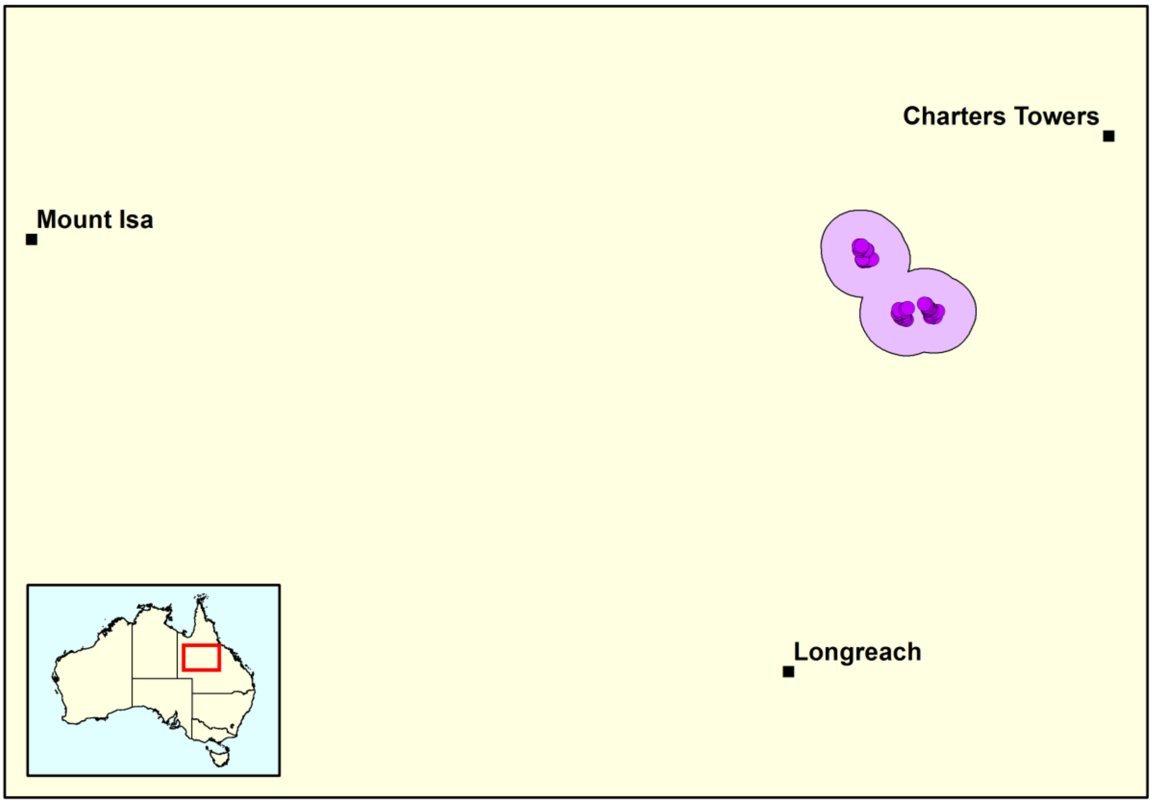

Figure 14: Desert Uplands plots within LTERN
The lighter shading seeks to highlight the distribution of plots and does not indicate an effective study area.

Background to the project

The Desert Uplands study is in the Desert Uplands bioregion in Queensland. Field sites are located to the west and to the south of Torrens Creek which lies approximately 250km to the south west of Townsville. The project developed in response to native vegetation management issues—the recruitment of woodland species and the encroachment of native woody weeds is commonly regarded by graziers as undesirable due to an associated reduction in pasture productivity resulting from woodland `thickening'. In conjunction with this perceived loss of grazing resource, it is thought by the researchers that, due to increased visibility of some bird species in areas where native vegetation has been removed, pastoral leaseholders may believe that a more open, cleared native woodland community is more suitable for native birds than vegetation with a denser ground and midstorey layer. The motivation for the project is to inform the debate of how native vegetation management practices affect native avifauna. At the start of the study, reptile surveys were completed but these are no longer undertaken.

Objectives

The objective of the Desert Uplands study is to investigate the effects of different vegetation management strategies on bird communities in the Desert Uplands. The primary aim is to explore how bird communities change with time since clearing and thinning.

Research Questions

The research questions that the scientists are examining are:

1. How does the intensity of mechanical disturbance affect bird diversity and abundance?
2. How do populations recover after cessation of such disturbance?
3. What are the size and directions of the natural population fluctuations, and how do they compare with human-induced disturbance?

Study Design

The effects on bird fauna of the following three vegetation management strategies will be contrasted in this study: 1) clearing (where all trees and shrubs are pulled); 2) thinning (where ground and mid-storey vegetation is removed); and 3) unmodified native woodlands where significant thinning or clearing has not occurred. Sites in the unmodified or intact class of management are further distinguished by two classes of percentage canopy cover: 30-45% and 45-60%. The project commenced with 60 1ha field sites distributed across four leasehold cattle properties that lie within an area approximately 50km by 50km. Two properties have ten sites each while the other two properties have 20 sites each. Not all of the three different types of vegetation management strategies are represented on each of the four properties. Sites with different management strategies are grouped among the leasehold properties in the following way: unmodified woodlands occur on all four properties, thinned sites originally occurred on two properties but are now confined to only one, and all cleared sites occur on one property. Vegetation management strategies were not allocated to sites as part of the study but were undertaken by the four leaseholders independently as part of their respective property management activities.

The researcher who began the study no longer works in Queensland and it is unknown why the general area and the four specific properties were selected for the project. A current researcher on the project believes reasons contributing to the selection of properties were likely to have been: an interest in particular land-types; the ability to gain access and work with leaseholders reliably over time; and having a set of sites that differed in the vegetation management strategies of interest that were not so geographically dispersed that seasonal field work could be completed in a reasonable time. Having as many different management strategies on the one property as possible was regarded as advantageous, not least because it reduced the need for liaison and negotiation among multiple leaseholders to get field surveys done at the desired time.

It is understood that the specific location of the 1ha survey sites were chosen so they lie in large contiguous areas considered typical or characteristic of the respective vegetation management strategy. Within a property, sites are generally a minimum of 1km apart but may be within 500m of one another in some cases. It is also understood that sites are located a minimum of 500m from any water point, commonly 50-100m from the nearest access track and that the demarcation used for site selection within the Unmodified vegetation management class (30-45% vs. 45-60% canopy cover), was made using crown canopy mapping based on 1996 1:250 000 aerial photography. Sites occur within the same, broad, Ironbark woodland community (*Eucalyptus whitei, E. melanophloia}*). Two Queensland land zones are mapped across the four properties with sandy plains and alluvial systems each represented by two properties.

One of the leaseholders (with five thinned and five unmodified sites), withdrew from the study following the July 2008 survey, leaving 50 sites distributed across three leasehold properties remaining in the study.

Measurement protocols

At each 1ha site in a given survey year, eight five-minute diurnal bird searches are made over a 3-4 day period. The numbers of individuals of each bird species are recorded. Two observers are commonly used for the surveys where the approximate time of visit and the observer is rotated when completing the eight surveys for each site. Using more than two observers is avoided to minimise potential effects from (many) different people taking the measurements and to spread the eight surveys over 3-4 days to capture potential short-term variation in recording species rather than the field work being completed in a shorter time-frame. Prior to the bird survey being done, the perimeter of the 1ha plot is marked to help observers determine whether detected birds are on or off the site. Birds that are `off-site' but present in the same management class as the 1ha plot are recorded separately.

Floristics and habitat structure variables are recorded across a nested series of quadrats and transects on the 1ha site. Within five 1m by 1m quadrats spaced 10m apart along a central 100m transect, a range of percentage ground cover elements are estimated visually including: native perennial grasses, native shrubs and exotic grasses, herbs and forbs. Coarse woody debris is recorded through counting the number of fallen logs across a central 50m by 10m belt transect. Along a central 100m by 10m belt transect, tree and shrub species counts are made within several diameter at breast height classes and additionally, whether tree hollows are present in the individual. Species richness for shrubs and trees is calculated from data collected within the 100m by 10m belt transect and tree and shrub canopy cover is estimated along the central 100m transect using line intercepts. Other factors recorded at the sites include: basal area and ordinal scores for time since fire, weeds, grazing impact and erosion.

Bird and vegetation surveys are undertaken periodically and have been completed in 2004, 2005, 2006, 2008 and 2013.

Analysis

No analysis has presently been completed on the longitudinal dataset, but the researchers anticipate a mix of ordination and regression approaches will be used to address the research questions.

Discussion

Working in agricultural landscapes on private or leasehold properties can be difficult as available study locations can be limited and the frequency and timing of when they can be visited is often restricted. This study uses repeat observations following historical vegetation management practices on four leasehold properties to explore the relationship between bird diversity and abundance, and the degree of native vegetation disturbance. The study design is the positioning of survey sites in contrasting areas of native woodland---cleared, thinned and unmodified. Supplementary habitat measurements are made at the sites to help explain the faunal response.

The ability to identify a relationship between faunal response and native vegetation management practices relies on isolating the variation in the response due to management practices from variation in the response due to other factors. That is, we would like to be confident that the observed pattern is likely to be due to a particular management practice rather than being driven largely by an effect from a specific leasehold property or as a result of an idiosyncratic effect arising from the site selection process. It is understood that while all sites are located in the same broad vegetation group, there are subtle differences between the properties perhaps due to minor differences in terrain or geomorphology. This heterogeneity may be expected to result in observations from the one property being more similar to each other than observations from sites among different properties. The two land zone classes that are mapped across the properties may be useful in understanding where these similarities and differences will be most evident.

Where possible, the analysis should include `property effects' in the analysis to more clearly identify the relationship of interest---between management practice and fauna response. There are a small number of unmodified sites to estimate the contrast with cleared vegetation on the one property so estimates of management effects may have greater uncertainty than is desired. Additionally, the cleared sites are all on the one property, so there are questions whether property-level effects such as fertility or particular land zone characteristics at that locality (or leaseholder-specific practices), may result in the observed response being a poor basis to draw conclusions across the broader district or subregion. There are similar challenges with efficiently estimating effects due to thinning—a small number (five) of remaining sites with this management strategy are located on one property.

In addition to accommodating the clustered nature of the survey sites on the four properties in any analysis, examining spatial dependence between adjacent survey sites (within a property) may be useful in providing appropriate measures of uncertainty around parameter estimates. The researchers are aware that even with sites 1km apart, there is evidence that dependency remains in the faunal response data.

Variation in the methods and/or timing of clearing and thinning may be expected to result in corresponding variation in fauna response and broader confidence intervals around estimates than would be the case if the work was done contemporaneously. Two types of vegetation clearing have occurred on the properties: older activities from 1997 where vegetation was pushed up and burnt and where regrowth has now established; and more recently clearing from around 2004-05 where the resulting coarse woody debris remains on the site unburnt. It is understood thinning activities occurred from about 2000.

With regard to survey sites being located in areas of unmodified woodland, or cleared or thinned areas, there are other factors that may influence faunal response. It is unknown how large the different contiguous management class areas are where the survey sites are located or whether there is much variation in the distance from a survey site to the nearest vegetation management area of a different class. One or both of these factors may be useful to consider when analysing the response of the bird fauna.

Researchers acknowledge the difficulties in counting birds accurately and the importance of being confident in their survey technique where the accuracy of the measurement may be influenced by the vegetation management strategy. For example, it may be expected that counts for some species may be biased or less accurate in sites that are `thickened' and more difficult to walk through. In these cases, it also may be harder to determine whether birds detected occur on or off the survey site. Some exploratory ordination analysis has been completed by the researchers on field sites where the same bird survey protocol has been used in geographically different (but structurally similar) areas. Two dimensional species assemblage patterns were largely consistent whether researchers used abundance of individuals, species presence/absence or species presence/absence including off-site records. Results using presence/absence data may be expected to be more robust against the above detectability issue and the general agreement with abundance data provides some reassurance about these survey difficulties.

There is a variety of vegetation habitat measurements recorded across the 1ha sites. The usefulness of these measurements in helping to meet the project objectives should be assessed with the aim of discontinuing those that are not likely to be helpful.

Summary

The Desert Uplands study has a limited ability to meet its objectives. Opportunities to contrast the effects of vegetation clearing with unmodified woodland is restricted to one property, and since 2009, with three properties remaining in the study, this also will be the case for comparing thinning with unmodified vegetation into the future. It is expected that confounding between management strategy and whole-of-property, land zone or other effects, and variation in the methods and timing of historical clearing and thinning activities will make it difficult to reliably estimate effects of interest. It would be hard to implement an experimental study in such a pastoral landscape, and here, cause-and-effect relationships cannot be clearly identified from this observational study. The lack of probability-based sampling in site selection means the dependability of applying study conclusions across the broader subregion and bioregion is reduced.

Desert Ecology Plot Network

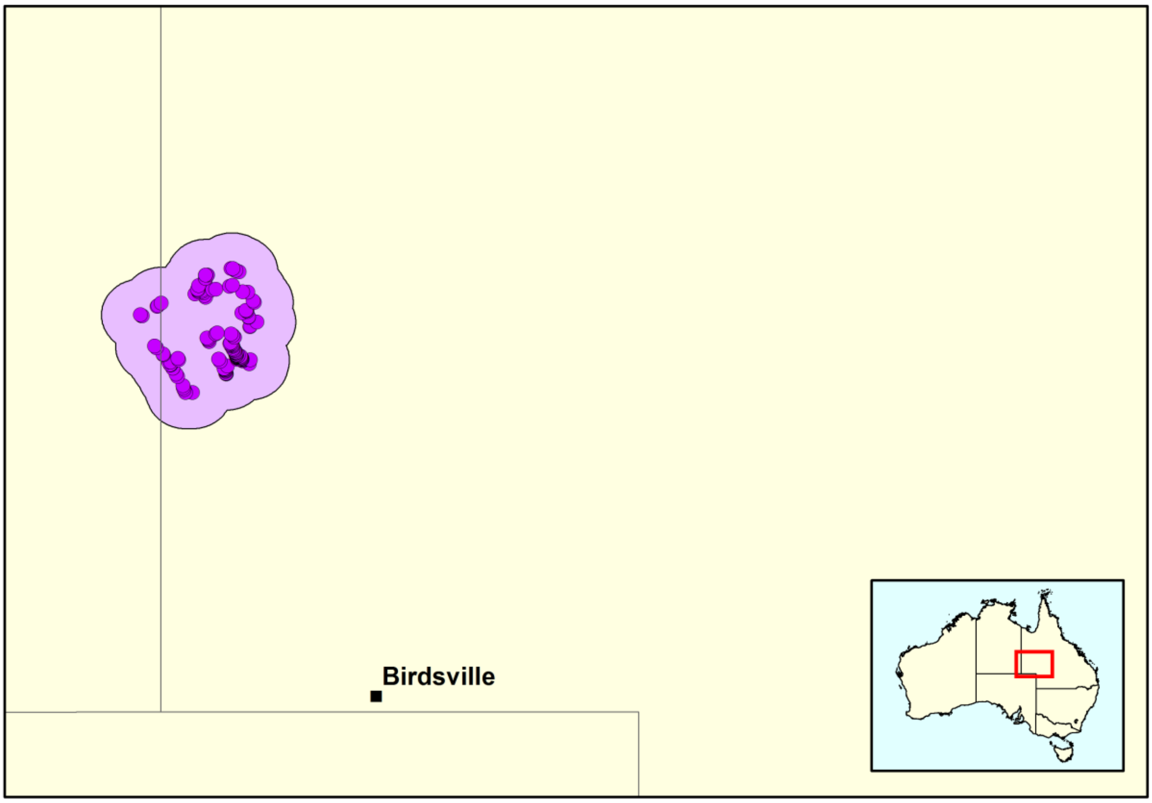

Figure 15: Desert Ecology plots within LTERN
The lighter shading seeks to highlight the distribution of plots and does not indicate an effective study area.

Background to the project

The Desert Ecology Plot Network is located in the Simpson Desert in central Australia and aims to track long-term shifts in biodiversity and ecological processes in relation to key drivers including unpredictable rainfall and droughts, fire, feral predators and grazing. A key motivation for undertaking the work in the Simpson Desert was the largely unfragmented nature of the native vegetation communities. The Desert Ecology Plot Network has gathered data on mammals, reptiles and frogs in the Simpson Desert since 1990. While several sub-projects have been, and are being undertaken by the researchers in the Simpson Desert, including manipulative experiments, the focus of this review is only on annual collection of pitfall data as this component of their overall research program has been nominated by the researchers as a discrete component of their work that is TERN funded.

Objectives

The objectives of the Desert Ecology Plot Network is to examine long-term patterns in the relationships between elements of biodiversity and rainfall, fire, feral predators and grazing.

Research Questions

The key research question that the scientists are examining includes: how will increased climate extremes impact on the dynamic network of interactions among species and their role in maintaining biodiversity?

Study Design

Currently, the Desert Ecology Plot network uses a core of 12 sites with two 1ha trapping grids, or plots (for mammals and herpetofauna), at each site. The 12 primary sites are spaced at least 15 km apart, with a weather station at each site. Trapping grids within sites are spaced between 0.5-2 km apart. Vegetation attributes are also recorded at selected point across the trapping grids.

The researchers chose the general study area because they were looking for a relatively intact region to locate their trapping sites. In contrast to areas of NSW, Queensland pastoralism was regarded as being less intense. No randomisation was used for site selection and factors influencing the location of sites, and trapping grids within sites included: the intactness of the vegetation community; the species richness of the small mammal community (as indicated by fauna tracks in the sand); and logistical reasons--it was important to be able to obtain fresh water. In addition, a criteria was to place grids a minimum distance of 10km away from water bores to minimise degradation of the vegetation by cattle and also to minimise trampling of the traps by cattle.

Measurement protocols

Within each of the 24 grids, thirty-six pitfall traps are arranged in a grid covering 1 ha. Each grid comprises 6 lines of 6 traps spaced 20 m apart. The top line of traps extends along the dune crest, where consecutive numbering starts, and finishes along the sixth line 100m distant in the dune swale. Traps on each grid are opened for 1-6 nights (usually 3) during Autumn and checked in the mornings and sometimes afternoons. Animals are removed for processing (weight, size, reproductive status). To increase trap success, by intercepting and guiding surface-active animals into the trap, a drift fence of aluminium wire mesh (flyscreen) extends outwards from the top of each trap, secured in place by means of a shallow trench. The fence is 30 cm high and runs for 2.5 m on each side of the pitfall opening. The bottom end of the pit is covered with flyscreen to form a floor to prevent captured animals from digging their way out, and all pits are capped with metal lids when not in use. A tiny amount of pyrethrum-based insecticide is sprinkled around each trap to prevent ant attack.

Vegetation measurements are made at 6 trap locations on each grid (at one trap on each of the six trap lines). Trap locations at which vegetation measurements are made were selected systematically from one end of the dune crest trap line running in a diagonal orientation down across the face of the dune slope to the trap location at the other end of the dune swale trap line. Within a 2.5m radius around each of these six traps, a vascular plant species list is compiled and cover estimates are made to the nearest 5%. The amount of flowering and fruiting for each species is scored using a five-level ordinal classification.

A combination of ground-based inspections and satellite imagery is used to identify fire extent and fire history across the study area. Other non-TERN funded study components are undertaken including camera surveys and sand plots for predators, more comprehensive vegetation surveys and invertebrate collection at a selection of trapping grids. Rainfall is highly variable across the study area and automatic weather stations are located at the 12 primary sites to record temperature and rainfall.

Analysis

A range of analysis methods have been used to explore the relationships between fauna and the variety of biotic and abiotic factors in the desert environment including graphics, ordination techniques, linear models, and auto-regressive hierarchical models.

Discussion

The 12 primary sites at which trapping takes place are well-separated being at least 15km apart. The origin of the 12 sites being this distance apart stems from an early predator study where the researchers wanted enough distance between the individual study locations to make it unlikely that predators would move between the 12 different survey clusters. This spatial separation stands to ensure that independent data is being collected from the 12 sites for the variety of the studies they undertake. Trapping grids within a site are placed between 0.5-2km apart and dependency in the data at this level may be accommodated through fitting a random 'site' effect in a mixed model approach to analysis. The subjective nature in choosing the location of the 12 primary sites, and the locations of the individual grids within them introduces the potential for inadvertent site selection bias. As a result, researchers should be cautious in extending their conclusions beyond their survey sites to the broader desert region.

Grazing and fire have occurred across the study area. The researchers believe that the area has not historically been subject to intensive grazing to any large degree. There is generally an east-to-west gradient of grazing across the broader study area corresponding to the progression in the establishment of tracks, then bores and then subsequently cattle. The researchers commonly score grazing pressure in their studies by using an ordinal (light/heavy) or nominal class (grazed/ungrazed). At a finer property level two properties were removed from grazing in 2004 and 2006, while the other two properties across the study area remain as grazing properties. The researchers have used dung counts from cattle to gauge grazing activity for some of their studies.

The researchers acknowledge that the scoring of species flowering and fruiting effort is subjective. To help minimise the variability that may come from having multiple observers recording these attributes, researchers use a small, experienced team to record the attributes and new staff spend extended time with the existing crew to ensure a consistent approach to recording is undertaken.

Summary

The Desert Ecology Plot Network has gathered data on mammals, reptiles and frogs in the Simpson Desert since 1990. The study area was chosen due to the native vegetation remaining largely unmodified by historic and contemporary grazing. Fire occurs periodically across the study area and can cover large areas. With the TERN-funded component of this research group being an observational study, cause-and-effect relationships cannot be reliably identified. The lack of probability-based sampling in site selection means the dependability of applying study conclusions across the broader region is reduced.

Mallee Plot Network

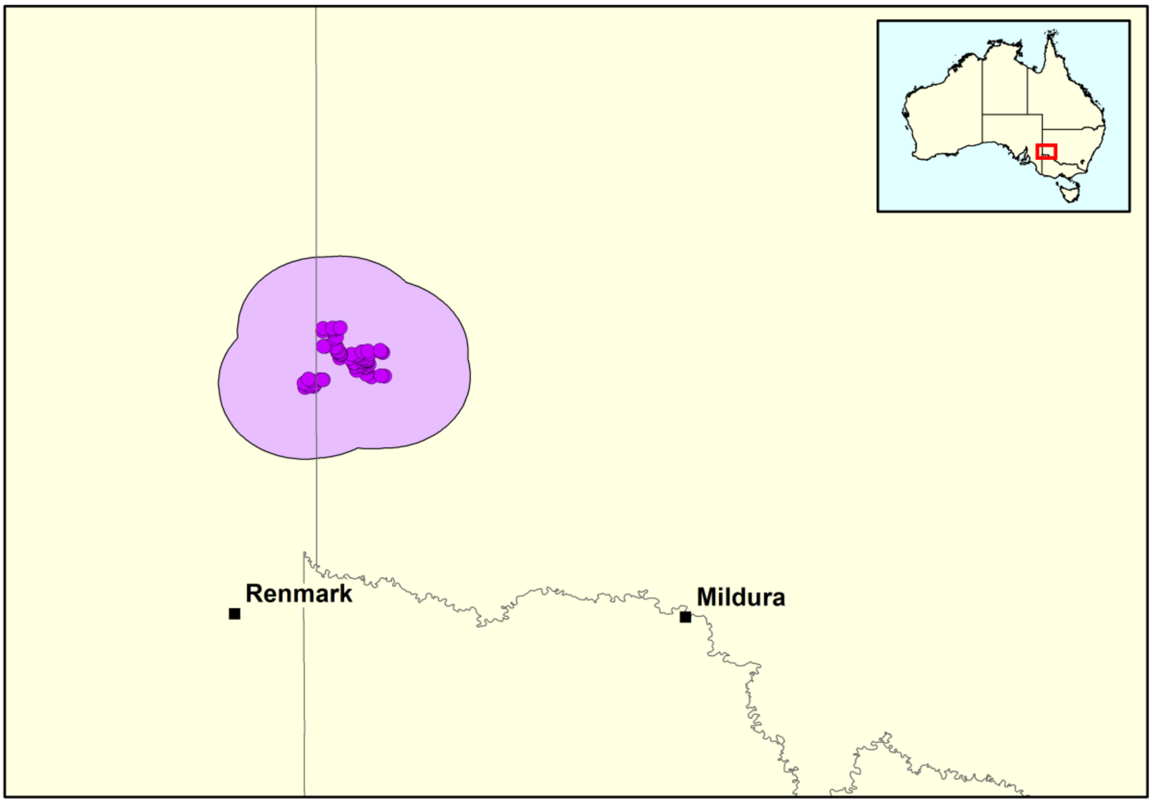

Figure 16: Mallee plots within LTERN
The lighter shading seeks to highlight the distribution of plots and does not indicate an effective study area.

Background to the project

The study area of the Mallee Plot Network is located approximately 120km north west of Mildura. Survey sites are located in NSW in Tarawi Nature Reserve and Scotia Wildlife Sanctuary and extend into South Australia within Danggali Nature Reserve. The study area sits on the south-eastern edge of the Australian arid zone. This location is close to the arid limits of distribution of the mallee woodland biome. Mallee woodlands typically occur within regions receiving 200-500 mm rainfall per year. The study explores the relationships between the dynamics of semi-arid mallee vegetation, fire regimes and grazing. The researchers plan to use the results to inform options for achieving conservation objectives.

Objectives

The Mallee Plot Network seeks to produce insights into the dynamics of semi-arid mallee vegetation by focusing on fire regimes, grazing regimes and climatic variation and the effect they have on distribution and abundance of plant species in the mallee over long time scales.

Research Questions

The research questions that the scientists are examining include:

1. How do fire regimes, herbivory and rainfall influence mallee vegetation dynamics?
2. Does plant diversity decline with long intervals between successive fires?
3. How long does it take mallee trees and shrub species to accumulate seed banks after fire?
4. How do survivorship and fecundity of different plant species vary with time since fire?
5. Do different herbivore species have contrasting effects on standing vegetation?
6. How does herbivore activity vary with time since fire?

Study Design

Fifty-three survey sites have been established on dune crests and upper slopes during 2000–2011. Twenty-nine sites are located within Tarawi Nature Reserve, 16 in Scotia Wildlife Sanctuary and eight in Danggali Nature Reserve. The researchers have constrained their study sites to dune crests and upper slopes due to limited resources and the lower flammability of swales (the topographical depression between two ridges), under prescribed fire conditions.

Progressively, in a staged process over several years (2000-2011), researchers have established herbivore-specific grazing exclosures, and associated control plots at survey sites. These have been established following various prescribed management burns (33 sites) or after wildfire events (19 sites). One of the established survey sites has remained unburnt. With wildfires being unplanned by definition, the procedure for establishing the survey sites following wildfire differs to that for sites established after prescribed burning. A preliminary pilot study was undertaken from 1996-1998, during which the design of the herbivore exclosures was developed.

For the survey sites located in areas burned by prescribed fire, site locations are largely determined by the Reserve Burning Plan for the conservation reserve. Reserve staff undertake burns to reduce the risk of large areas of the reserve burning out from the one fire event. With most of the large fires coming from a westerly direction, fuel reduction fires are commonly lit along north-south running tracks in the reserve to enhance the functioning of these tracks and the reserve immediately adjacent to them as fire breaks. While most of the fires run in a north-south direction along management tracks, the dunes (and swales) run longitudinally in an east-west direction. Fires lit from the track-side burn along the east-west running dunes to varying degrees. Most prescribed burns extend from the track less than one hundred metres while other unplanned fires may be more extensive, burning areas with dimensions of several kilometres. Within the constraint of locating survey sites on dune crests that are within scheduled prescribe burn areas, and commonly, for logistical reasons being close to vehicular management tracks—researchers stratified on fire history by choosing site locations within any given establishment year, that differed with regard to the time elapsed since the last fire. For example, of the four sites established in 2001 that corresponded to an April 2001 prescribed burn, two sites had been long unburnt (last burnt in 1918), and two had been burned more recently (last burnt in 1984). As part of the study objectives, researchers wish to investigate a variety of plant responses in relation to the interval between fires.

Based on planned prescribed burns by Reserve staff, researchers chose and marked out survey sites and commenced the implementation of a staged set of measurement protocols. Information on the measurements recorded in the field is provided in the section below, but the staged sequence in implementing the protocols may be considered part of the design and is described here. The staged protocols begin with:

a) a pre-burn vegetation survey 1-3 months before the fire;

b) within 1-3 months following the prescribed burn, five contiguous 15m by 15m fenced plots are erected to exclude all vertebrate herbivores;

c) approximately 12 months after the exclosures have been established a second vegetation survey is undertaken (the first post-fire survey);

d) within 1-2 months of the second survey the fencing is modified in the exclosures permitting access to selected herbivores across the five cells (all in, rabbit only, kangaroo only, all out (2)); and

e) approximately one year after the second survey above, a post-grazing vegetation survey is conducted.

As the study has continued over time, further post-grazing surveys have been undertaken at some sites. From the second survey, additional plots (three contiguous 13m by 7.5m) were established outside the exclosures where herbivores had uninhibited access to the vegetation prior to and after burning.

Prescribed fires varied in area from 1–70ha and were implemented in 2000, 2001, 2003, 2005, 2006, 2009, 2010 and 2011. Four sites were established in each of these years except 2005 (five sites), 2009 and 2010 (two sites each) and 2011 (eight sites). In some instances, scheduled fuel reduction fires did not precede but Reserve staff burnt small areas out for the researchers. Difficulties involved with working in a remote location, combined with other logistical challenges, has meant that there have been irregularities or delays implementing the staged design at some sites. Pre-burn surveys are not carried out at sites burnt by wildfire. During the main study (from 2000), wildfires occurred in 2006 and 2008 and varied in area from 70ha to 3000ha.

Measurement protocols

Two sets of plots are established at the survey sites. There are a set of five contiguous 15m by 15m plots formed by the fenced exclosures in a 3 by 2 configuration (with the sixth plot omitted). Within 5-10m of the fenced plots there is an L-shaped configuration of three external unfenced plots each measuring 13m by 7.5m. Selective exclusion of herbivores within the five-plot set is obtained through a combination of different wire fence and wire mesh construction at different heights.

The number of individuals of each vascular plant species are recorded in each of the 15m by 15m and 13m by 7.5m plots. The total counts made in each plot are aided by informally dividing each plot up into segments for logistical purposes. Counts of each species are recorded against six categories:

1) live reproductive plants;
2) live non-reproductive established plants;
3) fire-killed established plants;

4) plants that had emerged as seedlings or re-sprouted after fire and have subsequently died;

5) live seedlings less than two years of age; and

6) dead seedlings.

Within each of the eight plots, the heights of ten randomly selected *Triodia scariosa* hummock grass individuals are measured. Counts of macropod, goat and rabbit scats are recorded in all plots as an approximate measure of herbivore activity.

From Spring 2011, several additional attributes recording vegetation structure have been visually estimated in each exclusion and external plot. Collected primarily to provide supporting information, these currently include: single estimates per plot for: tree cover and height range; shrub height (median and range); shrub cover; hummock grass cover; ephemeral grass cover; leaf and twig litter cover and bare ground cover.

Automatic weather stations located at the homesteads at Tarawi Nature Reserve and Scotia Wildlife Sanctuary record: precipitation; temperature; relative humidity; and wind speed and direction. Before 1994, rainfall records had been maintained since 1941 by visually monitored rain gauge. Four additional manual rain gauges were established in Tarawi Nature Reserve in January 1997, a further five were established in May 2001, and two were established in Scotia Wildlife Sanctuary in September 2007. In May 2011, soil moisture probes were installed for monthly monitoring along two swale-to-crest-to-swale transects. The probes record soil moisture at depths of 100, 200, 300, 400, 600 and 1000cm below the soil surface.

Analysis

Other than some preliminary exploratory work, no analysis has yet been undertaken by the researchers on this project.

Discussion

The Mallee Plot Network is a repeated measures design with staged interventions implemented early in a site's survey history. The first intervention occurs between the first and second vegetation surveys and is a prescribed burn followed by fencing to exclude herbivores. The second intervention is the relaxation of selected herbivore access restrictions on the fenced exclosures, and occurs between the second and third vegetation surveys.

As a whole, the study uses a combination of wildfire and prescribed burning with herbivore exclusion to examine the relationships between fire and grazing regimes, and the abundance of plant species. Limited resources, and working in a remote location, means researchers are usually only able to visit twice a year. There are therefore logistical and financial difficulties in implementing the sequential survey design. Such difficulties include the limited capacity to set up multiple plots contemporaneously, inconsistencies in the duration of time that exclosures are fenced during stages of a survey site's establishment, gaps in the recording of soil moisture, and the inability to establish herbivore treatments at some sites. Factors beyond the researchers control include, necessarily, by definition, no pre-fire surveys on wildfire sites.

Reflecting the scheduling of Reserve fuel management burns, and the limited resourcing for the researchers—study sites have been established progressively over the duration of the project from 2000 when the formal study commenced. Commonly, four sites, but sometimes more, are established within a year. The staggered, multi-year aspect of establishing the sites means response data obtained from particular stages of the experiment—e.g. the first post-fire survey where all herbivores are excluded—are collected in different years. For example, for sites established in 2001, the first post-fire survey was undertaken in 2002, and for sites established in 2007, the first post-fire survey was undertaken in 2008. Within a fire history class (e.g. long unburnt before the prescribed burn treatment), there may well be substantial differences in plant responses although the two measurements may be considered replicates for early post-fire response on a long unburnt dune crest. The rainfall during different times of the project can be expected to cause such differences. Researchers are well aware of the role that rainfall can play in the regenerative response of the vegetation, and will use the rainfall data they have collected when interpreting and analyzing data from their study. The researchers feel the staggered nature of establishing the sites over several years is a useful feature of the study as it has enabled them to obtain some 'early treatment data' in years where rainfall has been higher than what was commonly recorded when the project first commenced.

Constrained by practical aspects of conservation reserve management, the location of the survey sites have not been selected randomly. Site locations were constrained by the location of dune crests (by design), and by the location of fire boundaries. For the prescribed burns, there are logistical constraints such as ignition points originating from a management track. For the 'prescribed fire sites,' the available pool of dune crests as sites for selection was determined by the Reserve Burning Plan. In considering whether the opportunistic manner of site selection has resulted in any bias in the sites that they are using, the researchers have documented or considered attributes like: distance from each site to the permanent watering points and watering soaks on the reserve; grazing history of different parts of the reserve; and effects associated with working adjacent to fire trails (e.g. past vegetation clearing activities). Another aspect the researchers have considered, which may influence plant growth or survival, is the vegetation's ability to access soil water. The researchers believe that this may be influenced by differences in terrain or dune crest height. That is, plants on the higher, more elevated dunes, may have reduced access to water through their roots compared to lower, less well-defined dune crests. The researchers are seeking to address or accommodate this potential issue by choosing a mix of sites across both high and low dunes where they have been able to do so. The researchers have given considerable thought to factors that are not part of their study design, but that may influence the plant responses they are interested in. The researchers feel confident that despite some distinctions across the study area, their survey sites provide a firm foundation on which to draw conclusions across the population of dune crests in the landscape they are working. It is useful to think deeply about (known) factors that may influence the response variable you are interested in. However, without some form of randomisation being used to select survey sites, the potential for inadvertent bias is introduced. For selection of survey sites from a pool of those available, whether stratified by a design variable or not, incorporating some element of randomisation offers insurance against bias from unknown factors that may influence the response variables of interest. It is therefore recommended that researchers use caution when generalising their results across the population of dune crests they are interested in.

There are several research questions that the scientists are interested in, and irregularities in establishing the staged design at some sites doesn’t mean data cannot be used productively from such sites. For example, where inadequate resourcing meant herbivore exclosures couldn’t be established at the Danggali Nature Reserve sites, data can be still be used effectively to examine questions of vegetation response to fire (while accounting for differences in fire histories between sites). While investigating herbivore treatment effects is an important focus of the study as a whole, the researchers anticipate that subsets of the data will be used to examine different research questions of interest.

Through the repeated measurements undertaken at the sites, there will be some dependency in the data. It is recommended that researchers investigate analytical approaches that accommodate this temporal dependence such as a random effects modelling, and which reflects the structure of data collection.

Field work is demanding in the Mallee Plot Network with long days of reasonably high temperatures spent on tedious tasks such as the counting of thousands of post-fire seedlings across the plots. There is often uncertainty in the work, such as the identification (and counting) of fire-killed shrubs. The researchers acknowledge the difficulties in parts of their field work and appear to be realistic about the confidence they should have in their measurements where these challenges arise.

Summary

The Mallee Plot Network is an ambitious but thoughtfully designed project that seeks to examine several aspects of Mallee vegetation dynamics in relation to fire, herbivory and rainfall. The large investment of time in censusing all vascular plant species is uncommon, and combined with the largely consistent application of herbivore exclusion and burn treatments, stands to return a unique dataset. With the focus on fire, constraining the study sites to more flammable dune crests is understandable, and accordingly, research findings will be limited to those parts of the landscape. The opportunistic (non-randomised) manner in which study sites were selected reduces the dependability of applying study conclusions across the broader extent of Mallee vegetation.

Upland Heath Swamps Plot Network

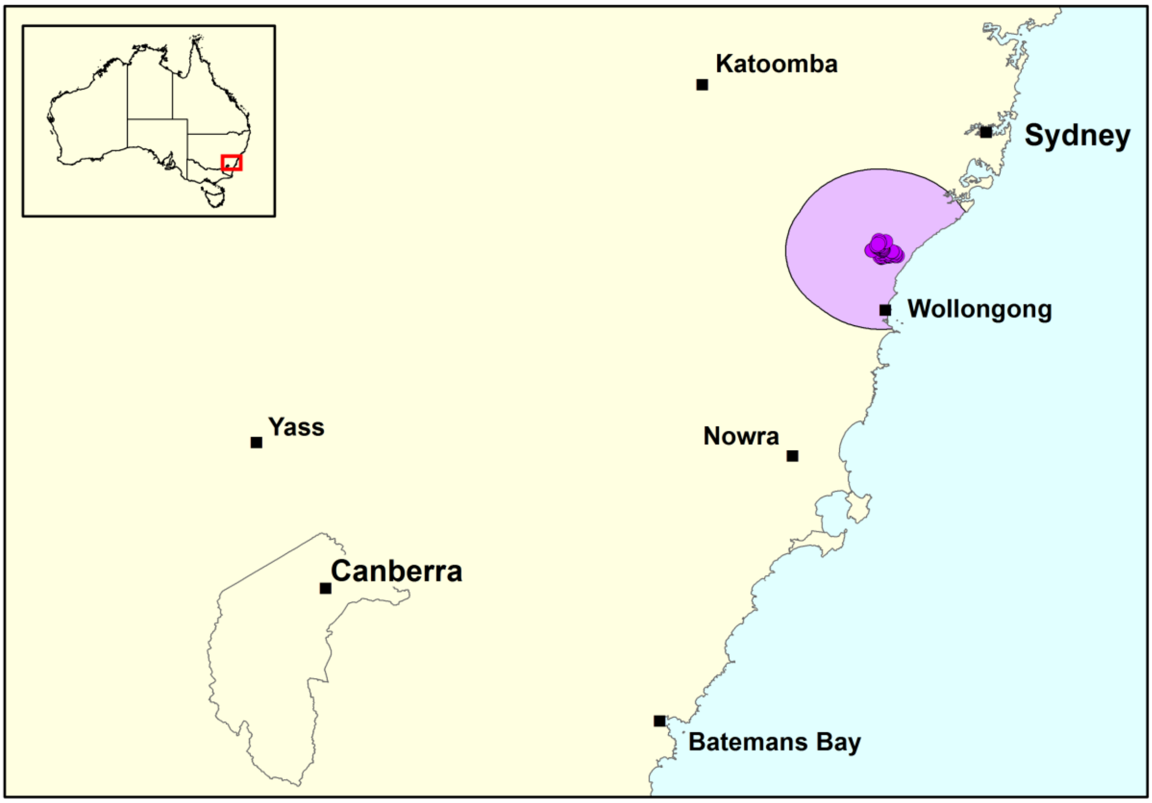

Figure 17: Upland Heath Swamps plots within LTERN
The lighter shading seeks to highlight the distribution of plots and does not indicate an effective study area.

Background to the project

The Upland Heath Swamps Plot Network is located on the Woronora Plateau west of Stanwell Park, which is located approximately 50km south of Sydney. The Upland Swamps of Woronora were poorly surveyed and an original motivation for undertaking this project was to describe the vegetation communities and examine the relationships between vegetation and soil, and vegetation and soil water moisture. The study takes place in O'Hares Creek Catchment, near Darkes Forest.

Objectives

The objective of work in the Upland Heath Swamps Plot Network is to improve understanding of the roles of climate, substrate and fire regimes in the dynamics and persistence of upland swamps and their biodiversity.

Research Questions

The research questions that the scientists are examining are:

1. How do environmental moisture gradients structure the diversity of heath and sedgeland vegetation within upland swamps at local and regional scales?
2. What structural and compositional changes are occurring in the vegetation of upland swamps?

3. What are the effects of alternative fire regimes on upland swamp vegetation and how can responses be characterised by trends in functional groups of species?

4. What models of ecosystem dynamics best explain and predict changes in upland swamps and their biota in response to changing climate and fire regimes?

Study Design

Following field-based assessments, vegetation structure for the Upland Heath Swamps Plot Network was classified into three categories based on shrub height and extent of lateral branching. As soil moisture varied substantially across the study area, researchers identified three soil drainage classes: dry upper slopes, intermediate seepage slopes, and wet seepage zones. Sixty survey sites were allocated in a crossed design across the nine strata represented by the three classes of soil moisture and the three classes of vegetation structure. Within each site, a 0.5m by 30m belt transect comprising 60 contiguous 0.5m by 0.5m quadrats are orientated along the contour, perpendicular to the drainage gradient. Placing the transect in this manner helps ensure that the survey measurements for a site corresponded to the nominated soil moisture class. Visual assessments are made to ensure belt transects are placed in an area that is typical or characteristic of the soil moisture /vegetation structure class.

The sites were originally surveyed in 1983. Examination of the 1983 data showed that the floristic relationships between the 60 sites could be adequately retrieved if species frequencies were only calculated from 30 quadrats within each transect. As a result, researchers chose to use only the first 30 quadrats of each transect (0.5m by 15m belt transect) for future surveys. Vegetation surveys were repeated in 2004, 2009/2010 and 2014. The next census is scheduled for 2019 or within 12 months of the next bushfire, whichever occurs first). The Upland Heath Swamps Plot Network now comprises 54 sites due to six sites being removed from the study because they were either located on private land, which was subsequently developed, or the sites could not be relocated with certainty following the initial 1983 survey as stakes/markers were subsequently consumed in wildfires.

Measurement protocols

Each survey site in the Upland Heath Swamps Plot Network is a belt transect of 30 contiguous 0.5m by 0.5m quadrats, in which presence/absence of all vascular plant taxa is recorded and tallied to give a frequency out of 30. Quadrats are marked in the field by two steel pickets at either end of the belt transect, and plotted on a 1:10 000 aerial photograph.

On each survey occasion, vegetation structure is measured by estimating the height and canopy cover for both the shrub and herbaceous layers of the vegetation and by calculating a light penetration ratio for the vegetation canopy. Height and canopy cover values were estimated within the first quadrat (0m), in the 10th quadrat (at 5m), in the 20th quadrat (at 10m), and in the 30th quadrat (at 15m). The four values for each attribute are then averaged to record a value for the transect (site).

Light intensity was measured with a light meter on cloudless days close to noon above the vegetation canopy (i.e. direct sunlight) and below the vegetation canopy at ground level from four randomly selected locations within a transect. Duplicate samples of surface soils (0-7cm depth) are collected from a stratified random subsample of transects from the nine combinations of the moisture-by-vegetation classes for analysis of exchangeable cations, pH, electrical conductivity (EC), water content, total phosphorus (P), total iron (Fe) and nitrate (NO3).

The fire history from the mid-1960s to the present has been compiled from records and maps. Since 1982, fire occurrences have been verified by personal observations. Hydrological climate variables are monitored adjacent to, and within 5km of, the study area at Bureau of Meteorology and Sydney Catchment Authority facilities. In 2013, three automatic weather stations were installed across the study area. The stations record data for precipitation and pan evaporation at 30-minute intervals. In addition, three soil probes placed along local soil moisture gradients in the vicinity of each station record soil moisture, conductivity and temperature at depths of 10, 20, 30 and 40cm below surface at 30-minute intervals.

Analysis

In exploring the relationship between vegetation, soil and fire history graphics, ordination, cluster analysis, regression and hierarchical models have been used by the researchers.

Discussion

With the researcher's key interest in examining the relationship between vegetation, substrate and fire, they used soil moisture and vegetation structure as design variables to help more clearly identify the relationships between these variables. The stratification uses three classes of soil drainage: drier upper slopes, intermediate seepage slopes, and wet seepage zones. Vegetation structure is distinguished by three categories based on growth forms in the shrub stratum: all shrubs short and slender, a mixture of slender and spreading short shrubs, and tall spreading shrubs mixed with various short shrubs. Two soil by vegetation structure combinations are not available across the study area: tall and short shrubs on intermediate seepage slopes; and short slender shrubs only on wet seepage zones. Within strata, the location of survey sites is chosen subjectively, with the number of sites representing the combination of the two design variables approximately corresponding to the spatial coverage of the respective classes. The use of design variables to more clearly provide contrasts between sites of different vegetation structure and soil moisture levels is a useful approach. The lack of randomisation in selecting the location of the survey sites within stratum introduces the potential for inadvertent bias.

Summary

The Upland Heath Swamps Plot Network is a stratified observational study that uses design variables of vegetation structure and soil moisture to explore the relationships between vegetation, soil, fire and rainfall in the poorly documented Upland Heath Swamps vegetation community. While the stratified design is likely to help identify the relationships between key variables of interest, being an observational study, confounding is likely to remain among the variables making cause-and-effect relationships difficult to identify.

Australian Transect Network

Here we provide a review of three ATN projects. Initiatives within the ATN which are not funded by TERN were not subject to the review.

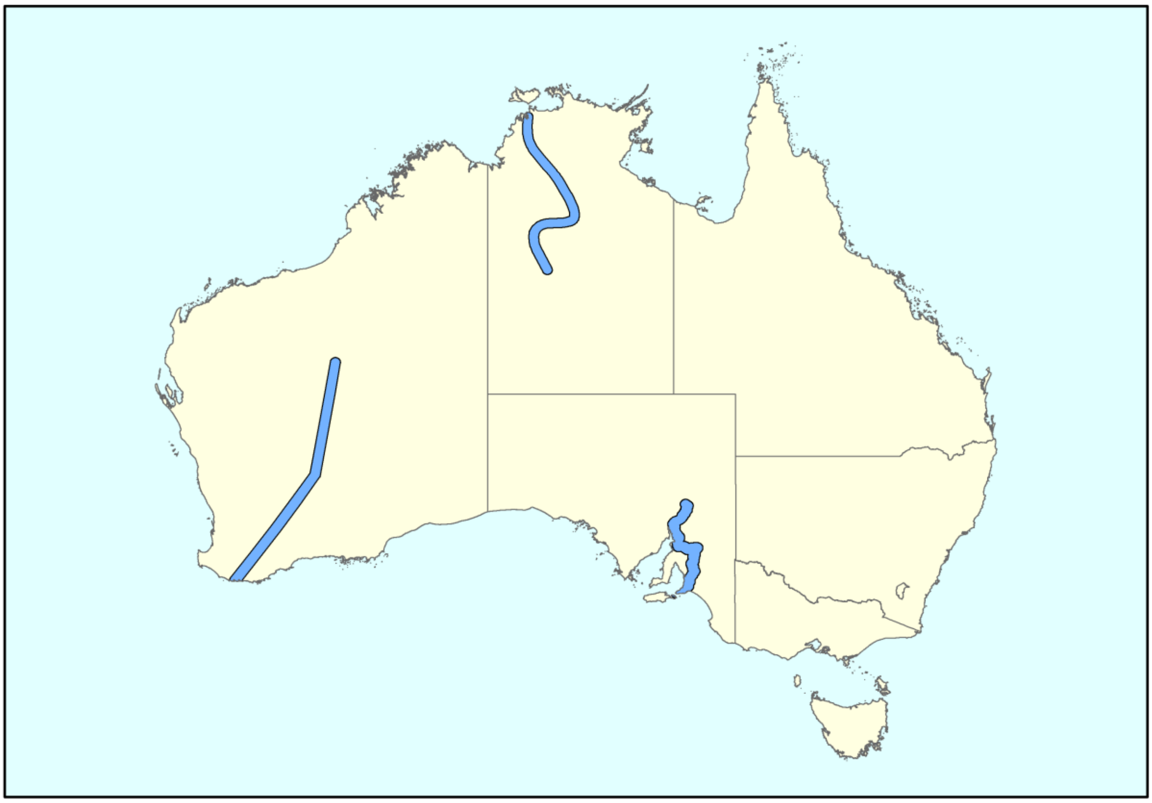

Figure 18: Spatial distribution of transects within the ATN within TERN
The shading seeks to highlight the general location of the study sites.

South Australian TREND

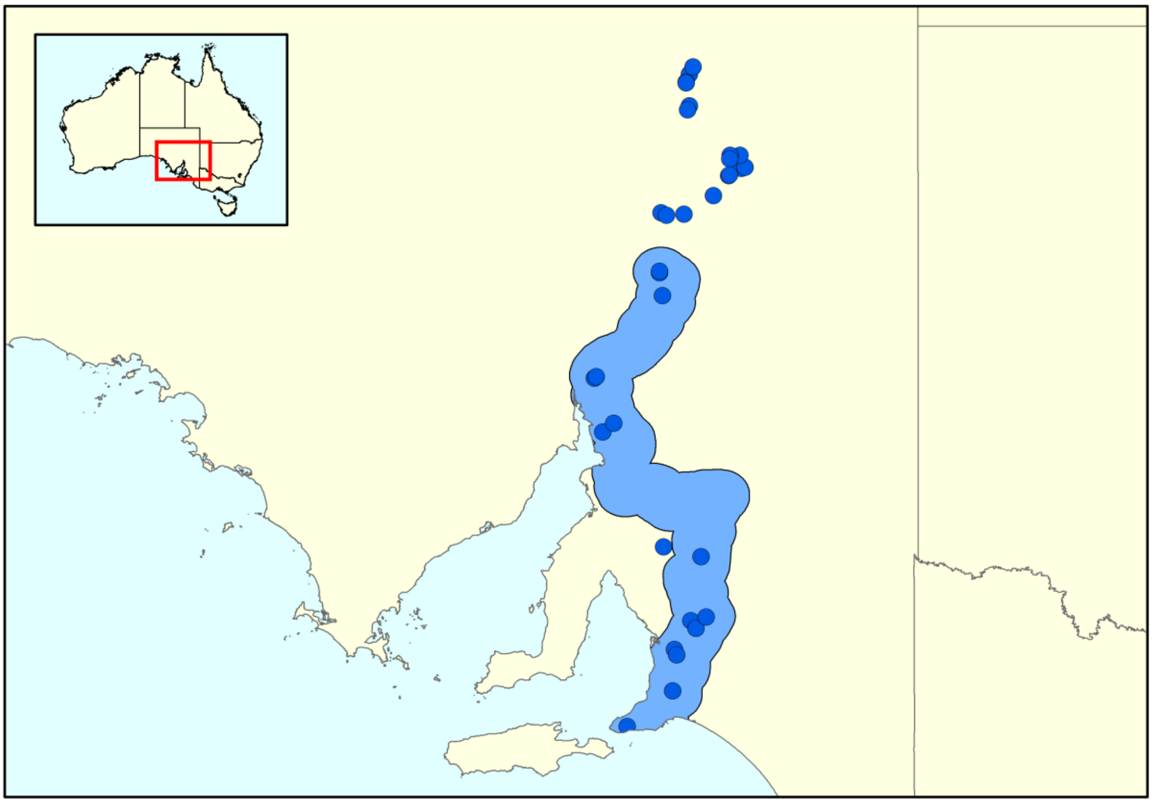

Figure 19: Plot locations within the South Australia TREND Transect network
The shading seeks to highlight the distribution of plots and does not indicate an effective study area.

Background to the project

The South Australian Transects for Environmental Monitoring and Decision Making (TREND) has been established to explore how climate change may influence species and genetic composition. The focus is on vegetation community composition, and for selected flora species, the genetic composition, measured at field plots along the Adelaide Geosyncline east of Adelaide. The researchers have chosen the ranges of the Adelaide Geosyncline because they are an iconic, biogeographically isolated landscapes that have high biodiversity and are potentially vulnerable to climate change. Within the ranges of the study area, there are isolated pockets of more mesic (wetter habitat) species that also occur in other parts of south-eastern Australia. There are also endemic species that occur in these restricted areas. Part of the motivation for undertaking the work is to help understand how resilient these species are likely to be to climate change given they are presently confined to restricted, more mesic areas.

There are two components to the project: a set of 85, 30m by 30m plots organised into 17 clusters of five plots ('clustered plots') and 40, 1ha Ausplot Rangelands plots ('Rangelands plots'). The two sets of field plots are overlapping and have been geographically distributed along the approximately north-south orientation of the Adelaide Geosyncline to collect field measurements over a mean annual temperature gradient.

Objectives

The overall focus of the South Australian TREND project is to establish infrastructure (a set of field plots with the collection of foundational data), that lies along a rainfall gradient across elevated ranges to help investigate the potential effects of climate change. For the 'clustered plots' more specifically, an objective of the project is to investigate climate change impacts by examining the influence that climate-related variables (versus landscape and geographic factors), have on community and genetic composition.

Research Questions

The research questions that the scientists are examining are:

1. How does species composition respond to spatial variation in climate? What are the implications of temporal climate change for species composition?
2. Does the rate of species turnover vary along climate gradients, and can this be used to identify vulnerable ecosystems and refugia?
3. Do species assemblages in the Flinders Ranges represent climate change analogues for the cooler, wetter Mount Lofty Ranges?

Study Design

For the 'clustered plots' part of the South Australian TREND project, the researchers chose a constrained temperature envelope around significant vegetation communities as the key framework to design the project. Within this spatial envelope (represented by a set of mean annual temperature values), the researchers established survey plots in clusters of five following consideration of a range of environmental, logistical and administrative factors in deciding where to place the plots (see below).

The cooler climate communities that were of interest to the researchers from the start of the project, provides an illustration of how the plots were established. Two-three degrees of warming may correspond to the loss of species with communities along the mesic (wetter)-arid ecotone more sensitive to loss than species within more mesic communities.

Using interpolated WorldClim mean annual temperature values with a 1km resolution, researchers identified where these cooler climate communities presently occur in the ranges. They then delineated a 2-3 degree envelope around these areas to produce an expanded extent that included the current cooler climate areas plus additional areas characterised by those warmer (present) mean annual temperature values. This exercise provided a spatial extent that was 2-3 degrees warmer than that represented by the present cooler climate communities and provided the range in mean annual temperature (and corresponding geographic area), that the researchers chose to use as the basis for examining the effects of climate change. The temperature envelope described by the above approach was later expanded from 2-3 degrees to about 5 degrees with plot clusters placed in locations that represented a broader range of temperature values than was initially planned with the 2-3 degree envelope. Other bioclimatic variables were also considered (e.g. rainfall, summer maxima), but were not formally used in the process. Established plots now span a mean annual precipitation range of 800mm or more.

Within the geographic area delineated by the above temperature envelope, researchers established 85, 30m by 30m field plots grouped into clusters of five plots. Key considerations that researchers made when deciding where to place survey plots included: avoiding degraded habitat (areas that were grazed and heavily fragmented); maintaining consistent landscape positions (mid to upper slope and aspect); public land or other secure areas for continued access; and a preference for locating sites where previous SA government biological surveys had been undertaken. Only a small proportion of the plots where placed at sites where earlier survey work had been completed as the purpose of the earlier surveys and their plot selection protocol was fundamentally different from the current project. For the current project, it is understood there was no emphasis on locating plots next to access tracks for ease of access. On the contrary, trails and access tracks were actively avoided with some plots located in relatively remotely areas of the ranges.

Some effort was made by the researchers to locate the plots within relatively large blocks of vegetation where the structure and floristics of the communities did not change abruptly across that general area. The researcher's motivation for this preference was the desirability of having a relatively homogenous area that could be investigated for detecting change, but partly also was based on advice from other TERN scientists that it would be helpful to have a good size block of consistent vegetation to assist with remote mapping applications of the data. Researcher's reported that an additional motivation for selecting comparatively large blocks of vegetation was to enable the establishment of larger 1ha plots within areas of homogeneous vegetation.

Once an area had been identified as being suitable, the location of the five plots within a cluster was separated as much as possible depending on the extent of the community at the site. This was difficult in some places, particularly in the south, where topography (and correspondingly the vegetation type), can change abruptly over short distances making separation of the plots within a cluster more difficult. The researchers believe there is no systematic pattern to these difficulties. That is, plots within a cluster are not more tightly grouped in the cooler south, and more spread out in the warmer north. There is generally a mix of how effectively sites can be separated across the study area. For the placement of the five plots within a cluster, while there was an interest in capturing the heterogeneity of the vegetation at the location, there was no deliberate attempt to locate plots so as to encompass as much diversity as possible. In this sense, the sampling may be described as 'haphazard', where there is an effort to distribute the survey locations across the area in an informal, non-systematic way, and there is no demonstrable element of randomisation used in the process. Within a cluster, plots were generally within 500m of each other.

There are currently 17 primary clusters distributed over a distance of approximately 600km. The sites receive mean annual rainfall between 275-1100mm. Current plans are to periodically re-measure the plots but the researchers do not have a frequency scheduled.

For the 'Rangelands plots', the locations of the field plots were determined within the Ausplots Rangelands site selection framework. That is, within a 21-strata bioregional grouping, a number of factors were used to determine which bioregion within the strata should be surveyed. Factors influencing the decision included the presence (absence) of historically collected data, dominant land uses, logistical considerations, ease of access and the likely ability to have continued access to sites. Following the decision on which bioregion within a stratum should be surveyed, information was collated about the respective bioregion to identify areas of interest that could motivate site selection. Similar considerations made in deciding which bioregion to survey, were used also to help decide where within the selected bioregion the plots should be placed. For example, there may be preferences for conservation reserves where access is secure, types of historical land management, and/or for typical examples of both common and more restricted vegetation communities.

For this project, the locations of the existing 'clustered plots' were considered when deciding on plot placement, just as consideration of the presence of historical (largely, pastoral) monitoring plots, was considered during plot establishment for the AusPlots Rangelands project. Additional information on the framework used for site selection for the 'Rangelands plots' can be found in the AusPlots Rangelands section of this report and in White *et al.* (2012).

It is understood that at least 13 of the 40, 1ha 'Rangeland plots' have been located adjacent to a corresponding number of the established plot clusters. Approximately half of the 'Rangeland plots' are located north of the 'cluster plots', extending the temperature range of the plots further into higher temperature regions of the ranges.

Measurement protocols

For the 85, 30m by 30m 'clustered plots' within the South Australian TREND project, vascular plant species presence on the plots was recorded through a comprehensive (untimed) search and a visual estimate of projected foliage cover to the nearest 5% was made (scored 1% as present but having low cover). A voucher specimen and a tissue sample for genetic analysis of each species was collected at each plot cluster. Aspect and slope were recorded and the percentage surface cover of stones and outcropping rock was visually estimated at each plot. Top soil was collected from four random locations across the plot and then mixed to provide the one bulk sample.

For the 'Rangelands plots' within the South Australian TREND project, the Ausplots Rangelands Survey Protocols Manual provides an illustrated description of the field measurement protocols used in the program (White *et al.* 2012). Only a brief summary is provided below of the Ausplots Rangelands protocol that was used.

The point-intercept method was used across the 1 ha plot at 1010 points along 10, 100m transects where intercepts were recorded at 1m intervals to provide cover estimates of individual species, total vegetation cover, and cover of different substrates (bare soil, litter, rocks). A full vascular plant species list is also compiled for the plot. Heights of canopy-intercepts were also taken during this exercise. Estimates of basal area for each woody species >1.3m height were taken at 9 points throughout the 1ha plot using sweeps with a basal wedge.

A five minute vegetation structural summary was made by recording the three most dominant species in the upper, middle and lower strata. As part of the protocol, an estimate was made of the shortest distance `to a different vegetation community' from the centre of the plot. It is understood this latter estimate was made to help with remote sensing validation, and was also undertaken for the ‘clustered plots’. Voucher specimens are taken for each vascular plant species with a sub-sample of leaves taken for genetic profiling. Photo-panoramas were obtained from three photo points located near the centre of the 1 ha quadrat. Up to 120 photographs may be taken from a plot with researchers indicating that developing technology for 3D reconstruction from the photos provides opportunities for estimating basal area and biomass for the photographs.

Ancillary data taken on behalf of other researchers includes leaf area index (AusCover) where conditions are suitable and equipment is available, and a variety of soil characteristics and samples (CSIRO). Some of the soil procedures require a soil scientist. The researchers estimate that marking the plot and recording the vegetation attributes, including the photographs, takes between 7-8 hours plus another 3 hours for the basic soil survey (or 6 hours if the full soil survey is undertaken by a soil scientist).

For the 'Rangelands plots', surveys were undertaken by teams trained in implementing the AusPlots Rangelands field protocol. It is unknown how many personnel were involved.

Analysis

For the 'clustered plots', a range of analyses has been undertaken to explore the relationships between changes in species composition and climate and geographical factors including, graphical, ordination and generalised linear mixed models. No approach to analysing the data from the 'Rangelands plots' has been nominated by the researchers. This is likely to be because, like the AusPlots Rangelands project, the plots have been established primarily for other scientists to use. Genetic analysis is also being undertaken from material collected at the 'clustered plots'. Information was requested on these methods but it is understood they were in development at the time of the request.

Discussion

For the 'clustered plots' part of the project, the researchers have chosen to focus their attention on a relatively constrained part of the temperature envelope of the ranges of the Adelaide Geosyncline. This seems like a sensible idea where limited survey resources have been directed to a part of the State where variation in elevation along a north-south running temperature gradient provides an opportunity to explore the relationship between temperature and species (genetic) composition while seeking to account for factors associated with geographic distance.

The underlying approach for undertaking the work are plots largely located on the ridges and mid and upper slopes of the ranges. The researchers acknowledge that these are the geographic communities they are interested in and that this limits opportunities to extend conclusions about the relationships they find to areas of lower elevation on the plains and lower slopes. Concentrating the work on a relatively narrow temperature range provides a more manageable project to work with, although the geographic (and taxonomic) relevance of the work is also reduced.

The researchers regard a key part of working in the ranges is the ability to vary the locations where survey plots were located along the latitudinal breadth of the ranges. In doing this they sought to take advantage of variations in elevation to try and reduce the confounding between temperature and factors associated with geographic distance. That is, instead of relying on comparing 'cool' sites in the south with 'warm' sites in the north, there were some opportunities to place 'cool' sites at high elevation in the north relatively close to 'warm' sites. In doing this the researchers were seeking to diminish the confounding that geographic distance and associated factors may have with temperature in influencing community composition (- the response of interest). It is expected this approach may be useful in isolating the effects of interest, but being an observational study and with opportunities to try and segregate effects being limited, it should be expected that confounding will remain among variables. The researchers are aware of this and that caution is required when interpreting results where multicollinearity is present in a statistical model.

The 'clustered plots' and 'Rangelands plots' are two different survey protocols with the location of plots determined by different people with different motivation. However, the researchers stress that the two sets of plots provide complementary data along the same temperature gradient where the 'Rangelands plots' provide detailed soil and vegetation composition and structure data, while both plots have recorded plant voucher specimens and plant DNA samples. Within the framework of a temperature gradient that was specified at the commencement of the study, researchers have used personal judgement in deciding the general area to survey, and subsequently, where specifically to place plots on the ground. As discussed above, a range of considerations were made in deciding where to establish plots including those related to ecological and land use factors. The use of personal judgement to select areas for survey is likely to introduce an unknown bias into the site selection process. As a result, the set of sites do not provide a secure basis for generalising results across the broader area of the ranges where the plots are located. The use of probability-based sampling, with some element of randomisation, is the mechanism to avoid site selection bias. Commonly, in ecological studies, scientists work within practical constraints. In these cases randomisation should be employed *within* the constraints that apply. For example, a restriction may be to have a minimum (and maximum) distance between replicate plots. In a similar way, if environmental gradients are of interest, stratified random sampling provides a more secure basis for inference than purposive (non-probability) sampling along the gradients. It is recommended that researchers exercise caution when generalising their results beyond their survey sites. Where the focus is on examining relationships across least-modified plant communities, working in regions where native vegetation cover is heavily fragmented or is typically degraded, limits the available sites on which survey plots can be established. It is understood that this is a reality of working in these systems, but those circumstances do not diminish the benefit of employing some element of randomisation in field survey site selection.

The researchers have remarked that they have adopted a *space-for-time* approach in investigating the potential effects of climate change with the 'clustered plots'. This has been a commonly used approach in the past for analysing some types of ecological data, where contemporaneous measurements are made at sites of different ages to infer an effect or pattern over time. In the conventional, successional-type applications in which it is commonly used—say, to examine the influence that different forest regrowth age may have on species presence—there are assumptions in using the approach including the uniformity of historical management or condition of the study sites. *Space-for-time* substitution applications are cross-sectional, observational studies and confer no additional inferential benefits above these types of common designs. For example, there is still a risk of confounding variables being present, and there is an inability to ascribe cause-and-effect relationships. In these respects, unresolvable difficulties remain for confidently identifying trends over time. As with other cross-sectional studies, the approach is useful for exploring associations and examining what factors may have an influence on the response of interest. A lead researcher with this project is aware of the limitations of the cross-sectional approach and acknowledges that some questions can only be examined by long-term monitoring programs.

For the 'clustered plots', spatial dependence has been deliberately introduced into the plot design layout to investigate the change in species composition over distances from hundreds of metres to hundreds of kilometres. The clustered nature of the 85 plots into 17 clusters is a feature of this part of the project and any analysis of data from these plots should explicitly assess or incorporate the likely spatial dependence that may occur within a plot cluster. In this respect, for statistical modelling of the 'clustered plots', the researchers have previously fit a 'site' random effect to accommodate the dependence of the five plots within a cluster (site). When researchers use statistical models to draw conclusions from the data, it is recommended that effects sizes are reported with their standard errors and model assumptions are evaluated through diagnostics to provide some indication of how well the model fits. When drawing scientific conclusions from statistical models, it is important to know how trustworthy they're likely to be.

The researchers have established infrastructure to examine a range of questions about how climate change may effect changes in community composition. The study will not be able to answer these questions definitively, but will be able to highlight and discuss the relevance of the relationships that are found. Characterising climate, and consequently climate change, using the variable mean annual temperature (or mean annual rainfall) will have limitations. This is acknowledged by the researchers that a variety of climate properties may need to be considered to more effectively characterise climate to help explore the consequences that a changing climate may have. Researchers have reported that they use a range of bioclimatic variables in their work.

Summary

For the South Australian TREND project, temperature has been used as a design variable to stratify field plots across the ranges of the Adelaide Geosyncline. Researchers have sought to establish field plots in locations that reduce the confounding between temperature and factors associated with geographic distance between survey sites. As a result, researchers may be able to more clearly identify associations between patterns of biodiversity and variables of interest. It is important for researchers to be aware that when using measures like mean annual temperature or mean annual rainfall to examine the effects of climate change, that each of these measures function only as one characteristic of climate. For observational studies like this one, no cause-and-effect relationships can be identified and the absence of probability-based sampling during plot selection, within the constraints of the fragmented landscape, means the dependability of applying study conclusions across the broader ranges of the Adelaide Geosyncline is reduced.

References

White, A., Sparrow, B., Leitch, E., Foulkes, J., Caddy-Retalic, S. (2012) Ausplots-Rangelands Survey Protocols Manual, Version 1.2.3

Northern Territory NATT

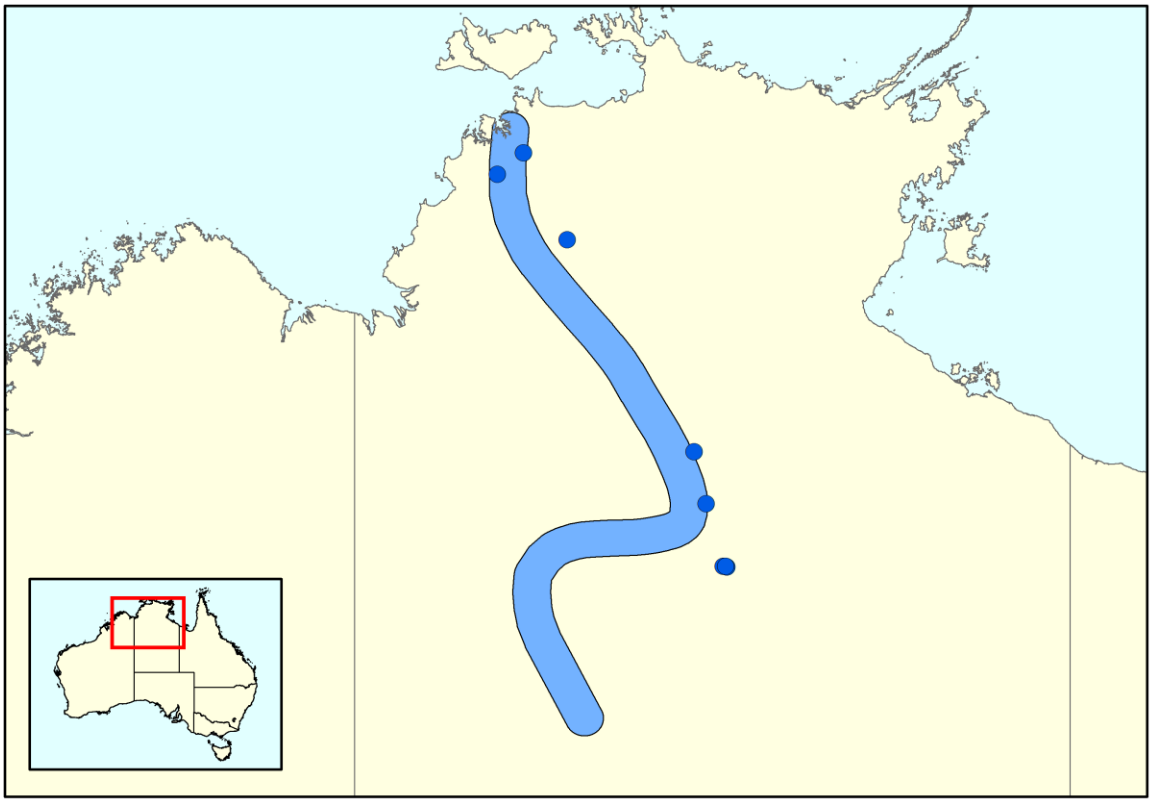

Figure 20: Plot locations within the Northern Territory NATT Transect network
Shading provides an indicative representation only.

Background to the project

The North Australian Tropical Transect project encompasses work undertaken across a range of sites that decrease in their mean annual rainfall from the north (1700mm) to south (500m) over approximately 800km. The project originated in the mid-1990's as part of the international network of sub-continental-scale transects under the UN's International Geosphere-Biosphere Program (IGBP). The North Australian Tropical Transect project currently has three main components: a) Tree dynamics, to examine tree growth and survival in relation to rainfall and disturbance; b) the integration of plot-based and flux tower measurements to assess carbon stocks and fluxes; and c) biodiversity survey using ants to explore faunal response over a rainfall gradient. This review is restricted to the first and third components---tree dynamics and the ant survey work.

Objectives

The North Australian Tropical Transect has the following objectives: to develop a predictive understanding of tree (and carbon) dynamics in relation to environmental stress and disturbance; to predict biodiversity responses to climate change, using ants as a target taxon to examine potential effects of climate change; and to provide baseline ant survey data at other ex-MSPN transects and TERN facilities.

Research Questions

The research questions that the scientists are examining are:

1. How do species abundances, composition, richness and ecological function change along large-scale environmental gradients?

2. Is there predictable variation in ecosystem resilience in relation to rainfall, temperature and soil type?

3. How might ecosystems respond to climate change?

Study Design

The tree dynamics component of the North Australian Tropical Transect is being pursued through two sub-projects: tree tagging along an approximately 900km stretch of the Stuart Highway running for Darwin in the north to Tennant Creek in the south; and the Territory Wildlife Park experiment undertaken at Berry Springs, 30km south-east of Darwin.

The tagged tree work is being undertaken at 11 sites spaced 100km apart along the north-south orientated Stuart Highway. Twelve mature individuals of Eucalyptus or Corymbia species were selected, tagged and had their heights and diameters measured in 2000. Trees were re-measured in 2012 and additionally, had their canopy diameters measured.

In June 2004, the experiment at the Territory Wildlife Park was established to study the influence of fire seasonality and frequency of burning on vegetation structure and floristics and tree mortality. Eighteen plots, each of,1ha representing a north-south edaphic/vegetation gradient were grouped into three blocks where six fire regimes treatments, comprising different seasons and frequencies of burning, were allocated in a complete randomised block design. Fire regime treatments have continued to be applied since 2004.

Remote sensing and hand-held LiDAR measurements are being made to complement the above field-based work. The developing LiDAR technology records measures of vegetation structure and helps estimate biomass at a landscape scale.

For the ant biodiversity survey work, locations were located systematically every 50km along the Stuart Highway from Hughes 50km south of Darwin, to Lake Woods, approximately 220km north of Tennant Creek.

Measurement protocols

For the tagged tree work along the Stuart Highway, diameter and height were recorded in 2000 and their height, diameter and canopy diameter recorded in 2012. A total of 180 mature trees (non-juvenile) was measured. For the tagged tree work at the Territory Wildlife Park, heights and diameters of 2200 mature trees (non-juvenile) were measured in 2004 and have been re-measured periodically following application of treatment burns.

For the ant survey work, 40 pitfall traps spaced at 10m intervals were placed parallel to the road every 50km along the Stuart Highway. The 400m trapping transect at each location was placed at least 50m away from any road disturbance. Soil was collected at the 0m, 200m and 400m points along the 400m transect and the dominant overstorey vegetation along the length of the transect was noted. The soils were sifted in the lab and the percent clay, sand and loam content were recorded.

Analysis

A variety of analysis methods have been used to examine the relationships between tree growth, tree survival, ant diversity, mean annual rainfall and soil including ordination and regression analysis.

Discussion

For the tagged tree work along the Stuart Highway, survey sites are located systematically every 100km adjacent to the highway. This conveniently distributes survey sites across the rainfall gradient. Vegetation adjacent to the highway where the survey has been undertaken is classified by the researchers as savanna on relatively flat, well-drained, non-rocky soils. Medium-large, non-juvenile trees were selected for this component of the project as the researcher's interest was in growth of mature trees. The roadside reserves along the Stuart Highway are uncleared and there is often difficulty in determining where the reserve stops and the uncleared pastoral paddock commences as fencing may not be present. Due to the un-fragmented nature of the vegetation in the roadside reserve, there was little need for researchers to 'find' a patch of savannah vegetation in which to tag trees when the study first commenced.

The extensive distribution of intact, savanna vegetation meant there was little need to carefully choose the right vegetation type. Employing some element of randomisation would have helped to reduce selection bias in the choice of the twelve mature trees to be tagged at each location. However, researchers stressed that they selected whatever trees were there and that they exercised no preference for one species over another. At the 'hundred km point' for the next survey site to be located, researchers avoided creek lines and trees that were in drainage depressions. This was because they wanted to record the growth and mortality of trees relying on soil moisture rather than trees being supplemented with stream-fed water.

The Territory Wildlife Park experiment seeks to accommodate the variation in soil moisture that occurs across the study area by using a three compartment block design (high, moderate and low soil moisture) to apply the fire treatments. By dividing the land up into more homogeneous blocks (with respect to soil moisture and corresponding vegetation type), and randomly applying each of the treatments within each of the blocks, the effects of interest between tree growth and mortality and fire frequency can be more precisely estimated than if a blocking approach was not employed. For this experiment, the researcher's interests are focused on survival of larger individual trees, rather than attempting to better understand recruitment. Therefore, the emphasis in the field measurements was on tagging and monitoring trees above a certain size. The researchers report that not all the medium-large trees of the size class that they were interested in have been tagged, but that a high proportion of them have been. The researchers believe there was little reason to be concerned about any selection bias in choosing the trees to be tagged in the study.

For the ant survey work, similar considerations were made to the tree tagging work when deciding when to stop at the next 50km mark. That is, researchers avoided rocky, outcropping ridges and low-lying areas subject to inundation as such places were regarded as being unrepresentative of the savanna vegetation they were interested in.

The tagging of 180 trees and the ant survey work along a rainfall gradient are conducted along the Stuart Highway. The use of this road provides a convenient way to quickly access sites for survey and then move to the next location. However, for the objective of representing the relationships of interest between tree height, tree growth, rainfall and soils (and ant diversity), across the savanna rainfall gradient, it is unknown what confounding may be present due to the survey sites located along the Stuart Highway. It is recommended that thought be given to how the alignment of the highway from Darwin to Tennant Creek may differ from other alignments that run in a north-south direction across the same latitudinal range. The particular alignment of the survey sites through space may result in confounding of unknown factors with some variables of interest in this study, for example, soils.

Summary

The North Australian Tropical Transect project provides opportunities to examine tree growth and ant diversity in relation to rainfall and soils within Savanna vegetation. When using measures such as mean annual rainfall to examine the possible effects of climate change, it is useful to remember that it is just one characteristic of climate and others like rainfall in the coldest quarter may play a role in tree growth and survival. For observational studies like the tree tagging and ant survey work undertaken along the Stuart Highway, it is unknown what confounding variables may be present and therefore no cause-and-effect relationships can be identified in these sub-projects. Experimental work in a high rainfall part of the savanna provides information on the relationship between tree growth and mortality and fire frequency.

Western Australian SWATT

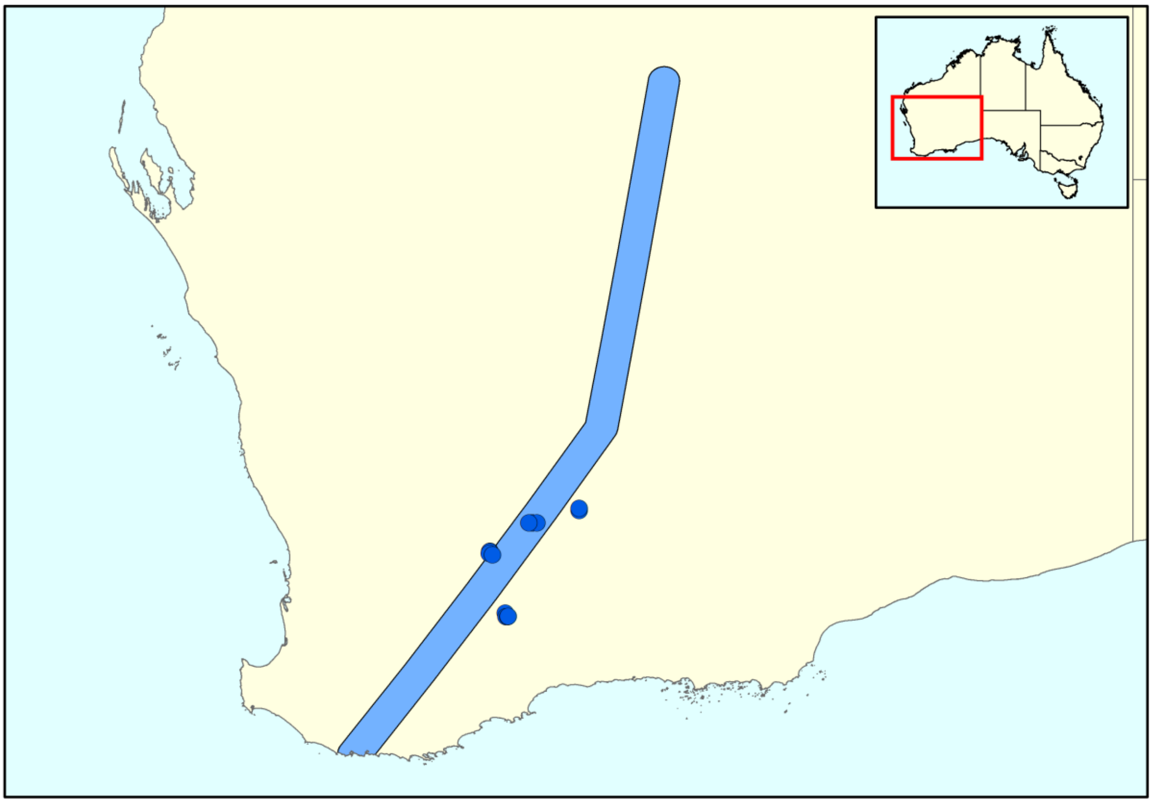

Figure 21: Plot locations within the Western Australian SWATT Transect network
The shading provides an indicative location only for SWATT.

Background to the project

The South West Transitional Transect is a conservation survey initiative undertaken collaboratively with the Australian Transect Network within TERN and the West Australian Department of Environment and Conservation. The project was initiated in 2012 and is interested in exploring several ideas, including how vegetation communities differ and the rate of floristic composition changes over a rainfall gradient of several hundred kilometres.

The project is focused on the establishment of 160, 20m by 20m survey sites located in 10 Western Australian conservation estates. The orientation of the study sites as a whole, runs from the tall eucalypt forests in the south near Walpole in a general north easterly direction, through the highly fragmented sheep-wheat belt and then into the rangelands. The survey sites are effectively stratified by rainfall, which is also closely associated with temperature, evapotranspiration and wildfire frequency. It is understood that the suite of sites in South West Transitional Transect span a distance of approximately 1000km. Survey sites are located preferentially on reserves to ensure continued access to the sites. Consideration also has been given to locating sites where previous survey work has been undertaken to build on the information that has previously been recorded from the sites. Field measurement protocols used at the sites have been adapted from the Ausplots Rangelands protocol with some additional measurements included to align with existing WA monitoring projects.

In developing the South West Transitional Transect project, researchers had an independent statistical review of this project completed. It is understood that this review was organized by the West Australian Department of Environment and Conservation and more information may be obtained from the principal investigator, Stephen van Leeuwen. A separate review is not undertaken here.

SECTION 3: Synopsis

The purpose of this report was to review the statistical aspects of the field-based projects that made up the Multi-Scale Plot Network (MSPN). The only sensible way to do this is to find out what people are doing and what goals or objectives they are working toward. Understanding, documenting and reviewing the individual component projects of the now dissolved MSPN, is a necessary first step in thinking about how parts of the MSPN may work together.

The MSPN was composed of five facilities—AusPlots, the Long Term Ecological Research Network (LTERN), SuperSites, and the Australian Transect Network (ATN). Field-based activities undertaken in the SuperSites facility have been discussed in a companion report. The five facilities were created, or brought together under the MSPN with a desire to incorporate field-based studies that provided scientific information at a range of spatial and information scales. This scale ranged from high, temporal information content at a low spatial coverage at the SuperSites, through LTERN and ATN on-ground activities, to the greater geographic coverage obtained through cross-State data collection undertaken by the AusPlots facility.

The LTERN projects largely operate over a local or district spatial scale, although some of the plot networks are implemented over district-to-regional scale, and the Tropical Rainforest Plot network has plots spanning regional distances in Queensland. The ATN facility is composed of a range of projects including a local-scale experimental study examining fire regimes, through to survey plots that are distributed over 1000-odd kilometres across rainfall gradients in the north and south of the continent. The two field projects undertaken as part of the AusPlots facility have their plots spread over greater distances still, with plots established in different States. Another characteristic of the studies being undertaken out of the five facilities is the range of environments in which they occur. There are examples of studies being undertaken in several key ecosystems: the tropical savanna, rainforests, tall eucalypt forest, deserts, temperate woodland, mallee, coastal heathland and the arid interior.

Having a collection of field studies where the survey plots span different lengths of the country or cover different size areas, does not necessarily provide reliable information across those lengths or across those areas of the landscape. This is an important consideration for many of the on-ground MSPN field-based projects. Study design characteristics, notably an absence of probability-based sampling, means that caution is required when generalising results beyond surveyed sites to the broader district or region of interest. Similarly, having a set of studies that are undertaken in several of the key ecosystems does not ensure that reliable knowledge can be obtained, in a more general sense, for those same environments. That is, where patterns are being observed across a set of study sites in an example of a particular vegetation community, we shouldn't be confident that the pattern would occur across all, or most, unsurveyed areas of that same vegetation community. Identification of study design characteristics that influence how secure inferences are likely to be are discussed for each of the projects in the report. The ideas of representativeness and selection bias are discussed below. If inference is desired beyond the study sites at which measurements are made, then the topics of representativeness and selection bias are relevant.

The field studies that made up the ex-MSPN facility have been developed by different people, at different times, for different reasons. Even among projects that have the same principal investigator (e.g. the ANU plot networks within LTERN), where there is some similarity among measurement protocols, there are issues that are not easily solved when considering bringing project data together. Among the broader ex-MSPN field projects, these matters are exacerbated and there are fundamental difficulties like the confounding of study with measurement protocols. Issues associated with bringing project datasets together is discussed below.

Some remarks also are provided below on the obligation of using diagnostic procedures to check assumptions when using statistical models to draw conclusions from data, and the role of power analysis. These issues arose frequently enough during our review and discussions with researchers for some extended comment to be made

Selection bias and representativeness

Having study sites which are representative of the district or region over which a researcher would like to generalise their results (the target population) is regarded as a valuable quality for a research or monitoring project. The word `representative' or the idea of `representativeness' has several meanings so it is important to be clear what we mean when we use these words and why we think it is important to have, say, a `representative sample' or representative study sites.

We could say that a common meaning of representative denotes the typical or ideal case of something. It has connotations of similarity with a larger group or population. That is, if a study unit (site, transect, quadrat) characterises well the class of objects of which it is regarded as a member, it may be considered representative of that class. This is the meaning of representativeness that was used for the JANIS criteria for forest management in the 1990's (Commonwealth of Australia 1997).

Assessing representativeness in this sense involves identifying a suite of *known* factors or characteristics that are believed to be important and then determining similarities with those accordingly. Simplistically, a conservation officer may ask themselves: *"I believe a typical or characteristic site of River-flat Eucalypt forest on Coastal Floodplain would have certain qualities or attributes present — yes, this one does — I consider this patch a representative example of that vegetation community."*

The above approach of characterising and selecting a study site can be contrasted with probability-based sampling. Using randomisation to select study sites offers protection (on average) against selection bias. This is because it removes personal judgement from the site selection decision and helps distribute the effects of influential, but *unknown* factors across the study units. For doing statistical inference---using a probability-based model to draw conclusions beyond your study sites---an absence of bias in how we choose study sites, and secondly, how we calculate the estimates of interest, are important. While selection bias is avoided through the mechanism of some form of probability sampling, bias also may arise from the choice of estimator (function) used to calculate the estimates of interest[5]. The use of probability sampling in site selection allows results to be generalised beyond the study sites to the broader region of interest. Randomisation offers support or protection against selection bias at the (nested) level at which it is implemented: for example, small quadrats within larger plot, plot within site or location of the primary observational unit (site).

Where some element of randomisation is not used for site selection (and neither was a transparent, purposive sampling scheme to enable adjustment of the estimator), researchers should think

[5] Reliable estimates can be obtained following the use of a biased sampling method but formal incorporation of additional information (e.g. the variables used to determine representativeness) into the analysis is required to make the necessary adjustment to the estimator. This information is not usually available in ecological studies due to the informal nature of the sampling method used.

carefully about how their sites were originally selected and consider how bias may have been introduced into that selection when discussing results. They should then proceed cautiously when drawing conclusions beyond their study sites.

Due to a variety of factors, including logistical constraints in the field, it can be uncommon for ecological studies to use some form of randomisation when selecting study sites. In such circumstances, it is useful to think about the history and context of the site(s) and how bias may have been introduced during the original site selection. Effort in describing how characteristic the site is compared to the surrounding region also may be useful. However, while having a high correlation between the characteristics of a chosen site and the broader region of interest may increase confidence that a given site shares characteristics with the broader region within which it is located (with respect to the factors used for the contrast), this doesn't grant an ability to claim `statistical representativeness' nor an entitlement to draw conclusions without fear across the broader region of interest.

Depending on the objectives of a study, random selection of a study site may not be needed or may not be important. If the purpose is to demonstrate the existence of a process or phenomenon, say, the relationship between carbon flux patterns and the competitive dynamics in tropical rainforest, working in a patch that is `not un-representative' may meet study objectives. Here, the study objectives may include demonstrating the complexity of the flux-forest dynamics relationships, but the focus is not on concluding that the relationships apply within tropical rainforest across the broader district or region. If a researcher is interested in drawing conclusions beyond their study sites at hand, it is important to think about how bias may have been introduced during the initial selection of on-ground study locations. It is a reality that probability-based sampling is often not used in ecology. Where it is absent, caution should be used when drawing conclusions beyond the surveyed study sites. Unbiasedness and the entitlement to generalise results beyond surveyed study sites is borne out of site selection procedures and cannot be secured through post-hoc comparisons with selected biophysical attributes.

Reference

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The role of diagnostics in statistical modelling

Statistical methods are based on models that involve probability distributions with parameters that need to be estimated for understanding and prediction. Familiar techniques like the one-sample *t*-test to investigate the value of the population mean is an example of a simple statistical method. When using this test, a researcher uses properties of *Student's t-distribution* to determine how plausible particular values are for the population mean. The one-sample *t*-test includes inherent assumptions about the data that researchers rely upon when they use the test: the population from which the sample has been taken is expected to be normally distributed and sample values are assumed to be obtained independently of one another. The assumptions of simple models like the *t*-test are comparatively easy to assess. The properties of more complex models, for example, that accommodate spatially clustered or temporally dependent data with a non-Gaussian response, are more difficult to understand and harder to evaluate as a result.

For a model to be relevant or informative, it needs to be a useful approximation to how the system under consideration is working[6]. For example: Is the relationship quantified by the researcher's statistical model between species richness and fire severity a good approximation to how the actual system is generating the data? Can this relationship be used reliably to recommend on-ground management or help design additional research studies? A well-fitting model that satisfies inherent assumptions affords confidence in using the approximation while a poor-fitting model does not. Diagnostic graphical plots can be used to evaluate a range of model assumptions that help determine the fit of a model and whether it is likely to be a good approximation of the system under consideration. For regression, as a minimum, assessing fit conventionally includes plots of residuals (unexplained variation[7]) to explore non-normality, temporal dependence, non-constant variance, the presence of `outliers' and the absence of required (additional) covariates.

Regression models are widely used and while assessing the fit of these models requires judgement, the principles and protocols for evaluating assumptions are well established. For more complex models with multiple sources of variation, dependent data structures and/or non-Gaussian response, this is not the case. Many researchers are familiar with the graphical tools to evaluate the assumptions of regression models. If statistical models are used for inference, it is necessary to assess the fit and evaluate model assumptions before the model is used. Fitting and evaluating more complex models that accommodate clustered or longitudinal data, like mixed models, is not straightforward due to the presence of both regression parameters and variance parameters and the uncertainty in how the relative importance of each of these should be apportioned during model selection. Evaluating distributional assumptions can be difficult with non-Gaussian responses (e.g. binary data). These challenges don't eliminate the need to consider model fit. On the contrary, using models that are hard to evaluate should induce greater caution when using them for inference.

Combining project datasets

An attractive idea for some is using datasets from different studies to investigate scientific questions. This may involve proposals to draw on remote-sensing or atmospheric flux data to use with on-ground plot-based measurements to explore relationships of interest. Here, different technologies, or methodologies more generally, are commonly used to measure different variables of interest, and there is nothing remarkable or unusual about this, other than perhaps scientists from different disciplines collaborating on the one investigation.

What is more unusual, and challenging, is the idea of combining raw data on similar themes that are collected from different scientific studies. The different projects may measure similar attributes in the same, or in different ways. Among studies, different field protocols are commonly used to measure the same attributes. For example, basal area or foliage cover may be calculated in different ways (using points, lines or plots as the survey framework). Small mammal abundance may be

[6]The emphasis here is on using a model for understanding. Statistical models can be used effectively for prediction in some circumstances in the absence of a direct physical relationship between the response and `predictor' variables.

[7]There are three residual quantities commonly used for model diagnostics: raw, standardised and studentised. The latter two quantities can be more effective in detecting influential observations than the raw residuals.

obtained using different types and configurations of traps. It is common for different projects to measure similar themes in different ways because particular field techniques are more efficient in certain environments, and scientists have individual preferences and/or different priorities for measuring certain attributes.

Attributes may be measured directly or an index may be used to provide a relative measure. For example, the number of animals in a population, or equivalently the number of animals per unit area, are both direct measures of abundance whereas relative measures of abundance are used with indices such as animals trapped per 100 trap nights, possums seen per km walked, or owls heard per hour. Generally, the relationship between such an index and absolute density is unknown. A contributing reason for this is when animals are more active or vocal, or the ability to see or hear them is increased, they are more likely to be detected. When using the same technique to make comparisons within a study site over time or across study sites at the one time, there is the potential for differences in animal activity and detectability to be confounded with differences in abundance. Higher counts per level of survey effort may reflect greater movement by individuals rather than differences in abundance *per se* (e.g. following wildfire; see Whelan, 1995). Where possible, ecologists seek to control factors that influence activity levels and detectability when deciding when to conduct surveys—weather conditions, season, time of day, food supply or observers. Factors that influence species activity can be problematic when investigating the effects of disturbance on biodiversity—reptiles in burnt and unburnt areas may have different activity levels or movement patterns[8] (Whelan 1995).

If seeking to investigate animal abundance by amalgamating data that has used different relative density survey techniques (e.g. birds recorded from stationary point-counts vs. 2ha timed-searches), the potential confounding aspects of activity levels and detectability remain, and are compounded by the uncertainty of the relationship between absolute density and relative density for the two techniques. Variation in the relationship between an index of abundance and absolute density also may occur using the same index but in widely separated ecosystems. Ecologists commonly work with indices due to the prohibitive cost of additional survey work involved in obtaining estimates of absolute density or total population size.

The challenges involved in combining data that measure the 'same' variable in different ways are not eliminated by moving away from the use of indices (nor are these challenges confined to faunal studies). The field survey protocols that are used in a study can be viewed as a measurement instrument with inherent variability and bias. Within a study, measurement error from the instrument helps comprise part of the variability in the data and the researcher assumes (usually) the unknown bias in the method remains constant over the duration or geographical extent of the study, so patterns in the response of interest can be reliably inferred. Where two different studies measure tree basal area using different methods, the researchers are measuring the 'same thing' but each method has its own variability and bias associated with it. A common approach to working with multiple datasets like this is not to combine the data, but to analyse them within the project-specific context in which they were collected. That is, the same relationship, say between basal area and biomass carbon, is examined in both studies, but parameters are estimated conditional on the field protocol used. Variability is captured in the statistical model and some consideration is given by researchers on the assumptions that (any unknown) bias associated with the methodology remains

[8] Aside from potential differences in detectability due to removal of vegetation cover.

constant over the particular study. Results between the two studies can then be contrasted informally—was the pattern between response and predictors consistent between the two studies? The situation becomes much less transparent when combining the data from the two studies as two different 'measuring instruments' have been used in the study, each with their own inherent variability and bias. Rather than increase the precision of an estimate, such an approach, if it doesn't strive to incorporate survey type effects, is more likely to obscure understanding of the relationships being studied. Researchers can try to adjust for bias if comprehensive evaluation exercises are done to understand the difference between the methods, but understandably, the resources are not usually available.

There are other important aspects that influence whether it is likely to be productive to combine data to answer a scientific question. The study design of the potential component projects is an important aspect that determines how well the individual projects can meet their original scientific objectives. This concerns how sites, individuals or study units in general were selected for inclusion in the study. Was an informal, idiosyncratic method used to choose study sites or was some principle of experimental or survey design employed? When thinking about combining data, consideration should be given to how useful those data are, given their origins. The use of survey design principles to initially design a study does not necessarily make it more valuable for subsequent data integration exercises, but it does provide necessary information to help evaluate how effective integrating data may be to help explore a new scientific question.

Careful thought should be given to drawing on and using data from different on-ground projects. No general prescriptions can be made. The merits of doing so should be considered on a case-by-case basis with a clear understanding of the objectives. The way the component (ex) MSPN field-based projects have been established affords no clear advantages in this regard. While what's measured on the ground is clearly an important characteristic of a survey program, it is the design, or how the study has been set up that more directly influences the breadth of inference or how reliable we can expect results to be across the broader landscape. The co-location of plots among different facilities can supplement the studies from different facilities and can provide valuable contextual information in helping to interpret results. However, collecting additional types of field-based data at a series of overlapping locations, does not, in itself, guarantee a more cohesive field-based program where inference can be extended into additional sub-topics of scientific interest. Where studies have not been specifically designed to investigate scientific questions it can be very difficult 'retro fitting' them so that reliable information can be obtained. Where drawing data together is being proposed to answer a new scientific question, it is recommended the following information is tabled in the discussions:

1. Why is there a desire to draw on data from the component studies? Clearly articulating the objectives and scientific question(s) of interest for the new endeavour is an obvious, but important task.

2. What is the population of interest? For the new analysis it is important to specify the population to which the inferences (conclusions) need to apply to. Without a clear understanding of the broader, targeted population that is of interest, the exercise should not proceed.

3. For the component studies that may potentially be useful, what is the survey or sampling design of each of them? Were informal, subjective methods used in selecting the survey sites or plots, or, for example, was some formal structure using stratification and randomisation within strata used?

This information is necessary to understand how secure inference is likely to be for each of the component studies.

4. What measurement protocols are used for the component studies? Within the respective studies are the protocols likely to measure the attribute of interest effectively and how great could measurement error be expected to be?

Collating the above information is a necessary first step in understanding what you have at the moment, what you want in future and the challenges involved in getting from one to the other. The motivation for drawing existing data together to answer a burgeoning question is understood. Implementing new studies can be prohibitively expensive and historically collected data may be able to be utilised. However, if it is unlikely that reliable information on new scientific questions can be achieved through drawing existing data together, then it is not sensible to proceed. Doing so risks study results being used inappropriately and poor natural resource management decisions being made.

When thinking about the benefits of combining data, it may be important to think about just how scientifically interesting such contrasts are likely to be across well-separated geographic areas. Single studies are typically located within the one district or region where climate, geomorphology and/or chronobiological rhythms are more or less constant. To undertake cross-regional and cross-continental comparisons among different studies is to invite factors into the mix that may influence the response of interest, but have not been incorporated in the original study designs. These factors may influence animal behaviour, for example, but be difficult to identify, or if known, difficult to measure. Differences between widely separated ecosystems may increase the risk of confounding the effects of interest (e.g., time-since-fire), with some unrecorded region-specific factor affecting activity or movement (detectability) of fauna species.

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Power analysis

Ecologists sometimes wish to complete a power analysis for their field projects. Generally, their motivation stems from wanting to know whether they have enough study sites to feel confident that they have a high probability of detecting an important effect, of an explicitly specified size, in the response variable of interest (if one exists). They would then like to use that information to help them make decisions about their project. For example, does the power calculation suggest that they need to establish additional sites within their study? Conversely, if a power analysis indicates that they have more than an adequate number of sites for detecting the effect size they are interested in, perhaps they should omit some sites from future surveys to reduce costs.

Power calculations assume an underlying model and often require some parameters to be given numerical values, so the more we know about the context and the data we are trying to collect, the more useful the analysis will be. To reduce the number of quantities that we have to specify to conduct the calculations, the problem and the model are often chosen to be very simple. For example, a single hypothesis test under an independent and identically distributed normal model. If the underlying model in the power analysis doesn't correspond to the project data at hand, the results of the power analysis cannot be expected to be reliable and facilitate good decision making.

Importantly, ignoring some structure can lead both to conservative calculations (the calculated power is lower than the actual power when covariates are ignored), and to over-optimistic calculations (the calculated power is higher than the actual power when dependence is ignored). To try and minimise these sorts of outcomes, the assumptions and their consequences need to be thought through carefully. On the other hand, over-elaborate analyses (that strive to reflect realistic structure in the data), are probably not very useful either because the specification of "nuisance aspects"[9] of the model are difficult. Power calculations are unlikely to be useful where probability-based sampling has not been used.

One issue with power calculations is how we react to the numbers they produce. We might be pleased if the power calculation suggests that we can reduce the number of sites, but we may still be reluctant to actually do so if we have simplified the model or restricted the goals of the study to obtain a feasible calculation. Similarly, a calculation that suggests that we need to increase the number of sites has to be qualified by the available resources. Especially with multi-objective studies, low power for one objective does not mean that we should not conduct the work. Even for single objective studies, low power does not mean that the study is pointless; the effect may be bigger than we expect but, even if it is not, the study may later be incorporated into a meta-analysis that achieves more than a single study could. Additionally, undertaking the work, even if the calculation suggests it would have low power, may result in an outcome that suggests useful modifications to other studies, interesting lines of research and generally help progress knowledge of some phenomena (such as ecosystem dynamics after fire).

Power calculations are useful in assessing the sensitivity of a (formal) experimental design in advance of project data collection. This is provided that useful estimates of data variability can be obtained (most reliably sourced through an appropriately designed pilot study) and there is a reasonably precise idea of the size of an important effect. Power calculations conducted after an experimental or observational study has been completed (sometimes called post-hoc or a posteriori power analysis), are often not particularly useful. First, the power calculation describes a general property of a test that holds over repeated samples so there are logical difficulties in trying to apply it post-hoc to a particular realisation. Second, the so-called observed power is completely determined by the p-value, so the calculation adds nothing to the interpretation of the results. Researchers should be clear about what their objectives are when they are thinking they would like to do a power analysis. Usually, completing a power analysis will be seen as a means-to-an-end, rather than the final, end result. Measures of uncertainty around parameter estimates from previous analysis may answer questions about where to enhance or where to rationalise an existing study more effectively than a formal power calculation.

[9] Those not of primary interest for the question at hand, but nevertheless an important component of the model being relied on.

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Appendix

Written material that was consulted as part of the review is listed below.

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AusPlots	
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