



LTERN

Long Term Ecological  
Research Network

# The Long Term Ecological Research Network, Australia

Objectives, design and methods



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## About LTERN

The LTERN Facility was established in 2012 under the Terrestrial Ecosystem Research Network Education Investment Fund Strategic Plan 2010–2013. A key part of that plan was the establishment of infrastructure for ecosystem science. Here, in this document, infrastructure refers to the layout and design of permanent field plots, the associated field measurement protocols and the survey staff that implement them, and the TERN-funded data that are collected from these plots. Correspondingly, *knowledge infrastructure* refers to knowledge and understanding that is obtained, and ideas that have been generated from the networks of plots that constitute the LTERN Facility. Throughout this document, when we refer to a research or monitoring study, or research or monitoring sites, we are referring to research or monitoring infrastructure.

This manual and the LTERN Data Portal ([www.ltern.org.au](http://www.ltern.org.au)) are important contributions to TERN's goal to:

... build the relationships, networks and infrastructure that will enable sustained, long-term collection, storage, synthesis and sharing of ecosystem data to meet terrestrial ecosystem science and ecosystem management needs in Australia. (Terrestrial Ecosystem Research Network Education Investment Fund Strategic Plan 2010–2013)

## Acknowledgements

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**LTERN**  
Long Term Ecological  
Research Network



**NCRIS**  
National Research  
Infrastructure for Australia  
An Australian Government Initiative



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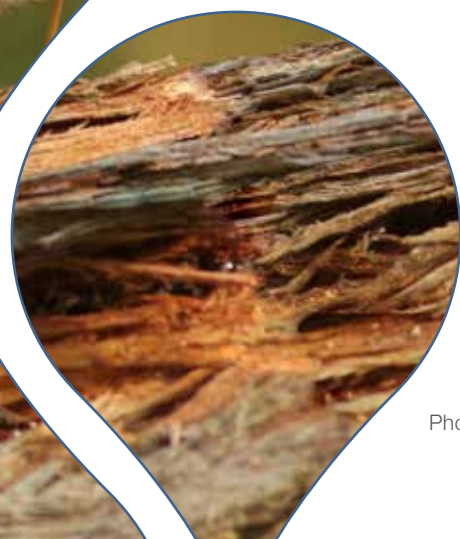
# Introduction

Understanding environmental change is a strategic priority<sup>1</sup> for Australian science and research because effectively adapting to environmental change is critical to a healthy, sustainable and prosperous Australia. A strong and sustainable ecosystem science enterprise that underpins the national wellbeing is also key to the strategy identified in the article 'Foundations for the future: a long-term plan for Australian ecosystem science' (Andersen et al. 2014).

There are many factors—operating at global to local scales—that influence the environment. These factors include climate, soil and water, nutrients, vegetation distribution and diversity, and faunal distribution and diversity (among several others). These factors affect Earth's systems, including atmospheric, terrestrial, marine, rural and urban systems. They also affect our social systems and wellbeing.

Detecting environmental changes and understanding them is challenging, because the Earth's systems are highly variable and operate over longer timescales than most research projects (or the life spans of researchers). Trying to understand a process that is inherently variable, over short time periods, can lead to a poor level of understanding (Burns et al. 2014; Lindenmayer et al. 2012). This is further complicated by the high degree of uncertainty and measurement error that can sometimes be associated with quantifying environmental change. It is therefore imperative that an appropriate long-term investment and sound statistical design is employed when implementing initiatives that aim to detect and understand environmental change for the purposes of public policy.

In complex modern societies such as Australia, communicating environmental changes and their potential impacts—so as to generate an effective social response—is extremely difficult. This is because environmental issues frequently encompass multi-scaled and multi-jurisdictional complexity, thus requiring inputs from many disciplines, sectors and stakeholders (Lynch et al. 2015). Nevertheless, informed and responsive environmental policy and management is what is needed to sustain ecosystems, human wellbeing and social prosperity. It is initiatives such as the Long Term Ecological Research Network (LTERN) that help position Australia to make intelligent responses to emerging environmental challenges.



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<sup>1</sup> [www.science.gov.au/scienceGov/news/Pages/PrioritisingAustraliasFuture.aspx](http://www.science.gov.au/scienceGov/news/Pages/PrioritisingAustraliasFuture.aspx)

Photo: Wren, D Blair

## What is the Long Term Ecological Research Network?

LTERN brings together leading ecologists from research institutions around Australia. Established in 2012, LTERN integrated a range of existing long-term ecological monitoring programs to establish a coordinated and collaborative approach to long-term research. While all monitoring programs had different goals, different methodologies for data collection, and were based on varying resourcing and governance models, they each had a common thread—namely, they had successfully investigated and identified environmental change over the long term. This long timeframe underpins their strength, but also sets them apart from the many other programs set up to monitor environmental change. The purpose of integrating them was twofold: to leverage off this success in sustaining data collection over the long term by sharing their expertise, publishing the data and synthesising the findings to help address pressing environmental challenges, and to ensure their continuation for the benefit of managers today, and into the future.

Collectively, the objective of LTERN is to:

*integrate key established plot networks across Australia to enable research to tackle critical questions associated with the impacts of disturbance on Australian ecosystems.*

In doing so, LTERN seeks to provide infrastructure to achieve a:

*sustainable set of long term data collection procedures and archives from plots across Australian ecosystems measuring selected flora, fauna and biophysical processes, suitable for key ecosystem science questions and for developing and testing ecosystem models.<sup>2</sup>*

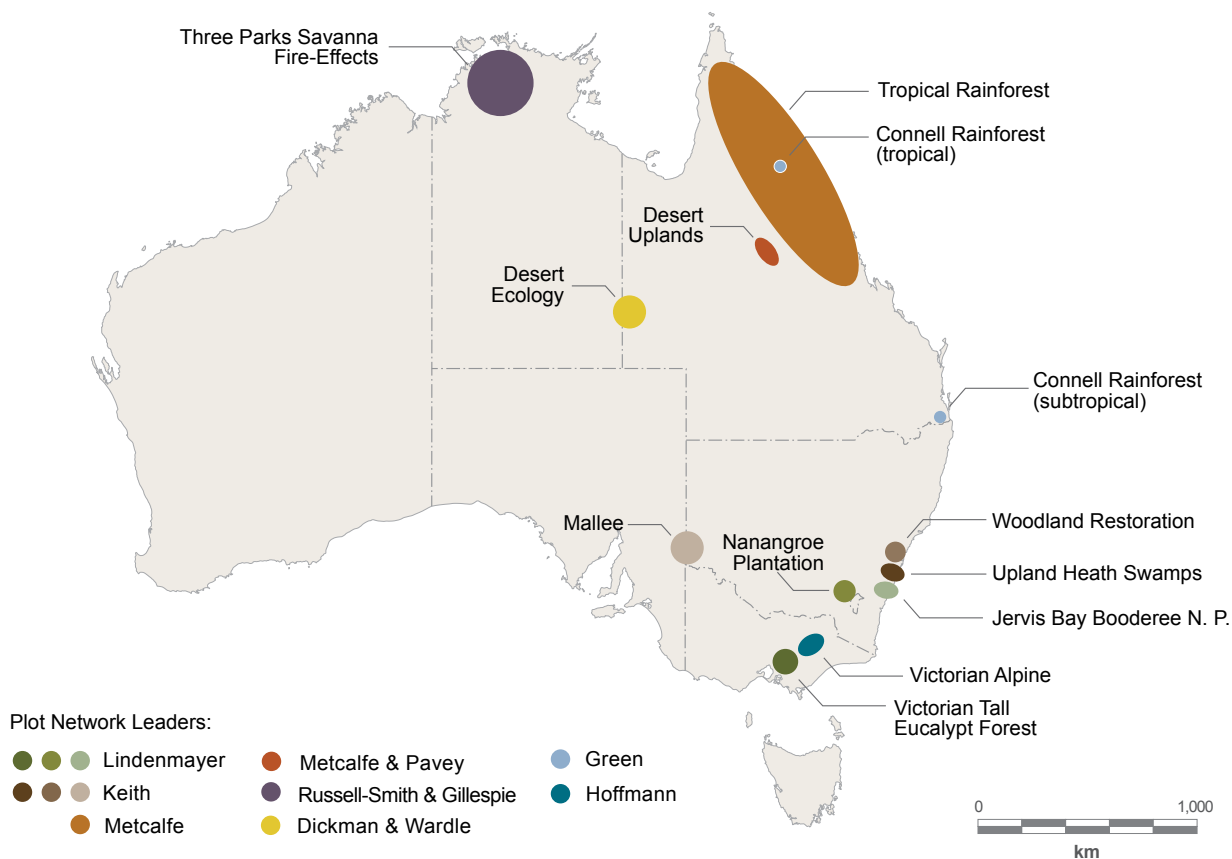
An overview of each plot network within LTERN is provided in the LTERN Facility brochure,<sup>3</sup> and on the LTERN web page.<sup>4</sup> In total, LTERN has 12 plot networks (Figure I.1), representing several different Australian ecosystems. These plot networks have been established for various reasons. LTERN field officers and associated researchers systematically record data on different groups of species in different ways, to address different key questions and quantify different ecological processes and drivers of ecological change. The breadth of species (from invertebrates to vascular plants) and ecosystem processes (from carbon to cyclones) monitored are shown in Table I.1 at the end of this section.

LTERN's approach to monitoring emphasises the importance of implementing appropriately



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- 2 A subset of an essential TERN requirement stipulated in the *Terrestrial Ecosystem Research Network Education Investment Fund Funding Strategic Plan 2010–2013*. The Education Investment Fund funded LTERN from 2012 to 2014. This was followed by the Collaborative Research Infrastructure Scheme and then the National Collaborative Research Infrastructure Strategy.
  - 3 Available for download at [www.tern.org.au/ltern](http://www.tern.org.au/ltern)
  - 4 [www.ltern.org.au/index.php/ltern-plot-networks](http://www.ltern.org.au/index.php/ltern-plot-networks)

Photo: Measuring Mountain Ash, D Blair



**Figure I.1** Distribution of the 12 LTERN plot networks across Australia

stratified, ecosystem-specific and site-based monitoring (see Burns et al. 2014 for further discussion). The focus on ecosystem-specific elements means that the majority of entities targeted for monitoring within LTERN vary among the plot networks according to differences in ecosystem characteristics, differences in biota and differences in the scientific questions being explored.

The core monitoring themes across the LTERN plot networks are listed in Table I.1.

Collectively, the design of the LTERN plots and data collection procedures provides research infrastructure to allow the research community to:

- develop a detailed understanding of key ecosystem functions and processes over decadal periods, from plot to landscape scales
- quantify critical relationships between vegetation condition and/or biodiversity and major disturbance regimes, such as those associated with fire, logging, livestock grazing, invasive species and extreme weather events, and their interactions with climate change.

LTERN's focus on fit-for-purpose, consistent, *long-term* monitoring is crucial to measure and understand key attributes of ecosystems—and the human and natural process that affect them. This need, its challenges and their potential solutions have been written about previously by members of LTERN. See, for example:

- Burns et al. (2015), which provides lessons and insights in booklet form for anyone involved in supporting, designing, undertaking or using the outputs of ecological monitoring

- Lindenmayer et al. (2015), a journal article that examines what we should begin measuring now that can help society better understand and manage natural resources by 2050 (and beyond) and, in turn, guide human societies through a likely transition to a less-bountiful world
- Lindenmayer et al. (2014), a data-rich book that describes changes in a range of Australian ecosystems that have been subject to detailed, long-term research. The overarching purpose of these long-term studies has been to document the changes, identify the drivers of change, and provide the evidence and knowledge needed to inform better natural resource management in Australia.

In addition, LTERN has also been centrally engaged with the development of a global ecosystem risk assessment protocol. The International Union for Conservation of Nature (IUCN) developed this protocol to support a global Red List of Ecosystems, analogous to criteria that support the IUCN Red List of Threatened Species (Keith et al. 2015). The IUCN Council formally endorsed the Red List of Ecosystems criteria in mid-2014. By contributing advanced scientific methods and data (Keith 2015), LTERN has helped place Australia at the forefront of this important global innovation. A recent special issue of *Austral Ecology*<sup>5</sup> showcases the application of LTERN expertise and data in providing detailed risk assessments for a diverse selection of Australia ecosystems—from the coast to the central deserts, the tropics to the temperate regions, and from the mountains to the sea. In applying the IUCN criteria to these ecosystems, researchers aimed to identify the defining features of their systems and the processes that threaten them, evaluate trends in key variables relevant to the persistence of the ecosystems, and assess the risk of ecosystem collapse in the 21st century.

## This manual

### Purpose

This document collates and describes the objectives of the LTERN Facility, the questions being examined and the field methodologies employed. It includes field data collection protocols (and associated templates) employed by the researchers, and reflections from lead researchers on what they would do differently if they were designing their monitoring networks today. The publication of this manual is a key step towards LTERN providing an archived and sustainable set of long-term data collection procedures. We also hope that other environmental

5 <http://onlinelibrary.wiley.com/doi/10.1111/aec.2015.40.issue-4/issuetoc>

Photo: Ethabuka Spring, G Wardle





professionals find the detail useful in the design and deployment of future ecological monitoring initiatives.

The LTERN Data Portal—released in October 2013—documents individual site protocols associated with published LTERN data packages (see [www.ltern.org.au](http://www.ltern.org.au)). The release of data packages from LTERN through the Data Portal will be progressive. In time, the LTERN Data Portal will become the most current and informative source for LTERN data collection procedures.

## Structure

This initial section provides context for, and an overview of, LTERN—its structure and goals, and the spatial distribution of the networks. The subsequent 12 sections provide detail on each of the 12 individual plot networks, primarily:

- a spatial map of the plot network
- a summary table
- the plot network’s objective
- the plot network’s research infrastructure goals
- the plot network’s research questions
- a description of the plot network’s methods as used at the monitoring sites
- a reflection on ‘if I had my time again’—what would our plot leaders do differently with the benefit of hindsight, if they were to establish their plot networks today.

The concluding section provides a brief summary of the value of long-term ecological research and its ongoing challenges. Throughout the document, additional reading is listed where further information about the methods or scientific questions can be found. Finally, there is a separate corresponding file of appendices (see [www.ltern.org.au/ltern](http://www.ltern.org.au/ltern)), which provides copies of field sheets used at the plot networks.

The LTERN plot networks measure different variables across a range of themes. These themes are summarised below and are used in the metadata associated with datasets published through the LTERN Data Portal (see [www.ltern.org.au](http://www.ltern.org.au)), and are also reflected in the publications produced by LTERN as shown in the LTERN Publications Catalogue (see [www.ltern.org.au/ltern](http://www.ltern.org.au/ltern)).

**Table I.1 Core LTERN monitoring themes**

	Victorian Tall Eucalypt Forest	Nanangroe Plantation	Jervis Bay Booderee National Park	Victorian Alpine	Three Parks Savanna Fire-Effects	Tropical Rainforest	Desert Uplands	Connell Rainforest	Desert Ecology Research Group	Upland Heath Swamps	Woodland Restoration	Mallee
Vegetation structure	●	●	●	●	●	●	●	●	●	●	●	●
Plant species composition	●	●	●	●	●	●	●	●	●	●	●	●
Plant species abundance	●			●	●	●	●	●	●	●	●	●
Individual plants	●				●	●	●	●	●	●	●	●
Carbon	●				●	●						
Plant phenology				●		●		●				
Invertebrates	●			●					●		●	
Herpetofauna		●	●		●				●			●
Birds	●	●	●		●		●		●		●	
Mammals	●	●	●	●	●				●			●
On-plot weather				●				●	●	●	●	●
Hydrology				●						●		●
Soil							●			●		
Fire	●		●	●	●	●	●		●	●		●
Cyclones						●		●				
Invasive plants		●	●	●	●	●	●			●	●	●
Grazing domestic livestock		●		●			●		●		●	
Logging forestry	●	●										
Land clearing		●					●			●	●	
Fragmentation	●	●		●								
Restoration											●	
Genetics	●		●	●					●			
Climate change	●			●		●		●	●	●		●
Behaviour									●			

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# 1 Victorian Tall Eucalypt Forest Plot Network

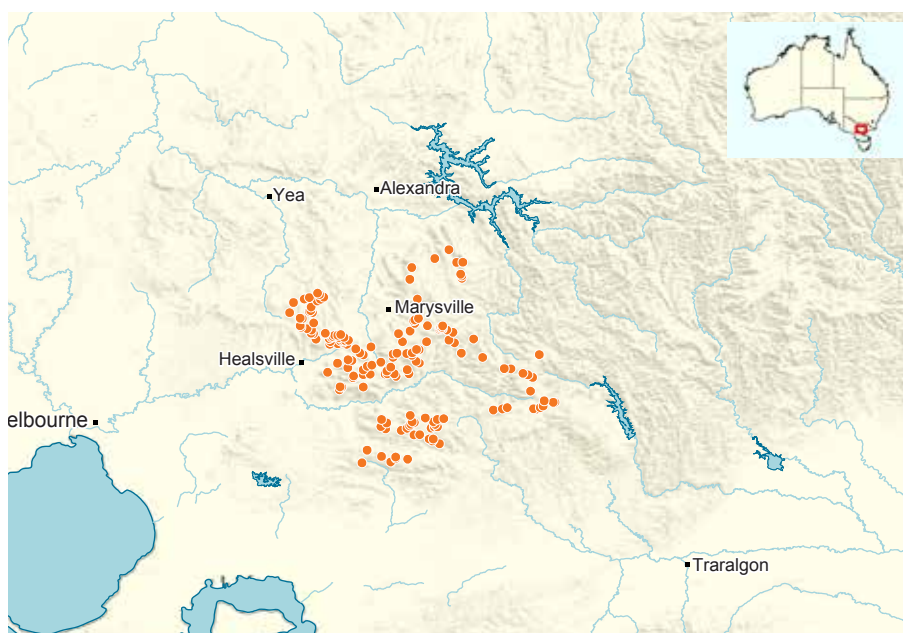


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## Location of the Victorian Tall Eucalypt Forest Plot Network

For the purposes of LTERN, a plot is a unit where flora and fauna attributes are measured. However, in the description of the data collection protocols for the Australian National University (ANU) Plot Networks in the following pages, the chief, independent locations at which attributes are measured are called sites (not plots) and each site may have between two and three (subsampling) plots. To help with consistency with the other plot networks, for locations run by the ANU, sites are referred to as plots.

Photo (opposite page): Burnt Mountain Ash forest Victoria, D Blair

## Objective

To quantify the inter-relationships between human and natural disturbance, and changes in vegetation condition and biodiversity response.

## Research goals

- A significantly increased understanding of environmental and biodiversity responses to timber harvesting and/or wildfire.
- A significantly increased capacity to rigorously evaluate the long-term effectiveness for biodiversity of timber-harvesting practices.
- A significantly increased ability to identify appropriate indicators, metrics and techniques for assessing, managing and monitoring vegetation and biodiversity conservation in the Victorian Tall Eucalypt Forest.

## Research questions

- What are the relationships between vegetation condition and biodiversity?
- Are relationships between vegetation condition and biodiversity consistent between vegetation types?
- Is the reference concept (e.g. old-growth forest) an appropriate benchmark for measured vegetation attributes in the context of biodiversity assessment?
- How does natural disturbance and/or management intervention alter vegetation condition and, in turn, the response of biodiversity?
- What is the relationship between vegetation condition and biomass carbon stocks?
- Are relationships between vegetation condition and biomass carbon stocks consistent across vegetation types and regions?
- What are the relationships between measures of biomass carbon stocks and various elements of biota? And are such relationships (if any) consistent across vegetation types?

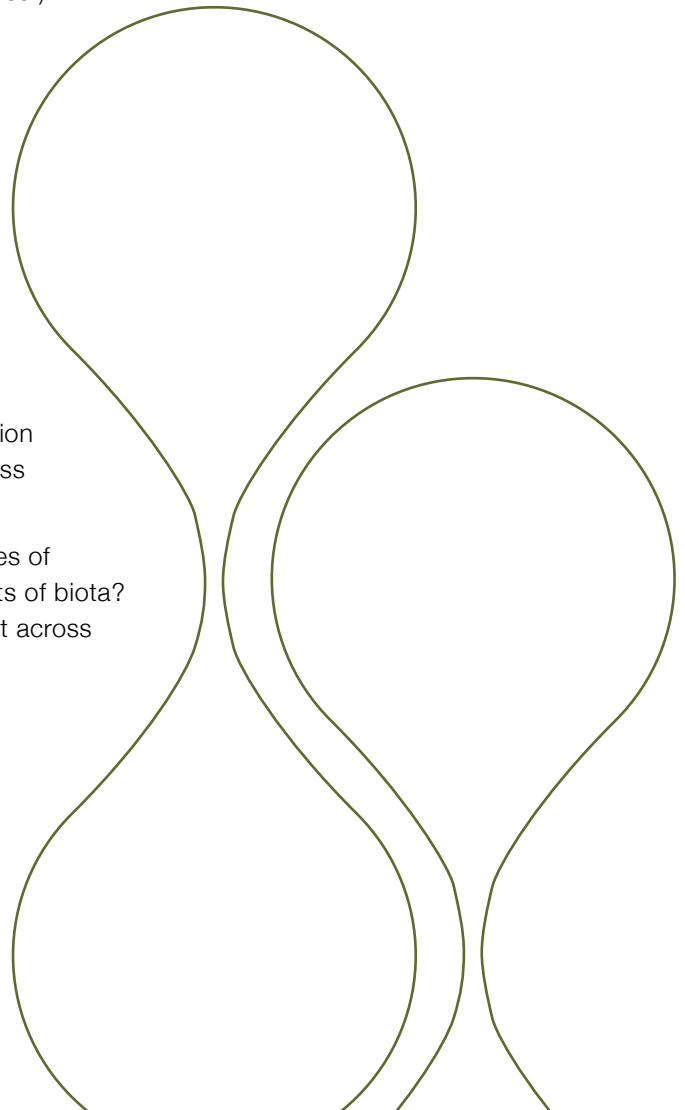




Photo: Tree measure, D Blair

**Table 1.1 Victorian Tall Eucalypt Forest Plot Network summary table**

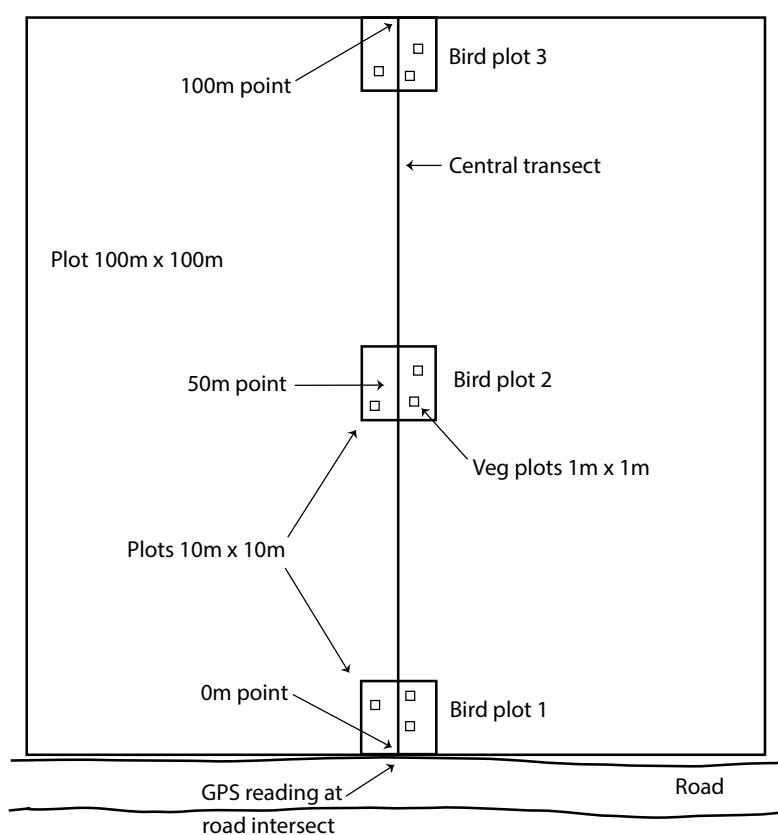
<b>Ecosystem</b>	Tall eucalypt forest
<b>General location</b>	Central Highlands, Victoria
<b>Other custodian(s) and/or partners</b>	Victorian Department of Environment, Land, Water and Planning (State Forest), Parks Victoria, Melbourne Water
<b>Disturbance type</b>	Fire, logging, park management, pests
<b>Data type (fauna/flora/vegetation structure)</b>	Arboreal nocturnal fauna, flora, vegetation structure, hollow-bearing trees, birds
<b>No. of plots (sites)</b>	163
<b>Plot size</b>	3 ha
<b>Start year</b>	1983
<b>Temporal revisit</b>	Birds annual, mammals rotational, full vegetation every 2nd year, stagfall intermittent

## Specific data collection protocols

The Victorian Tall Eucalypt Forest Plot Network is research infrastructure comprised of stratified 1-ha long-term plots within 3-ha monitoring sites. At these plots, carbon, vegetation, birds and arboreal marsupials are surveyed.

### Site setup

Each long-term monitoring site is 3 ha, with monitoring occurring only on the central hectare, which is usually square, being 100 m × 100 m. Occasionally where they back onto a gully, sites are 200 m × 50 m.



**Figure 1.1** Diagram of a survey site for the Victorian Tall Eucalypt Forest Plot Network

The central hectare ‘monitoring site’ has a transect line running up the middle from 0 m (usually on the road edge) to the back of the site (100-m mark), perpendicular to the road.

Along the transect are three 10 m × 10 m plots, located at 10–20 m (plot 1), 50–60 m (plot 2) and 90–100 m (plot 3). These straddle the transect, 5 m either side. The first plot is set back from the road to reduce roadside influences. Within each 10 m × 10 m plot, usually in the middle, is a 1 m × 1 m seedling plot that is marked out with marker pins. The central transect is flagged.



Bird counts are made at 0, 50 and 100 m along the central 100-m transect. See, for example, the field collection datasheet (available in Appendix A-3).

## Vegetation surveys

Standardised vegetation condition measurements include vegetation structure plots (three 1 m × 1 m, and three 10 m × 10 m) nested within 1-ha plots that are measured annually. The field collection datasheet is available in Appendix A-1.

### *Species diversity and abundance*

On the first page of the datasheet is a table with the most common species listed (see Appendix A-1). A record is taken whenever a species is observed within 5 m on either side of the central transect (marked 'T') and, if the species is seen within any of the three 10 m × 10 m plots, a '1', '2' or '3' are also listed in the box next to the species. For example, 'T/1/3 *Acacia dealbata*' would mean that *A. dealbata* was seen in plot 1 and plot 3 and on the transect. If a species is seen only within a 10 m × 10 m plot, it is still recorded on the transect because the transect includes the three plots. If a species is identifiable but dead, it is not recorded. Immediately after fire, species were recorded as live, dead or burnt.

If a species is associated only with the roadside vegetation, the species is marked 'R'. If the species is only observed elsewhere on the site outside the 10 m × 100 m transect, it is listed with a diagonal slash across the box, or 'S', to indicate it is present elsewhere on the site.

### *Height vs diameter matrix*

The height vs diameter (HvD) matrix records all the woody plants (no grasses, bracken, sedges, climbers, etc.) over 2 m high within the three 10 m × 10 m plots. Every stem has its diameter at breast height (DBH) and overall height measured, and the species is entered in the matrix. Multi-stemmed plants generally have a count for each individual stem more than 1.3 m high (DBH), so a single *Correa* or *Olearia* plant may be counted as multiple stems. Tree ferns with fronds that extend above 2 m are recorded in the diameter class of their trunk, even if this is below 1.3 m high. Tree ferns with trunks shorter than 1.3 m are still recorded as a single occurrence.

Stems are listed as either live ('L') or dead ('D'); species codes from the species list on the first page of the field sheet (see Appendix A-1) should be used. A typical entry would be 'Ad × 3 (D)', which is three dead *A. dealbata*.

The HvD matrix originally was a single table for each site, with all three plots entered into the same table. In 2012, this was split into three individual tables, one for each 10 m × 10 m plot, to help identify change over time in subsequent surveying, something that was very difficult with all three entered in a single table.

### *Basal wedge of Acacia*

A basal sweep is done in the middle of each 10 m × 10 m plot, over a 1-m<sup>2</sup> area. The number of each species of *Acacia* is recorded, as well as whether the tree is alive or dead. Trees shorter than 2 m are not counted, and neither are trees on a lean greater than 45 degrees.

### Seedling plots

All species that are rooted within the 1 m × 1 m plots (usually located in the centre of the 10 m × 10 m plots), alive and under 5 m are recorded by height increments in the table. Where the species is a sprawling ground cover (*Stellaria*, wire grass, geranium, etc.), an estimate of the number of rooting nodes is made.

### Fire severity

Within the months following the February 2009 Black Saturday fires, a number of variables were recorded.

#### Fire severity—scorch/consumption of strata

Three readings were taken on each site, one in each 10 m × 10 m plot. At each plot, the forest was divided into four strata based on height:

- 0–2 m, ground cover and low shrubs
- 2–10 m, shrub layer and small trees
- 10–30 m, understorey trees
- >30 m, overstorey trees.

Within each 10 m × 10 m plot, an estimate was made of the proportion (%) of each stratum that was:

- green/unburnt
- scorched
- consumed.

The total of the three burn classes should equal 100%. A fire severity scale was then developed. This was initially a scale of 1–3, then 1–4 and finally 1–5 as the severity was divided (Table 1.2). (The scale used by the Victorian Department of Environment, Land, Water and Planning is similar, but is scored in reverse order, with 6 = unburnt and 1 = highest severity).

**Table 1.2 Burn class survey table**

Fire severity	Forest stratum			
	0–2 m	2–10 m	10–30 m	>30 m
1	Unburnt	Unburnt	Unburnt	Unburnt
2	Light mosaic 'trickle burn'	Patchy scorch	Unburnt	Unburnt
3	Consumed scorched	Consumed/scorched	Mostly scorched	Unburnt/patchy scorch
4	Consumed	Consumed	Consumed/scorched	Scorched
5	Consumed	Consumed	Consumed	Consumed

Note: Scorch and consumption refers to fine fuels only, such as leaves and fine twigs.

### *Height of scorch/consumption*

An estimate of scorch and consumption heights (of fine fuels such as leaves, etc.) was measured at the three 10 m × 10 m plots; however, this did not prove to be very useful because flames ran up bark on trees and the fire effect at that scale was often very variable, especially for lower-severity fire.

### *Minimum tip diameter*

At each 10 m × 10 m plot, we measured the tip diameter of the first five major branches from two shrubs, choosing different species, where possible. In cases where shrubs had burnt down to a stump, we tried to measure five different stump diameters. This sometimes involved going slightly outside the 10 m × 10 m plot to get enough measurements. Callipers were used to measure the tip where the tapering cone from burning levelled out to a constant diameter.

### *Photo points*

Eight photographs were taken at each site during each vegetation survey:

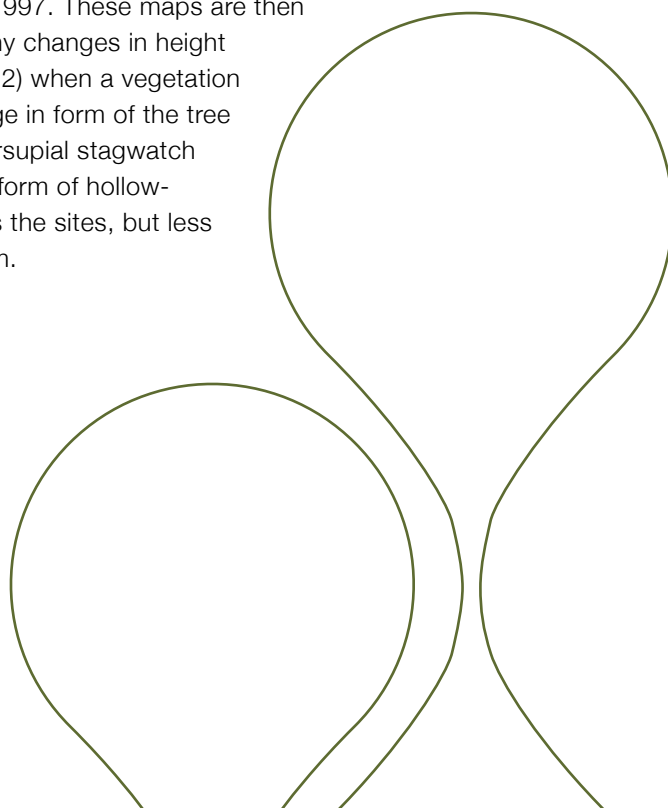
- one from the 0-m point looking along the transect towards the 50-m mark
- three at the 50-m mark, one looking back towards the 0-m point, one looking straight up (at the canopy), and one focused towards the 100-m mark
- one from the 100-m point looking back towards the 0-m point
- three of the 1 m × 1 m seedling plots, one for each 10 m × 10 m plot.

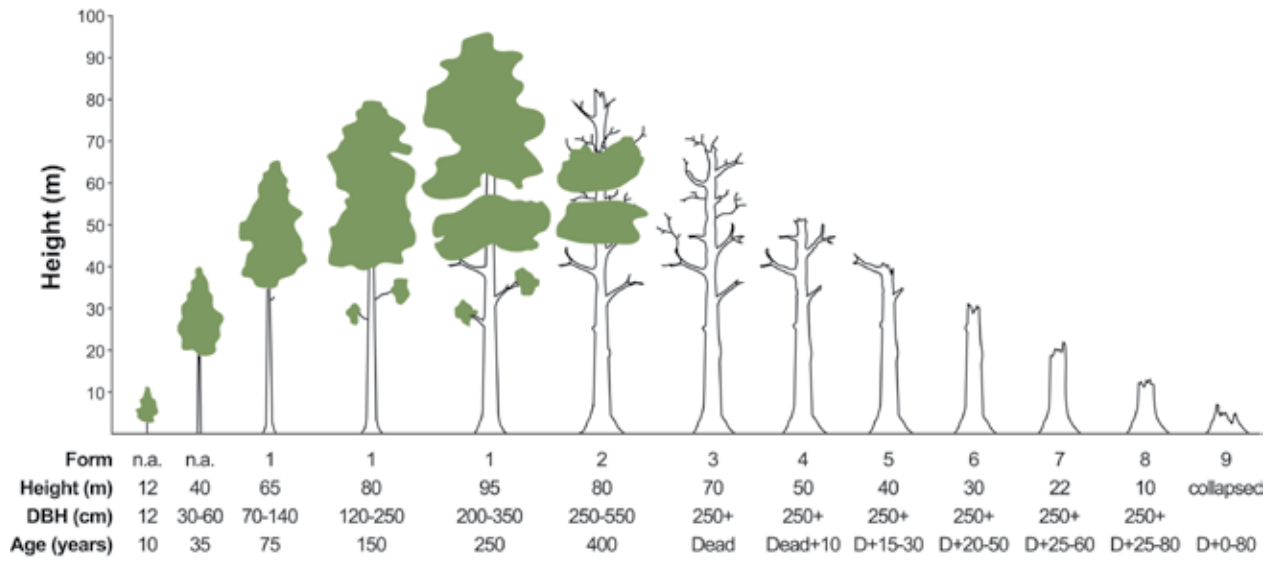
### *Habitat hectare*

In 2009, following the Black Saturday fires of that February, each site had a habitat hectare field assessment done, consistent with the guidelines set out by the Victorian Department of Environment and Primary Industries (DSE 2004; Parkes et al. 2003). There are no current plans to reassess the sites.

### *Stagfall surveys*

Within each site, hollow-bearing trees were marked, mapped and measured at the start of the study in 1997. These maps are then used to locate the trees and record any changes in height and form (level of decay; see Figure 1.2) when a vegetation survey is completed at the site. Change in form of the tree can also be noted during arboreal marsupial stagwatch surveys. In addition to the height and form of hollow-bearing trees, DBH is recorded across the sites, but less regularly than tree height and tree form.

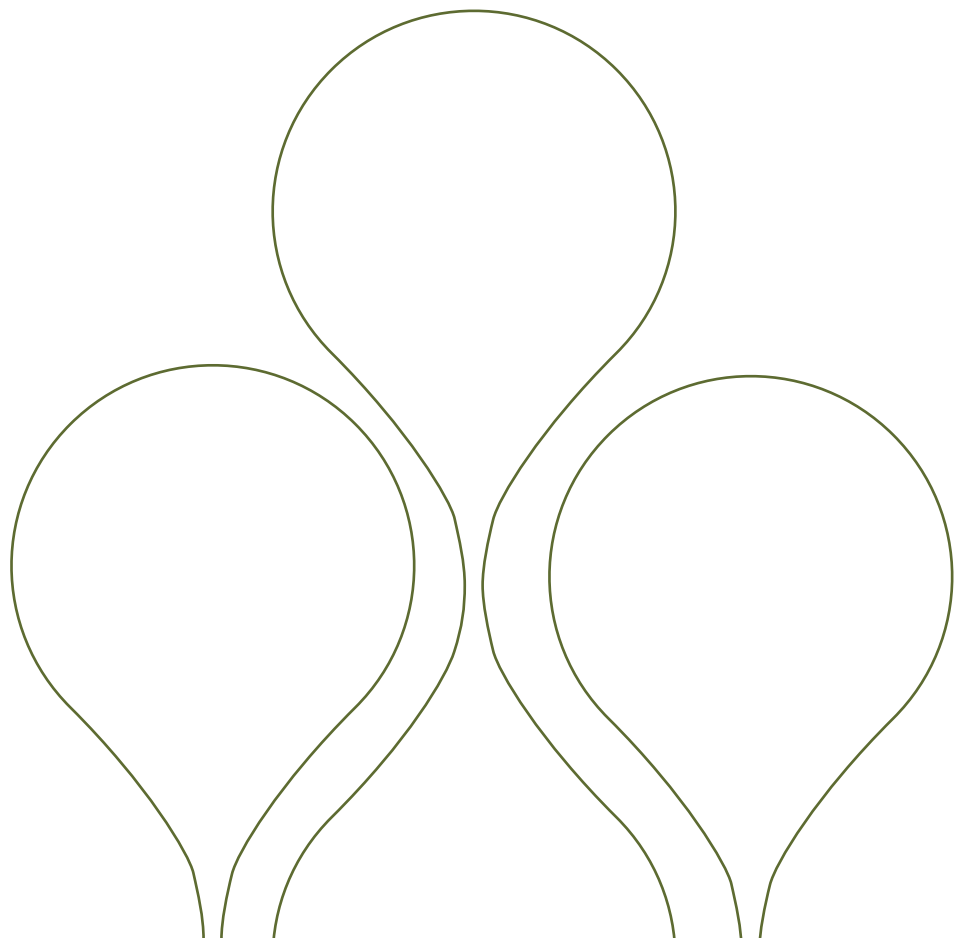




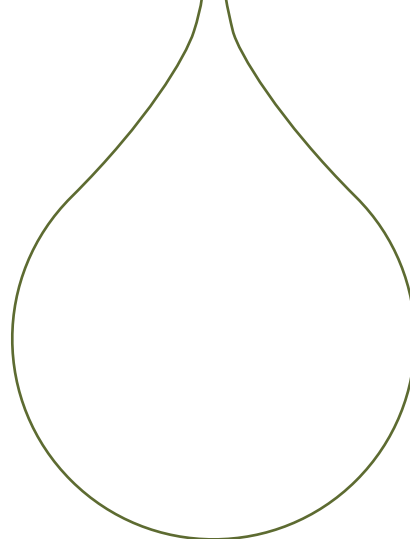
D = dead; DBH = diameter at breast height; n.a. = not applicable

**Figure 1.2** Sequential development of tree forms in mountain ash trees

Trees are marked with a number both with spray paint and a small metal tag. Heights are measured using a rangefinder. DBH is measured using a diameter tape. A compass and a rangefinder are used to help map the layout of stags within a site.







## Carbon surveys

See Appendix A-2 for a sample field sheet.

**Table 1.3** Methods for measuring carbon stocks in biomass components within 1-ha sites

Biomass component	Sampling time	Sampling strategy	Measurement
Trees (living and dead) <100-cm diameter	Post-fire, burnt and unburnt sites	Three 10 m × 10 m plots (0.03 ha)	Estimated height and diameter in size categories
>100-cm diameter		Two perpendicular intersecting 100 m × 30 m transects (0.51 ha)	Measured DBH and height
Understorey (living and dead)	Post-fire, burnt and unburnt sites	Three 10 m × 10 m plots (0.03 ha)	Estimated height and diameter in size categories
Coarse, woody debris <60-cm diameter	Post-fire, burnt and unburnt sites	Line intersect method six 10-m transects	Log diameter, decay class, hollows, charcoal and bulk density (Lindenmayer 1999; van Wagner 1978)
>60-cm diameter		Two 100-m transects	
Litter layer <sup>a</sup>	Post-fire, burnt and unburnt sites	25 points along transects per site	Measured litter depth
		30 quadrats randomly located at sites to cover range in litter depths	Measured litter dry mass

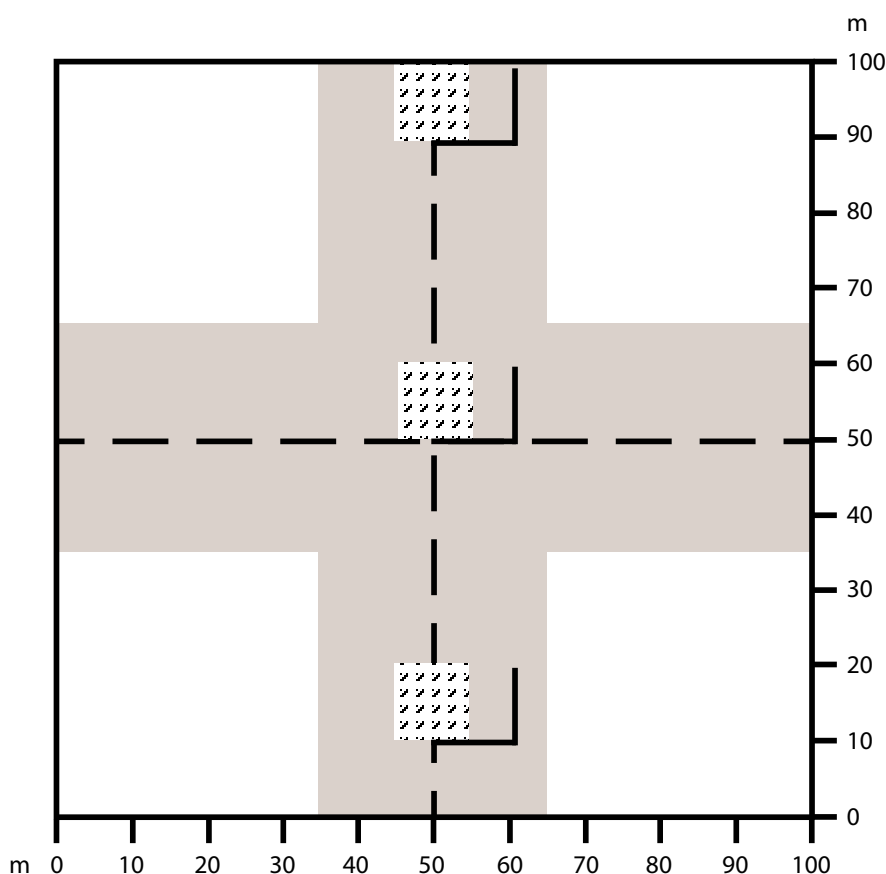
DBH = diameter at breast height

<sup>a</sup> Litter layer refers to fine litter (<2.5-cm diameter) that constitutes intact pieces of biomass, as distinct from undifferentiated organic material within the mineral soil; it excludes roots.

**Table 1.4** Methods for measuring changes in carbon stocks of biomass components after wildfire, within 1-ha sites

Biomass component	Sampling time	Sampling strategy	Measurement
Hollow trees (living and dead)	Measured in 2005 and 2011	All trees in 1 ha	Measured DBH and height
Bark decortivating	Post-fire, burnt and unburnt sites	Relationship derived from representative size range of trees. Total bark mass calculated for all trees in 1-ha sites	Measured relationship between tree DBH and bark mass
Bark rough			Measured relationship between tree DBH and bark thickness, plus bulk density
Canopy leaves	Observations and photos post-fire		Estimated biomass from litterfall and leaf longevity
Canopy twigs			Relationship between leaf and twig mass
Shrubs	Post-fire, burnt sites	Representative range of shrub sizes and species	Minimum size of tips remaining on stems after fire  Biomass in each stem diameter class
Coarse, woody debris	Post-fire burnt sites	Line intersect transects	Proportions of logs charred  Lines of charcoal remaining post-fire
Litter	Photos soon after the fire	Average from all low- and high-severity burnt sites	Proportion of litter layer combusted

DBH = diameter at breast height



**Figure 1.3** Design for carbon surveys

Note: A 1-ha (100 m × 100 m) experimental site showing the central and perpendicular transects (dashed lines), 10 m × 10 m plots (hatched), 10-m transects (black lines), and area sampled for large trees—two 30 m × 100 m = 0.51 ha (beige-shaded area, excluding overlap). Different biomass components were sampled in different parts of the site.

### Bird surveys

Birds are counted using repeated time-controlled (5 minute) point interval counts at 0, 50 and 100 m along a permanent 100-m-long transect every year. The field collection data sheet is available at Appendix A-3.

Bird surveys are conducted each year in November/December. A subset of 81 sites is surveyed each year by two different observers on two separate mornings. The observers start at dawn and work until 10–11 am depending on the temperature (on hotter days the birds stop calling earlier).

Each site has three 5-minute counts of all the birds seen and heard during each period. Species type, abundance and distance from the 0-, 50- or 100-m points are recorded (see field sheet or proforma for distance classes), as well as time and weather variables. A separate data sheet is filled in for each plot.

### Arboreal marsupial surveys

Arboreal marsupials are counted using the stagwatching method (direct counts of nocturnal animals emerging from tree hollows at dusk). Hollow-bearing trees located

within the 1-ha area are also measured, mapped and monitored over time. The field collection data sheet is available at Appendix A-4.

A selection of around 40 sites is surveyed for possums and gliders from December to March every year. The sites are selected on a rotational basis (Lindenmayer et al. 2003). Factors guiding site selection include presence of Leadbeater's possum in the past, numbers of hollow-bearing trees and fire severity.

Each site is surveyed from dusk for approximately 1 hour. The stagwatch method uses one volunteer/watcher per tree on a site. A site with 30 trees requires 30 people. Multiple trees can only be watched by one person if they are a very experienced surveyor and the trees are close to each other. Watchers are placed under their tree by an experienced member of the Australian National University team, who advises on the best place to sit, where to look and what to look out for. As dusk approaches, an informal list of birds at the site is taken by team members.

Before watchers enter the site, a team member gives them an overview of what the stagwatch involves, including site-specific information such as the habitat selected (e.g. tree used) for each animal. Details of possum/glider calls, silhouettes or possum sizes are also provided.

Animals are recorded as they emerge, noting species, abundance, time, which tree they emerged from or whether it was just 'on site', whether it came from 'off site', the type of hollow it emerged from (e.g. ranch, top spout, fissure) and the tree number. Animals heard in the distance are also noted (e.g. owls, gliders, deer).

Weather conditions, date, time and volunteers names are recorded. Stagwatching does not occur in heavy rain.

## If I had my time again

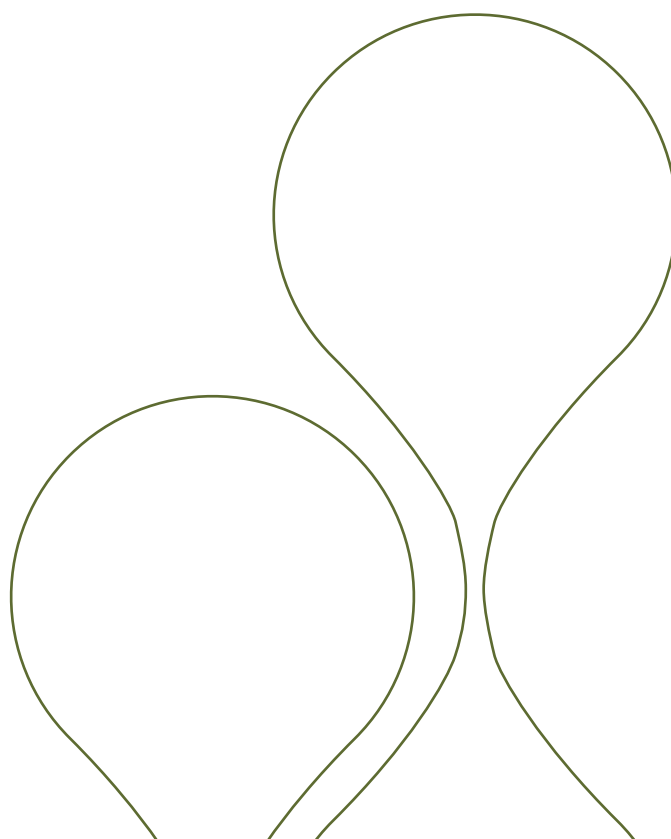
The long-term plot network in the Victorian wet forests has many strengths. However, with the benefit of hindsight (and the knowledge at its inception that work would still be going 32 years after it started), a number of things would have been done differently. First, the statistical design of the studies would have been more rigorous so that it was more reminiscent of a true experiment, with randomised site selection of sites subject to different formal treatments such as logged, unlogged and partial cutting. In addition, long-term sites would have been established to allow for subsequent quantification of the long-term changes in biota resulting from logging, rather than space-for-time, cross-sectional work that fails to account for key factors such as site history.

A number of experiments commenced in the early 2000s, but it would have been useful to have commenced these 15–20 years earlier to add to the timeframe and level of inference that can be gained from longer-term work.



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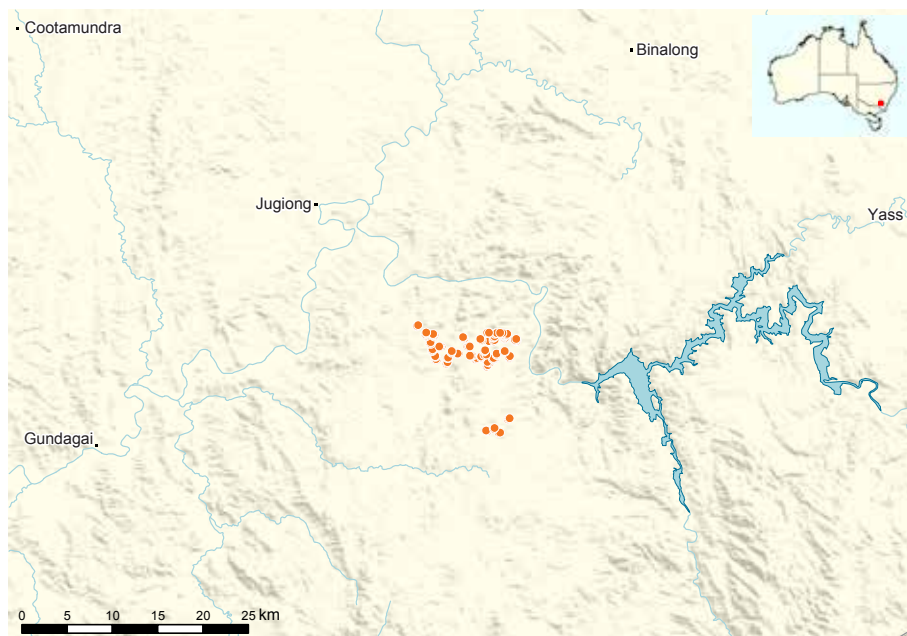
# 2 Nanangroe Plantation Plot Network



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## Location of the Nanangroe Plantation Plot Network

For the purposes of LTERN, a plot is a unit where flora and fauna attributes are measured. However, in the description of the data collection protocols for the Australian National University (ANU) Plot Networks in the following pages, the chief, independent locations at which attributes are measured are called sites (not plots) and each site may have between two and three (subsampling) plots. To help with consistency with the other plot networks, for locations run by the ANU, sites are referred to as plots.

Photo (opposite page): Nanangroe, M Crane

## Objective

To quantify the inter-relationships between human disturbance and a landscape-based management intervention, and changes in vegetation condition and biodiversity response.

## Research goals

- A significantly increased understanding of environmental and biodiversity responses to landscape-scale habitat modification.
- A significantly increased capacity to rigorously evaluate the long-term impact on temperate woodland biodiversity from plantation establishment.
- A significantly increased ability to identify appropriate indicators, metrics and techniques for assessing, managing and monitoring vegetation and biodiversity conservation in temperate woodland within a heavily fragmented agricultural environment.

## Research questions

- What are the relationships between vegetation condition and biodiversity?
- Are relationships between vegetation condition and biodiversity consistent across vegetation types?
- How does management intervention (e.g. plantation establishment) influence the response of biodiversity?

**Table 2.1 Nanangroe Plantation Plot Network summary table**

<b>Ecosystem</b>	Temperate eucalypt woodland
<b>General location</b>	Gundagai, NSW
<b>Other custodian(s) and/or partners</b>	Forestry NSW (state forest)
<b>Disturbance type</b>	Plantation forestry
<b>Data type (fauna/flora/vegetation structure)</b>	Fauna, flora, vegetation structure, vegetation type
<b>No. of plots (sites)</b>	131
<b>Plot size</b>	2 ha
<b>Start year</b>	1997
<b>Temporal revisit</b>	Annual/biennial (rotating sampling program)



## Specific data collection protocols

The Nanangroe Plantation Plot Network is research infrastructure comprised of an array of stratified 2-ha long-term plots. At these plots, vegetation, birds, and frogs and reptiles are surveyed (Lindenmayer et al. 2008).

### Vegetation surveys

Standardised vegetation condition measurements were made every five years in three vegetation structure plots (20 m × 20 m) nested within the 2-ha sites. The values estimated at each of the vegetation structure plots are number of trees (live/dead), tree stumps, tree hollows and mistletoe clumps; stand height; basal area (m<sup>2</sup>/ha using a basal area wedge for each vegetation strata); grass height; an ordinal regrowth index score and litter layer score (1–4); occurrence of dieback; and cover for eight attributes—exposed rock, weed cover, blackberry, grass, native ground layer, shrubs, dominant trees and subdominant plants—using the six ordinal classes None, 0–20%, 20–40%, 40–60%, 60–80% and 80–100%. 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. The field collection data sheet is available at Appendix A-5.

### Birds point count

Dawn bird counts take place every 1–2 years using repeated point interval counts. Bird observers count all birds seen and heard over 5-minute periods at each of the 0-, 100- and 200-m posts established at each site. Repeated point counts are taken by two different observers on two different days. The distance that each bird was seen at is recorded, along with bird abundance and any anecdotal comments (e.g. breeding behaviour). Anecdotal sightings outside the formal survey period are also recorded.

Bird species occurrence within 50 m of the observer is commonly used for analysis. The field collection data sheet is available at Appendix A-6.

### Frogs and reptiles—substrate and active search

Herpetofauna is 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 (Figure 2.1). A set of two sheets of corrugated iron placed on top of one another, four half-size railway sleepers and four roofing tiles are placed around a point at the 0-m and 100-m point of the permanent 200-m transect. These artificial substrates are gently turned over to record occupants, and some of the animals are hand captured to identify the species. Substrates are replaced and then the animals put carefully back underneath

the cover. Active searching is done by gently turning over any rocks, logs or fallen bark at locations along a 200-m transect. Several measurements, including head width, head length, snout-vent length, total body length and body mass, are also recorded. The field collection data sheet is available at Appendix A-7.

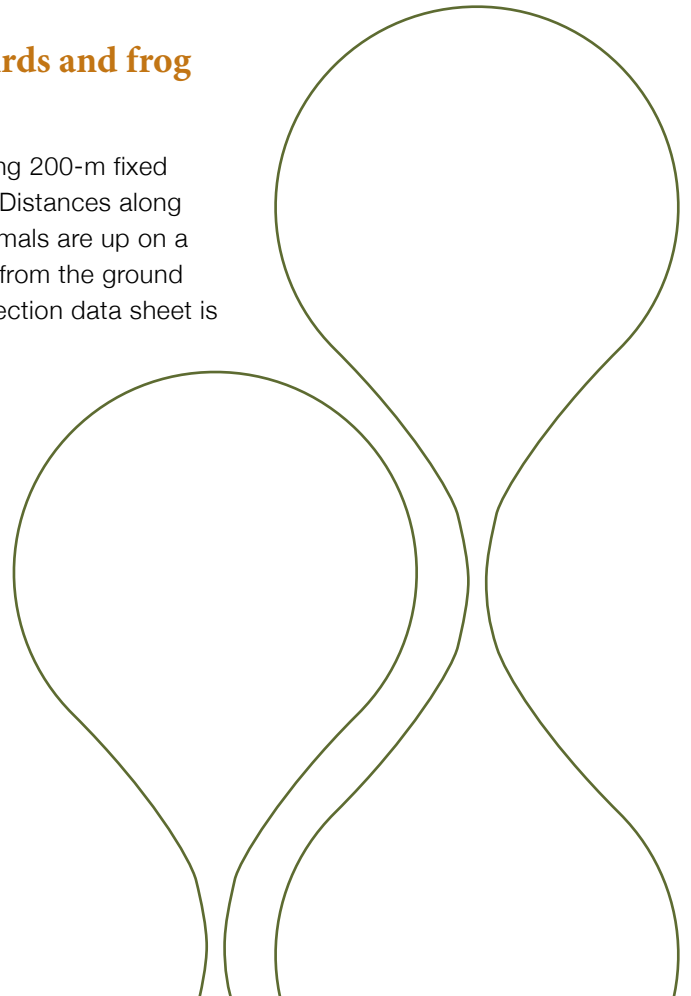


Photo: D Michael

**Figure 2.1** Example of artificial substrates—corrugated iron, railway sleepers and roofing tiles—used to sample herpetofauna at a plot within a site

### Arboreal marsupials, nocturnal birds and frog surveys

Spotlighting is conducted every two years along 200-m fixed transects at each site for 20 minutes per site. Distances along and adjacent to a transect are recorded. If animals are up on a tree, tree species and animal height (distance from the ground to the animal) are also recorded. The field collection data sheet is available at Appendix A-7.



## If I had my time again

The work at the Nanangroe Plantation Plot Network has many of the features of a 'natural experiment' and resulting strengths that come from randomised site selection and matched control sites. The long-term work has produced a number of important and often highly unexpected results. With the benefit of hindsight, the design of the study could have been coupled with other investigations running in parallel that focused on the ecological mechanisms underpinning the spatial and temporal patterns of occurrence that have been identified over the past 17+ years. These additional studies would have been important because, while the key temporal trends in changes in biota are compelling, the reasons why these have occurred remain poorly understood. More recently, mechanism-type studies have commenced, but it would have been more instructive to have begun them at the same time as the experiment at Nanangroe was being first implemented.



Photo: Lizard foot, D Michael

## References

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## Recommended further reading

Lindenmayer DB (2009). *Large-scale landscape experiments: lessons from Tumut*, Cambridge University Press, New York.

Lindenmayer DB, Welsh A, Blanchard W, Tennant P & Donnelly CF (2015). Exploring co-occurrence of closely-related guild members in a fragmented landscape subject to rapid transformation. *Ecography* 38:251–260.







# 3 Jervis Bay Booderee National Park Plot Network



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## Location of the Jervis Bay Booderee National Park Plot Network

For the purposes of LTERN, a plot is a unit where flora and fauna attributes are measured. However, in the description of the data collection protocols for the Australian National University (ANU) Plot Networks in the following pages, the chief, independent locations at which attributes are measured are called sites (not plots) and each site may have between two and- three (subsampling) plots. To help with consistency with the other plot networks, for locations run by the ANU, sites are referred to as plots.

Photo (opposite page): Jervis Bay, DB Lindenmayer

## Objective

To quantify the inter-relationships between natural disturbance and targeted management interventions, and changes in vegetation condition and biodiversity response.

## Research goals

- A significantly increased understanding of environmental and biodiversity responses to management interventions, including prescribed burning and weed control.
- A significantly increased capacity to rigorously evaluate the long-term impact of both prescribed burning and wildfire on coastal vegetation.
- A significantly increased ability to identify appropriate indicators, metrics and techniques for assessing, managing and monitoring vegetation and biodiversity conservation in the floristically complex coastal communities that have adapted to fire.

## Research questions

- What are the relationships between vegetation condition and biodiversity, and is this relationship consistent across vegetation types?
- How does natural disturbance and/or management intervention (including weed and feral animal control and prescribed burning) alter vegetation condition and the response of biodiversity?

**Table 3.1** Jervis Bay Booderee National Park summary table

Ecosystem	Heathland	Shrubland	Sedgeland	Coastal forest	Coastal woodlands	Rainforest	Summary
Other custodian(s) and/or partners	Wreck Bay Aboriginal Community and the Department of the Environment						
Disturbance type	Fire, exotic plants and animals						
Data type (fauna/flora/vegetation structure)	Fauna, flora, vegetation structure, vegetation type						
No. of plots (sites)	26	20	8	54	23	8	139
Plot size	1 ha	1 ha	1 ha	1 ha	1 ha	1 ha	1 ha
Start year	2002	2002	2002	2002	2002	2002	2002
Temporal revisit	Annual (vegetation 3 years, birds annual, arboreal spotlighting 2 years, reptiles annual, terrestrial mammals 2 years)						

## Specific data collection protocols

### Vegetation surveys

Standardised vegetation condition measurements are repeated every three years using the vegetation structure plots (1 m × 1 m, 20 m × 20 m) nested within 1-ha sites. Within the 100 m × 100 m 1-ha survey site, two 20 m × 20 m plots are located along a central transect at the 20–40-m and 60–80-m points. Within each of the 20 m × 20 m plots are four 1 m × 1 m subplots. The flora attributes measured are listed in Table 3.2. The field collection data sheet is available at Appendix A-9.

**Table 3.2** Covariates measured at (A) the transect level, (B) the 20 m × 20 m plot level, (C) the 1 m × 1 m subplot level and (D) in 200-m and 500-m polygons around each site (= landscape context variables)

Plot	Variable	Description
A. Transect level	Fire severity	Score based on the severity of the fire in 2003: 0 = no fire, 1 = understory burnt, 2 = midstorey burnt but not killed, 3 = midstorey killed, 4 = midstorey killed and overstorey burnt
	Time since fire	Four classes of time since fire: 0–10, 11–20, 21–30 and >30 years
	Wildfire frequency	Number of fires that have occurred since detailed vegetation and fire-mapping records were first collated (1977)
	Geology	Data extracted from geology maps for Booderee National Park
	Elevation	Data extracted from detailed topographic maps for Booderee National Park
	Dominant tree species	Based on assessment of trees on each transect, classified according to Costermans (1994) and Robinson (1994)
B. Plot data <sup>a</sup>	Slope	Measured using clinometer
	Aspect	Measured with compass (due north = 0, no aspect = 999)
	Max tree height	Measured using clinometer
	Basal count	Measured with dendrometer
	Variable	Description
	Canopy depth	Tree height, less height to lower branches

*continued*

**Table 3.2** continued

Plot	Variable	Description
B. Plot data <sup>a</sup> (continued)	Number of layers	Number of vegetation layers. Layers were classified as overstorey = >10 m, overstorey = >10 m, midstorey = 2 m < 10 m, understorey = <2 m
	Number of hollow-bearing trees	Number per plot
	Number of dead trees	Number per plot
	Number of dead shrubs	Number per plot
	Number of logs	Number >10-cm diameter and >1 m long
	Rock cover	Percentage rock cover in 20 m × 20 m plot
	Genera and species counts	List of plants species in a 20 m × 20 m plot— assigned into overstorey, midstorey and understorey, leading to a count of the number of genera and species
	Percentage cover	Estimate percentage cover of overstorey, midstorey and understorey plant species in each plot
	Count of live stems	Each stem assigned to one of three diameter categories (<15, 15–30 or >30 cm)
C. Ground cover assessment <sup>b</sup>	Percentage cover	Percentage cover of rock, leaf litter, bare earth/sand, bracken, grasses, regeneration (after a 2003 wildfire), bitou bush, forbs, ferns
D. Landscape context variables <sup>c</sup>	Number of vegetation types	Number of vegetation types in a polygon of 200-m and 500-m radius around each field site
	Area of vegetation type	Area of each vegetation types in a polygon of 200 m and 500 m radius around each field site
	Amount of human-disturbed vegetation cover	Area within a polygon of 200-m and 500-m radius around each field site that had been heavily altered by human infrastructure
	Distance to similar vegetation type	Distance from the edge of a polygon containing a given field site to the nearest (but spatially discrete) patch of vegetation of the same vegetation type
	Green cover	Percentage of green cover within 500 m of site post-fire

<sup>a</sup> Plot data are measured in two 20 m × 20 m plots at each site.

<sup>b</sup> Ground cover is measured in four 1 m × 1 m subplots located within each 20 m × 20 m plot.

<sup>c</sup> Landscape context variables are measured in polygons of 200-m and 500-m radius around each field site.

### Birds point count

Birds are counted using repeated time-controlled point interval counts along a permanent 100-m-long transect every 1–2 years (Lindenmayer et al. 2008).

Two 5-minute counts take place at each site, one at the 20-m mark and the other at 80-m mark of the transect. All birds seen or heard are recorded and assigned to different distance classes. Each site is surveyed on a different day by a different observer, to reduce day effects on detection and reduce problems with observer differences. Surveys are completed in late September.

The field collection data sheet is available at Appendix A-10.

### Arboreal marsupial surveys

Arboreal marsupials are counted using transect-based spotlighting surveys every 1–2 years along the 100-m transect at each site.

Each site is spotlit for 20 minutes per 100-m transect. Counts are not undertaken in poor weather (rain, fog or high wind). Abundance of species observed or heard is recorded. Presence of frog species is also recorded. Spotlight surveys were annual until 2007 and have been every second year since.

The field collection data sheet is available at Appendix A-11.



Photo: Eastern yellow robin, D Stojanovic



### Reptiles—substrate and active search survey

Until December 2010, pitfall traps were used to capture small reptiles and frogs. Each site was trapped annually in December. Six pitfalls were placed every 20 m along a 100-m transect and were opened for three consecutive nights.

Post-2010 sites are surveyed for reptiles and frogs using artificial substrates (tiles, tins and wooden sleepers). Two sheets of corrugated iron, four roof tiles and four 'half-length' railway sleepers have been placed at the 20-m and 80-m points of a transect. The transects are checked each year in August and again in December. A time-controlled active search along the permanent 100-m-long transect occurs every 1–2 years.

The field collection data sheet is available at Appendix A-12.

### Terrestrial mammal survey

Each site is trapped every 1–2 years for three consecutive nights. Ten Elliott traps and six cage traps are placed on each site (Elliott traps are spaced 10 m apart and cage traps are placed 20 m apart along the transect). Both Elliott and cage traps are baited with a mixture of peanut butter and rolled oats.

The field collection data sheet is available at Appendix A-13.



Photo: Black wallaby, D Michael

## If I had my time again

The Jervis Bay Booderee National Park Plot Network has benefited from scientist–manager partnerships that have connected research to on-the-ground management needs. It was carefully designed from the outset, but, nevertheless, no one study is perfect and a number of things would have been done differently if there was a chance to start over again. One key aspect we would have addressed would have been to commence studies of ecological processes and mechanisms that give rise to observed spatio-temporal patterns of change as the ongoing long-term monitoring proceeds. Many unexpected results have occurred, and studies of mechanisms would have been valuable to help determine why things changed in the way they did. A second key point would have been to build in triggers for management action into the monitoring program so that managers could more quickly respond when populations began to decline. In this way, park managers may have been able to intervene to prevent the regional extinction of species such as the greater glider.

## References

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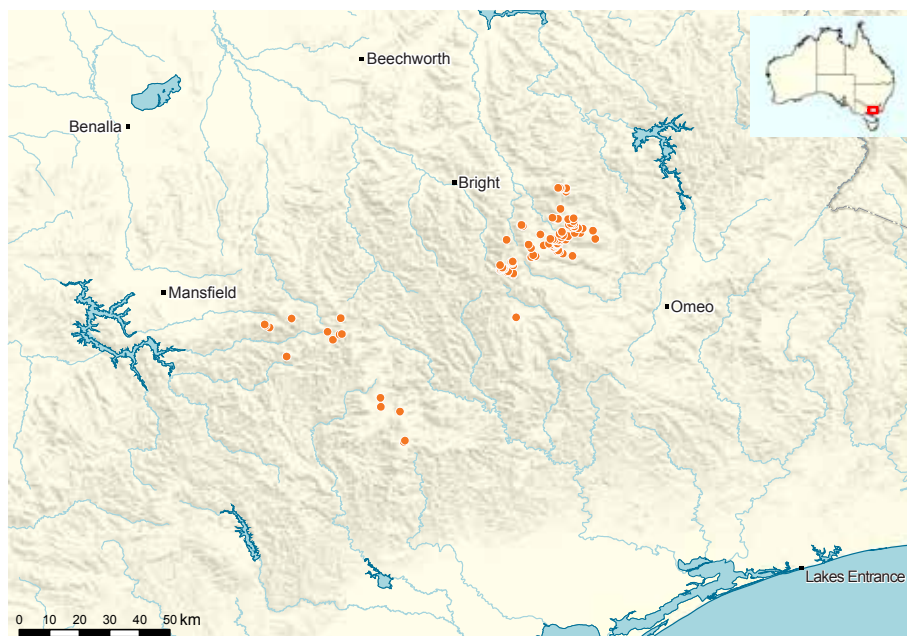
# 4 Victorian Alpine Plot Network



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## Location of the Victorian Alpine Plot Network

Photo (opposite page): An ATEX site with open-top chambers, H Wahren



## Objective

To provide a network of plots and data to monitor and assess the effects of human disturbance, fire, climate change, and invasive alien flora and fauna on biodiversity, soils and vegetation of the treeless alpine ecosystems. Also to identify ecological processes contributing to disturbance in this ecosystem and how evolutionary processes provide resilience.

## Research goals

- To provide an understanding of the long-term dynamics of vegetation communities, invertebrates and rare vertebrate fauna in the alpine region, and their uniqueness.
- To identify the main threats to biodiversity (e.g. genetic isolation, disturbance by livestock grazing, alien plants and animals, climate change) and the ability of vegetation communities to respond to these threats.
- To assess the impact of climate change on alpine ecosystems, and identify species suitable for ongoing monitoring.
- To identify appropriate indicators, metrics and techniques for assessing, managing and monitoring biodiversity in the face of change within the alpine region.

## Research questions

- What are the long-term changes in the major vegetation types and faunal assemblages? And what are likely future changes?
- What are the likely long-term effects on the alpine biota of human disturbance, climate change, drought, fire and altered biotic interactions?
- How is the invasion and expansion of non-native and native biota affecting treeless alpine ecosystems?
- To what extent do phenological changes indicate vulnerability to disturbance and climate change?
- What effects do disturbances have on faunal and plant communities?
- How genetically differentiated are vegetation and faunal communities in the Victorian Alps?
- Can new techniques (e.g. gene-pool mixing) be incorporated into conservation management?

Table 4.1 Victorian Alpine Plot Network summary table

<b>Ecosystem</b>	Alpine/ subalpine	Alpine/ subalpine Australian Tundra Experiment (ATEX)	Alpine/ subalpine (phenology)	Alpine/ subalpine (summit plots and roadside weed transects)	Alpine/ subalpine ( <i>Burramys</i> )
<b>General location</b>	South Eastern Highlands				
<b>Other custodian(s) and/or partners</b>	Parks Victoria	Parks Victoria	Parks Victoria	Parks Victoria, alpine resort management boards	Parks Victoria, alpine resort management boards
<b>Disturbance type</b>	Fire, invasive species, livestock grazing, feral animals, tourist development	Fire, invasive species, feral animals	Fire, invasive species, livestock grazing, feral animals	Ski-field and tourist development, fire, invasive species, livestock grazing, feral animals	Ski-field and tourist development, fire, invasive species, feral animals
<b>Data type (fauna/flora/vegetation structure)</b>	Vegetation structure and composition, invertebrates, fire intensity	Vegetation structure, composition and phenology; climate; invertebrates; soils	Phenology and invertebrate visitation networks	Vegetation composition and phenology, climate, disturbance (fire, invasive species and grazing)	Mammals
<b>No. of plots</b>	22 grassland sites  17 heathland sites  34 snowpatch herbfield sites  419 fire occurrence sites <sup>a</sup>	4 sites (multiple 1-m <sup>2</sup> plots per site)	18 transects	>100	12
<b>Plot size</b>	Site with multiple transects is the operational survey unit rather than the plot	1 m × 1 m	Transects 10–30 m long	1 m × 1 m summit plots; 50 m × 1 m roadside weed plots	Trapping grid is 0.25 ha
<b>Start year</b>	Earliest Carr and Turner plots established 1944	2003	2011–12	2001	1982
<b>Temporal revisit</b>	2–10 years	At least twice each year, measurements vary	4 times each year	Every 5 years	Every 2–3 years

a Including post-fire regeneration sites: 80 single visit, 10 long term at Bogong High Plains and 10 long term at Holmes and Wellington Plains.

## Individual experimental groups within the network

The alpine network of long-term monitoring sites has four principal components:

- Long-term vegetation (including post-fire) monitoring sites to document changes in plant community dynamics in relation to disturbance and land use, and to document fundamental ecological processes.
- Sites associated with a long-term climate change experiment, established under the auspices of the International Climate Change Experiment (ITEX)
- Sites established along elevational gradients and on mountain summits to detect changes in species diversity and abundance of alien, invasive plant species under the auspices of the Global Observation Research Initiative in Alpine Environments (GLORIA) and the Mountain Invasion Research Network (MIREN).
- Sites established to monitor the distribution and population dynamics of the rare mountain pygmy possum, *Burramys parvus*.

All four components have the following long-term monitoring objectives:

- To assess long-term changes in the major vegetation types in relation to disturbance and land use.
- To assess the extent to which invertebrate groups are unique, and at what scale.
- To monitor rare and restricted specialist alpine species.

All four components also have the long-term monitoring research questions:

- What changes in vegetation composition have occurred in the past 70 years, including incursions by alien exotic species?
- Which types of disturbance have the largest impact on the local flora and fauna?
- What are the genetic relationships between plants and invertebrates across the Victorian alpine region, and how might diversity be protected?
- What is the health and extent of discrete plant populations?

### History and rationale

Long-term vegetation monitoring sites are a feature of the research and management of the Australian alpine region. Sites have been established at various times for various reasons across the mainland Australian Alps and in Tasmania, with the explicit aim of documenting long-term changes in ecosystem composition and structure in relation to disturbance (Carr & Turner 1959a, 1959b; Kirkpatrick & Bridle 1999; Scherrer & Pickering 2005; Wahren et al. 1994; Wimbush & Costin 1979). In the Victorian Alps, monitoring sites were first established in 1944, and the number of sites was expanded considerably in the 1970s and 1980s. These sites have been used to document long-term ecological change in relation to disturbance (e.g. livestock grazing, fire) and land use (e.g. nature conservation, ski-resort development). Additional sample areas were established on a subset of these sites in 2011, to monitor long-term changes in invertebrates and plant genetic diversity. Following the fires of 1998 and 2003, additional monitoring sites were established to quantify patterns of burning across the alpine landscape, and to monitor post-fire regeneration. The development of our understanding

of the ecology of alpine environments, especially our understanding of fundamental ecological processes, has been influenced enormously by data from these long-term monitoring sites. The sites will continue to provide valuable data in the coming century as researchers and managers tackle problems such as climate change, potentially novel fire regimes and the increasing abundance of alien plants and animals.

The Victorian Alpine Network of long-term monitoring sites includes:

- The plots established by Mrs Maise Carr and Professor John Turner at Rocky Valley and Pretty Valley (Figure 4.1) on the Bogong High Plains in the 1940s (Carr & Turner 1959b; Wahren et al. 1994). These pioneering plots were established so that long-term changes in select vegetation types could be documented. This far-sighted research effort grew out of concerns that arose in the 1930s about the condition of the high mountain catchments, as a consequence of fire and livestock grazing.
- Sites established in a variety of vegetation types across the Victorian Alps. These sites were established to allow monitoring of long-term vegetation dynamics at a wider array of grassland sites, and in plant communities that were not sampled by the Carr and Turner plots—heathland, snowpatch herbfield and wetland. These long-term monitoring sites complement the detailed mapping of vegetation communities undertaken by Keith McDougall (1982). At the time the sites were established, cattle grazing was widespread across the Victorian Alps, the Alpine National Park was mooted or in its infancy, ski-resort development was expanding, and data were needed on long-term vegetation dynamics and vegetation state or condition in relation to land use.
- Post-fire monitoring sites established in various vegetation types following the landscape-scale fires of 1998 and 2003. Landscape-scale fire is rare in the alpine environment, and these sites were established specifically to take advantage of the opportunities presented by these infrequent events, so that patterns of burning and post-fire regeneration of vegetation could be documented.
- Additional sampling sites established on a select set of the long-term sites on the Bogong High Plains to survey invertebrate diversity and plant genetics. The aim of this suite of sites is to evaluate the effects of climate change on select components of the biodiversity of alpine ecosystems.

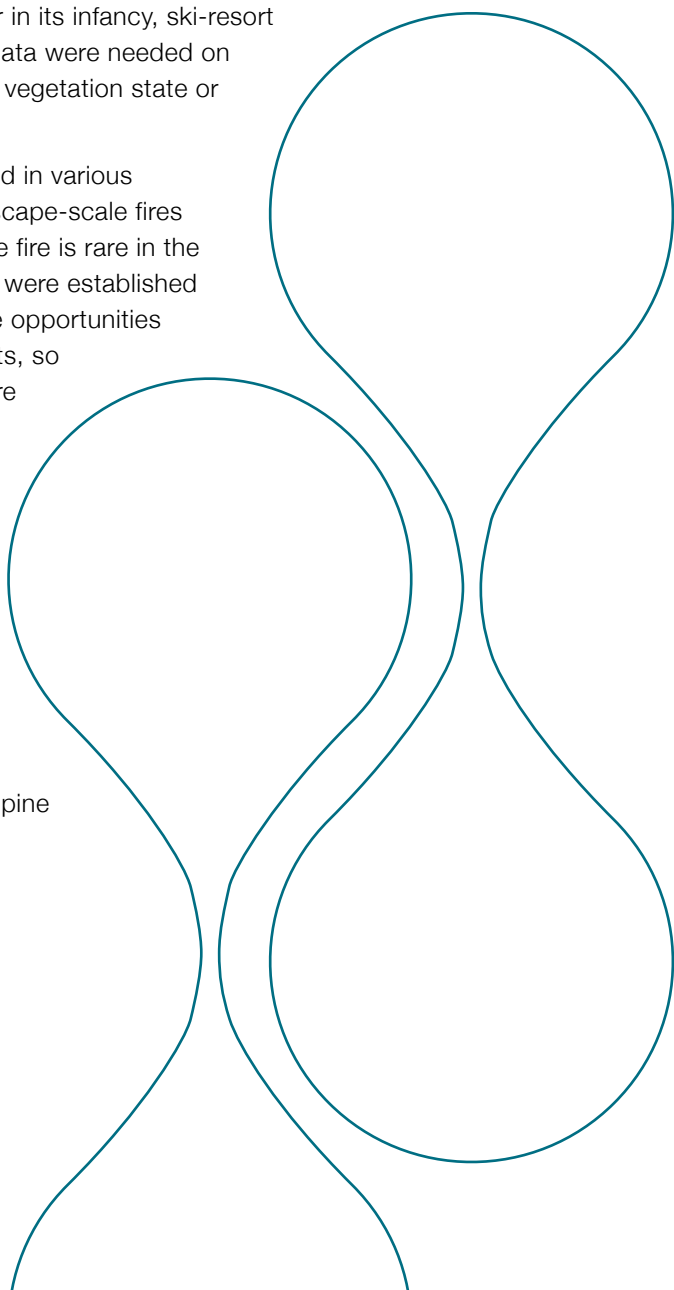






Photo from the Papst Collection

**Figure 4.1** Establishment of Pretty Valley plots, 1947

### Long-term vegetation monitoring—specific data collection methods

The sampling regime within the Victorian Alpine Plot Network mostly consists of multiple, randomly positioned transects within sites (rather than ‘plots’ in the strict sense), with each site and/or transect referenced by geographic coordinates. Point quadrats or vegetation intercepts are taken at fixed intervals along each transect. Point quadrats are taken using a 4-mm-diameter steel pin inserted vertically into the vegetation. The number of transects within sites varies, and sampling frequency varies from annual to decadal, depending on site and purpose.

#### *Vegetation sampling*

##### *Carr and Turner long-term monitoring plots*

At the Carr and Turner sites, fixed plots vary in area from 200 m<sup>2</sup> to 1200 m<sup>2</sup>. At the Pretty Valley site, one plot has been fenced (and thus ungrazed by livestock) since 1946; adjacent to this plot is an unfenced plot that has been grazed by livestock (chiefly cattle) from the late 1800s until 2003 (Figure 4.2). At the Rocky Valley site, there is an approximately 7-ha fenced area with monitoring plots in open heathland, closed heathland, snowpatch herbfield and wetland vegetation. Livestock has been excluded since 1944. Four plots corresponding to each of the fenced, ungrazed vegetation types and having similar slopes and aspects were established in 1944 outside the fenced enclosure, for comparison. These companion plots were grazed by domestic livestock until 2003. A total of eight plots are at Rocky Valley.

The four corners of each plot are marked with steel pickets, wooden stakes or fence posts, and their spatial coordinates (universal transverse Mercator) are recorded. Multiple

parallel transects are in each plot, the ends of which are fixed with 5 cm × 5 cm wooden pegs. The length, number and distance between transects within plots varied from plot to plot when they were established, and this arrangement has been preserved. Point quadrats are sampled at 50-cm intervals along the transects to give a total of 600–1200 point quadrats per plot. Measurements were taken at each plot annually from 1945–1951, then once or twice per decade thereafter (Wahren et al. 1994). All plots were sampled in 1979; since then, the Pretty Valley plots have been sampled every 5 years, and the Rocky Valley plots every 10 years.



Photo: H Wahren

**Figure 4.2** Pretty Valley plots that have been grazed from the 1840s to 2003 (right) and ungrazed since 1946 (left)

*Vegetation monitoring sites—grasslands, heathlands, snowpatch herbfields and wetlands*

Establishment of these long-term monitoring sites commenced in the late 1970s on the Bogong High Plains. In the ensuing decades, more sites were established on the Bogong High Plains, Dargo High Plains, Holmes Plain and Wellington Plain (Wahren et al. 1994, 1999, 2001a, 2001b, 2013; Williams et al. 2012). Sites have been established in all of the major vegetation types—grasslands, heathlands, snowpatch herbfields and wetlands.

In the grasslands, each site is approximately 0.2–1 ha in area and contains 10–12, 10-m transects. Transects are located randomly within sites and point quadrats are taken at 20-cm intervals along each transect. This gives a total of 50 points per 10-m transect and 500–600 points per site. All species touching the pin are recorded, along with the state of the ground surface (whether bare or covered by litter; see Appendix B-1). At present, 17 monitoring sites are established in grassland on the Bogong High Plains and 5 at Holmes Plains.

A similar set of transects within sites has been established at 34 snowpatch herbfield sites across the Bogong High Plains. At each site the sampling regime is similar to the grasslands: 10 10-m transects with 20-cm intervals, providing 50 point quadrats per

transect. Complementary floristic data are also collected at each site from within 5–15 3 m × 2 m quadrats that are randomly located in each snow patch. Quadrat size was determined using species–area relationships for a range of quadrat sizes (0.1–20 m<sup>2</sup>; Swengel 2001). Within each quadrat, all species are identified and the cover of each is estimated visually using the Braun–Blanquet scale (Wahren et al. 2001a).

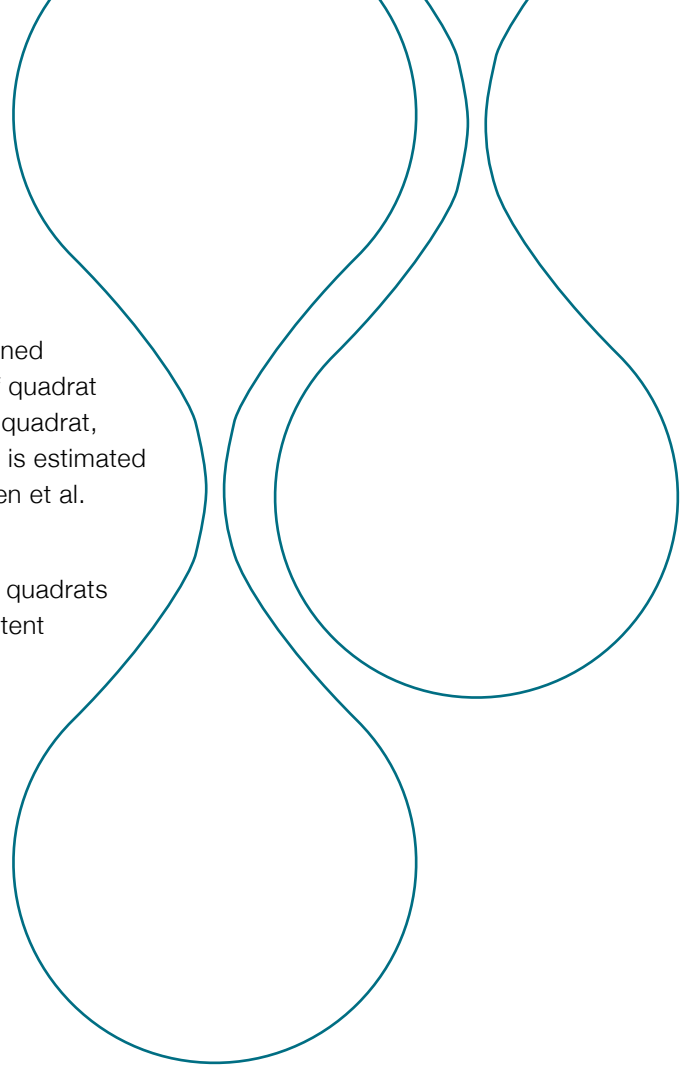
This general array of sampling transects, point quadrats along transects and floristic quadrats is consistent between grassland and snowpatch monitoring sites. However, the number of transects and floristic quadrats needed to detect change at each site varies. The optimal number per site has been determined by power analysis to adequately sample the composition and structure of the grassland and snowpatch communities, and detect change in key variables (including vegetation cover and bare ground) over time.

Long-term monitoring sites have also been established in wetlands, including two sites at the head of Middle Creek on the Bogong High Plains.

#### *Post-fire monitoring sites*

Major fires occurred in the Victorian Alps in 1998 (the ‘Caledonia fire’), in 2003 (the ‘Alpine fires’) and in 2006–07. The Caledonia fire burnt several thousand hectares of high subalpine treeless vegetation (Wahren et al. 2001c), and the Alpine fires burnt about half of the alpine vegetation of the Bogong High Plains (Williams et al. 2006). Both fires presented an opportunity to document post-fire regeneration and, in the case of the 2003 Alpine fires, examine factors affecting fire extent and severity.

The question of fire in the Australian alpine environment is controversial, particularly the putative effects of livestock grazing as a fire mitigation tool. The 2003 fires provided an opportunity to examine the hypothesis that ‘alpine grazing reduced blazing’. Immediately after these fires, 419 sample sites were established over an area of approximately 100 km<sup>2</sup> along transect lines that followed the major ridge and valley systems of the Bogong High Plains, such as Mount Nelse, Spion Kopje, Rocky Knobs, Mount Fainter, Pretty Valley and Rocky Valley (Williams et al. 2006). Survey points were distributed along the transects at intervals of 50, 200 or 500 m, with each interval predetermined randomly. Approximately half of the points were established in the southern section of the Bogong High Plains, south of Langfords Gap, which had been grazed by cattle since the mid-1800s. The remainder were established on the northern section of the Bogong High Plains, where cattle grazing ceased in 1991. This design captured the full range of topographic situations (e.g. slope, aspect) and vegetation types (grasslands, herbfields and heathlands) across the alpine landscape. The interval between sample points was varied to reduce the possibility of systematic error in sampling the spatial pattern of burning, and to reduce the likelihood of spatial auto-correlation.



At each point the following data were collected: latitude and longitude ( $\pm 10$  m), altitude, slope, aspect, vegetation type (snowpatch herbfield, grassland, open heathland, closed heathland; wetlands were not surveyed), and whether the site was burnt or unburnt. For burnt sites within heathland, the severity of burning was determined using minimum twig diameter as a proxy measure. At each site, the diameter ( $\pm 1$  mm) of burnt twigs was recorded on five branches of 10 randomly located dominant shrubs. The larger the minimum diameter of a burnt twig, the more severe the fire at that point. In open heath, the target shrub species was *Grevillea australis*; in closed heath it was *Orites lancifolia*. Methods are described in more detail in Whight and Bradstock (1999) and Williams et al. (2006).

Post-fire vegetation long-term monitoring sites were also established immediately after these fires in grassland and heathland at Holmes Plain and Wellington Plain in 1998 (Wahren et al. 2001b) and on the Bogong High Plains in 2003 (Wahren, Papst & Williams, unpublished data). The specific aims of these sites is to document post-fire regeneration, in particular the rate of development of vegetation cover and trends over time in plant diversity, species composition and vegetation structure. The sampling design and protocols follow those outlined for the long-term monitoring vegetation sites described above—multiple, randomly located 10-m transects, with 50 point quadrats taken along each transect. Some sites were pre-existing because they were part of the network of long-term vegetation monitoring sites described above; others were established immediately post-fire. There are three burnt sites and three unburnt sites within each of the grassland and heathland vegetation communities.

To assess the state of regeneration in heathland in relation to fire severity, a subset of the 419 points established on the Bogong High Plains in 2003 was surveyed for vegetation composition and structure in 2008. The survey was restricted to heathlands, and 80 sample points (40 in open heathland, 40 in closed heathland, half burnt and half unburnt) were selected at random from the 419 points established in 2003 (Camac et al. 2012). Fire severity had been determined at each site in 2003, and in 2008 the sites were sampled for vegetation composition and structure in relation to fire severity. A single 50-m transect was established at each site, and geolocated. Along each transect, five 2 m  $\times$  3 m quadrats were sampled for species composition, vegetation structure (shrub height, cover) and shrub seedling density. Methods are described in more detail in Camac et al. (2012).

### *Invertebrate and plant genetic diversity on long-term vegetation plots*

#### *Invertebrate diversity*

This protocol assesses diversity of ground-dwelling arthropods. The aim is to sample all sets of long-term monitoring sites established in snowpatch herbfields (see above); sites were sampled initially in 2012–13. Ten pitfalls at each long-term plot site are arranged in a 5 m  $\times$  2 m grid, and pitfalls are spaced 2 m apart. This effectively gives an area 4 m  $\times$  12 m, which has to avoid other sampling in the site. For example, permanent line transects used to sample vegetation must be located before establishing invertebrate sample areas.

Pitfall traps are used to 'catch' arthropods. The traps are constructed from plastic sleeves 22-mm diameter by 150 mm deep and are sunk 150 mm into the ground using a specially designed pin. A 120-mm-deep by 20-mm-diameter glass test tube containing 50 mm of propylene glycol is inserted into the sleeve so that the top of the trap is flush or slightly below the soil surface (method adapted from Majer 1978). Sleeves are sealed



with foam plugs when test tubes are not in place. These permanent sample points (sleeves) need to be marked with something (e.g. white, plastic sticks) that will resist extreme climatic conditions. Sampling occurs more than once per season with traps opened for a period of one week for each sampling period. Sampling time depends on many factors, such as the community being surveyed, seasonal road closures and storm conditions. When collecting data for specific experiments, the sampling needs to coincide with activity of taxa under investigation. Under experimental conditions the number of traps and layout will vary. For snow patches, four lines of five pitfalls are used at each plot ( $n = 20$ ) and an additional four lines of five pitfalls are placed in the vegetation directly above the snowpatch, which forms a continuation of a transect running upslope from the bottom of the snowpatch. The distances between lines of five pitfalls are determined by the size of snowpatch. This paired design (with snowpatch and adjacent vegetation) enables examination of differences between locations and between vegetation within location.

Samples are returned to the lab for sorting and identification. Voucher specimens are collected for formal identification purposes, but collection is limited to minimise disturbance. Descriptive names for insects tied to vouchers and photos are also used. Vouchers are verified against holotype specimens and lodged at the Australian National Insect Collection. Labelling is per museum convention (see Appendix B-2), and information is entered into a database. Relevant samples are stored in 100% ethanol for subsequent genetic analysis.

#### *Plant genetic diversity*

Genetic analysis involves traditional (microsatellite and sequence data) and/or novel (single nucleotide polymorphisms) techniques aimed at providing a baseline phylogenetic profile of the Victorian Alps. The aim is to collect plant material for genetic analysis from up to 15 species sampled from the long-term snowpatch sites (see above) and to sample at all long-term sampling sites in the future. The samples comprise five common, relatively widespread species; five common, localised species; and four common species. For each species, we collect from different plants and up to 16 plants per plot. In collecting plant material, the focus is on fresh growth, where possible, with a shoot or 2–3 new leaves being adequate. Harris size four filters (10–12 cup) are used to place individual samples. We fold the sides in a couple of times (because the filters are a really annoying shape), then fold the top over a couple of times and put a paper clip on so that it doesn't unfold. We put all individual samples (approximately 15) per species into a single, airtight ziplock bag, then add silica gel and put the bag into an airtight container. We keep samples from the same plot in separate airtight containers with additional fresh silica gel. We write the collection number on the bag (in pencil in case things get wet) and in a fieldwork book with the sample details, including plot, date, and latitude/longitude.

#### *Climate data*

Monitoring of a suite of climatic variables occurs at a subset of long-term plots. Average hourly air temperature is recorded using two temperature data loggers (DS1920 Thermochron®, Maxim Integrated Products, 120 San Gabriel Drive, Sunnyvale, CA, USA). This protocol was established during the 2011–12 season. Loggers are set to the highest resolution (0.06 °C) and are set so that readings are recorded on the hour. We place both loggers 50 mm above the bare soil surface, attached to a wooden stake (100 mm wide) and facing south, hence shaded. Where temperature data from the two loggers are not within a 0.5 °C range of each other we exclude the data, which is

consistent with procedures followed by the Australian Bureau of Meteorology. Data are downloaded every five months before rollover occurs (4028 readings gives 167 days at the settings recommended).

## Long-term monitoring for climate change impacts—the Australian Tundra Experiment (ATEX) plots

### Objective

To determine the responses of alpine plants and invertebrates to passive, experimental warming and drying, and to use the results to predict potential responses of alpine biota to climate change.

### Research questions

- How does passive warming affect plant growth and phenology?
- Which life forms (grasses, shrubs, forbs) are most sensitive to warming?
- Does warming result in a change in species composition and a decline in plant diversity?
- How does the interplay between experimental warming, disturbance and biotic interactions affect the alpine biota?

### Rationale

Alpine environments globally are vulnerable to the effects of climate change, particularly warming. To examine the effects of climate change on alpine ecosystems, a climate change experiment was established on the Bogong High Plains in 2003. The experiment aims to assess the likely response of vegetation and invertebrates to temperature increases attained via a passive warming experiment. The basic experimental unit is a 1-m<sup>2</sup> plot, and the passive warming is achieved by perspex, open-top chambers (OTCs). These chambers change the microclimate of the plots during the growing season—raising the ambient temperature by about 1–1.5 °C and reducing soil moisture by 5–10%. Responses in the growth and phenology of individual species and life forms, and changes to community composition and diversity are monitored according to internationally agreed-to protocols. Data collected from the plots can then be used to generate predictions, which can be across elevation (and thus temperature) gradients, and assess above-ground effects on carbon storage.

### Specific data collection protocols

#### Plot set-up

Following the International Tundra Experiment (ITEX) protocol (Jarrad et al. 2009; Molau & Mølgaard 1996; Wahren et al. 2013), four open-heathland ATEX field sites—two burnt and two unburnt—were established in the Rocky Knobs area (36.90°S, 147.27°E) on the Bogong High Plains in 2003 (Table 4.2). The burnt and unburnt sites were ca 1.7 km apart and, within burn type, each site is separated by approximately 0.5 km. At each of the two unburnt sites, 26 1-m<sup>2</sup> plots are located along permanently marked transects. Transects are 10 m apart, 50 m long, and marked with sturdy, red gum

end-pegs. At each unburnt site, 13 of the plots are covered by a hexagonal OTC (height 50 cm, base diameter 168 cm, top diameter 110 cm) and the remaining, control plots are uncovered. At each of the two burnt sites there are 14 1-m<sup>2</sup> plots, 7 of which are covered by an OTC, and 7 of which are uncovered controls.

**Table 4.2 Site information**

Site	1	2	3	4
Code	I1UB	I2UB	I3B	I4B
Size (ha)	0.72	0.54	0.27	0.3
Burnt in 2003			◊	◊
No. of transects	11	10	6	7
Baseline	225	30	325	295
Transect angle	345	120	55	205
Total no. of plots	26	26	14	14
No. of OTCs	13	13	7	7
UTMs	0524305, 5915582	0523839, 5915931	0525210, 5917026	0524843, 5917353

B = burnt; OTC = open-topped chamber; UB = unburnt; UTM = universal transverse Mercator coordinates

Note: Sites are all in zone 55H.

More information on the set-up of the ATEX plots can be found in Wahren (2006), which is available on request.

The OTCs, which increase ambient temperatures inside the chambers at these sites by about 2–2.5 °C, are constructed from lightweight, shatter-resistant fibreglass with high light transmittance (86%) and low transmittance of infra-red (<5%) (Figure 4.3). The OTCs are large enough to accommodate all species to be monitored, without influencing growth habits or reproductive structures via, for example, edge effects. Phenology, growth and species composition are measured according to Jarrad et al. (2009), using the protocols of Molau and Mølgaard (1996), as described on the following pages.

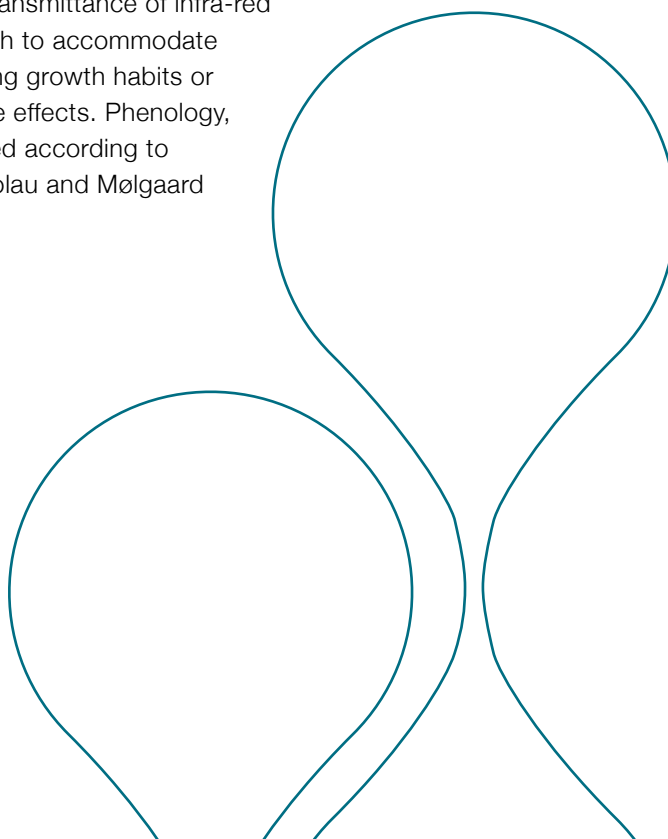




Photo: H Wahren

**Figure 4.3** An ATEX site with open-top chambers

#### *Vegetation phenology monitoring*

Phenology is monitored two days per week throughout the snow-free season. The target species are common or widespread, and the monitored pheno-phases are standard within the ITEX network (Molau & Mølgaard 1996). The phenological data for each target species within each plot comprise the dates for the following pheno-phases: appearance of first leaf; appearance of first flower bud; scape or stem elongation; opening of first flower; first petal shed; last petal shed; and seed maturation. Note that not all phases are present in all species. The plot is sampled using a 1-m<sup>2</sup> PVC quadrat frame placed over the plot, making sure that the outer diagonal corners touch the 'inner' corner of each red gum peg. The relevant phenological dates are then recorded for each ATEX species found in the plot. The species monitored are listed in Wahren (2006).

#### *Vegetation growth measurements*

Every second snow-free season, vegetative growth is recorded in seven species and the measurements converted into a relative rate (i.e. relative rate of growth =  $(t_{i+1} - t_i)/t_i$ , where  $t_i$  = measurement at time  $i$ ). Measurements of selected species involved leaves of *Carex breviculmis*, *Poa hiemata* (graminoids) and *Celmisia pugioniformis*, *Erigeron bellidioides* and *Plantago euryphylla* (forbs), and stems of *Asterolasia trymalioides* and *Pimelea alpina*. By using the relative rate of growth, the effect of initial size on measurements is removed. At the beginning of each growing season, plants are selected randomly for monitoring at every subplot within all ATEX plots. The first measurements are taken as soon as the snow melts and sites can be accessed in October or November, the second measurements is taken mid-season in January and the final measurements are taken in March, the end of the active growing season. For



the graminoids and *C. pugioniformis*, leaves are gathered and the longest live leaf is measured to the nearest 0.25 cm for three random plants of each species per plot.

For the forbs, two random leaves on three random plants of each species per plot are measured for length (from base to tip, excluding petiole) and width (at the widest point) to the nearest 1 mm. Older leaves at the base of the rosette are avoided, because they have already grown to their full length. For the shrubs, the lengths of three random new shoots are monitored on three random plants of each species per plot. The ITEX protocol recommends a variety of vegetative measurements (Molau & Mølgaard 1996), from which a subset of measurements are selected that are appropriate for the species in this study. Further details are in Jarrad et al. (2009).

### *Plant species composition*

Every second year, vegetation is sampled by point quadrats using a 4-mm-diameter steel pin, inserted vertically at 10-cm intervals within a grid of 100 points defined by a 1-m<sup>2</sup> point frame. At each point, the top, intermediate and bottom species; canopy height; and condition of ground surface (bare soil, attached live or dead vegetation, loose litter) are recorded.

### *Invertebrates*

Within each plot, three pitfall traps (see previous description) are used for sampling arthropods. The same points are used each season. A seven-day sampling period is repeated three times during the snow-free season (October–April), to help survey the full range of organisms present.

### *Climate data*

Air temperature is recorded 50 mm above the surface with Onset Hobo data loggers (Onset Computer Corporation, Bourne, MA, USA) in eight subplots (four OTC; four CTL) per plot (Hoffmann et al. 2010).

### *Phenology transects*

#### *Objective*

To describe the phenological responses of alpine plants to environmental variables and assess the usefulness of this measure to assess vulnerability to changing abiotic (e.g. climate) and biotic (e.g. invasive species) factors.

#### *Research questions*

- What environmental variables determine phenology in different plant groups?
- What are the patterns of selection action on phenology, both directly through climate and indirectly through biotic interactions (e.g. invertebrate predation and pollination)?
- Are phenological patterns (and their plastic responses to environmental variables) predictive of population decline?

#### *Specific data collection protocols*

These transects were established to help validate the findings from the ATEX experimental plots. The aim is to describe the phenological responses of alpine plants to environmental variables and assess the usefulness of this measure to assess vulnerability to changing abiotic (e.g. climate) and biotic (e.g. invasive species) factors. The transects

are aimed at understanding environmental variables determining phenology in different plant groups, patterns of selection acting on phenology, and whether phenological patterns (and their plastic responses to environmental variables) are predictive of population decline.

These new transects were established in November 2011 to cover a range of elevations. On the Bogong High Plains, one set of six transects runs from Buckety Plain to Mount Nelse and another set of plots from Wild Horse Creek to Mount Nelse, with the Mount Nelse point common to both sets. Five sampling transects were also established at Mount Hotham. There are 18 transects in total, which range in altitude from 1400 m to 1880 m. At each site a permanent transect has been established with a geolocated red gum peg marking the start. Transects are sampled on the same dates, three times a year: early season (Bogong High Plains 10–13 November, Hotham 15 November), mid-season (Bogong High Plains 17–20 December, Hotham 22 December) and late season (Bogong High Plains 18–22 February, Hotham 24 February).

Within a transect, a 30-m tape is run from the red gum peg with the temperature sensors. The transect is a minimum of 10 m with the tape usually run out to 30 m. Species are recorded along the tape and, where necessary, within 1 m each side of the tape. If a larger search area is required, we continue beyond 30 m and a greater distance either side of the tape. The search area is variable in area so that each species on the data sheet is located, and to ensure that enough individuals are sampled at each site to estimate flowering time (for a sample data sheet, see Appendix B-3).

The plant phenological traits recorded are listed in Table 4.3.

**Table 4.3** Plant phenological traits

Code	Term	Description
B	Bud	Appearance of first floral bud or inflorescence
BO	Bud open	When the bud has just opened; usually you can see the petals
FO	Flower open	When the flower is open but less than 50% of anthers are showing or less than 50% of the ray florets have opened
FF	First flower	When the first flower has opened on a shrub
F<50	Flowering under 50%	When less than 50% of the buds on a shrub have opened and are flowering
F	Flowering	When the flower is open and more than 50% of the anthers are showing or more than 50% of the ray florets have opened
LF	Last flowers	When only a handful of flowers are left on a shrub
LP	Last petal	When all petals have dropped and the flower has finished flowering
SM	Seed mature	When the first seed has matured
SM<50	Seed mature under 50%	When less than 50% of the seeds on a shrub have matured
SD	Seed dropped	When the seed has dropped. Mainly for <i>Pimelea alpina</i> because it is hard to tell if it has aborted or dropped all its seed

Twenty-five species have been selected for the phenology transects (Table 4.4), including 16 that are common in the Victorian Alps and 9 that are uncommon or rare. For each species present at the site, we record the phenological traits occurring on 20 plants.

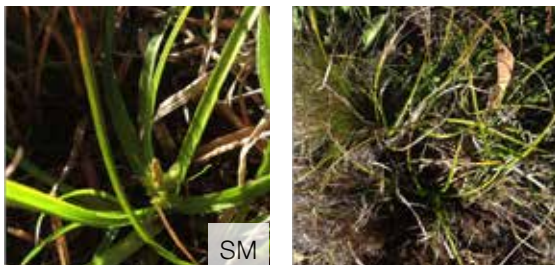
**Table 4.4** Species selected for monitoring on phenology transects

Rarity	Species	Code	Life form	Family
Common	<i>Carex breviculmis</i>	CARBRE	Monocot	Cyperaceae
	<i>Poa fawcettiae</i>	POAFAW	Monocot	Poaceae
	<i>Poa hiemata</i>	POAHIE	Monocot	Poaceae
	<i>Rytidosperma nudiflorum</i>	RYTNUD	Monocot	Poaceae
	<i>Brachyscome decipiens</i>	BRADDEC	Forb	Asteraceae
	<i>Celmisia costiniana</i>	CELCOS	Forb	Asteraceae
	<i>Celmisia pugioniformis</i>	CELPUG	Forb	Asteraceae
	<i>Craspedia aurantia</i>	CRAAUR	Forb	Asteraceae
	<i>Craspedia coolaminica</i>	CRACOO	Forb	Asteraceae
	<i>Craspedia jamesii</i>	CRAJAM	Forb	Asteraceae
	<i>Erigeron bellidioides</i>	ERIBEL	Forb	Asteraceae
	<i>Erigeron nitidus</i>	ERINIT	Forb	Asteraceae
	<i>Ranunculus victoriensis</i>	RANVIC	Forb	Ranunculaceae
	<i>Asterolasia trymalioides</i>	ASTTRY	Shrub	Rutaceae
	<i>Grevillea australis</i>	GRE AUS	Shrub	Proteaceae
	<i>Pimelea alpina</i>	PIMALP	Shrub	Thymelaceae
Uncommon or rare	<i>Arthropodium milleflorum</i>	ARTMIL	Monocot	Asparagaceae
	<i>Aciphylla glacialis</i>	ACIGLA	Forb	Apiaceae
	<i>Euchiton fordianus</i>	EUCFOR	Forb	Asteraceae
	<i>Geranium antrorsum</i>	GERANT	Forb	Geraniaceae
	<i>Oreomyrrhis argentea</i>	OREARG	Forb	Apiaceae
	<i>Plantago euryphylla</i>	PLAEUR	Forb	Plantaginaceae
	<i>Ranunculus eichlerianus</i>	RANEIC	Forb	Ranunculaceae
	<i>Hovea montana</i>	HOVMON	Shrub	Fabaceae
	<i>Pultenaea tenella</i>	PULTEN	Shrub	Fabaceae

### Species-specific phenology examples

*Carex breviculmis* (short-flowered dryland sedge) Code: CARBRE

We record the phenological traits (B, F, LP, SM) present for the first five plants or plants in a clump closest to the tape measure at regular 1-m intervals.



*Poa hiemata* / *P. fawcettiae* (soft snow-grass/horny snow-grass) Code: POAHIE/ POAFW

We record the phenological traits (B, F, SM) present for an individual tussock closest to the tape measure at regular 1-m intervals.



*Rytidosperma nudiflorum* (alpine wallaby-grass) Code: RYTNUD

We record the phenological traits (B, F, SM) present for a plant closest to the tape measure at regular 1-m intervals.



*Brachyscome decipiens* (field daisy) Code: BRADEC

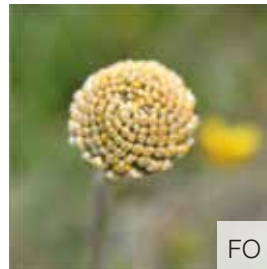
We record the phenological traits (B, BO, FO, F, LP, SM) present for each plant.





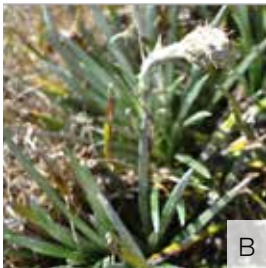
*Craspedia aurantia* / *C. coolaminica* / *C. jamesii* (orange billy-button/mountain billy-button/James's billy-button) Code: CRAAUR/CRACOO/CRAJAM

We record the phenological traits (B, BO, FO, F, LP, SM) present for each plant.



*Celmisia costiniana* / *C. pugioniformis* (carpet snow-daisy / dagger-leaf celmisia) Code: CELCOS/CELPUG

We record the phenological traits (B, BO, FO, F, LP, SM) present for the first five plants or plants in a clump closest to the tape measure.



*Erigeron bellidioides* / *E. nitidus* (violet fleabane / sticky fleabane) Code: ERIBEL/ERINIT

We record the phenological traits (B, BO, FO, F, LP, SM) present for the first plant or plant in a clump closet to the tape measure.



*Ranunculus victoriensis* (Victorian buttercup) Code: RANVIC

We record the phenological traits (B, BO, FO, F, LP, SM) present for each plant.

*Asterolasia trymalioides* (alpine starbush) Code: ASTTRY

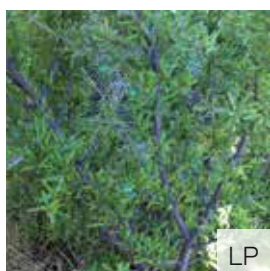
We record the phenological traits (B, FF, F<50, F, LF, LP, SM<50, SM) for each shrub sampled. Each plant is to be measured at the first sampling period (width × width × height).

*Pimelea alpina* (alpine rice-flower) Code: PIMALP

We record the phenological traits (B, FF, F<50, F, LF, LP, SM<50, SM, SD) for each shrub sampled. Each plant is to be measured at the first sampling period (width × width).

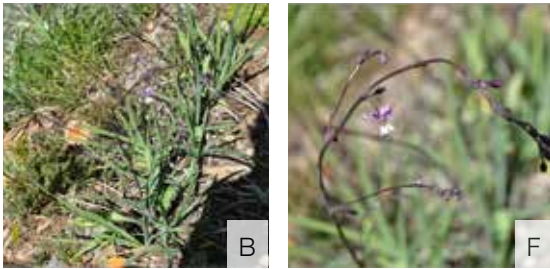
*Grevillea australis* (alpine grevillea) Code: GRE AUS

We record the phenological traits (B, FF, F<50, F, LF, LP, SM<50, SM) for each shrub sampled. Each plant is to be measured at the first sampling period (width × width × height).



*Arthropodium milleflorum* (pale vanilla-lily) Code: ARTMIL

We record the phenological traits (B, BO, F, LP, SM) present for each plant.



*Aciphylla glacialis* (mountain celery) Code: ACIGLA

We record the phenological traits (B, BO, F, LP, SM) present for the first plant or plant in a clump closet to the tape measure.



*Euchiton fordianus* (soft cudweed) Code: EUCFOR

We record the phenological traits (B, BO, FO, F, LP, SM) present for the first five plants or plants in a clump closet to the tape measure.

*Geranium antrorsum* (rosetted crane's-bill) Code: GERANT

We record the phenological traits (B, BO, F, LP, SM) present for each plant.

*Oreomyrrhis argentea* (silver carraway) Code: OREARG

We record the phenological traits (B, BO, F, LP, SM) present for each plant.



*Plantago euryphylla* (broad plantain) Code: PLAEUR

We record the phenological traits (B, FO, F, LP, SM) present for each plant.

*Ranunculus eichlerianus* (Eichler's buttercup) Code: RANEIC

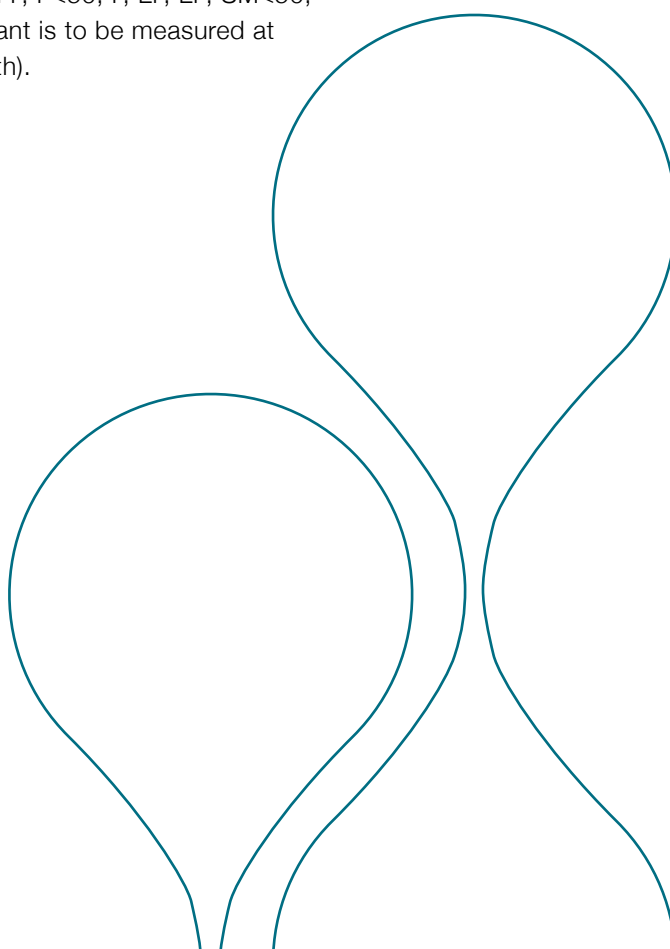
We record the phenological traits (B, BO, FO, F, LP, SM) present for each plant.

*Hovea montana* (alpine hovea) Code: HOVMON

We record the phenological traits (B, FF, F<50, F, LF, LP, SM<50, SM) for each shrub sampled. Each plant is to be measured at the first sampling period (width × width × height).

*Pultenaea tenella* (delicate bush-pea) Code: PULTEN

We record the phenological traits (B, FF, F<50, F, LF, LP, SM<50, SM) for each shrub sampled. Each plant is to be measured at the first sampling period (width × width).





### *Phenology transects: insect flower visitors*

To provide sufficient data on visitations, long quadrats—1 m × 20 m—adjacent to the plot sites are used to observe insects visiting flowers. Wooden stakes 50 mm × 25 mm are used to mark the ends and right-hand edge of the quadrats, determined by the peg with the metal label. Where possible, the edge along which one walks to record is downslope to the quadrat, since this makes observations easier. The floral units for each flowering species in the quadrat are recorded for the entire season, with 10 minutes spent observing insect visits for each quadrat. Floral units are defined as non-connected florets. For shrubs, it can be difficult to determine if a unit is a non-connected floret, so a rough guide is to count the number of stems with flowers and record the number of individual shrubs flowering within the quadrat. With *Pimelea alpina* and other similarly structured species, the number of flowers can be estimated quite easily, but the number of individual plants flowering is also recorded. Recordings are initiated under conditions suitable for insect activity; they are not done in the rain. Plant species are recorded. Insect records follow the same convention; however, in most cases, identification is at the family level. Vouchers need to be collected for formal identification; however, these need to be limited to minimise disturbance. We use descriptive names for insects tied to vouchers and photos. Vouchers are verified by specialists and are lodged at home institutions.

### *Climate data*

Average hourly air temperature is recorded along the transects using two temperature data loggers (DS1920 Thermochron®, Maxim Integrated Products, 120 San Gabriel Drive, Sunnyvale, CA, USA). Transects were established during the 2011–12 season. Loggers are set to the highest resolution (0.06 °C) and are set so that readings are recorded on the hour. They are placed 50 mm above the bare soil surface, attached to a wooden stake (100 mm wide) and facing south; hence they are shaded. Where temperature data from the two loggers are not within a 0.5 °C range of each other we exclude the data, consistent with procedures followed by the Australian Bureau of Meteorology. Data are downloaded every five months before rollover occurs (4028 readings gives 167 days at the settings recommended).



Photo: *Brachyscome decipiens* (field daisy), R Woodward

## Alpine summit plots and lowland-to-highland transects: data collection protocols

### *Objective*

To determine changes in plant species composition and diversity, and the abundance of weed species, using elevational gradients.

### *Research questions*

- Will warming result in a change in species composition and a decline in plant diversity?
- Which life forms (grasses, shrubs, forbs) are most sensitive to warming?
- What species of introduced plants pose the most risk to alpine environments and can we detect them before they become a problem for conservation management?

Alpine environments globally will be subject to invasions by species from lower elevations as the world warms. These species will be both native and introduced. To detect such changes, two sets of long-term monitoring plots have been established to monitor changes and detect changes in species diversity, community composition and the abundance of exotic plant species. The first is a set of plots established on the summits of the highest mountain peaks on mainland Australia. The second is a series of plots established along altitudinal gradients, using a network of roads and tracks, from lowland to highland elevations. Both contribute to global research efforts on climate change in high mountain environments.

### *Summit plots*

#### *Life-form cover*

A global climate change and mountain environments monitoring network—the Global Observation Research Initiative in Alpine Environments (GLORIA; [www.gloria.ac.at](http://www.gloria.ac.at))—was established in 2001 to detect long-term vegetation change on alpine mountain summits. Observations focus on changes in species richness with respect to local temperatures and altitude. Five mountain summit survey sites were established in the Kosciuszko National Park in 2004 and several in the Victorian Alpine National Park in 2006. There are currently 12 such summits, encompassing the geographic distribution of high alpine summits in the Australian Alps, with each to be surveyed at five-year intervals.

For each mountain summit, four variable-length permanent transects have been established that run from the summit, downslope, to a contour 5 m in elevation below the highest point (the ‘–5 m contour’). Transects run from the summit to the north (0 degrees), south (180 degrees), west (270 degrees) and east (90 degrees). Along each transect, line intercepts (to the nearest centimetre) are recorded for each of the dominant classes (grasses, herbs, shrubs), noting dominant species, as well as ground cover condition when vegetation is absent (bare ground, rock). These data are converted to percentage cover per transect to detect structural changes.

### *Species composition*

For each transect, 20 1-m<sup>2</sup> quadrats are randomly distributed from the summit to the 5-m contour, five on each slope/aspect. All species are recorded and assigned a percentage cover (<1%, 1%, 5%, then to the nearest 5% thereafter). Litter, rock and bare ground are also recorded. These data allow compositional changes to be detected over time. Across the entire summit, to the –5-m contour on all aspects, a species list is compiled to indicate the species pool. All species are then assigned an abundance based on an approximately log scale of the number of individuals seen: fewer than 10, in the 10s, in the 100s, in the 1000s. These data allow species invasions (and losses) to be examined.

### *Roadside weed detection plots*

The data collection protocol follows the guidelines of the Mountain Invasion Research Network (MIREN; [www.mountaininvasions.org](http://www.mountaininvasions.org)). The aim is to determine where exotic (and native) species are distributed on mountain roadsides, and to use these data against background quadrat data collected over past years and decades to test hypotheses about roads as vectors for dispersal of invasive species.

The sampling regime consists of five altitudinal transects, with plots located at altitudinal intervals along the transects. The transects follow major roads and management tracks in the Victorian Alps. The five roadside transects are:

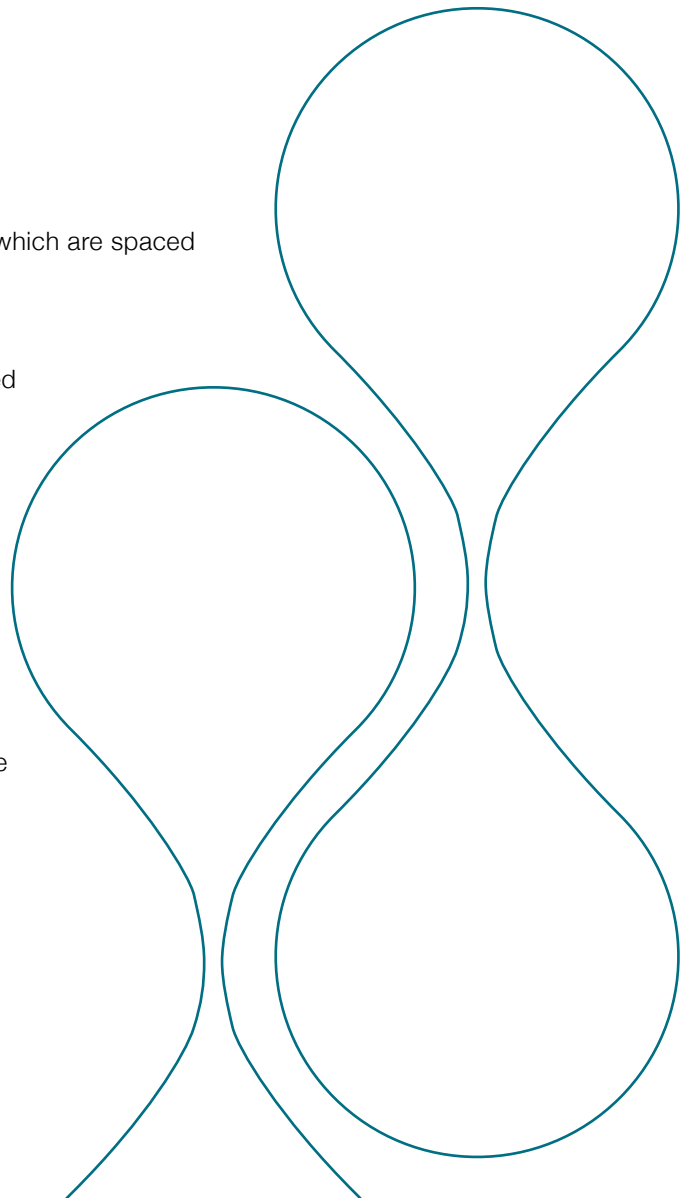
- Mount Beauty to the Bogong High Plains
- Shannonvale to the Bogong High Plains
- Harrietville to Mount Hotham
- Dargo to the Dargo High Plains
- Licola to the Howitt Plains.

Each road is divided into 20 altitudinal sectors, which are spaced according to a simple formula:

$$(\text{highest altitude} - \text{lowest altitude})/20$$

In each sector, one quadrat 2 m × 50 m is placed parallel to the roadside. Each quadrat is geolocated, and altitude, aspect, slope, tree cover (five classes) and degree of disturbance (low, moderate, high) is recorded for each.

Within each quadrat, we identify all species and assign a rank abundance score: 1 = 1 or few plants, 2 = 10s to 100s of plants, 3 = 1000s of plants. We also assign a cover score: 1 = <1%, 2 = 1–5% and 3 = >5%. The two methods are used to detect species that are numerous but have low cover values.



## Burramys plots

### Objective

To determine the distributional range and long-term patterns in the population ecology of *Burramys parvus*, to ensure effective conservation management of the species.

### Research questions

- What is the distribution and habitat requirements of *B. parvus*?
- What are the long-term population dynamics of the species?
- How can this rare mammal be most effectively conserved?

*B. parvus*, the mountain pygmy possum, is one of the rarest mammals on earth. Thought to be extinct, it was rediscovered in the early 1960s near Mount Hotham in Victoria. Since then, considerable research effort has been devoted to understanding its biology and conservation management.

Systematic surveys for *B. parvus* commenced in Victoria in 1982, and the network of trapping sites has expanded since then. Initially, trapping frequency was monthly, but since about 1987, survey times have been targeted to the breeding season (November–December). The standard trapping grid (0.25 ha), as described by Mansergh (1984), has been used throughout: three 100-m lines 12.5 m apart with Elliot traps placed 5 m apart (= 60 traps) on three days = 180 trap-nights per standard visit. This standard site could be expanded spatially (more lines) or temporally (up to five days).

More than 90 trapping sites have been established across the Victorian Alps and most have been visited more than once:

- Mount Hotham surrounds: Mount Higginbotham (4 sites, annually since 1982; >15 sites with >3 visits), Mount Loch (3 sites visited 7 times since 1983), Mount Little Higginbotham (3 sites visited 6 times since 2004).
- Bogong High Plains and surrounds: Mount McKay annually/biannually since 1995, Timms Spur (7 surveys since 1992), Bundarra scree (>2 sites with 10 visits since 1984), Pretty Valley and Falls Creek surrounds (>10 sites with at least 3 visits; see Heinze et al. 2004).
- Mount Buller: 4 sites visited annually since 1996 and 7 sites with at least 3 visits; sampling times include both breeding and non-breeding seasons.

There are other so-called non-successful areas (e.g. Mount Wombargo, Cobberas, Mount Stirling) where surveys have failed to detect populations of *Burramys*.

Vegetation and substrate surveys were undertaken at each site in 1982–84. Surveys used standard Braun–Blanquet methodology at six standard points using circular plots (radius of 2 m) at each site. Vegetation surveys were conducted in 2004 and 2008 at fire-affected sites such as Mount McKay.

Hair samples (non-intrusive) for genetic analysis have been routinely collected since the early 1990s. Currently, 20 genetic markers have been established for the species (Weeks, pers. comm). Trapping in Kosciuszko National Park by Linda Broom and others has been conducted since 1985, with similar methodologies, but the spatial layout of the traps differed from that above due to the nature of the habitat (granite vs basalt). These locations and sampling protocols are not included here.

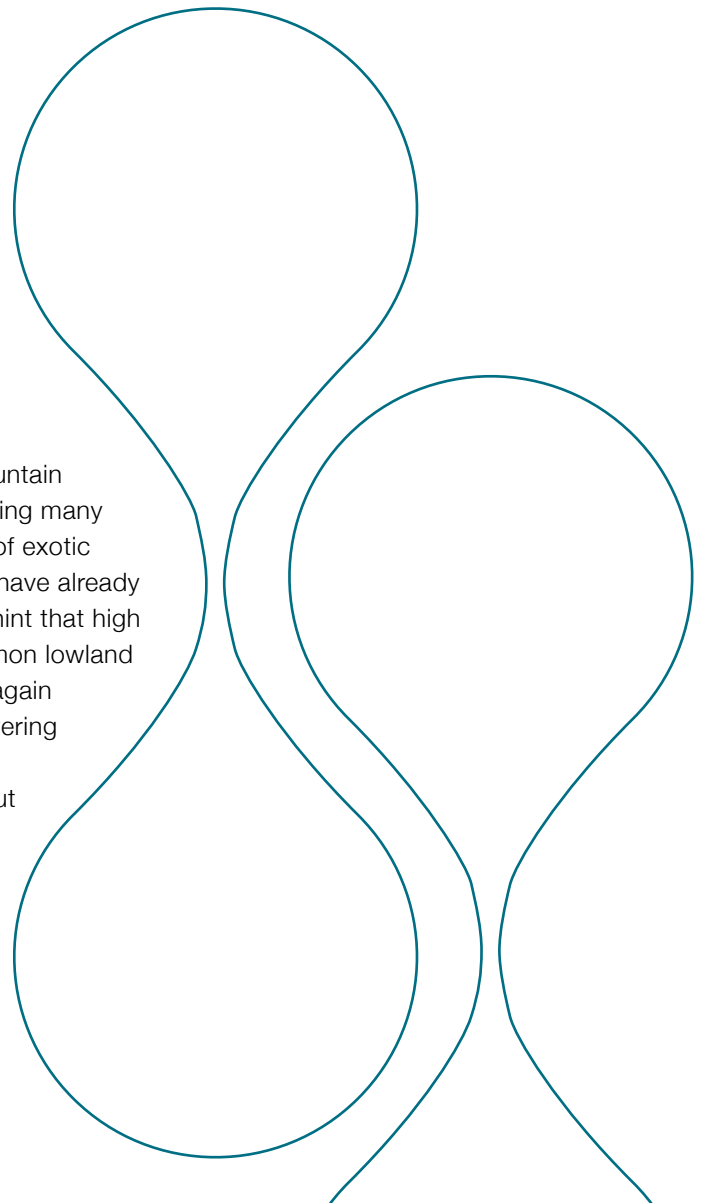


## If I had my time again

The alpine plot network has benefitted enormously from the efforts and foresight of other researchers in the past who were interested in investigating grazing. This has meant that some plots have now been running for many decades, providing a truly long-term perspective on vegetation changes. Many other plots have now been added to this original network, tackling specific issues around fire and climate change, as well as providing extended data on plots considered in the earlier work. The design of the additional plots has often been different to provide additional power to test specific questions, to take advantage of natural events like widespread fire, to meet funding limitations and to fit in with requirements of agencies managing alpine areas. Some changes that have been made are not necessarily ideal, but this type of research will always need to take place within such constraints. Long-term ecology has its challenges, chief among them being the types of questions to be explored (can you really set up a program with uncertain funding), the experimental design that is possible (space and time always add complexity), data management (where and by whom) and drawing conclusions from datasets designed to become increasingly valuable with time (rather than immediately).

We've overcome some of these problems by thinking about space-for-time studies (altitudinal transects comparisons) and undertaking plot manipulations (e.g. ITEX plots) to get both immediate understanding and to foster a research plan that allows revisitation to build on these initial data. Both the transect experiments and manipulations that increase temperature can be used to predict what can happen in the future, which can then be validated in the long-term comparisons. These types of comparisons using multiple modalities are critical if we want to move beyond untested models in understanding the future. Their results can then also be linked to those that have been running over a longer timeframe.

In the gradient plots, carefully thinking about questions led us to focus on species distribution change, a key prediction one would make for mountain ecosystems in a rapidly changing world. By focusing many of our questions around the current distributions of exotic plant species across a number of mountains, we have already gained insight into invasion patterns—and these hint that high mountains are already invaded by a suite of common lowland species. We're not sure we would have our time again when thinking about this basic framework, but layering more information about the traits of species that underpin patterns would have made us think about the reasons for patterns. Currently, we know



which exotic species are where, but not so much about why. These hints are implicitly factoring in process-based questions in LTERN, not just patterns.

In the gradient work we have also added phenology measurements because changes in timing are known to underlie shifts in the distribution and abundance of species. Timing data are difficult to collect because they require continuous monitoring across an extended period, which can be challenging in remote areas. We have now devised a way of measuring timing across a season that captures spatial variability and does not require ongoing monitoring, instead relying on snapshots across time. It would have been good to have these data across an extended period to see if the timing data might have predicted ecological decline. But, with our current base levels and some early phenological data from manipulation plots, we are hoping that this information can be valuable in the future.

In retrospect, it also would have been beneficial to have had samples of invertebrates for long-term monitoring and samples of vegetation for genetic monitoring. Genetic technologies have improved markedly in the past few years, allowing them to be used to track genomic changes in species to complement interspecific comparisons. Invertebrate biodiversity remains challenging, but insects, in particular, can act as sensitive environmental indicators and quite a few well-defined taxa have now been identified. These provide a baseline for future monitoring and can also be used to investigate the impact of invasive species.

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# 5 Three Parks Savanna Fire-Effects Plot Network



**Plot Leader Vegetation:** Jeremy Russell-Smith

Charles Darwin University

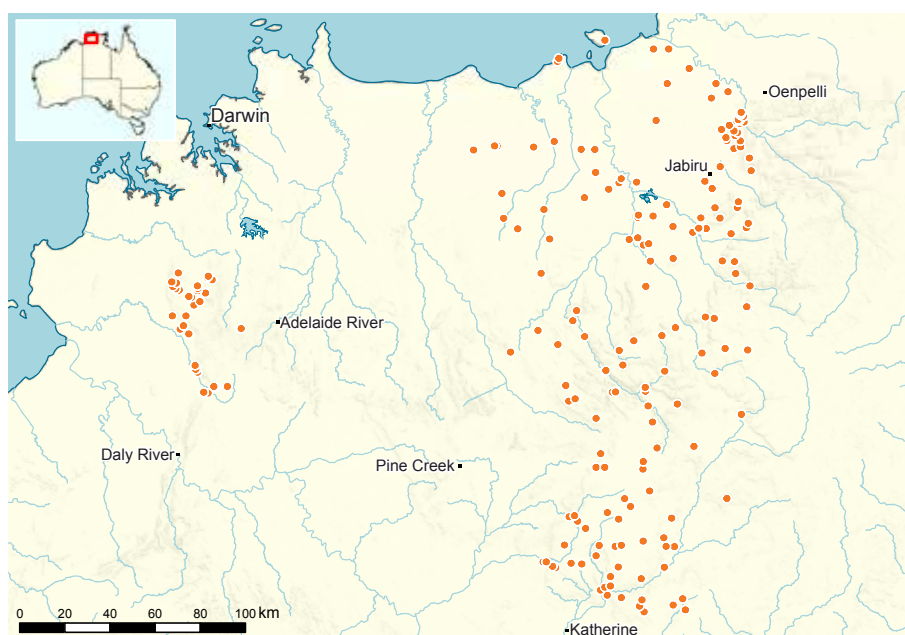
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**Location of the Three Parks Savanna Fire-Effects Plot Network in the Northern Territory**

Photo (opposite page): Riparian complex, courtesy of Bushfires NT

## Objective

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. This objective will be met by addressing a suite of general and specific questions.

## Research goals

- A significantly increased understanding of vegetation structure, plant species and vertebrate fauna responses to imposed fire regimes in savanna landscapes.
- A significantly increased understanding of the implications of different fire regime conditions for biomass and associated carbon dynamics in savanna landscapes.
- A significantly increased capacity to rigorously evaluate the long-term effectiveness for biodiversity and carbon dynamics of different management interventions.
- A significantly increased capacity to identify appropriate indicators, metrics and techniques for assessing, managing and monitoring imposed fire regimes in savanna landscapes.
- Maintaining and enhancing reliable plot-based species and population inventories and associated fire histories, based on inventories undertaken every five years, annual revisits to record fire occurrence and severity, and ongoing fire-history mapping based on Landsat imagery.

## Research questions

- What are the effects of management-imposed fire regimes on the responses of the savanna matrix, and flora and fauna species?
- What are the effects of management-imposed fire regimes on vegetation and associated biomass dynamics?
- What are the implications of the above questions for biodiversity conservation and management in the three parks and, more generally, across the tropical savannas?
- What is the trajectory and status of biodiversity values on the three parks with respect to ambient fire regimes?
- How does the recruitment and the growth dynamics of small-sized (i.e. non-tree) savanna woody species respond to ambient fire regimes?
- What are the implications of 20 years of woody growth and population dynamics with respect to ambient fire regimes for the three parks, and for north Australian mesic savannas more generally?

**Table 5.1 Three Parks Savanna Fire-Effects Plot Network summary table**

<b>Ecosystem</b>	Tropical savanna
<b>General location</b>	Kakadu, Litchfield and Nitmiluk national parks
<b>Other custodian(s) and/or partners</b>	Bushfires NT; Australian Government Department of the Environment; Land Resource Management (NT); Kakadu, Litchfield and Nitmiluk national parks; Parks and Wildlife Commission (NT)
<b>Disturbance type</b>	Fire, park management
<b>Data type (fauna/flora/vegetation structure)</b>	Fire occurrence and severity, fauna, flora, vegetation structure
<b>No. of plots</b>	220
<b>Plot size</b>	800 m <sup>2</sup>
<b>Start year</b>	1994
<b>Temporal revisit</b>	6 months (fire occurrence), 4 months (fire mapping), 5 years (vegetation), opportunistic (fauna)

## Specific data collection protocols

The fire monitoring program comprises two complementary components: satellite-based mapping of fire events and on-ground assessment of change in biota at a set of permanent plots.

### Satellite monitoring

Fire histories have been assembled for all three parks from interpretation of subhectare resolution Landsat multispectral scanner (MSS) (in early years for Kakadu) and, principally, Landsat thematic mapper (TM) and enhanced thematic mapper (ETM) imagery. For Kakadu, fire history is available from 1980. For Litchfield and Nitmiluk, fire histories are available from 1990 and 1989, respectively. For all parks, annual fire mapping has been derived from at least three sampled scenes: a first image obtained ideally early in the dry season (approximately late May / early June), a second obtained around the end of the main burning early season period (late July / early August) and a third image obtained as late in the year as possible before the onset of extensive cloudy conditions associated with the developing wet season. More frequent sampling of imagery is required early in the dry season, given regrowth of perennial grasses under still relatively favourable soil moisture conditions. To account for issues associated with cloudiness in the late dry season, fire mapping from Landsat imagery is regularly augmented with coarser-resolution, daily imagery available from Advanced Very High Resolution Radiometer (AVHRR) instrumentation and, in recent years, Moderate Resolution Imaging Spectroradiometer (MODIS) sensors. Fire mapping data have been validated annually since the mid-1990s for all three parks, based on stratified aerial transect assessments.

## Permanent plots

A total of 220 permanent monitoring plots (40 m × 20 m) were established in the three parks in 1994–95, to monitor change in vegetation and fauna. Of these, 133 plots are located in Kakadu, 41 in Litchfield and 46 in Nitmiluk. These sample a variety of landform and vegetation type / habitat conditions. A substantial proportion of plots was positioned deliberately at sites likely to reveal environmental dynamics, especially at ecotones and in patches of fire-sensitive vegetation (e.g. stands of *Callitris*, sandstone heaths). As well, many plots are located at, or in the near vicinity of, intensively managed sites such as campgrounds and other tourist destinations.

Resurvey of plot vegetation attributes across all three parks is to occur every five years, with the third resampling (fourth sampling visit) completed over the 2010–11 wet season. Monitoring plot establishment and resampling exercises are conducted at the end of the wet season, to facilitate flora identification (i.e. before herbaceous plants wither or the vegetation is burnt). Fauna sampling in general follows the same sampling regimen but has not been undertaken so consistently at each of the three parks (see 'Fauna sampling').

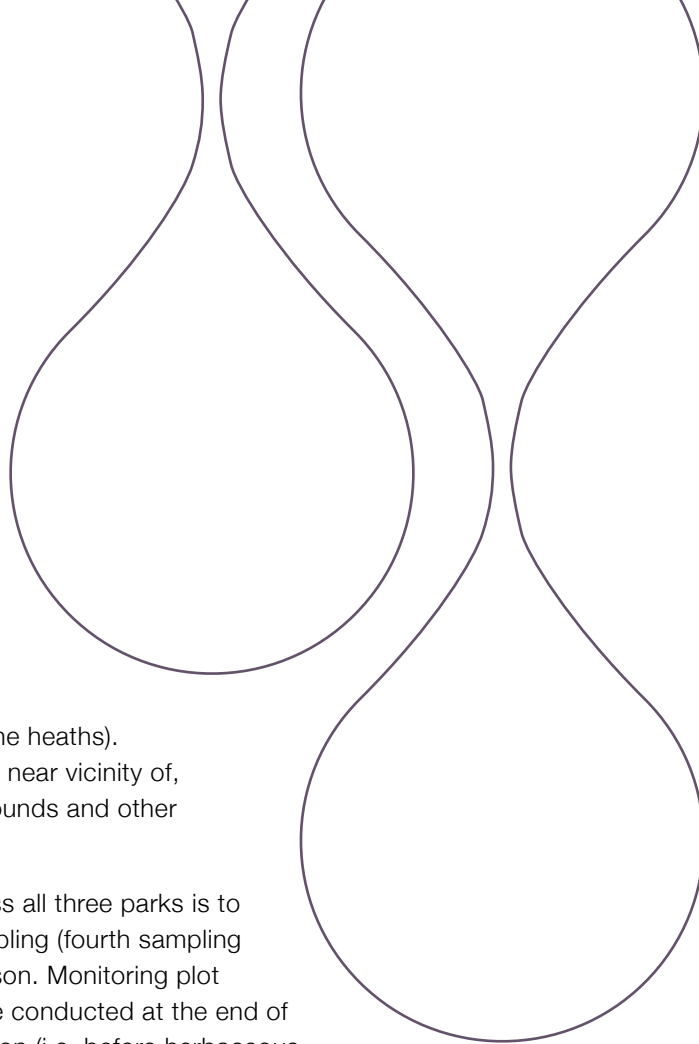
## Fire occurrence and severity

The occurrence of fire at each plot is assessed at least annually by on-ground visits by ranger staff. This record is used with records from aerial surveys to assess the reliability of the fire history developed from the satellite imagery. For Kakadu and Nitmiluk, the photo record assembled for these visits for 1995–2004 has also been used to develop a practical field-based index of fire severity. Leaf scorch height has been shown to be closely related to measured Byram's fire-line intensity in these savannas ( $R^2 = 0.85$ ) (Williams et al. 2003).

## Vegetation sampling

Sampling is designed to assess all levels of habitat strata, including non-woody and woody species diversity. Plots are permanently marked with metal star pickets and their GPS location is recorded. At each visit the plots are redefined by measuring tapes run between star pickets and droppers that permanently mark the plot.

Detailed information on vegetation and other environmental factors is recorded at each plot. For trees (woody stems >5-cm diameter at breast height [DBH]), all individuals in the plot are counted and tagged to assist relocation. Tree basal area is determined from all the trees within the plot area, and the botanical name, height, fire scar and DBH are recorded. New trees are tagged and dead missing trees are recorded in each visit. Shrub density is measured by counting all woody shrubs within three height classes in a smaller area within the plot. For taller shrubs (>0.5 m), all individuals are counted within





a fixed 40 m × 10 m subplot (Figure 5.1); counts of small shrubs (<0.5 cm) are recorded in two 40 m × 1 m fixed transects (Figure 5.1); and for herbaceous ground-layer species, cover is recorded in each of 40 fixed 1 m × 1 m quadrats (Figure 5.2). All species occurring in each of three height strata (trees, shrubs and ground layer) are included, such that any species may be recorded in more than one class.

The fourth resampling (fifth sampling visit, commenced in 2013) includes measurement of some extra variables, including woody debris and foliage percentage cover (FPC). Woody debris is recorded in size classes, with 'logs' recorded across the whole plot and 'coarse' woody debris collected from within two 1-m-wide transects (Figure 5.3) and weighed. A subsample of 'coarse' woody debris is collected to dry and calculate dry weights. FPC is measured for the upper strata only using the step-point method with a minimum of 200 points (Figure 5.4).

Implementation details of methods are provided below for the 2013 survey trip.

### *Plot design and set-up*

- The total vegetation plot size is 40 m × 20 m. The plot is permanently located by a central metal star picket and GPS waypoint. Plots located by helicopter have a round, large, white lid on top to assist sighting the plot from the air.
- A permanent photo picket with a number plate is placed 10 m inside the plot parallel with the plot sides.
- The corners and inner transects are marked by metal droppers.
- The inner 40 m × 10 m plot is delineated with measuring tapes when resurveying. Two 50-m tapes are laid out 5 m either side of the central photo picket, parallel to the longer central axis (Figures 5.1–5.4):
  - starting at zero on the left-hand side heading to the back of the plot
  - again at zero on the right-hand side heading to the top of the plot.

Some plots are not strictly 40 m due to topographical constraints.



Brown Falcon (*Falco berigora*), C deLacey

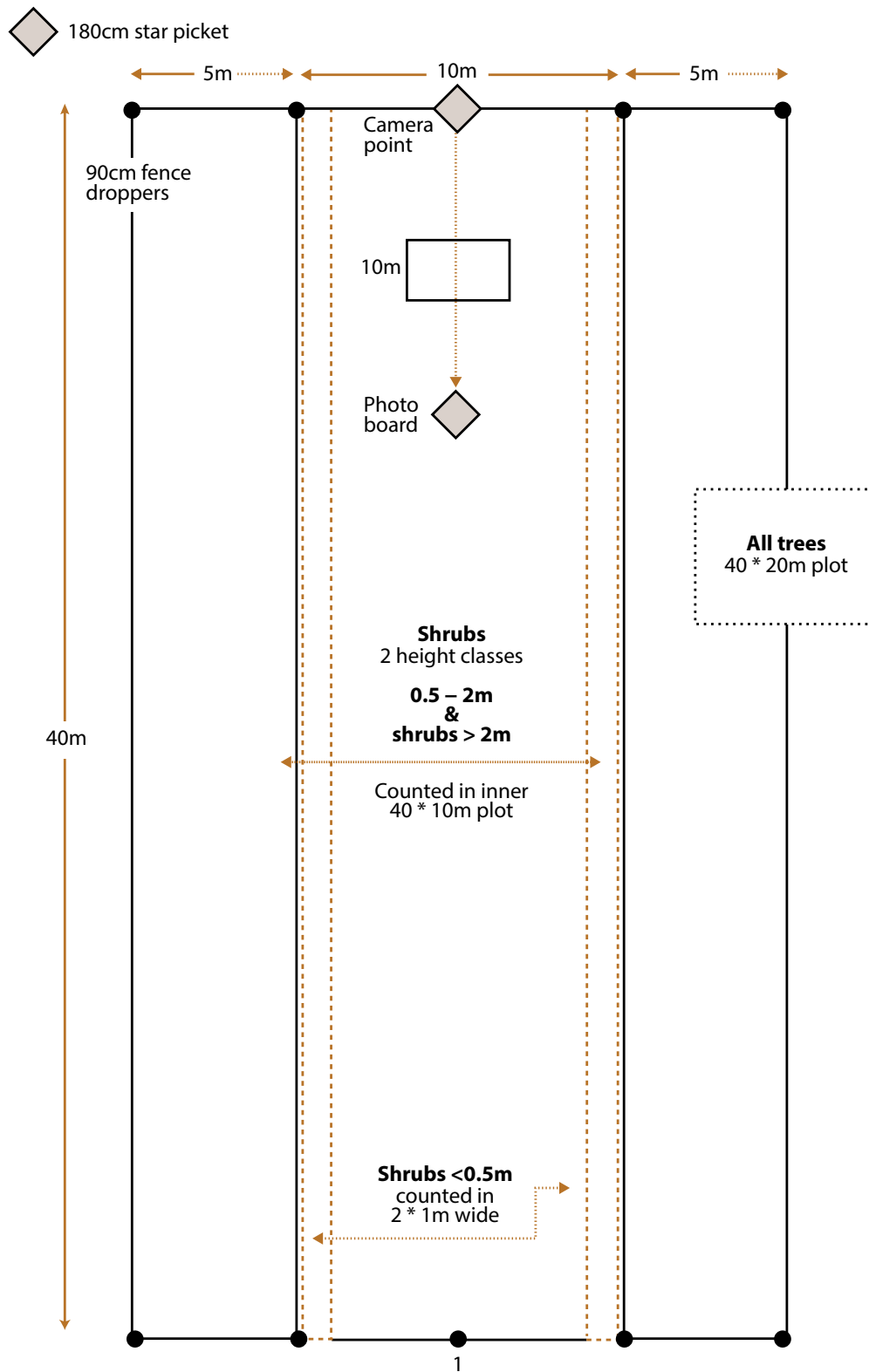


Figure 5.1 Design and set-up of vegetation monitoring plots for tree and shrub counts

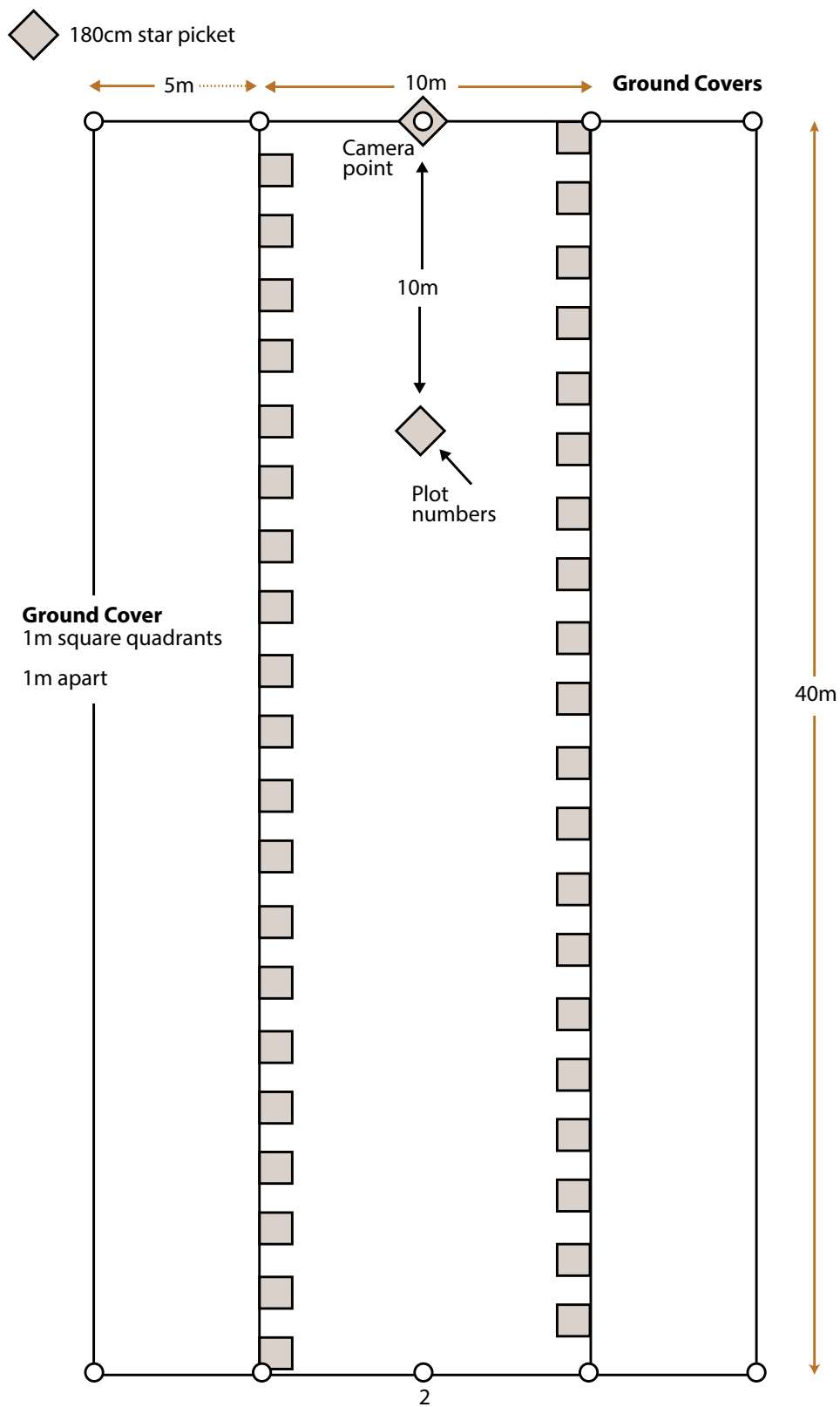


Figure 5.2 Design and set-up of vegetation monitoring plots for ground cover assessments

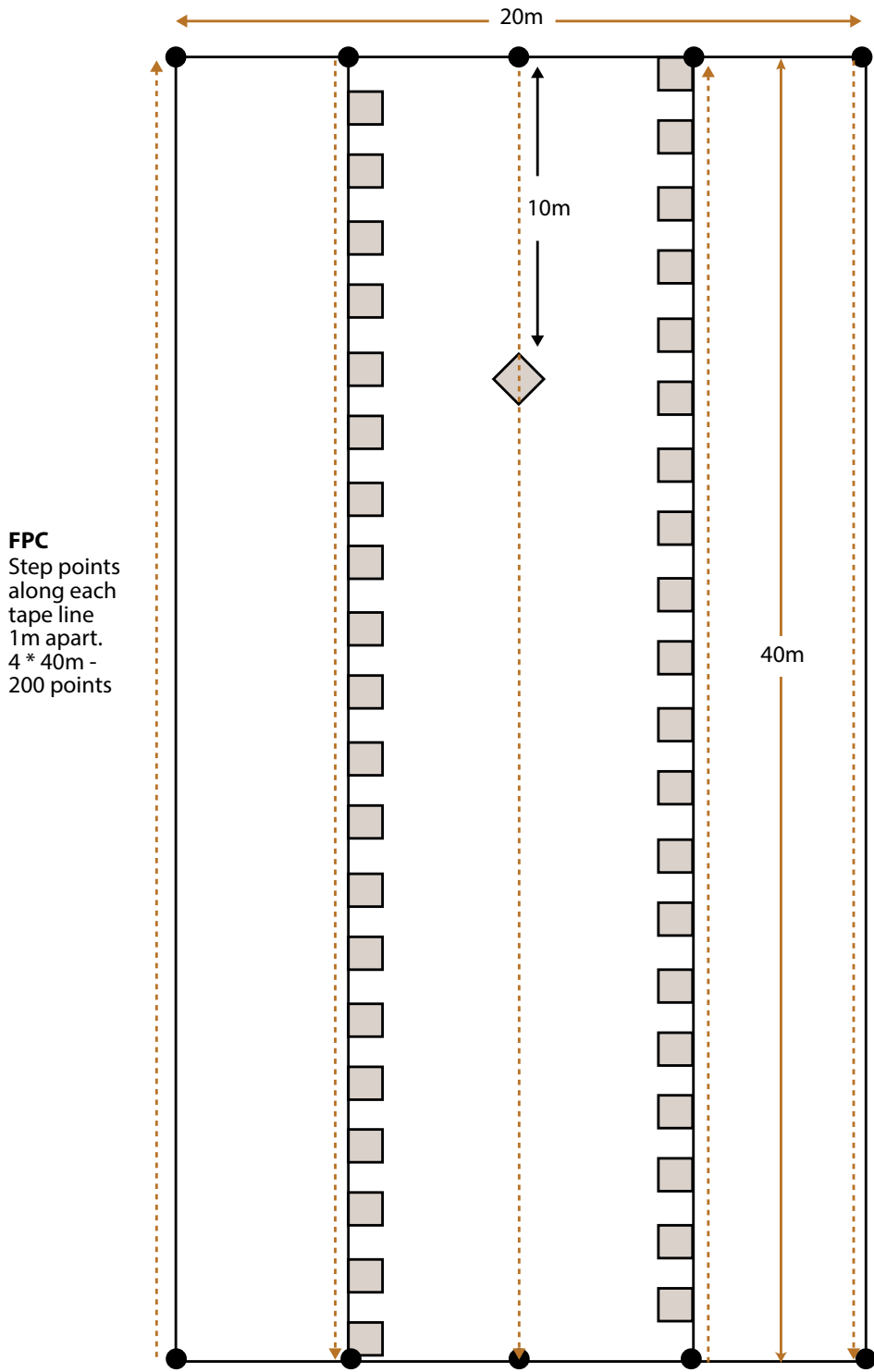
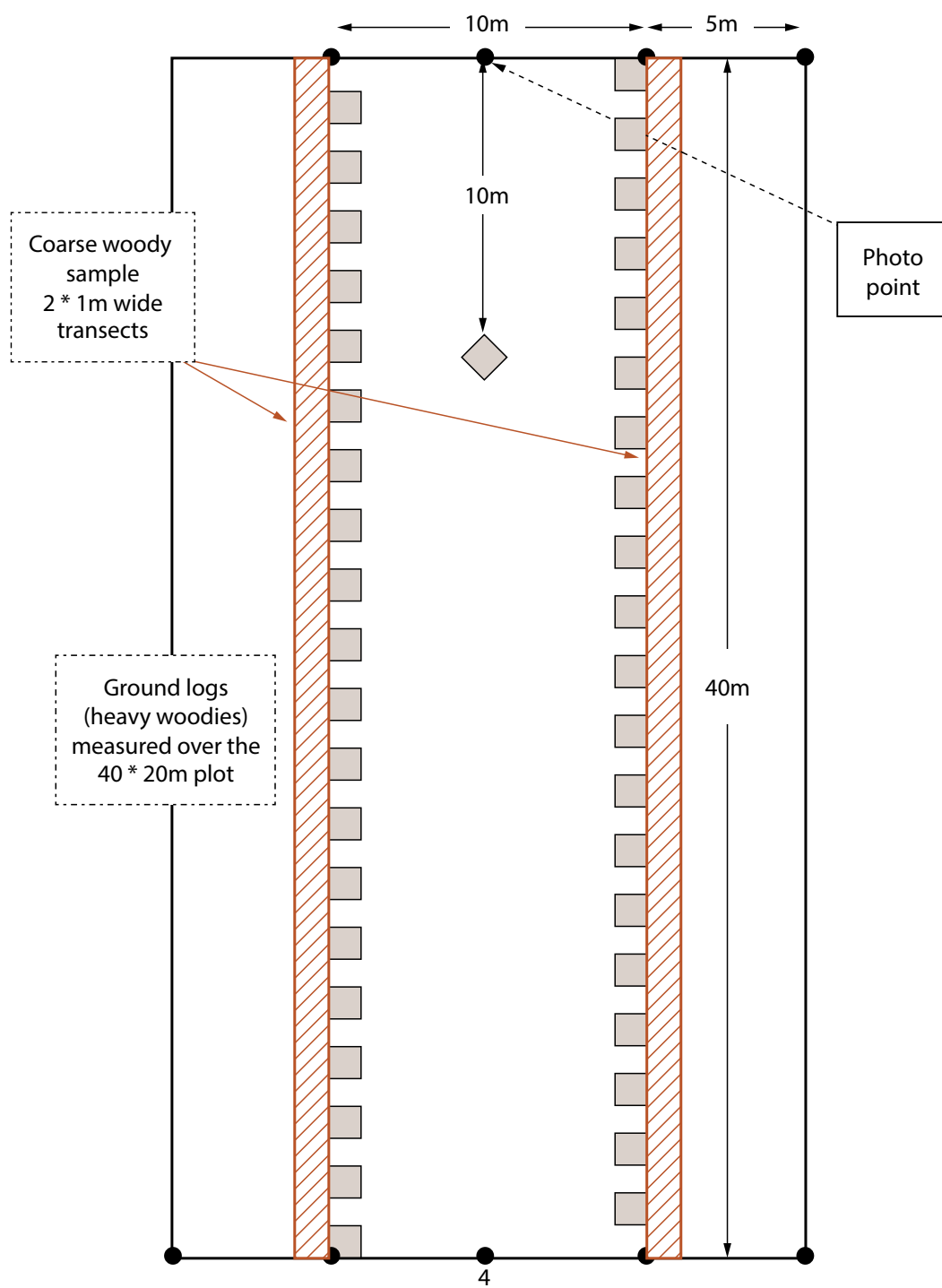


Figure 5.3 Design and set-up of vegetation monitoring plots for foliage percentage cover (FPC)



**Figure 5.4** Design and set-up of vegetation monitoring plots for assessment of ground logs and coarse ground fuels



### *Floristic inventories*

Full floristic inventories were undertaken using the methodology below

#### *Photo*

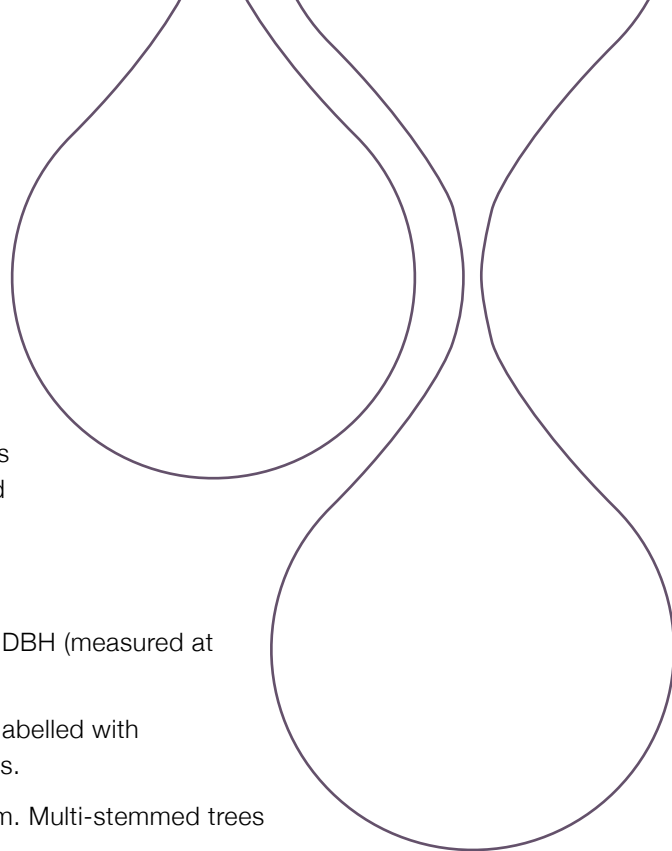
- The photo is taken looking down the long axis of the plot from the centre front picket toward the plot number plate—see Figure 5.1.

#### *Trees*

- Trees are defined as any woody species with DBH (measured at 1.3 m from the base of the tree) >5 cm.
- All stems occurring within the whole plot are labelled with numbered metal tags and identified to species.
- Only one tag is required per tree, not per stem. Multi-stemmed trees will have more than one DBH per tree.
- The canopy top height in metres of each tree is estimated visually or with a clinometer.
- Scarring from fires is recorded on the following scale:
  - 0 = no scarring
  - 1 = charcoal on surface of bark only
  - 2 = scarring damage to cambium
  - 3 = scarring on trunk over large area
  - 4 = severe scarring on trunk over large area likely to result in death
  - 5 = dead.
- Fire scars are recorded only once per tree.
- DBH is measured for each separate stem that has >5-cm DBH, using a diameter tape or callipers.

#### *Shrubs*

- A woody shrub is a woody species with DBH <5 cm.
- All woody shrub individuals are counted in three height classes:
  - <0.5 m
  - 0.5–2 m
  - >2-m and <5-cm DBH.
- Counts of individuals by species in the <0.5-m height class are undertaken along 1-m-wide transects that define the ground stratum quadrats for the length of the plot (see 'Ground stratum' below).
- For consistency, shrubs in the <0.5-m height class should only be recorded along the entire 1 m transects defining the ground stratum quadrats.
- Counts of individuals of each species in the 0.5–2-m and >2-m height classes are undertaken in the internal area of the plot equivalent to 40 m × 10 m.



### Ground stratum

- Forty 1 m × 1 m quadrats are systematically located every second metre along inner transects. The quadrat transects are always on the side of a measuring tape and orientated towards the centre of the plot (see Figure 5.2).
- Poles 1 m long are used to measure the 1 m × 1 m quadrats along the length of the tapes on the inside of the tape.
- Woody species are not recorded in the quadrat data.

Values estimated in each quadrat include:

- total FPC of non-woody species
- total percentage litter cover
- total percentage rock cover
- a tree Canopy Closure Index (CCI), as follows
  - 0 = zero cover over quadrat
  - 1 = partial tree cover
  - 2 = >75% tree canopy cover
- percentage cover of each grass or herb species present.

Note: Most plots have 40 quadrats on either side of the plot; however, there is some variation because of rocks and other limitations.



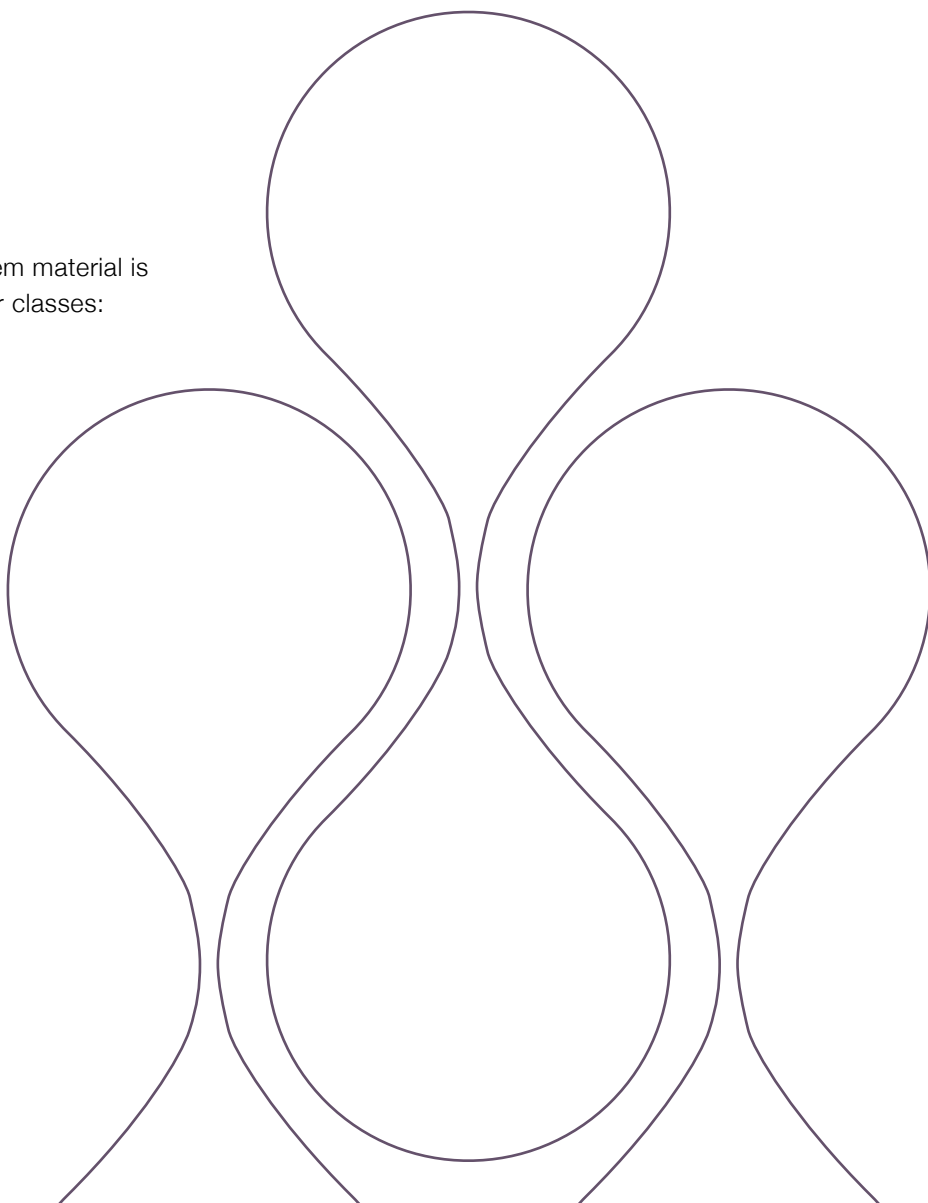
Ooldea Mallee (*Eucalyptus youngiana*), C deLacey

### *Additional data being collected in 2013*

#### *Ground logs*

Ground logs (heavy woody debris) within the whole area of the main plot are recorded. Logs recorded are any dead stems >5-cm diameter on the ground. If lengths are >5 m long, recording is undertaken in sections. Refer to the proforma datasheet in Appendix C-4 to understand how the measurement is completed.

- The length is measured in ranges:
  - 0–0.5 m
  - 0.5–1 m
  - 1–2 m
  - 2–3 m
  - 3–4 m
  - 4–5 m.
- The diameter of each stem is measured in ranges:
  - 5–10 cm
  - 10–15 cm
  - 15–20 cm
  - 20–25 cm
  - 25–30 cm
  - 30–35 cm
  - 35–40 cm
  - 40–45 cm
  - 45–50 cm
  - >50 cm.
- The solid volume of stem material is allocated to one of four classes:
  - 90–100%
  - 75–90%
  - 50–75%
  - <50%.



### *Coarse ground fuels*

Transects 1 m wide along the inside of the subplot tapes are sampled for coarse woody debris. All coarse woody debris >6-mm diameter and <5-cm diameter is collected and weighed; a bulked subsample is collected and weighed, and kept to dry and reweigh to give a percentage moisture to calculate dry weight.

### *Foliage percentage cover*

FPC is measured using a point step method and a densitometer. FPC is only recorded for cover intercepted from trees (those with a diameter >5-cm DBH). The transects walked will optimally follow the sides of the main plot and subplot. At least 200 points, 1 m apart, must be collected and at each point a recorded is made indicating:

- sky
- green
- branch
- dead
- in crown.

### *Fauna sampling*

The monitoring program was designed originally to sample vegetation. Its suitability for the monitoring of fauna was recognised at a later date. As a consequence, the monitoring of fauna generally has lagged behind the vegetation monitoring program. Whereas all 133 monitoring plots in Kakadu have been surveyed for vegetation four times from 1995 to 2009 (with the fifth resampling commencing in April 2013), fauna surveys have been less frequent: 15 of the Kakadu plots have been monitored for fauna three times, 121 plots twice, 39 plots only once, and 6 plots have not been sampled at all. Sampling intensity has been better for Litchfield, where 40 of the 41 plots were surveyed in 1995–96 and 2001, 37 plots in 2006 and 32 plots in 2011. Although different sets of fauna sites were monitored during the surveys, 23 of these sites have now been sampled four times, more or less coincident with the vegetation sampling. The 46 plots in Nitmiluk were sampled in 2005 and 42 of these were resampled in 2011.

Fauna surveys are restricted to terrestrial vertebrates. Invertebrates have not been included, partly because of the taxonomic impediment of a generally very poorly known invertebrate fauna. A survey protocol has been established (described below), now widely used for fauna surveys in northern Australia, allowing comparative links of trends and inventory to a far broader base than simply this set of monitoring plots.

Fauna survey sites (50 m × 50 m) are set up adjacent (preferably to the left) to the fixed vegetation monitoring plots. The fauna survey protocol comprises searches and trapping over 72 hours, including (i) eight ‘instantaneous’ counts (predominantly in the early morning) of birds present in a 1-ha plot; (ii) two nocturnal spotlighting searches, each 10 minutes long, of a 50 m × 50 m plot within the 1-ha plot for frogs, reptiles, birds and mammals; (iii) three 10-minute daytime searches for reptiles, frogs and mammals in the 50 m × 50 m plot; (iv) an array of 20 Elliott traps (metal box traps 30 cm × 7 cm × 7 cm) and four cage traps (65 cm × 15 cm × 15 cm) evenly spaced along the perimeter of the 50 m × 50 m plot (chiefly for small mammals), baited with a mixture of peanut butter, honey and oats, and checked early every morning; and (v) two pitfall traps (20-L plastic buckets dug into the ground), with 8 m of 30-cm-high flywire driftline netting. For each

species, an abundance value is calculated as the sum of all individuals captured or reported in searches.

This survey protocol is notably more demanding than the vegetation sampling. The protocol requires the monitoring plot to be visited repeatedly over three days, and the need to spotlight search at night obviously requires nocturnal access (typically involving camping near the site). Further, the equipment required for sampling is far more substantial than that for vegetation monitoring. Hence, fauna sampling tends to be more expensive (especially so for plots requiring helicopter access) and to take much more time. Partly because of this logistical constraint, fauna sampling, at least in Kakadu, has been spaced over more months of the year than vegetation sampling, albeit with the requirement that subsequent sampling of any plot should occur at approximately the same time of year as any previous sampling of the plot (+/- one month).

Details for the 2013 survey trip are listed below, to supplement the information provided above.

At sites accessible by vehicle, the following is implemented:

- trapping/survey period = 3 days, 3 nights
- trapping quadrat = 50 m × 50 m
- cage traps = 4 (one on each corner)
- Elliott traps = 20 (evenly spaced around the perimeter)
- pitfalls = 3 (3 fences, 18 pegs, 3 buckets)
- funnels = 2 if possible, and 4 extra pegs to secure them against one of the fences
- diurnal bird counts (in a 100 m × 100 m quadrat centred on a trapping quadrat) = 8 × 10 minutes each
- diurnal herp searches in trapping quadrat = 3 × 10 minutes each
- nocturnal spotlight searches = 2
- habitat assessment proforma = 1
- fauna summary sheet = 1
- genetic samples from any mammals caught.

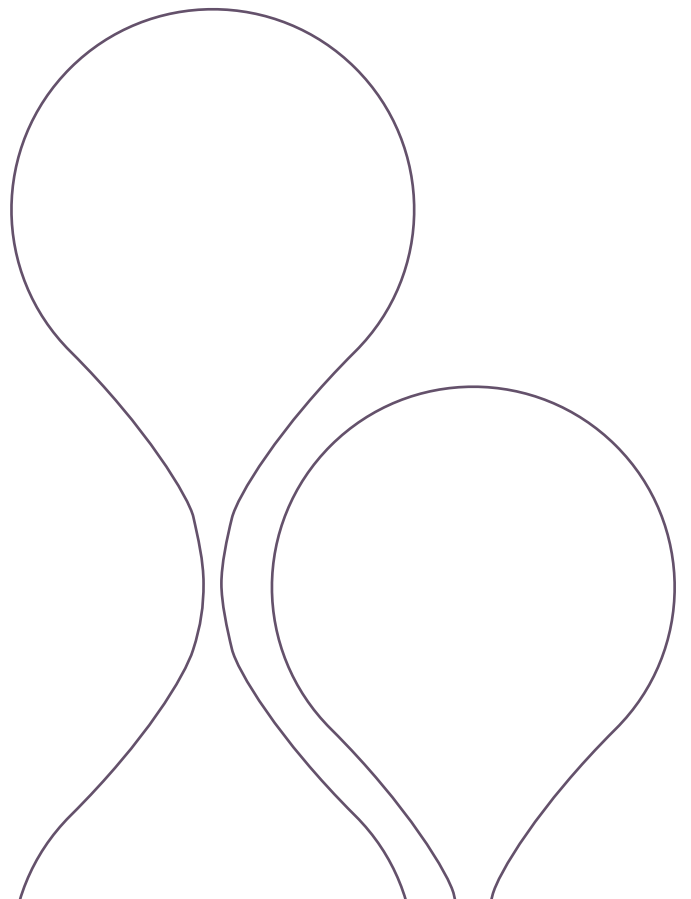






Photo: Graeme Gillespie leading education session, J Dielenberg

Sites previously accessed by helicopter are surveyed for two nights rather than three. At sites surveyed for two nights, the numbers of Elliott traps, cage traps and pitfall traps are increased by 50% so that the number of trap nights at every site are the same regardless of how many nights they are sampled. All other elements of the survey (e.g. bird counts, frog and reptile searches, spotlighting and habitat assessment) are as per the standard surveys above. To summarise, for sites previously accessed by helicopter:

- trapping/survey period = 2 days, 2 nights
- trapping quadrat = 50 m × 50 m
- cage traps = 6 (one on each corner and one in middle of two sides)
- Elliott traps = 30 (evenly spaced around the perimeter)
- pitfalls = 3 (3 fences, 18 pegs, 3 buckets)
- funnels = 2 if possible, and 4 extra pegs to secure them against one of the fences
- diurnal bird counts (in a 100 m × 100 m quadrat centred on a trapping quadrat) = 8 × 10 minutes each
- diurnal herp searches within trapping quadrat = 3 × 10 minutes each
- nocturnal spotlight searches = 2
- habitat assessment proforma = 1
- fauna summary sheet = 1
- genetic samples from any mammals caught.

Where possible, fauna survey sites are set-up adjacent to the left-hand edge of the fire plots. In the case of a creek line site, the fauna quadrat often needs to be upstream or downstream of the site.

## If I had my time again

After 20 years of operation of the three parks fire monitoring program (also known as the Three Parks Savanna Fire-Effects Plot Network within LTERN, led by Jeremy Russell-Smith), it is perhaps strange to say that, if starting again, there is little that I consider needs to be changed. This is essentially because the program started out with a strong understanding by the original partners (the Kakadu, Litchfield and Nitmiluk national parks managers and operational staff) of their requirements at the time—a monitoring program that met the information requirements of park managers, first and foremost.

In hindsight, key issues that could have been better addressed at establishment are more structural in nature than operational:

- Putting in place a formal governance agreement between the three parks involved and their head agencies (now Parks Australia—for Kakadu; now Northern Territory Parks and Wildlife Commission—for Litchfield and Nitmiluk). Such an agreement usefully would have included commitments by these respective organisations to (a) ongoing operational, infrastructural and training support; (b) program time horizon and review issues; and (c) core funding. As it happens, the program has been maintained less formally through personal commitments by individuals in respective partner organisations.
- Given that the fauna sampling and monitoring component commenced some years after the vegetation component, in hindsight it would have been useful to have accommodated for this at the outset—and, in fact, it is quite likely that the overall program protocol may have been substantially modified accordingly (see below). However, this was not a strong consideration when the program was established, given the habitat management focus at that time.

The vertebrate fauna component of the three parks monitoring program (led by Graeme Gillespie) has provided some incredibly important insights into recent changes in the mammal fauna of the Top End as, both fortuitously and unfortunately, sites were initially sampled when small mammals were abundant. The severity and rapidity of the subsequent decline and the very large number of plots sampled has meant that the program was sufficiently powerful to detect these declines. However, now that we are sampling within a new paradigm of sparse populations of many native species, it is useful to consider, with hindsight, what different approaches, protocols or approaches may have further strengthened the monitoring program (or which may be appropriate to implement in the future). These are briefly summarised below:

- As noted above, the fauna sampling was an add-on to the existing fire monitoring plots. If site selection was undertaken a priori to sample the range of fauna communities and key sites for fauna conservation within the parks, then a somewhat different site stratification would likely have resulted.
- The spatial distribution of the monitoring sites was designed to suit the logistic requirements for vegetation sampling—a relatively brief visit to each site by a team of botanists and park managers. By contrast, adequate fauna sampling requires a much longer visit to each site, so that sampling a large number of widely scattered sites becomes logistically challenging and very expensive. A number of measures were introduced into the fauna monitoring program to maximise efficiency and achievability, including limiting sampling to two days for sites accessed by helicopters, spreading sampling of sites over a broad time window and introducing secondary sites near the fire plots accessed by helicopter. While driven by operational necessity at that

time, each of these measures introduced further complexity into the analysis and interpretation of data, and an early decision to sample fewer sites more intensively may have been preferable.

- The fauna sampling methods implemented in the monitoring program drew heavily on extensive experience in the Top End with systematic fauna inventory surveys, without necessarily considering carefully how appropriate these may be for a monitoring focus. In retrospect, it would have been useful to rigorously test some of these methods early in the program, and make adjustments to sample methods and intensity as appropriate. For example, the size of observer bias in undertaking active visual searches for reptiles was indubitably underestimated, and a greater reliance on a high intensity of pit trapping would likely have resulted in more robust data for these taxa. Similarly, it was probably not considered at the start of the program that it would continue for more than 20 years, and therefore involve many bird observers with inevitable variation in detection rates and subtle differences in understanding of how presence and abundance should be accounted.
- An early decision was made to commit to a five-year sampling interval, matching that for the vegetation component. In retrospect, it would have been valuable to test some more frequent sampling intensities to evaluate trade-offs between high and low sampling frequency. Ultimately, this may have resulted in a hybrid approach where a subset of sites were sampled every year or every second year, leading to a more detailed understanding of the potential drivers of temporal change in the animal communities.
- The other aspect of sampling intensity that would likely have benefited from some early trials is the number of days/nights spent at each site. Based on experience from inventory surveys and the abundance of (particularly mammal) fauna at the commencement of the program, two or three nights of sampling appeared adequate. With the benefit of hindsight, a longer sample time per site may have reduced noise in the data and provided greater sensitivity to link declines to environmental change, even at the cost of sampling fewer sites.
- Inevitably, experience has also shown that improvements in the way data were recorded and stored could be made. One notable weakness for this program was that the census method for each fauna observation (e.g. pit trap, Elliott trap, visual search) was not captured during databasing, so data could not subsequently be partitioned by method and the effectiveness of various methods tested.

## References

Williams R, Gill AM & Moore PR (2003). Fire behavior. In A Andersen, G Cook & R Williams (eds), *Fire in tropical savannas*, Springer, New York, 33–46.







# 6 Tropical Rainforest Plot Network



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## Location of the Tropical Rainforest Plot Network in Queensland

Photo (opposite page): Semi-deciduous rainforest on basalt, D Metcalfe



## Objective

The Tropical Rainforest Plot Network was established to monitor growth, mortality and recruitment of commercially important cabinet timber species across soil fertility, altitude, latitude and rainfall gradients. With the inscription of the Wet Tropics of Queensland on to the World Heritage list in 1988 and the consequent cessation of commercial logging, the plots have been maintained to further our understanding of rainforest community dynamics under natural disturbance systems. Growth rates; species turnover; patterns of mortality and recruitment; impacts of cyclones, disease and invasive weeds; and recovery from such disturbance supports ongoing monitoring of World Heritage values and their management.

## Research goals

- To collect and collate summaries of recent disturbances (including cyclones, drought, and direct and indirect human disturbances) to allow for interpretation of the stand structure or of the floristic, growth or mortality data of rainforest plots.
- To build a comprehensive database of rainforest tree growth, extending over a useful range of sites and a biologically meaningful span of years. Data collected from 1971 to 2013 have been published (Bradford et al. 2014) and are available online through the CSIRO Data Access Portal. Subsequent time-series data are available from both the CSIRO Data Access Portal and the LTERN Data Portal.

## Research questions

- How do forests recover from landscape-scale disturbance events such as cyclone and disease outbreaks?
- 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?



Photo: *Archidendron lucyi*, D Metcalfe

**Table 6.1 Tropical Rainforest Plot Network summary table**

<b>Ecosystem</b>	Rainforest
<b>General location</b>	North and Far North Queensland
<b>Other custodian(s) and/or partners</b>	Department of National Parks, Sport and Racing
<b>Disturbance type</b>	Natural
<b>Data type (fauna/flora/vegetation structure)</b>	Vegetation structure, flora, soils
<b>No. of plots</b>	20
<b>Plot size</b>	0.5 ha
<b>Start year</b>	1971
<b>Temporal revisit</b>	Initially every 2 years, then every 5 years from 1990

## Specific data collection protocols

### Plot layout

The slope-corrected dimensions of all 20 plots were 100 m × 50 m, enclosing a projected plan area of 0.5 ha. It is important to note that, because the topographic settings of the plots are highly variable (from flat to steeply sloping) the actual land surface areas of the plots differ. Where logging activities were scheduled to occur in the future, a buffer zone (typically not less than 20 m wide) was established around the plot. All plots were subdivided into 16 subplots (A–P), each 25 m × 12.5 m. The orientation of the four rows of subplots varied between plots, although the sequence of subplots within the rows was consistent: A–D, E–H, I–L, M–P. This intersite variation in subplot layout should be considered in any computerised mapping or site-related analysis of the data.

### Site establishment and remeasurement procedures

The initial assessments of tree trunks  $\geq 10$ -cm diameter at breast height (DBH) were made at 1.3 m above the ground, where possible. When the plot was established, the DBH lines were painted on all trees  $\geq 10$ -cm DBH. Individual tree trunks  $\geq 10$ -cm DBH were numbered using an alphanumeric code that represented both the subplot (A–P) and the number of the trunk within that subplot. This code was painted on each enumerated tree.

Epiphytic trees, or the aerial roots of such trees, were not enumerated when  $< 20$ -cm DBH, regardless of the size of the tree in the canopy. Where appropriate, these epiphytic tree species were recorded on the supplementary species list of the plot. Vines were not enumerated, even if  $\geq 10$ -cm DBH at establishment, but were noted on the plot supplementary species list. In subsequent surveys, vines  $> 10$ -cm DBH have been measured, identified, mapped and given an alphanumeric identifier.

When the plot was established, height estimates for all trees  $\geq 10$ -cm DBH were recorded. No further height measurements were taken until 1998, when all stems in 18 plots were accurately remeasured either by the triangulation method or direct readings using a Bushnell laser rangefinder. Tree heights were also measured on plot 14 (EP37) Eungella in 2001 and on plot 9 (EP31) Woopen Creek in 2005.

At a number of plots, the positions, sizes and identities for stems  $< 10$ -cm DBH but  $\geq 2$  m, or sometimes  $\geq 3$  m in height for all *Flindersia* species, were recorded, and in some cases, every *Flindersia* stem was enumerated.

The terminology for descriptions of forest structure (cf. forest structural typology, described below) follows Walker and Hopkins (1984). Soon after each plot was established, forest structural profiles were drawn to scale, representing a 100 m  $\times$  5 m transect, based on the long axis of each plot commencing from the corner peg of subplot A.

### Plot remeasurements

Plots were remeasured every two years for a minimum of 10 years, and then the timeframe for further assessments was reviewed. After 1990, remeasurements generally occurred every five years. At the time of each remeasurement, general maintenance of painted tree markings are carried out, and records and maps are made of tree deaths, deformities and disturbances.

Throughout the project, brief descriptions are made of both current and past disturbances (e.g. condition of the forest at plot establishment, any management interventions and activities such as mining or natural events, including cyclones or major tree falls). Locations of large-gap tree falls or of multiple tree falls caused by cyclones are mapped.

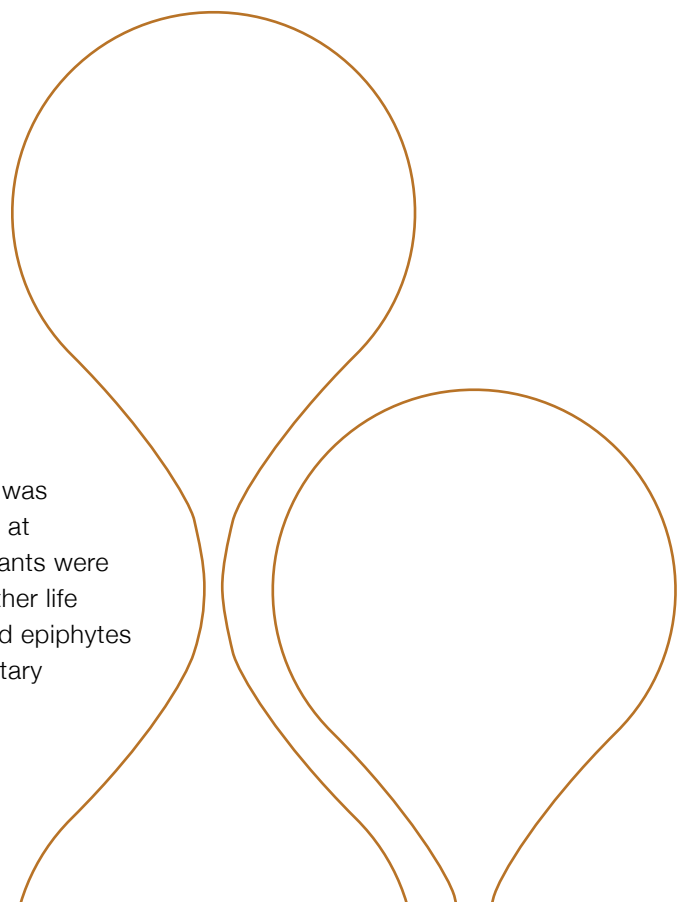
The extent, development and recovery of 'patch death' phenomena (i.e. incidence of *Phytophthora infestans*) were also noted at affected sites.

### Historic and prehistoric fire

During field inspections in 2000 and 2001, soil samples were collected to refine estimates of forest biomass and carbon stocks at 10 of the 13 revisited plots. Any observations of relict soil charcoal extracted from soil cores relevant to the site histories of the plots were reported. At each site, six soil cores were taken in a stratified random sampling design that included each of the major landform elements present on the site.

### Floristic identification, vouchers and lists

At all plots, the floristic composition of each subplot was recorded for all plants  $> 0.5$  m high but  $< 10$ -cm DBH at establishment. Species lists for these understorey plants were compiled by subplot at the time of establishment. Other life forms such as epiphytic trees, vines, herbs, ferns and epiphytes present within the plot are recorded on a supplementary



species list and reference voucher specimens collected when feasible. Resurvey of each plot to assess floristic composition is currently being completed. Initially, plant species identification followed the Queensland Herbarium (see Bostock & Holland 2010). For this paper, these names were matched with the Atlas of Living Australia ([www.ala.org.au](http://www.ala.org.au)) standards.

## If I had my time again

It's not really fair for me to say what I'd have done differently—to start with I was only two years old when the first tree was measured and, secondly, the rainforest plots were never established to be a single set of plots representing a range of the environmental gradients that impact on community composition and structure.

More reasonably, I can talk about some of the eccentricities in design that have made analyses difficult today. Firstly, if we were going to establish 20 long-term plots today of similar size, we would have thought hard about replication. We recently established new plots—a single 25-ha plot, which was a huge task and not one that would be feasible to replicate nearby, and a number of 0.5-ha plots to replicate particular environmental conditions. These will provide insights into community dynamics without the risk that a sole representative of a single forest type would be impacted by an event such as a cyclone, which would dominate all processes at that one site for decades to come. Secondly, the point of having a series of 0.5-ha plots is to enable us to gain comparative insights into forests exposed to different environmental conditions: soil fertility, rainfall amount and pattern, temperature range and extremes, and so on. Our legacy set doesn't adequately address any one of these environmental axes adequately—for example, we have two northern and one southern bioregional outlier; we have too few plots in the lowlands and too many on poor granitic soils; we do have plots in seasonally dry, infertile soils but not in ever-wet, high fertility forest, so the plots don't encompass both extremes of habitat. Thirdly, at the individual plot scale, they are not all identically laid out. If we were repeating the exercise today, we might try and align the long axis of each plot with the north–south line, and consistently number the subplots sequentially from the same corner, to make use of satellite imagery easier, rather than aligning the main axis with a terrain feature, and numbering the subplots according to whichever corner we started at.

So it is unfair to criticise my predecessors, who established a series of plots for a completely different purpose, but it is worth thinking that if I were to establish a new set of long-term plots they would likely be put to uses in the future that I can't conceive of today. That should make me conscious of all aspects of location, establishment and documentation to ensure that my successors have the greatest possible latitude in using the data long after I am available to explain my own eccentricities.

## References

- Bostock PD & Holland AE (2010). *Census of the Queensland flora, 2010*, Queensland Herbarium, Department of the Environment and Resource Management, Brisbane.
- Bradford MG, Murphy HT, Ford AJ, Hogan D & Metcalfe DJ (2014). Long term stem census data from tropical rainforest plots in Australia. *Ecology* 95:2362. doi: 10.4225/08/53C4CC1D94DA0
- Walker J & Hopkins MS (1984). Vegetation. In RC McDonald, RF Isbell, JG Speight, J Walker & MS Hopkins (eds), *Australian soil and land survey field handbook*, Inkata Press, Melbourne, 44–67.







# 7 Desert Uplands Plot Network

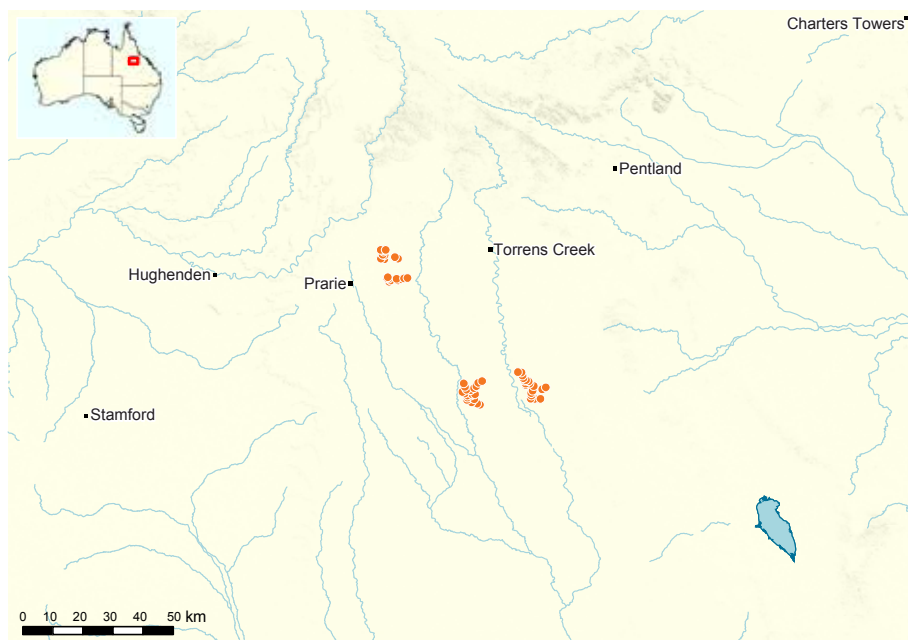


**Primary plot contact:**

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## Location of the Desert Uplands Plot Network in Queensland

Photo (opposite page): Desert Uplands, D Metcalfe

## Objective

The Desert Uplands long-term bird monitoring plots were established to investigate the effects of different woodland management strategies on bird assemblages in the Desert Uplands. There is fairly widespread belief among graziers that woodland ‘thickening’ is bad, not just for grazing enterprises, but also for bird assemblages. Often, birds become more obvious to graziers when areas are highly disturbed or cleared, and this may lead to the perception that clearing and grazing are good for bird diversity. However, many of the species that are noticed by graziers are common, ‘disturbance increasers’—that is, species that benefit from clearing and other activities associated with grazing, such as the creation of water points. Examples include species like galahs, yellow-throated miners and crested pigeons. Small forest birds, on the other hand, may be disadvantaged by clearing or thinning activities. The primary aim of the Desert Uplands long-term bird monitoring plots is to examine how bird assemblages change with time after clearing and thinning activities. Initially, 60 plots were established, but since 2008 only 50 of these plots have been accessible.

## Research goals

- A significantly increased understanding of the effects of past vegetation clearing and modification activities on bird assemblages in savanna ecosystems.
- Creation of defensible arguments regarding clearing and thinning policies in Queensland in regard to bird assemblages.
- An increased ability to predict effects of perverse outcomes of management activities—such as the effects of increased numbers of hyper-aggressive ‘despotic’ species such as yellow-throated miners.

## Research questions

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



**Table 7.1 Desert Uplands Plot Network summary table**

<b>Ecosystem</b>	Tropical ironbark woodlands
<b>General location</b>	North Queensland
<b>Other custodian(s) and/or partners</b>	Pastoral leases
<b>Disturbance type</b>	Tree clearing, grazing
<b>Data type (fauna/flora/vegetation structure)</b>	Birds, vegetation structure
<b>No. of plots</b>	60
<b>Plot size</b>	1 ha
<b>Start year</b>	2004
<b>Temporal revisit</b>	2004, 2005, 2006, 2008, 2013 and 2014

## Specific data collection protocols

Each of the 50 (originally 60) Desert Uplands bird monitoring plots is 1 ha in size, and located at least 1 km from any other site, 500 m from any water point and 50 m from the nearest access track. Plots are stratified according to vegetation management history:

1. cleared (vegetation has been pulled, removing all trees and shrubs)
2. thinned (subcanopy vegetation such as currant bush [*Carissa* species], which is normally prevalent in the woodlands, has been largely removed with a mechanical device called a 'crocodile', which is towed behind a tractor)
3. unmodified woodlands.

Within each 1-ha site, eight 5-minute wandering diurnal bird counts take place over four days. Two counts will be made per day at each site: one count in the morning within three hours of dawn, and the other a minimum of three hours after the first count and before dusk.

Vegetation composition and structure is recorded across each 1-ha plot in a series of nested quadrats and transects (Figure 7.1).

Within five 1 m × 1 m quadrats located along a central 100-m transect, the following ground cover elements are visually estimated:

- native perennial grasses (increaser and decreaser species)
- native perennial hummock grasses
- native perennial herbs and forbs
- native shrubs
- exotic grasses, herbs and forbs
- litter, rock and bare ground.





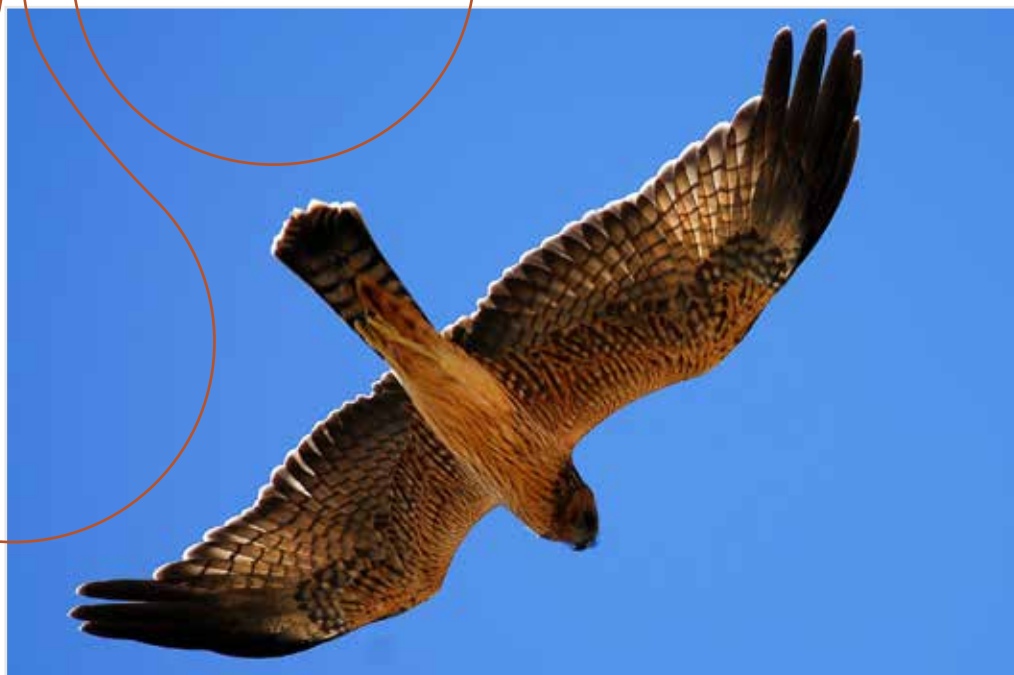


Photo: Spotted harrier, E Vanderduys

## If I had my time again

Given the opportunity to establish the Desert Uplands plots today, we would do several things quite differently. Firstly, we would pay much more attention to working with the landholders to determine exactly how interested they were in us visiting their properties on a regular basis to assess change over a long period of time. One-sixth of our plots are now not accessible due to prohibitions on future access. Secondly, to in some way protect against the vagaries of change of tenure or attitude, we would better encompass the range of variation we are interested in within each property, rather than relying on continued access to a small number of properties to maintain a data stream on a particular treatment. Thirdly, we would pay much more attention to detailed vegetation surveys at the outset, because woodland clearance affects more than simply tree cover, yet we lack some of those insights as the serious botanical work was only done long after the plots were established. Finally, the focus of the project has been on bird populations, which have certainly changed, but we should also have included some less mobile, more critically woodland-dependant groups in our survey to better understand the broad community responses to vegetation management. We are still collecting interesting and informative data, but as we get further down the track, the more we are kicking ourselves that some really important baseline data were not collected right at the start of the exercise.

## Recommended further reading

Eyre TJ, Kelly AL, Neldner VJ, Wilson BA, Ferguson DJ, Laidlaw MJ & Franks AJ (2011). *BioCondition: a condition assessment framework for terrestrial biodiversity in Queensland*, assessment manual, version 2.1, Department of Environment and Resource Management, Biodiversity and Ecosystem Sciences, Brisbane.

Walker J & Hopkins MS (1984). Vegetation. In RC McDonald, RF Isbell, JG Speight, J Walker & MS Hopkins (eds), *Australian soil and land survey field handbook*, Inkata Press, Melbourne, 44–67.







# 8 Connell Rainforest Plot Network

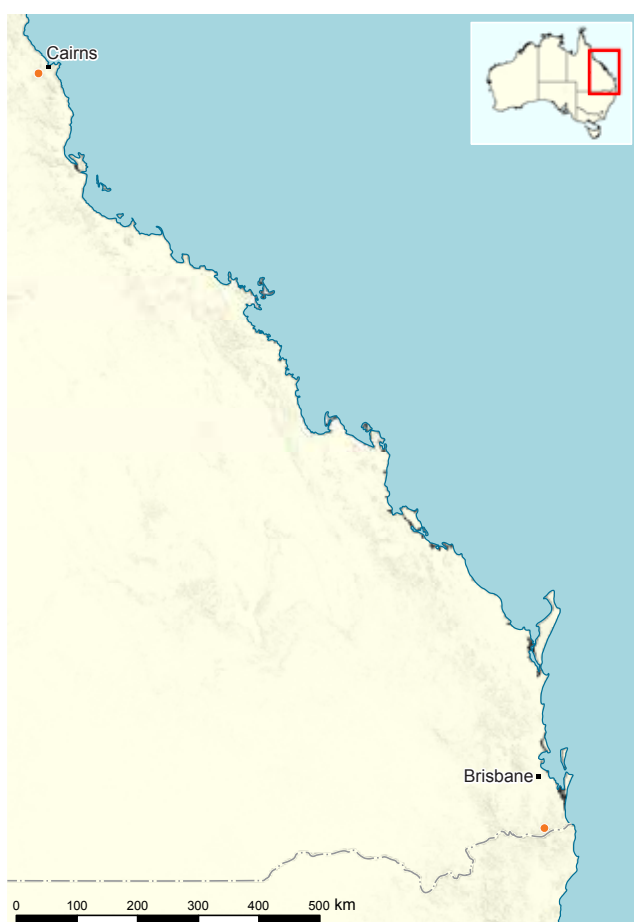


**Plot Leader:**

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## Location of the Connell Rainforest Plot Network in Queensland

Photo (opposite page): Peter Green at Connell, D Metcalfe

## Objective

The Connell Rainforest Plot Network was established to collect demographic data (recruitment, growth and mortality) on rainforest trees to improve our understanding of the mechanisms that maintain plant species diversity in complex, species-rich tropical and subtropical rainforests. This objective has remained consistent throughout the study.

## Research goal

To build a decades-long, comprehensive database of rainforest tree demography at two sites to enable tests of hypotheses for the maintenance of diversity in tropical and subtropical rainforest.

## Research questions

- How do long-term demographic patterns vary across life stages within and between species?
- Is this variation correlated with plant functional traits?
- Can interspecific variation in key demographic processes explain the maintenance of species diversity in these forests?
- Can compensatory density and frequency-dependent recruitment, growth and mortality explain the maintenance of rare species in species-rich forests?

**Table 8.1** Connell Rainforest Plot Network summary table

Ecosystem	Tropical rainforest	Subtropical rainforest
General location	Dinden National Park, Queensland	O'Reilly's: Lamington National Park, Queensland
Other custodian(s) and/or partners	Department of National Parks, Sport and Racing	Department of National Parks, Sport and Racing
Disturbance type	Not applicable	Not applicable
Data type (fauna/flora/vegetation structure)	Vegetation structure, flora	Vegetation structure, flora
No. of plots	1	1
Plot size	1.7 ha	2.0 ha
Start year	1963	1963
Temporal revisit	1–6 years	1–6 years



## Specific data collection protocols

### Plots and units of measurement

Professor Joseph H Connell (University of California at Santa Barbara) established two long-term forest dynamics plots in 1963, one in tropical rainforest at Davies Creek in Dinden National Park (1.7 ha, 25 km southwest of Cairns; see Figure 8.1, Table 8.2) and another in subtropical rainforest near O'Reilly's Guest House in Lamington National Park (2 ha, 65 km south of Brisbane; see Figure 8.1, Table 8.3) (Connell et al. 1984; Connell & Green 2000; Green et al. 2014). The Davies Creek plot was put in over an existing 0.4-ha plot established by the Queensland Department of Forestry in 1951 (Nicholson et al. 1988), so the central part of the Davies Creek plot has records extending back more than six decades. This plot was originally an untreated 'control' site against which the effects of various silvicultural treatments could be assessed, so this site has never been logged or thinned. The O'Reilly's plot consists of two 1-ha plots spaced approximately 600 m apart, but for analyses they have always been treated as a single unit. This plot has never been logged, but some selective logging has occurred just outside the plot boundary.

The plots were originally laid out and trees were mapped using imperial units (feet and tenths of feet). Stems were either measured for girth at breast height using inches and tenths of inches, or measured for height using feet and tenths of feet. These units have been used throughout five decades of monitoring, using measuring tapes especially imported from the United States. All measurements are converted to SI units for analyses and publication. The descriptions below use imperial measurements, with SI equivalents in parentheses.

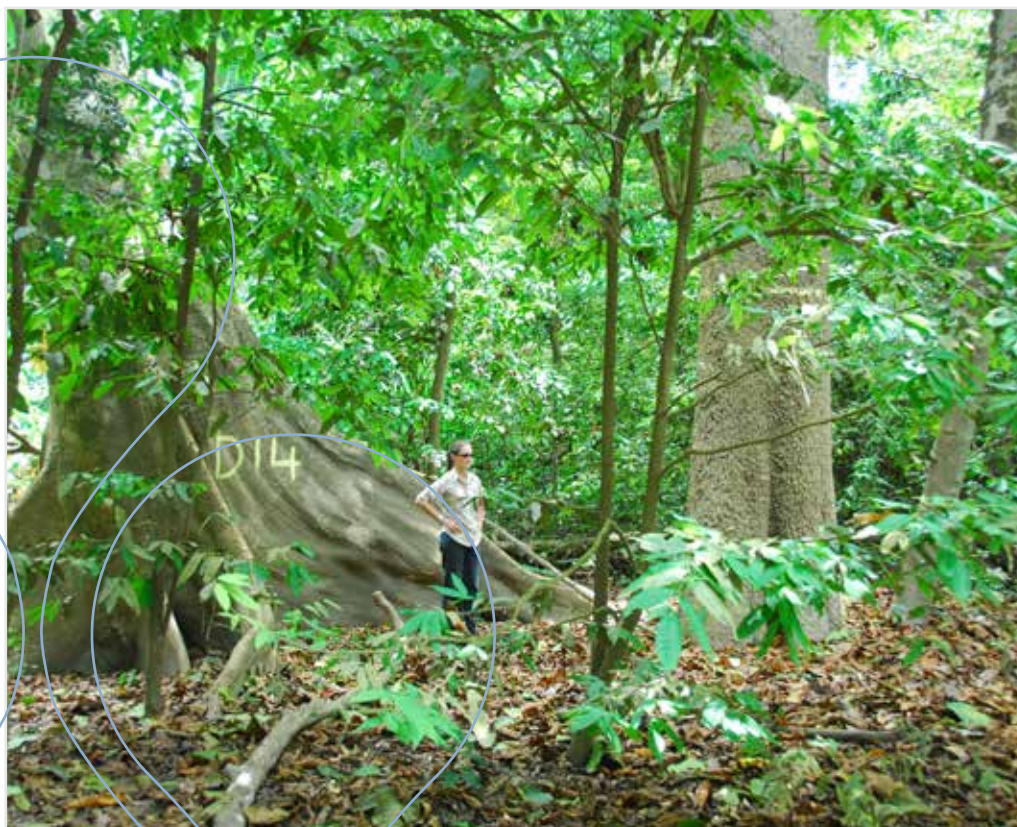
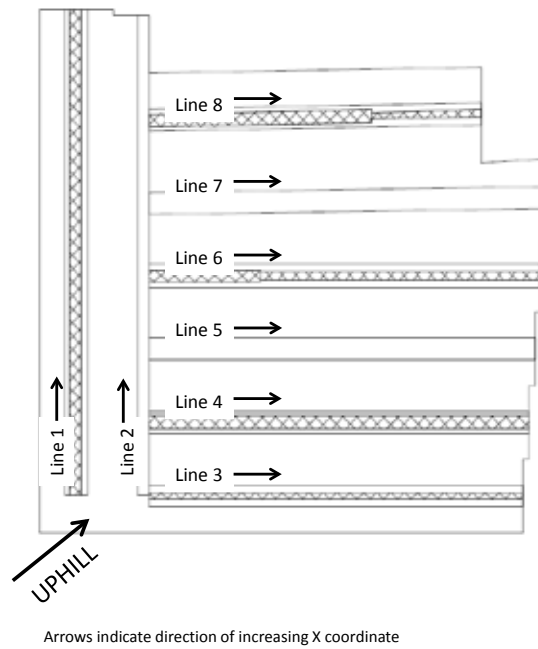
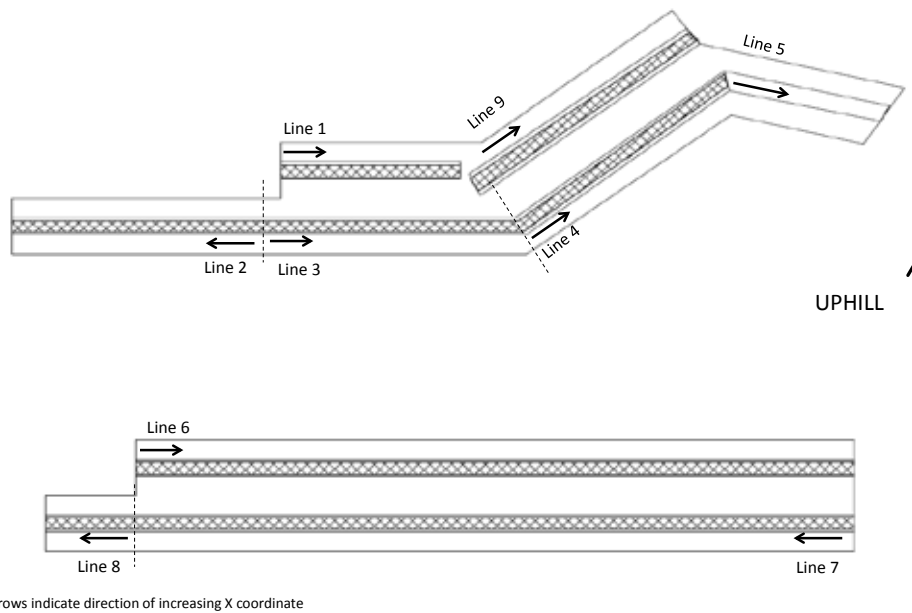


Photo: Iron Range, D Metcalfe

(A) Dinden National Park, Davies Creek Connell plot



(B) and (C) O'Reilly's Connell plots



**Figure 8.1 Plot layout of the Connell Rainforest Plot Network**

Davies Creek (A): The 1.68 ha plot is located at approximately 17°02'18.9"S, 145°37'31.3"E, at about 850-m elevation in tropical rainforest. O'Reilly's 1 (B) is 1.0 ha and located at 28°12'59"S and 153°07'36"E, and O'Reilly's 2 (C) is 0.94 ha located about 600 m from O'Reilly's 1 at approximately 900-m elevation in subtropical rainforest. All maps were redrawn from Connell et al. (1984), to approximately the same scale (Davies Creek extends 140 m east–west at its widest point; O'Reilly's 1 extends 290 m east–west at its widest point; and O'Reilly's 2 extends 270 m east–west at its widest point). All large trees  $\geq 12.5$ -inch girth at breast height (GBH) are censused throughout the plots. Medium trees ( $\leq 12.4$ -inch GBH;  $\geq 3.2$ -inch GBH) are censused in belt transects 20 feet wide inside the plots; each of these transects lies parallel to at least one plot border. Small trees (seedlings and small saplings  $\leq 3.1$ -inch GBH) are censused in narrower strips (6–12 feet wide) nested within several of the 20-foot-wide belt transects (represented by cross-hatching).

**Table 8.2 Davies Creek Connell plot, transect details**

Line	X coordinates (ft)	Comments
1	0–38, 100–500.0	Small trees $\pm$ 6 ft entire transect. Negative is left-hand side in the direction of X along the transect
2	0–33, 100–500.0	Negative side only, no small trees. Negative is left-hand side in the direction of X along the transect
3	0–337.2	Small trees $\pm$ 3 ft entire transect. Negative is right-hand side in the direction of X along the transect
4	0–343.0	Small trees $\pm$ 6 ft entire transect. Negative is right-hand side in the direction of X along the transect
5	0–347.5	No small trees. Negative is right-hand side in the direction of X along the transect
6	0–354.0	Small trees $\pm$ 6 ft for the first 100 ft, then reduces to $\pm$ 3 ft for remainder. Negative is right-hand side in the direction of X along the transect
7	0–356.2	No small trees. Negative is right-hand side in the direction of X along the transect
8	0–300.0	Small trees $\pm$ 6 ft for the first 200 ft, then reduces to $\pm$ 3 ft for remainder. Negative is right-hand side in the direction of X along the transect

Note: Further details can be found in documentation accessible through a link at the Connell Plots LTERN webpage ([www.ltern.org.au/index.php/ltern-plot-networks/connell-rainforest](http://www.ltern.org.au/index.php/ltern-plot-networks/connell-rainforest)).

**Table 8.3** O'Reilly's Connell plot, transect details

Line	X coordinates (ft)	Comments
1	0–200.0	Negative is right-hand side in the direction of X along the transect
2	0–272.8	Negative is left-hand side in the direction of X along the transect
3	0–283.9	Negative is right-hand side in the direction of X along the transect
4	284.0–446.8	Negative is right-hand side in the direction of X along the transect
5	0–300.0	No small trees. Negative is right-hand side in the direction of X along the transect
6	0–800.0	Negative is right-hand side in the direction of X along the transect
7	800.0–1600.0	Negative is left-hand side in the direction of X along the transect
8	1600.0–1700.0	Negative is left-hand side in the direction of X along the transect
9	300.0–600.0	Negative is right-hand side in the direction of X along the transect

Note: Further details can be found in documentation accessible through a link at the Connell Plots LTERN webpage ([www.ltern.org.au/index.php/ltern-plot-networks/connell-rainforest](http://www.ltern.org.au/index.php/ltern-plot-networks/connell-rainforest)).

### *Size classes, mapping and tagging stems*

Samples of trees in three broad size classes have been monitored on the plots over several decades. Large trees are  $\geq 12.5$ -inch GBH (10.1-cm diameter at breast height [DBH]) and were first tagged, mapped and measured in 1963 across both plots. Large trees whose trunks were rooted outside the plot boundaries but whose canopies fell over boundary were also mapped. These are identified in the databases as '9' in Index 2, and should be excluded from analyses when calculating plot-wide stem density and basal area. Also commencing in 1963, medium trees  $\geq 3.2$  but  $\leq 12.4$ -inch GBH ( $\geq 2.6$  cm but  $\leq 10.0$ -cm DBH) were mapped and tagged along several belt transects 20 feet (6.1 m) wide running through the plot, centred on survey lines one chain, or 66 feet (20.1 m) apart. These belt transects are known as 'lines' (Figure 8.1). The medium-tree belt transects comprise 30% of each plot (see Figure 8.1). In 1965, small trees (seedlings to saplings  $\leq 3.1$ -inch GBH [2.5-cm DBH], measured for height), were mapped and tagged along narrower transects, either 6 feet (1.8 m) or 12 feet (3.6 m) wide, centred on the same survey lines used to sample medium trees. All small-tree belt transects at O'Reilly's are 12 feet wide, and small trees are mapped on all lines except line 5. At Davies Creek, small trees are mapped and monitored on lines 1, 3, 4, 6 and 8, but the width varies: 12 feet on line 1, 6 feet on line 3, 12 feet on line 4, 12 feet for the first 100 feet of line 6 and then 6 feet thereafter, and 12 feet for the first 200 feet of line 8 and then 6 feet thereafter. In the field, the start and endpoints of all lines are marked with a metal star picket, and at 25-foot intervals with smaller metal stakes.



In the databases, all plants are assigned 'line coordinates' with X being the distance along the central line of the belt transect, and Y the distance perpendicular to the line. Using a convention established in 1963, the negative side is always downhill. The lines at Davies Creek are not strictly orthogonal to each other, while some of the lines at O'Reilly's follow contours. A set of equations, one for each line, are used to convert line to plot coordinates for both sites. These equations are given in full with the metadata accompanying the databases. Line coordinates are typically used for recensus work, but plot coordinates are useful for producing whole-plot maps and for nearest neighbour analyses.

The original mapping of large trees in 1963 was based on line coordinates. Joe Connell used a purpose-built optical rangefinder to measure the perpendicular distance away from the line to the target tree. In subsequent recensus work, trees that recruit into the large tree size class are mapped by triangulation from at least three near neighbours, and their coordinates are calculated and entered into the database after a census is finished. The line coordinates of recruited medium and small trees are determined in the field by direct measurement from the central transect line. For large and medium trees, the point of GBH measurement is 51 inches (1.3 m) above the ground. If the trunk is deformed at that height, a position above or below is used, and that height noted for all subsequent censuses. Ladders are used to obtain GBH above buttresses.

Large and medium trees are tagged with numbered aluminium tree tags inscribed with a unique number, nailed into the trunk with galvanised nails. Many of the original tags survive and are still perfectly legible after 50 years in the field. Small trees are also tagged with numbered aluminium tags, attached to the plant using loops of insulated copper wire. Only trees and shrubs are monitored. The seedlings of vines are occasionally tagged by inexperienced workers, but these are excluded from analyses.

Many species at both sites mast<sup>6</sup> flower and fruit, and sometimes there are thousands of new seedlings in a single species to tag, map and measure. Mortality of young seedlings is very high, so rather than invest time, energy (and tags) in mapping thousands of new recruits that are likely to be dead by the time of the following survey, we count but do not tag these new recruits. Wherever they are common, the recruit seedlings of masting species are counted in 3 feet × 3 feet squares (Appendix E-1). All seedlings in a square are assigned the same coordinates (the centre of the square) and assigned the same height. This approach trades off precision of mapping and measuring individual plants against effort. In the database, these counts are entered in the 'Replicates' column (a plant that is tagged, mapped and measured individually has a replicate of 1). In the following census, any survivors are tagged, mapped and remeasured individually, and the number of dead individuals is counted by subtraction (no. deads = replicates from previous survey – no. survivors for that square). Edits to the database are best explained by an example. For instance, say there are 25 new recruit seedlings of a single species in a 3 feet × 3 feet square in a 2014 survey. A single record will be created for this square, with replicates = 25, tag = 0, a single set of X, Y coordinates, map date = 2014, and a single measure for Ht1. Then, say 19 of these seedlings are dead at the time of the next survey in 2016. The original record will be altered to replicates = 19, all with a dead date of 2016. At the same time, six new records will be created for the survivors, using the map date 2014, the original Ht1, the new tag numbers for each plant, and

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6 Massive, concentrated periodic flowering and fruiting that may be synchronised within a species.

individual X, Y coordinates. These edits preserve the total number of new recruits for that square, through the transition from a single count to the mapping of individuals.

### Preparing maps and datasheets for major recensuses

Many years of experience indicate that the most efficient way to relocate and recensus large and medium trees is to use maps that show the location and identity (tag number) of individuals. The steps for creating these maps and lists is described below. How to search for and map new tree recruits is described in Box 8.1.

Using the master database, set the filter on dead = 0 to capture all individuals that were alive at the previous census. Using the Gth columns, further filter this set to capture all live trees with GBH  $\geq$  3.2 inches (medium and large trees). This is the set of trees that needs to be recensused. It is most convenient to create maps that span the full width of a line (typically 66 feet or 20 m), in 120-foot segments. At this scale, individual trees can be plotted using the line X, Y coordinates, and numbered so that there isn't too much overlap on the map and the tag numbers are legible. Field crews also find it useful to have some indication of the size of the tree they are searching for. An exemplar map is shown in Appendix E-4. Numbered triangles indicate medium trees (within 10 feet of the central line), while three sizes of circles are used to indicate relative size within the large tree category. The 'Series' function in Excel is useful for plotting these different groups. Freeware add-ins for Excel can be used to label the trees with their tag numbers. Each map is accompanied by a data sheet that lists just those trees plotted on the map, sorted in order of their tag number. Maps (and their matching data sheets) do not overlap—that is, a tree only ever appears on a single map. On the data sheets it is useful to include the previous GBH measurement to further help field crews locate the target tree, and it is essential to include the comments column because the records for many trees are annotated with instructions on where to measure, if not the standard 1.3 m above the ground.

There are too many small trees to be mapped and, in any case, maps are not useful at these very small scales. Using the master database, set the filter on dead = 0 to capture all individuals that were alive at the previous census. Using the Ht columns, further filter this set to capture all live trees with height, but not girth records—by definition, these are small trees. Sort this set of individuals by their Y coordinate. Insert a temporary column next to the column for the Y coordinate, and enter one identifier for all Y = positive and a different identifier for all Y = negative. Then, conduct a hierarchical sort Line>Identifier>X coordinate. The resultant list will be sorted by line, the side of the line (Identifier), and then by increasing X coordinate. This will reflect how the field crews should encounter the plants in the field—a worker will work their way up one side of the survey line remeasuring the tagged plants they can find, while crossing off as dead the tagged plants that are missing.

### **Box 8.1 Notes for field teams searching for and mapping 'large' and 'medium' tree recruits**

#### **Large tree recruits $\geq 12.5$ -inch girth (10.1-cm diameter at breast height)**

Large trees are mapped and tagged over the entire plot, so all trees inside the plot boundary with a girth of  $\geq 12.5$  inches should have a tag on it. A 'recruit tree' is one that would have had a smaller girth at the previous census, but which has grown into the large tree size class since then.

**What do I do if I find a tree of this size within the plot boundaries that does not have a tag?** First check your maps to see if a tree of the correct size already exists at that position on your map. Identifying the species and matching that to the identity of the one you think it matches in the database is an additional check, but it's rarely the case that volunteers know the flora well enough to do this. If you are sure that the location and size of your tree matches that of a listed individual on the data sheet, assume that your target tree has simply lost its tag. Write a new tag using the existing tag number and nail it to the tree.

If you are convinced that your tree is not on the map, then assume it is a new 'recruit', especially if it's only just bigger than 12.5-inch girth. Because trees with a girth of less than 12.5 inches are already tagged within 10 feet of the lines, you are most likely to find a true recruit to the large tree size class more than 10 feet away from the lines.

**Mapping a recruit large tree.** Map the tree by triangulation—sketch the approximate position on your map, and then measure off and record the distances from your new recruit to three surrounding trees that already have tags. We know the coordinates of these trees, so we can calculate the coordinates of the new tree back in the office.

**Tagging a recruit large tree.** Traditionally, we have tagged recruit large trees in relation to the tag numbers of the trees around it. For example, say you've found a recruit tree near an existing tree tagged 432. It would make sense to call the recruit tree something like 432.1, which indicates close proximity to 432. Before deciding on a new number for your recruit tree, check the data sheets to see if the number 432.1 has already been used for another tree. We've been doing this for 50 years and there have been many recruits since the initial censuses. Someone in a previous census may already have used the number 432.1. If that number already exists, make your new tree 432.2, for example. This system works well, but one way it might come unstuck is if the number 432.2 has been used in the past, and that recruit tree is now dead. Because it is dead, it won't appear on your map. You have no way of knowing this in the field, so there is a slight chance you'll choose the tag number of a dead tree. Well, that's a risk we take, and if it happens, we can deal with it later (the alternative is for field crews to carry around a complete list of all tag numbers ever used for large trees, which would be cumbersome). Decide on your number, write the tag and nail it up on the tree—away from the standard 1.3 m above the ground. Trees often form a swelling around the nail, so in anticipation of that we position the nail away from the measurement position. Don't hammer the nail all the way in—just enough for it to be sturdy.

**Identifying a recruit large tree.** If you can, get a sample of leaves from a low branch or a sucker, and place the leaves in a labelled envelope (tag number, map number and labelled as 'new recruit') and pass it to Pete for ID. If it's not possible to get a specimen, annotate your map to indicate that Pete needs to ID this tree.

**Do not tag recruit trees that you think fall outside the plot boundaries.** If your assigned maps fall along the plot boundary, you will see that many tagged trees fall outside the 'official' plot boundaries. These trees were mapped in 1963 because although their trunks were rooted outside the boundary, their canopies were big enough to fall across the boundaries. We still keep track of these trees, but we do not tag new recruits to the 12.5-inch girth size class outside the plot boundaries. If you've found a recruit large tree near the plot boundary, make some measurements, and use the boundary line marked on the maps to decide whether your tree is 'in' or 'out'. If it's 'in', tag, map and measure, as above.

**What do I do if I find a large tree that has a tag and should be on my map, but isn't?** In all probability this will be a mistake from a previous census—either the coordinates were recorded incorrectly and your tree has been mapped in the wrong part of the plot, or, more likely, someone called it dead in the past and that's why it wasn't included on the map and data sheets this time. Your discovery of such a tree has effectively brought it back from the data-dead, so we call it a Lazarus plant, or Laz plant for short. Record the tag number, sketch the position on the map and record neighbour distances, as you would for a real recruit. Clearly mark it as 'LAZ tree' on your map. The data entry operator will bring it back to life in the database and record its latest DBH.

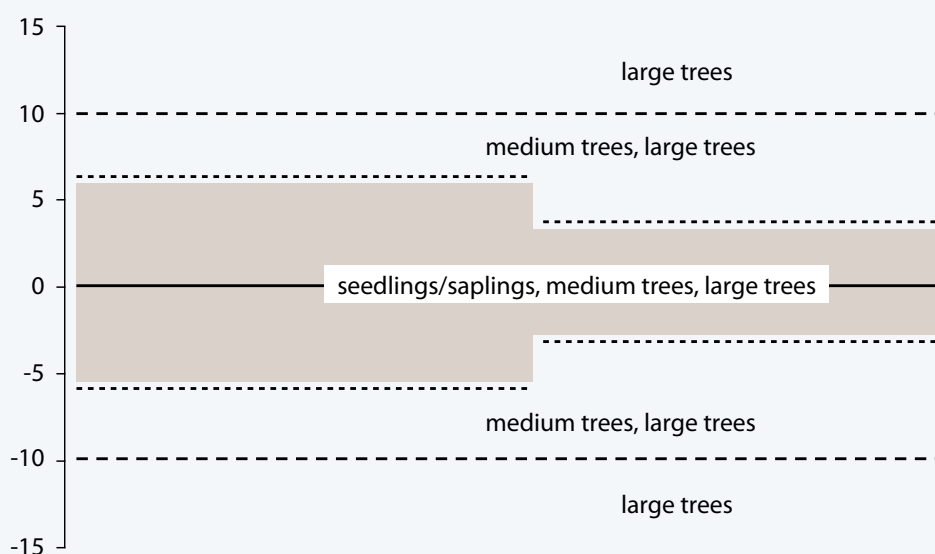
### **Medium tree recruits $\geq 3.2$ but $\leq 12.4$ -inch girth (2.6–10.0-cm DBH)**

A medium recruit tree is one that had a girth smaller than 3.2 inches at the previous census, but which has grown into the medium tree size class since then. Medium trees are mapped and tagged along transects 20 feet wide ( $\pm 10$  feet), centered on the lines. All trees in this size class within 10 feet of the transect tape should be mapped, tagged and identified.

**What do I do if I find a tree of this size within the  $\pm 10$ -feet boundaries that does not have a tag?** First check your maps to see if a tree of the correct size already exists at that exact position on your map. In that case, you would assume that your target tree has simply lost its tag, so write a new tag using the existing tag number and fix it to the tree using a long wire if the tree is slender, and a nail if it's bigger.

**Where would I expect to find these medium tree recruits?** If you are convinced that your untagged tree is not on the map, then assume it is a new 'recruit'. These are most likely to occur in the area between the small tree transect boundaries, and the 10-foot transect boundary beyond that (Figure 8.2). Small trees are mapped within 3 feet or 6 feet of the transect lines. Medium trees are mapped out to 10 feet, and large trees are mapped over the entire plot. In effect *all* stems are mapped within 3 feet or 6 feet of the transect lines, so on the central part of the transects we do an excellent job of detecting when a plant's girth transitions from being less than 3.2 inches (when its measured for height) to when it becomes  $\geq 3.2$  inches, because such plants already have tags and get checked regularly.





**Figure 8.2** Diagram of where to carefully check for medium tree recruits (shaded area)

Figure 8.2 shows a segment of transect, with the line (X coordinate) running horizontally and the distance away from the line (Y coordinate) running vertically.

The place where we need to check carefully for medium tree recruits is that area outside the small tree boundaries but inside the 10-foot transect boundaries—that is, between 3 feet and 10 feet either side of the line, or between 6 feet and 10 feet either side of the line. There are no seedlings tagged in these areas, so we need to check for untagged stems that had a girth less than 3.2 inches at the previous census, which have since grown to a girth of 3.2 inches or more by the current census. These will be ‘medium tree recruits’.

**What do I do if I find a medium tree recruit?** Tag the plant using the decimal system outlined for the large trees above. If possible, don’t use a nail—use a long wire instead, but give the plant plenty of room to grow without choking. If possible, fix the wire above a branch to stop it sliding down the stem. If that’s not possible, attach the wire around the trunk and then pinch it tight around the trunk to hold it up, but so the pinch can open as the tree grows. Map the plant with your tape measure—use standard X, Y coordinates (X = distance along the tape, Y = distance away from the tape). Your maps will indicate which side of the line your plant is on). Collect a voucher specimen and place it in a labelled envelope (tag number, line/map number, coordinates, girth), and hand it to Pete for identification.

**What do I do if my medium tree has snapped off or died back, but resprouted?** This happens frequently, and often the stem is dead at the breast height point of measurement. Instead of measuring girth at breast height, measure plant height and make a note that the main stem has died and resprouted.

**What do I do if I find a medium tree that has a tag and should be on my map, but isn’t?** Same applies as for large trees—this is probably a Laz plant, so record all the details (tag, size, X and Y coordinates) on your data sheets and clearly label it as a Laz plant.

### Schedule of censuses

Large, medium and small trees have been sampled on the plots on varying schedules over several decades (Table 8.4). In some years, just the new seedling recruits are mapped, tagged and identified (Appendix E-2). In other years, this survey may be completed in conjunction with a mortality survey in which all stems that were alive at the previous survey are checked again to determine if they still alive. A complete census in which recruitment, growth and mortality in the three sizes classes is undertaken on both plots occurs about once every six years, most recently in 2013. These full recensuses take approximately 100 person-days to complete at O'Reilly's and about 120 person-days at Davies Creek (Appendices E-3–E-5).

**Table 8.4** Schedule of censuses within the Connell Rainforest Plot Network

Date	Large and medium trees $\geq 3.2$ -inch GBH		Small trees $\leq 3.1$ -inch GBH		New recruits	Comments
	Mortality	Growth	Mortality	Growth		
1963, Jun		1st census	–	–	–	First mapping of stems $\geq 3.2$ -in. GBH, both sites
1965, Jun	+	–	–	1st census	–	<3.2-in. GBH, first complete mapping
1967, Jan	+	–	+	–	–	
1969, Jun	+	–	+	–	+	First mapping of new seedling recruits
1971, Jul	+	–	+	–	+	
1972, Apr	–	+*	+*	–	–	*OR recount of sp. 38 only. Also $\geq 3.2$ -in. GBH measured near some gaps
1974, Jun	+	+*	+	–	+	*Remeasure $\geq 3.2$ -in. GBH at Dav, most trees; at ORE, only line 5, X >300 ft (these data not yet in database)
1976, Jun	+*	–	+*	–	+*	*Only in or near gaps, both sites
1978, Jun	+	+	+	+*	+	*Only at DAV
1980, Jun	+*	–	+*	+*	–	*Only at ORE
1980, Sept	+*	–	+*	–	–	*Only at DAV
1981, Jul	–	–	–	–	+	Large trees: only notes on causes of deaths
1983, Jun	–	–	–	–	+	Large trees: only notes on causes of deaths

Date	Large and medium trees $\geq 3.2$ -inch GBH		Small trees $\leq 3.1$ -inch GBH		New recruits	Comments
	Mortality	Growth	Mortality	Growth		
1986, Jan	+	+	+	+	+	
1988, Jun	+	-	+	-	+	
1990, Jun	+	-	+	-	+	
1991, Jul	-	-	-	-	+	
1992, Aug	+	+	+	+	+	*Partial: DAV, parts of all lines; ORE, both sides of lines 2, 6 and 7
1993, Aug	-	-	-	-	+	
1994, Sept	+	-	+	-	+	
1995, Aug	-	-	-	-	+	
1996, Aug	+	+	+	-*	+	*Live seedlings and saplings on DAV line 1 (all), line 6 (bottom end) and line 8 remeasured, but not entered into database. At ORE, special effort to get recruits by growth $\geq 3.2$ but $\leq 12.5$ -in. GBH, between Y = 6 ft and 10 ft
1997, Aug	-	-	-	-	+	
1998, Aug	+	-	+	+	+	
1999, Aug	-	-	-	-	+	
2000, Aug	+	-	+	-	+	
2001, Jul	-	-	-	-	+	
2002, Sept	+ <sup>1</sup>	-	+ <sup>2</sup>	-	+	<sup>1</sup> At ORE only, but missed first 200 ft of line 6, and all line 8. Not done at DAV <sup>2</sup> At DAV, only lines 1, 3 and 4
2003, Jul	-	-	-	-	+	
2004, Sept	-	-	-	-	+	
2006	+	+	+	+	-	Single handed, by Bob Black
2013	+	+	+	+	+	Census conducted July at ORE, October at DAV

+ = demographic variables assessed during each census; \* = partial census; - = census not conducted; DAV = Davies Creek, GBH = girth at breast height; in. = inch; ORE = O'Reilly's; ft = feet

Note: For large and medium trees, new recruits were added during each mortality census. Stems were first measured and tagged during the census identified as '1st census'. For small trees, 'new recruits' are seedlings that had germinated and survived to the indicated census.

## Floristic identification, vouchers and lists

The majority of plant identifications have been done by just three individuals over five decades: Mr Geoff Tracey of the CSIRO in the earlier years, Dr Meg Lowman in the middle years and Dr Peter Green in the latter years. Voucher specimens have been collected on an ad hoc basis over the years for many plants on both plots. These specimens are curated at La Trobe University. Species lists are updated as taxonomic changes are published. Major taxonomic revisions of the rainforest Myrtaceae and Lauraceae pose some problems for analyses, especially at the Davies Creek site. These revisions have erected many new species and redefined the morphological boundaries of others, and of course it is impossible to retrospectively apply the revised taxonomy to unvouchered, dead stems.

### *Archival material*

All of the original field sheets, notebooks, plot maps and other archival material are held by the University of California at Santa Barbara (UCSB). Copies of field data sheets from 1993 onwards are held by Peter Green at La Trobe University (LTU). Peter Green holds the most up-to-date version of the master data files for both plots at LTU, and all archival material is expected to be transferred from UCSB to LTU over the next few years, and will then be available through the LTERN Data Portal.



Photo: Davies Creek, P Green



## Associated studies and datasets

### *Disturbance*

Natural disturbance has been monitored at both sites throughout the study. Gaps created by the death of large canopy trees have been systematically surveyed many times over the decades, with the boundaries of the gaps being noted on hand-drawn maps. These maps have never been digitised, and the originals are held at UCSB. Copies of some more recent maps are held by Peter Green at La Trobe University.

### *Light environments*

Under LTERN, a new survey for canopy cover and understorey light environments commenced in 2013. At both sites, hemispherical ‘fisheye’ photographs were taken at 12.5-foot intervals along all lines on which small trees are monitored. The fisheye camera is mounted in a self-levelling gimbal so that the camera points directly upwards. The gimbal is also equipped with an electronic compass, so that whatever the orientation of the camera, one or two small LEDs of many arranged in a ring around the lens always indicates north in the image. The gimbal and camera are placed on a monopod above the ground. These surveys will be repeated at every future recensus of the plots.

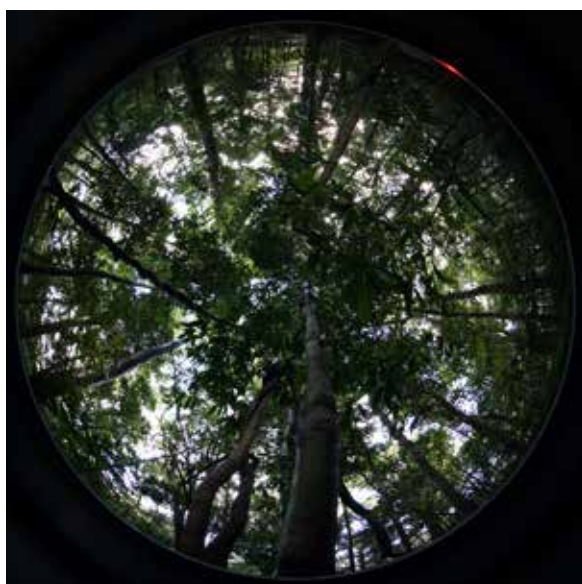


Photo: P Green

**Figure 8.3** A hemispherical photograph of the rainforest canopy at Davies Creek

Specialised software is used to analyse such images to calculate percentage of canopy openness, the direct site factor, indirect site factor and total site factor. The red flare on the edge of the image at bottom right indicates north.

### *Phenology and seasonal seedling recruitment*

A phenological study was initiated at Davies Creek in January 1995 in an effort to understand temporal variation in seedling recruitment documented in the long-term censuses. Monthly observations of flowering and fruiting were made on more than 700 stems from 103 species for six years to the end of 2000, and then on a subset of 25 species for an additional three years to the end of 2003 (P Green, unpublished).

data). Concurrent with this phenological study, new seedling recruits were monitored on 20 transects, each 100 m long and 1 m wide, placed both on the long-term plot between the lines and around the margins of the plot. Surveys were conducted about every three weeks for 6.3 years between September 1994 and December 2000 (P Green, unpublished data). Together, the phenological and seedling recruitment surveys explored recruitment bottlenecks at much finer temporal scales than had been revealed by monitoring of the long-term plot (e.g. Connell et al. 2005). There are no plans to recommence this monitoring under LTERN with current resourcing levels.

### *Ground-dwelling vertebrates*

The abundance and diversity of ground-dwelling vertebrates (mammals and birds) were monitored at the Davies Creek site for several years during the mid-1990s by Dr Tad Theimer and Dr Catherine Gehring (Northern Arizona University, USA), as part of a large vertebrate exclusion experiment (Theimer et al. 2011). There are no plans to recommence this monitoring under LTERN with current resourcing levels.

## If I had my time again

I inherited these plots from their originator, Professor Joe Connell of the University of California. Like the man himself, the Connell plots have many charming idiosyncrasies of design that make working on them in the field, and using the data for analyses, a little tricky for naïve workers. For example, the units of measurement for both mapping and measuring trees are odd to say the least – inches and feet, and tenths of both. To many, these ‘decimal feet’ and ‘decimal inches’ units are unfamiliar or even completely foreign (France has used the metric system for almost 200 years, and the occasional French volunteer is completely nonplussed by these units). With the benefit of hindsight, it would be all too easy to rail against Joe’s decision to use these units, but they were completely familiar to him as a US citizen. In the early 1960s, Australia’s conversion to the metric system was a long way off, and the original Queensland Forestry plot at Davies Creek had been established using the chain (66 feet; the distance between adjacent lines) as the unit of measurement. Once you’re used to them, it is actually quite easy to use ‘decimal feet’ as the unit of distance to do the field work, and conversion to metric units for analyses is easy enough using spreadsheets. We can only hope that the US continues to rely heavily on the imperial system, because they are the only suppliers worldwide of 100-ft tape measures, marked with feet in tenths.

Another idiosyncrasy is that many of the lines along which the small and medium trees are mapped are of variable length, follow landform contours, or both. At Davies Creek, these variable lengths have resulted in a plot whose border is highly irregular and devilishly difficult to map—instead of just four sets of coordinates to mark the corners of the plot, there are 18! At O’Reilly’s, lines 1 and 9 follow contours but don’t meet, while lines 3 and 4 meet but change direction to follow the contours. It gets worse—at Davies Creek, line 1 is actually 438 feet long, but the X coordinates for plants on this line go to 500 feet. There is a star picket at 38 feet, at which point the X coordinates restart again at 100 feet; coordinates between 38 and 100 feet do not exist. The reason for this idiosyncrasy has been lost in the sands of time, but it is coded into the equations converting line coordinates to plot coordinates. At O’Reilly’s, line 4 terminates at exactly 446.8 ft—why not 450 or 500 feet? The answer has nothing to do with plot design. In 1965, Joe’s CSIRO collaborator Geoff Tracey had agreed to tag, map and identify the first 1000 plants along this line, with Joe recording data. Joe said nothing when target

1000 was reached, and Geoff kept tagging. When he twigged to the deception, Geoff simply downed tools and declined to continue—at exactly 446.8 feet. My advice to a younger Joe would have been to make the plots regular shapes, maintain dead-straight transects, and have them all of a consistent length!

Annoying as they are, these idiosyncrasies are insignificant and can be dealt with relatively easily in both the field and the office. However, two aspects of the Connell plots deserve special mention as being prescient in their design, and which I would certainly retain if given the opportunity to set-up a new plot network.

First, the inclusion in the standard monitoring of the smallest plants, right down to new seedlings. At the time Joe set up his plots and for several decades thereafter, the standard tropical forest dynamics plot included stems down to 10-cm DBH or, starting in the 1980s, stems down to 1-cm DBH. It hasn't been until relatively recently that forest dynamics plots now routinely include the smallest size classes in their monitoring protocols. Joe's early intuition was that an understanding of seedling dynamics was important for a broader understanding of the mechanisms that maintain diversity in tropical forests, a hunch that we have recently tested with the long-term data and for which we found solid empirical support (Green et al. 2014).

Second, the seedlings and small saplings are monitored along continuous belt transects, rather than within discrete quadrats arranged across the plots. There are obvious logistical advantages to doing this, but there are analytical advantages too. Many of the latest ideas about the mechanisms for maintaining species diversity in tropical rainforests are being tested by analysing focal-plant neighbourhoods, using nearest-neighbour distances and phylogenetic neighbourhoods. These kinds of analyses can achieve better sample sizes if the plants are mapped along belt transects than if they are mapped within small, discrete quadrats.

If we could rewind the clock and start again, would I have urged Joe to do anything differently? A few things, but not much.

## References

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# 9 Desert Ecology Plot Network



## Plot Leaders:

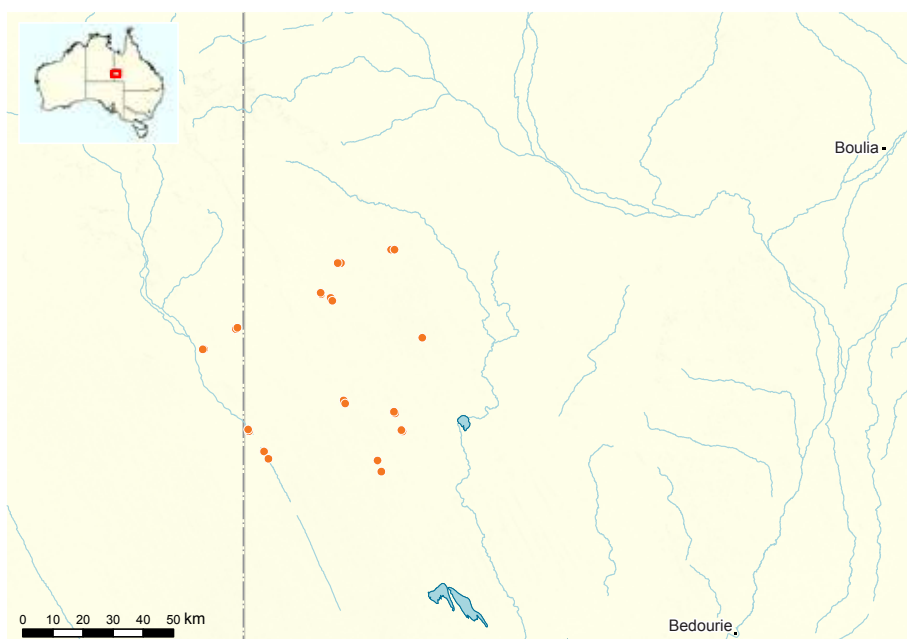
**Glenda Wardle**  
 Heydon-Laurence Building A08  
 The University of Sydney, NSW, 2006  
 Email: [glenda.wardle@sydney.edu.au](mailto:glenda.wardle@sydney.edu.au)



**Chris Dickman**  
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[www.desertecology.edu.au](http://www.desertecology.edu.au)



**Location of the Desert Ecology Plot Network, in Queensland and the Northern Territory, showing 12 core sites (each with two 1-ha grids) and other sites used in related studies of the Desert Ecology Research Group (DERG) for additional aims not supported directly by LTERN**

## Objective

The network, located in the Simpson Desert in central Australia, aims to track long-term shifts in biodiversity and ecological processes in relation to key drivers, both those intrinsic to the resource-pulse dynamics and those due to human disturbance. These drivers include unpredictable rainfall and droughts, fire, feral predators and grazing.

## Research goals

Through this network, we will quantitatively track multiple causal relationships between key environmental drivers, the main components of the structure and composition of the vegetation, and other components of the biodiversity in the Simpson Desert bioregion. Collectively, the datasets resulting from this long-term investment will significantly:

- address the knowledge gap in our current understanding of the response of arid systems to extreme environments
- increase our knowledge of the complexity of biological and abiotic interactions that support the resilience and persistence of the myriad components within these arid systems
- increase the evidence available to land managers and policy-makers to guide our decision making and actions to sustain and conserve biodiversity in this bioregion.

## Research questions

- How will increased climate extremes impact on the dynamic network of interactions among species and their role in maintaining biodiversity?
- How do complex predator–prey interactions regulate vertebrate diversity in arid Australia?

**Table 9.1** Desert Ecology Plot Network summary table

<b>Ecosystem</b>	Arid zone
<b>General location</b>	Simpson Desert
<b>Other custodian(s) and/or partners</b>	Bush Heritage Australia and pastoral lease
<b>Disturbance type</b>	Fire, predation and other feral animals, grazing, weather (drought and rainfall events)
<b>Data type (fauna/flora/vegetation structure)</b>	Fauna, flora, vegetation cover, weather
<b>No. of plots</b>	24
<b>Plot size</b>	1 ha
<b>Start year</b>	1990
<b>Temporal revisit</b>	Annual

## Specific data collection protocols

The vegetation in the study region is dominated by hard spinifex (*Triodia basedowii* E. Pritz), with scattered small woodlands of Georgina gidgee (*Acacia georginae* F.M. Bailey) interspersed throughout (Figure 9.1). The long-term plots for which data are provided as part of LTERN infrastructure are all located within the spinifex hummock grasslands, but additional survey plots, situated in gidgee woodlands, exist and have been surveyed since 2006 and are revisited whenever possible. Within the LTERN plots, flora and fauna are surveyed once a year, and manipulative experiments have previously been conducted to disentangle the multiple interacting processes that influence biodiversity. These are described at the end of this section. Climatic variables of rainfall and temperature are recorded continuously from 13 automatic weather stations installed in 1995–96.

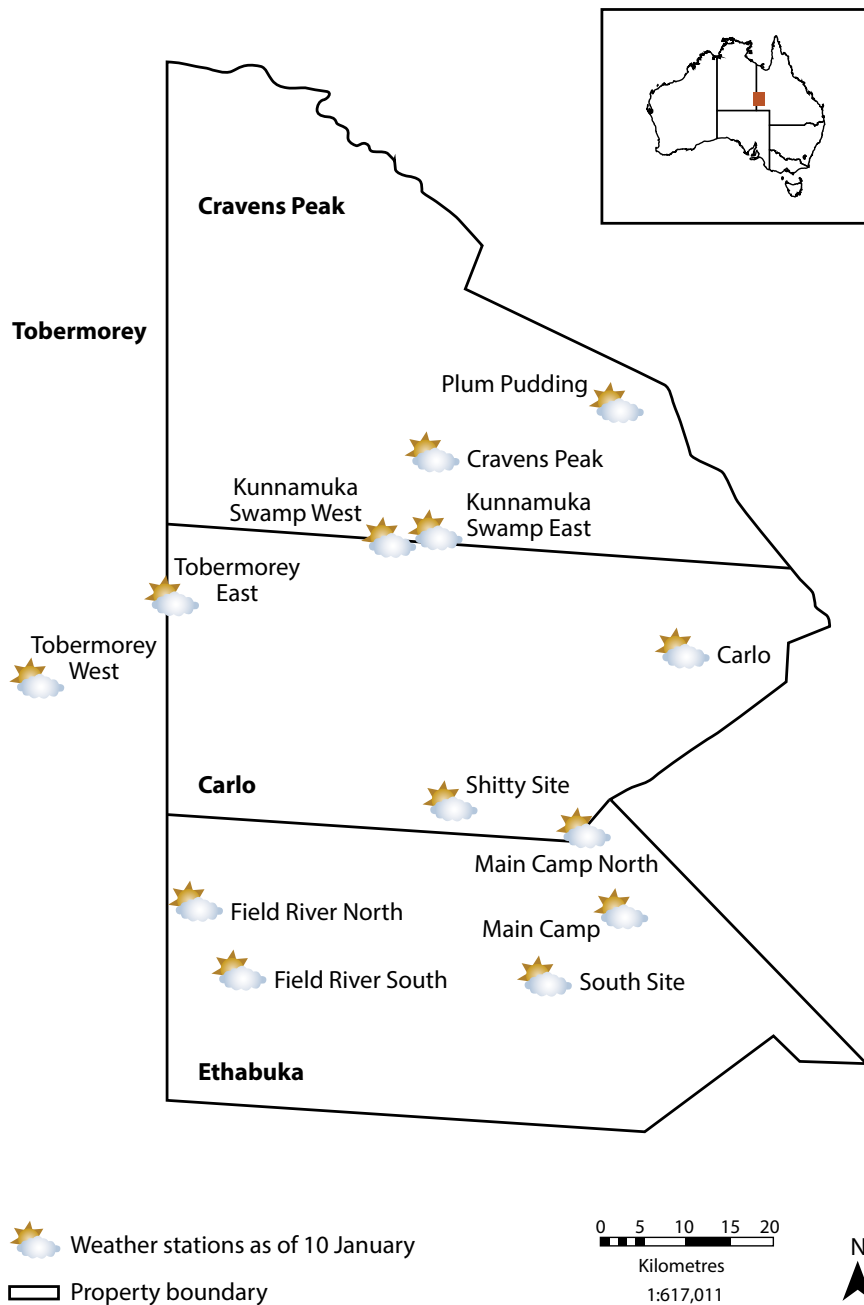


Photo: G Wardle

**Figure 9.1** Spinifex hummock grassland dominated by *Triodia basedowii* in the foreground and small woodlands of *Acacia georginae* in the middle distance and background

The photo is of grid A on Ethabuka Reserve looking from the dune crest in an approximately southerly direction, taken in November 2007. A single fence dropper pole marking a mammal trap is just visible in the mid-left side of the image.

Currently, the Desert Ecology Plot Network uses a core of 12 sites with two 1-ha trapping grids, or plots (for mammals and herpetofauna), at each site (24 plots). The 12 primary sites are spaced at least 15 km apart, with a weather station at each site (Figure 9.2). Trapping grids within sites are spaced between 0.5 and 2 km apart. Vegetation attributes are also recorded at selected points across the trapping grids.



**Figure 9.2** The study region with locations of the 12 LTERN sites

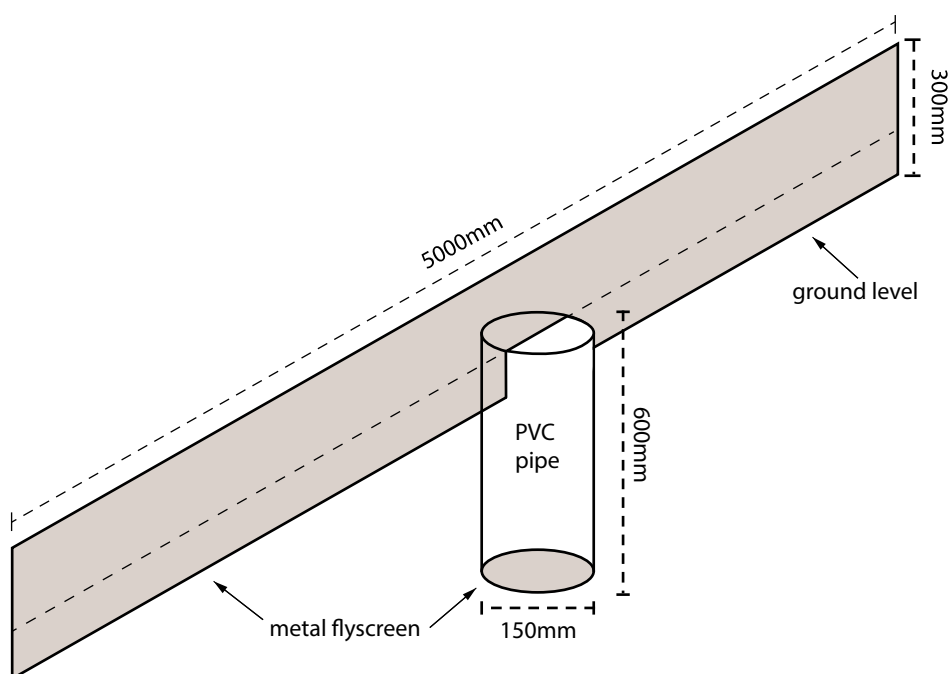
The 13th weather station at Main Camp North collects data on wind speed and direction, as well as rainfall and temperature (see text).



## Mammal and herpetofaunal sampling

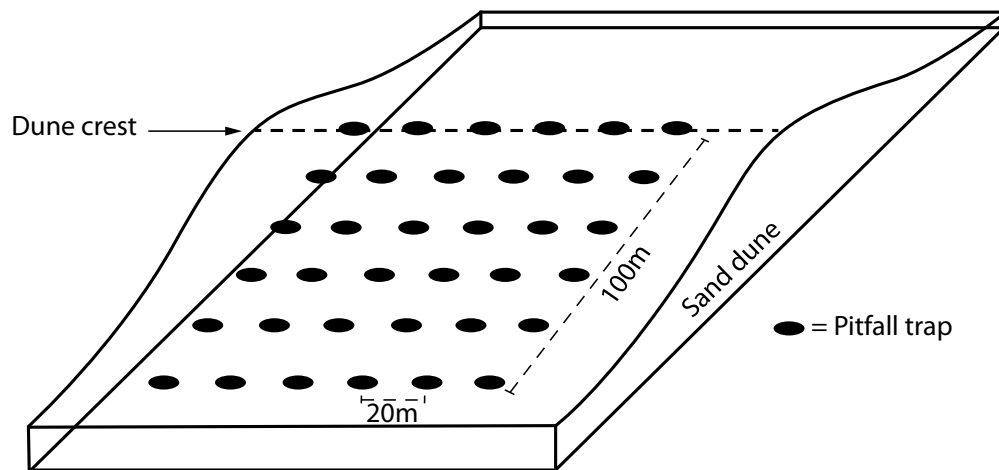
This project has gathered data on mammals, reptiles and frogs in the Simpson Desert since 1990.

Fauna are captured in pitfall traps. Each trap is made from PVC stormwater pipe, 160 mm in diameter and 600 mm deep, sunk vertically into the ground so that its top is flush with ground level (see Figure 9.3). 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 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 (Coopex™) is sprinkled around each trap to prevent ant attack.



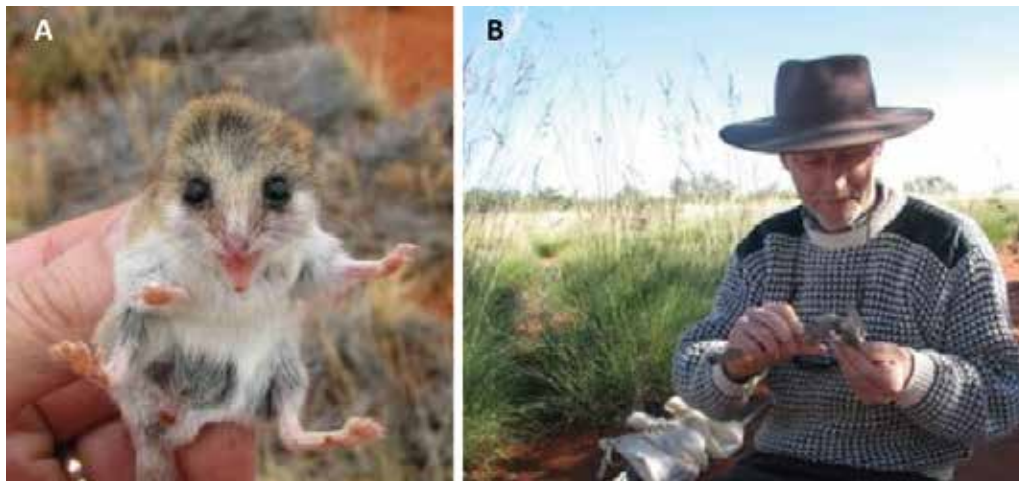
**Figure 9.3** Pitfall trap design and configuration

Each 1-ha plot has a grid of 36 traps comprising 6 lines of 6 traps spaced 20 m apart (Figure 9.4). The top line of traps extends along the dune crest; consecutive numbering starts here and finishes along the sixth line, 100 m distant in the dune valley or 'swale'. Traps on each grid are opened for 1–6 nights (usually three) at sampling intervals of usually 2–3 months, and checked in the mornings and sometimes afternoons. Any animals are removed for processing.



**Figure 9.4** Layout of a single trapping grid

Captured animals are identified, weighed, sexed and inspected for reproductive condition. Other condition indices are also recorded (e.g. tail width for marsupials) (Appendix F-1). Reproductive condition in rodents is recorded as non-parous, parous, lactating, pregnant, non-scrotal, semi-scrotal or scrotal, and for marsupials as furred pouch, bare pouch or lactating (if present, the number of pouch young is recorded and sometimes young are sexed and marked). Male marsupials have their scrotal width measured and recorded (see Figure 9.5).



Photos: G Wardle

**Figure 9.5** (a) Male *Sminthopsis youngsoni* (b) Chris Dickman measuring a mammal

Herpetofauna are also measured (snout-vent length, total length and jaw length for reptiles, and snout-urostyle length for frogs) (Appendix F-2). Date, site, grid and trap number are recorded for all captures.

Captured animals are also marked with unique ID numbers by ear notching (mammals) or toe clipping (reptiles) before release. This allows recaptured animals to be identified. Ear and toe samples are retained in ethanol as DNA samples. Exceptions to the marking process are animals with few or no toes such as flap-footed lizards and snakes. Any scats that are produced by animals during handling, or while they are in handling-bags, are kept in separately labelled vials for later analysis of their diet. Animals are then released within 10 m of the trap at which they were captured, either in vegetation or at sites offering local shelter.

### ***Vegetation cover on trapping grids***

The project has sampled vegetation structure and plant species composition on the live-trapping grids (used for mammal and reptile sampling) in the Simpson Desert since 1990. Vegetation attributes (plant species occurrence and cover estimates) are recorded in a 2.5-m radius around six pitfall traps on each vertebrate trapping grid (one trap/line, selected at random—see Figure 9.4). The same traps on each grid are resurveyed each trip; in general, these surveys are conducted around two traps each on the swale, side and crest of the dune. Percentage cover of all species, flowering index and seeding index (from 0 to 5, where 0 is no flowering or seeding, and 5 is maximal flowering/seeding) are recorded. This index represents the total amount of flowering or seeding. For example, a score of 5 is awarded if all plants are flowering or seeding at their greatest extent. Sampling intervals are usually 2–3 months apart and samples are taken at the same time as the animal trapping. Data are recorded on paper field sheets (Appendix F-3). Data are entered electronically into an Excel spreadsheet using a customised template that allows for data validation. Data are rechecked for errors in transcribing and for consistency in species names and outlier values. Once verified, data sheets are imported into a database (MS Access) that can be queried, and for long-term archiving.

### **Vegetation—phenology, abundance, seed bank and soil hardness**

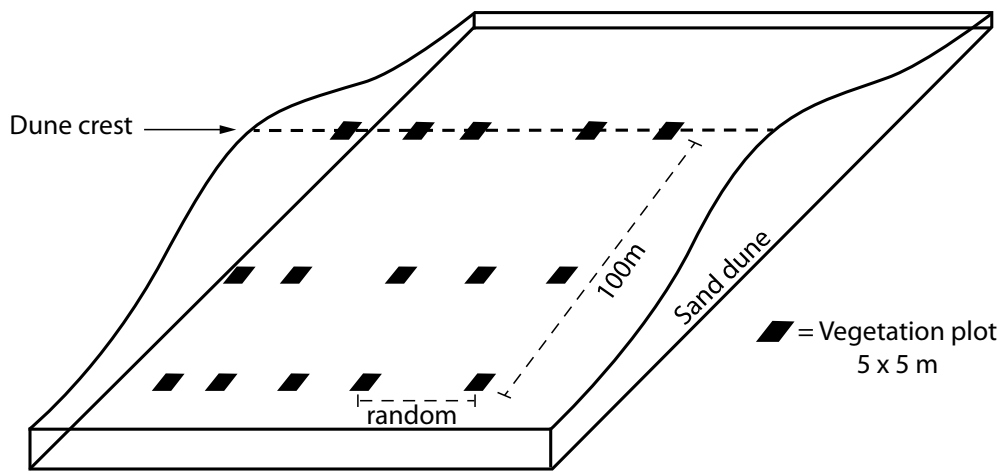
An additional project, not funded under LTERN, collects more comprehensive data on plant diversity. It has sampled vegetation, the seed bank and soil hardness in the Simpson Desert since 2004.

Adjacent to 16 trapping grids are vegetation grids consisting of 15 plots (5 m × 5 m; total 240 plots) over 1 ha. These grids are spaced out over six sites (Field River South, Main Camp, Carlo, Carlo-Shitty, Shitty Site and South Site) (Figure 9.2).

Five plots are randomly placed along a 100-m transect on the dune crest, side and swale of the dunes (Figure 9.6). Within each plot, all plants and seedlings, both dead and alive, are identified and counted. For spinifex, cover (m<sup>2</sup>) is recorded instead (Appendix F-4). In addition, flowering and fruiting is scored using the index described in 'Vegetation cover on trapping grids'.

For some species, when resources permit, plants are marked and counted to estimate survival rates (Appendix F-5).

Vegetation, seed bank and soil hardness surveys were conducted 3–4 times per year from 2004 to 2006, and then 1–2 times per year from 2007 (Figure 9.7). Data are entered electronically into an Excel spreadsheet using a customised template that allows for data validation. Data are rechecked for errors in transcribing and for consistency in species names and outlier values. Once verified, data sheets are imported into a database (MS Access) that can be queried and for long-term archiving (Appendix F-6).



**Figure 9.6** Placement of vegetation plots on the dune (15 plots per grid)

Individual plots are randomly allocated along a 100-m transect in each dune zone.





Photo: A Greenville

**Figure 9.7** Glenda Wardle and Max Tischler survey the vegetation on a plot that is recovering from a wildfire

### *Seed bank and soil hardness*

As part of the vegetation surveys, individuals and species, present only below ground as seeds, are sampled. To sample the seed bank, a soil sample (20 cm × 20 cm; 2 cm deep) is taken outside but adjacent to each plot using a rigid, metal, purpose-designed tool (Figure 9.8a). Effort is made to never resample the same area of sand. Because the samples are destructive (meaning that material is removed), the samples are taken from different locations. Using plot corners, or sides, as standardised guides to a predetermined starting location, the sampling tool is haphazardly tossed to minimise bias. Once located, the area is checked to ensure the soil surface is undisturbed from trampling; if not, the tool is rethrown. Each sample is sieved using a prospector's type A 200 mm (diameter) × 530 micron-aperture sieve to leave approximately 5 mL of sand, which is placed in a resealable plastic bag with the seeds to protect them during transport and storage (Figure 9.8b, c). Samples are brought back to the laboratory at the University of Sydney where a count of each species is made (Figure 9.8d–f). Species are identified using an inhouse reference collection of seeds and digital images, with examples of species *Pterocaulon sphacelatum* (Labill.) F. Muell, *Crotalaria cunninghamii* R.Br. and *Triodia basedowii* E. Pritz (Figure 9.9). The seeds are scored as viable, nonviable or with evidence of predation (Appendix F-7). Since spinifex can produce husks without seed, the numbers of spinifex husks that do not contain seeds are counted separately. Data are entered electronically into a spreadsheet using a template that allows for data validation. Data are rechecked for errors in transcribing and for consistency in species names and outlier values. Once verified, data sheets are imported into a database (MS Access) that can be queried and for long-term archiving.



Photos: G Wardle (A–C, F) and D Nelson (D, E)

### Figure 9.8 Seed bank sampling

Seed bank sampling, showing (a) the rigid metal quadrat used to prescribe the area and depth of soil that is sampled, (b) the circular sieve that is used to remove most of the sand from the sample before (c) residual sand and seeds are placed in individually labelled resealable plastic bags. In the laboratory, seeds are sorted further using (d) a sieve and (e) trays, and (f) are identified based on a reference collection.



Photos: D Nelson

**Figure 9.9** Seeds from more than 100 species that may be removed, identified and counted from the soil seed bank during regular sampling; *Pterocaulon sphacelatum* (left), *Crotalaria cunninghamii* (middle) and *Triodia basedowii* (right)

To measure the soil hardness, four readings (one at each plot corner) are taken with a modified penetrometer that has a foot with a diameter of 25 mm (Humboldt MFG Co.). Each measure represents an index of 0–5, with 5 equalling the highest (i.e. hardest soil). Data are entered into Excel and then rechecked for errors in transcribing and for consistency in species names and outlier values. Once verified, data sheets are imported into a database (MS Access) that can be queried and for long-term archiving.

### Invertebrates on trapping grids

Surface-active invertebrates have been collected at one site (Main Camp on Ethabuka Reserve) several times each year since 1990. The numbers of samples collected for the first 4–5 years varied according to the requirements of different, often individual, student projects. An additional 11 sites have been sampled more systematically, with collections from 1995 to 2006. These sites, established as part of a project to sample biotic diversity at sites near temporary water (ephemeral river courses, swamps and rainfall run-on areas or ‘oases’) and in the open desert landscape are no longer used for invertebrate sampling, but continue to be visited to sample vegetation and small vertebrates (Figure 9.2). Invertebrates are sampled at the same grids used for vertebrate and vegetation sampling.

To sample invertebrates, pitfall traps (plastic vials 40-mm diameter, 90 mm deep from Sarstedt Australia Pty Ltd; part number 75.9922.421) are buried vertically into the ground with the top edge flush with the ground surface. A total of 12 traps are placed at each grid, using the same two mammal traps—one on the crest (usually trap 1) and one in the swale (usually trap 36—to site them during each survey (see Figure 9.4). These two traps are also the sites of two of the vegetation surveys (see above). Six invertebrate traps are placed equidistant in a circle, roughly 2.5 m from each of the two vertebrate traps. All invertebrate traps are placed away from the drift fence located across the vertebrate pitfall to avoid areas of disturbed soil and interfering with vertebrate sampling.

The pitfall trap vials are three-quarter filled with a 3% formalin solution for temporary preservation of specimens, and left open for three consecutive nights and days during each trapping session. Traps are removed from the ground at

the close of each survey and are transported to the University of Sydney. From 1990 to 2008 (or 1995 to 2006 in the oasis project noted above), invertebrate trapping effort (number of grids, sites, trap-nights and surveys per year) generally mirrored that for vertebrates. From 2009 onward, at Main Camp, invertebrate sampling still always accompanies vertebrate sampling, but takes place on a smaller number of grids (at least one, usually five) per survey.

Upon return to the laboratory, invertebrates collected during surveys are transferred to a 70% ethanol solution for long-term storage. Specimens are sorted to order and morphospecies, where possible. Once sorted, data are entered into a central database as per vertebrate and vegetation data in Excel spreadsheets (Appendix F-8).

### **Weather data**

Weather data have been collected in the Simpson Desert since 1995. Automatic weather stations are situated at 13 sites and record temperature and rainfall. In 2010, the weather station at Main Camp North was set up to also record wind speed and direction.

The Environdata™ (Warwick, Queensland) automatic weather stations (Figure 9.10) installed across the study sites are separated by distances of between 5 km and 80 km. The air temperature, rainfall and, at one station only, wind speed and wind direction, are recorded in a data logger (Figure 9.11), which is housed within the instrument stand. Each weather station is protected against stock and other animals within a 6 m × 4 m area enclosed by 'three strand' fencing. As an added protection measure (against rats and dingoes), all exposed cables are enclosed in electrical conduit. Vegetation is cleared from within the fence and to 1 m outside the fence to reduce the risk of fire damage (Figure 9.12a). Regular maintenance is required and substitute units are used while repairs are made. Supporting these instruments in remote locations takes considerable time from a research assistant (Figure 9.12b).

### **Temperature**

The weather stations record minimum, maximum and average temperature each day. Air temperature is recorded using an air temperature sensor that is housed in a sensor shelter located under the data logger housing.

### **Rainfall**

The weather stations record and measure rainfall via a tipping bucket every minute. Data are pooled for each day. The automatic rain gauge is set up approximately 3 m from the instrument stand and housing (Figure 9.12a).

In addition to the automatic rain gauge, a manual rain gauge has been set up at each site (Figure 9.13a). The manual rain gauge collects rainfall in a 100-mm polyvinyl chloride pipe (which has the same 'mouth' dimensions as commercially available rain gauges) that has a stopcock attached to the base cap (Figure 9.13b). A 25-mm layer of vegetable oil is placed in the gauge to prevent evaporation of collected rainfall. The water is removed and measured using a commercially purchased rain gauge cylinder. Although daily rainfall intensity cannot be measured, the manual rain gauge provides a backup if (and when) any of the automatic components fail.



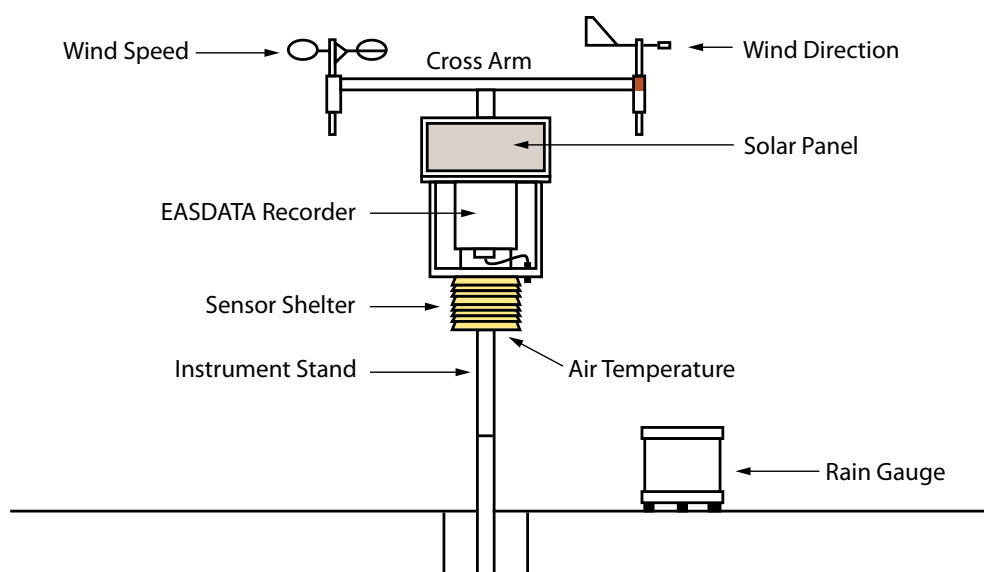


### Wind speed and direction

The weather station at Main Camp North has recorded wind speed and wind direction since 2010.

### Data retrieval

Power is provided by a solar panel, which is angled towards the north. The information stored in the data logger is retrieved using a laptop computer (or personal digital assistant / tablet) at roughly three-month intervals. Information recorded in the data logger is partitioned into different memory areas. Memory 1 contains a daily summary of the weather, including maximum and minimum temperatures, any rainfall, and wind direction and speed (at the site with the wind speed and wind direction sensors).



Reproduced with permission from Envirodata™

Other stations are similar, but omit the instruments on the top horizontal bar.

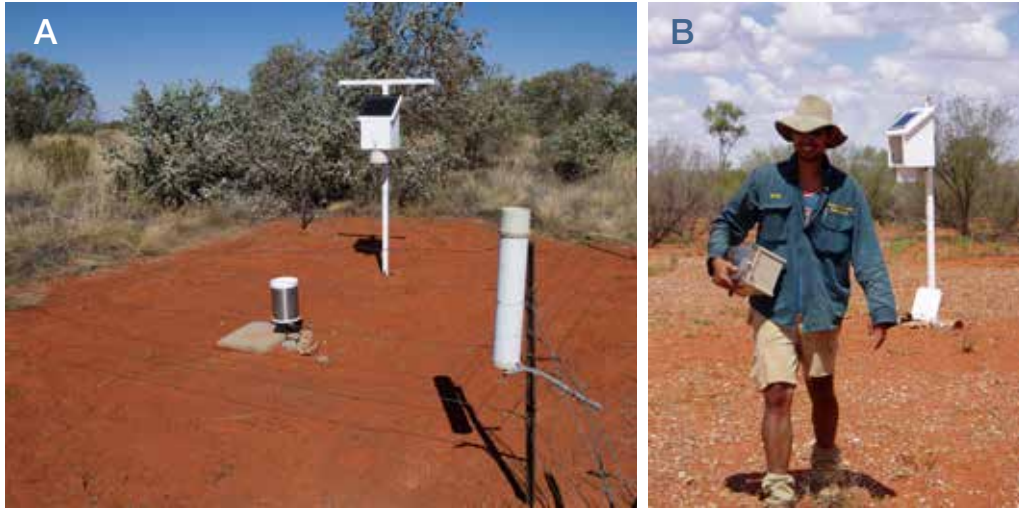
**Figure 9.10** Weather station set-up for complete data recording, including wind speed and direction



Photo: B Tamayo

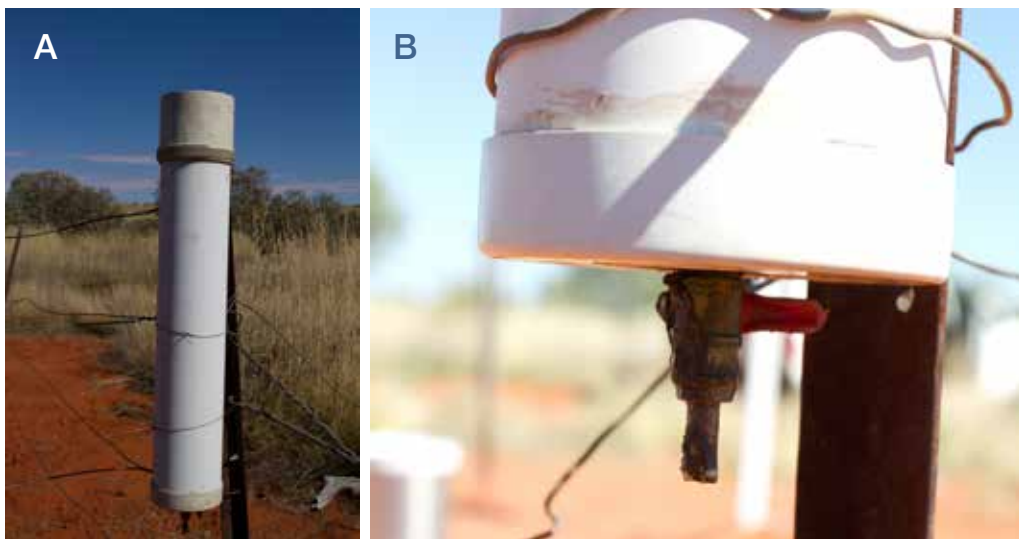
Extra connections for extra sensors are available, if required.

**Figure 9.11** Data logger within housing



Photos: B Tamayo (a) and G Wardle (b)

**Figure 9.12** (a) Weather station set-up, with vegetation cleared 1 m from the fence and within the fenced area, and (b) Bobby Tamayo with a data logger removed for repair



Photos: B Tamayo

**Figure 9.13** Manual rain gauge (a) and (b) the stopcock at the base

The manual rain gauge is 600 mm long to ensure that all rainfall is captured, even during periods of high rainfall and for long periods when the rain gauge is not cleared. The stopcock facilitates removal of water.

## Occasional data collection protocols

Since 1990, many of the 1-ha sampling plots in the Desert Ecology Plot Network have been used for short-term projects involving Honours, Masters or PhD students (Table 9.2). In almost all cases, the 24 plots used for long-term monitoring have acted as control plots, with additional observations or experimental manipulations taking place on the many other (non-LTERN) plots that have been established in the Simpson Desert study region.

**Table 9.2** Student projects

Honours projects	Masters/PhD projects
Ant ecology	Bilby ecology
Bat ecology	Bird ecology
Gecko physiology	Dragon population dynamics
Lizard and termite ecology	Fire ecology
Marsupial diets	Goanna ecology
Marsupial foraging ecology	Herbivore grazing
Pollination ecology	Marsupial ecology
Predator–prey ecology	Plant ecology
Rodent behaviour	Pollination ecology
Rodent diets	Predator diets
Rodent habitat use	Predator–prey interactions
Rodent movements	Reptile ecology
Seed ecology	Rodent ecology
Skink physiology	Rodent foraging behaviour
	Rodent population dynamics
	Rodent–seed interactions
	Seed bank dynamics
	Seed dispersal
	Spider ecology
	Vertebrate–environment interactions

Several of these projects have used radio-tracking to address their objectives; radio-tracking has also been used on many additional occasions on an ad hoc basis to take advantage of opportunities as they arise, such as when unusual or seldom-encountered species (e.g. *Planigale* spp.) are captured. A generic data sheet developed for recording radio-tracking data is presented in Appendix F-9. Bird sightings have not been recorded systematically over the monitoring period, but species of particular interest (e.g. grey falcon, painted snipe) are recorded if and when they are seen (Appendix F-10).

Several sampling procedures take place on a regular basis in association with the LTERN monitoring at the plots, and provide essential support for the work that has been described earlier. The first of these is spotlighting. Begun in 1990 at Main Camp, spotlighting takes place for 1–2 nights at all plots on every field trip, and involves a 10–15-km traverse of the main access tracks that run through the plots. Traverses are made in a vehicle moving at 10–15 km/h with two observers sitting on the roof of the vehicle, each scanning one side and in front of the vehicle using high-power spotlights. Spotlighting is done primarily to obtain an index of mammalian predator (feral cat, fox, dingo) activity, but owls, nightjars and other species of interest are noted (Appendix F-11).

To further survey the predators, their small vertebrate prey and other species such as kangaroos and camels, each of the 12 sites is equipped with a pair of remote cameras. From April 2010 until April 2012, 24 Moultrie™ i40 cameras and one Reconyx™ RapidFire were used, but all Moultrie™ units have since been replaced by Reconyx™ PC800 Hyperfire cameras. The cameras are set 1–10 km apart next to access tracks in spinifex in the interdune swales, since animals—especially the predators—frequently use these tracks. Cameras are mounted atop 1.5-m metal stakes, and angled at ~10° so the field of view covers the track. Cameras are downloaded at least twice per year. Each photograph is tagged with the site name, camera identification number, download trip, moon phase, species and number of individuals recorded, and the tags are written to the exif data of each file (jpeg) using EXIFPro 2.0. EXIFPro 2.0 is used to database the photographs and export the exif data as a text file for analysis. To ensure independence, a delay of one minute is programmed on-camera between each trigger, and multiple photographs of the same presumptive individual (photographs taken <2 minutes apart) are removed before analysis. This results in a total of at least three minutes between photographs, which then can be used in analyses (see Greenville et al. 2014).

Other activities are undertaken as required, and include collecting specimens of plants, their flowers and seeds that may be under-represented in the whole plant and seed herbaria; mapping of fire scars on ground to understand fine-scale patterns of fire behaviour and help validate remotely sensed imagery; habitat mapping; and various kinds of animal tracking, including the use of spool-and-line devices, fluorescent pigments and cyalumes (tiny night-lights), which are attached to animals and allow recording of their movements after release. The scats and pellets of predators are collected each trip and analysed to determine patterns in the predators' diets.

To ensure that all activities are recorded at the conclusion of a visit to each of the sites, we have developed a trip report (see below). This ensures that a record is kept of all activities that were carried out at all sites on a field trip, and helps to maintain the integrity and completeness of data.



## Wildfire mapping

After wildfires, satellite imagery (e.g. Landsat) is used to map the perimeter of wildfire boundaries (e.g. Greenville et al. 2009). Wildfire maps are verified by ground-truthing and recording GPS locations of wildfire boundaries.

## Administration, risk and safety protocols

As well as state scientific licences and animal ethics approvals that are required to undertake research of the kind performed by the Desert Ecology Research Group, a very large amount of additional paperwork, training and induction is needed to allow the program to continue safely and to achieve its objectives. Some of this is described in brief below.

After every field trip, a 'trip report' is written to document the activities, key results, events and personnel that took part. This provides a permanent record of field trips and maintains key information in a central location (the university server) that can be accessed by all personnel in the group. Parts of the trip report also are sent to key stakeholders to keep them informed of activities and results. At present, the main stakeholder is Bush Heritage Australia, owner of Ethabuka and Cravens Peak reserves. The manager of Carlo Station also received the report until a recent decision by the property owner to change to a remote management strategy that requires no on-site personnel. As soon as possible after every field trip, all collected data are entered, checked and cleaned. Paper copies are then made of the data sheets, and the originals and copies kept securely but in different locations.

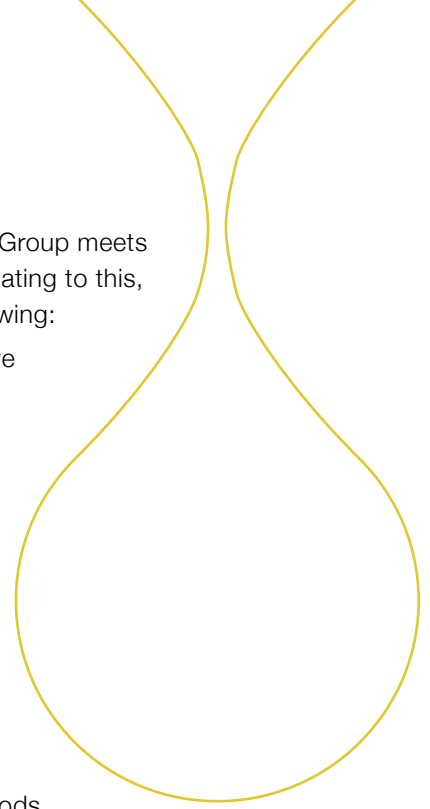


Photo: *Moloch horridus* (thorny dragon/devil),  
A Greenville

Between trips to the Simpson Desert, the Desert Ecology Research Group meets to discuss the progress of the research and monitoring, all issues relating to this, and planning for future visits to the field sites. This includes the following:

- Ensuring that all personnel and students involved in the work have requisite training to drive the modified Toyota Hilux vehicles that are used on each trip (i.e. advanced 4WD training), first aid competency (St John's remote first aid training), and any specialist equipment that will be needed for forthcoming field visits.
- Ensuring that volunteer personnel will be available to assist on future field trips. A database is maintained that contains the details of many hundreds of people who have volunteered to assist in the office (e.g. with data entry), the laboratory (e.g. with the sorting, counting and identification of collected field materials such as seeds, invertebrates and scat samples) and, most particularly, in the field. Because field trips involve periods of three weeks in a remote area under often extreme climatic conditions, volunteers are given full information about what each field trip will entail and as much advance notice as possible so that they can leave their 'civilian' lives behind for the period required. Before being signed on as field volunteers—and to fulfil all university requirements for personal liability insurance—volunteers need to provide details of their prior experience in remote areas, relevant medical history, next of kin, and be prepared to be inducted and follow instructions by the designated trip leader(s) from the group before the field trip begins.
- Ensuring that field vehicles are serviced after every return visit to the Simpson Desert. Trip leaders need to check and confirm that vehicles are in good condition and have all necessary equipment (e.g. recovery gear, UHF radio) at least three days before a field trip is scheduled (Appendix F-12).
- Ensuring that food for the field trip is purchased in advance—there are no corner stores in the Simpson Desert.
- Reviewing safety protocols. Each field vehicle is equipped with a satellite phone (plus an in-car charger and inverter), spot-check device, emergency position beacon, GPS, maps and lists of emergency phone numbers and protocols in the event of an emergency or a vehicle breakdown. These components are maintained in a secure case. Daily call-in procedures are employed using spot-checker devices, and messages received by designated personnel in Sydney (Appendix F-13). Instructions on the use of the devices are provided by team leaders.
- Ensuring that any necessary materials or equipment for the next field trip are ordered and available. At the conclusion of each field trip, an inventory is made of food, materials and equipment that will be left on site and of what will be needed for the next field visit. This is acted upon between field trips to ensure that all necessary materials are available when field trips are under way.

In addition to adhering to these procedures, the Desert Ecology Research Group needs to meet regularly scheduled audits of its safety and risk procedures that are imposed by the University of Sydney.



## If I had my time again

We take this opportunity to reflect back and offer some thoughts on how we would have proceeded with the benefit of hindsight. As with many long-term ecological studies, the Desert Ecology Plot Network started with relatively modest goals and resourcing. There was no injection of funding to design and implement a monitoring program that could stand the test of time and continue to deliver valuable ecological insights into the future. Rather, this network grew from the research interests of just two academics: Chris Dickman, who founded the desert research to understand the biology of dasyurids and other small mammals; and Glenda Wardle, who expanded the scope of the work to include a focus on plants and how their interactions help drive the dynamics of the system. From there it has expanded considerably and continues to do so.

In pulling these ideas together, we note that each project will necessarily differ in priorities and resourcing, and so there can be no single prescription for success. However, looking back, some aspects of how we deliberately chose to do things have been crucial in the plot network's long-term sustainability; others have emerged serendipitously. We also draw from some of the material and lessons we contributed to the LTERN booklet, *Making ecological monitoring successful: insights and lessons from the Long Term Ecological Research Network* (Burns et al. 2014), because that contains the collective wisdom for sustaining monitoring over the long haul.

First, start with compelling ideas about what you want to discover about the natural world and give careful consideration to why the study system or site(s) are suited to that purpose. Without this solid conceptual framework, it will be difficult to sustain

the necessary motivation to keep the project fresh enough in each new funding application and to ensure that it is highly competitive. Be pragmatic about what can be achieved at the outset, and grow from there. We are pleased that the plot network was started in the remote area of the Simpson Desert on what were originally pastoral properties because the spinifex hummock grasslands are an understudied biome with rich diversity, and this system is subject to strong environmental drivers of unpredictable rainfall and wildfire. The conversion of two of the four properties to reserves provided an unexpected opportunity to compare

large-scale changes in management (e.g. cattle removal, closing of bores). We have also engaged closely with the reserve managers to inform fire management and control of feral predators and camels. It has been quite deliberate to begin with fundamental ecology and to also pursue applying that knowledge to property-scale management.

Second, good experimental design is essential to weathering the changes to the scope of the project over the decades and to the environmental factors that may disrupt the planned comparisons. For example, wildfires, storms, change of ownership and management of the properties you work on can all alter the intended



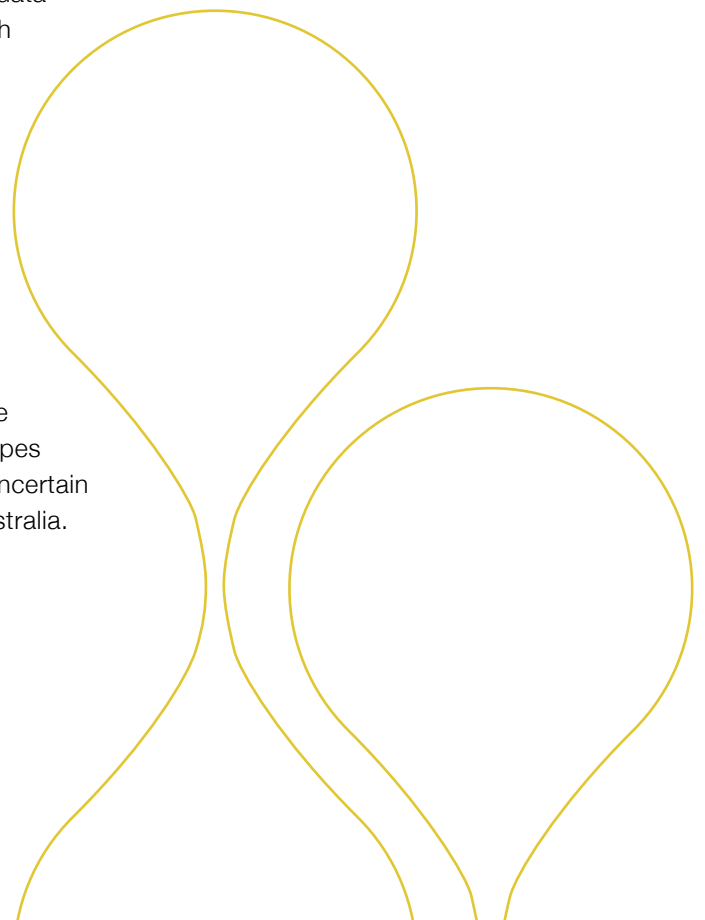
condition of study plots. A key aspect of good design is to be aware of all spatial scales that may be operating to drive changes in the system, by having modular units for monitoring arranged across a hierarchy of spatial scales. Plots of 1 ha have served us well for both fauna and flora work, and can be subsampled or analysed in nested designs across 1 m to 10s of kilometres, as needed.

Third, besides good sampling methods, we have found that simple equipment has worked well. Perhaps as our sites are remote from built infrastructure and we could not therefore rely on sophisticated gear or anything that required power (including refrigeration), it has freed up precious field time to concentrate on the primary task of making observations and accumulating data. Before starting, it is important to check the assumptions of your methods and to confirm that they are fit for purpose at your site. If not, tailor the sampling for your system (e.g. using 60-cm-deep pitfalls, not buckets, to ensure all mammals are caught and not subject to undue heat stress in traps). We trialled several types of stakes for plot markers but settled quickly on metal star pickets and fence droppers because they are most resilient to the harsh conditions in our desert study site. We store samples in plastic bags, use a reliable brand of permanent marker and transport equipment in plastic bins, when we can afford them. We have also benefitted from having staff who are ingenious in their reuse and repurposing of simple materials for cages, constructing exclusion areas and designing manual rain gauges, and we house our field research equipment in a caravan. Our deliberate prioritisation of data collection in the field would be top of the list if we were starting over.

Fourth, we would definitely keep our culture of training and supporting our field personnel to enjoy what they are doing, to develop professionally, and to involve well-selected volunteers to expand the capacity of the field and lab work to deliver outcomes and remain productive as a research team.

Fifth, the key area where we would have benefitted, from hindsight, would have been to have a data management plan from the outset. We struggled in the early years, due to low resourcing, to adjust to the ever-changing technologies and to keep up with the curation of samples and data management. We have now progressed to a much smoother pipeline where field data are entered into a comprehensive database that can be interrogated with standard queries, metadata are provided to ensure that checks and version controls are appropriate, and data have begun to be published on an open access data portal, to help to ensure that they are available and valued in perpetuity.

Finally, if we were establishing this plot network today, we would probably still throw caution to the wind and start over with great enthusiasm and hopes for the long-term future of the work, even in the uncertain funding environment for long-term research in Australia.





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## Recommended further reading

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Photo: Ethabuka sunset, A Greenville



# 10 Upland Heath Swamps Plot Network

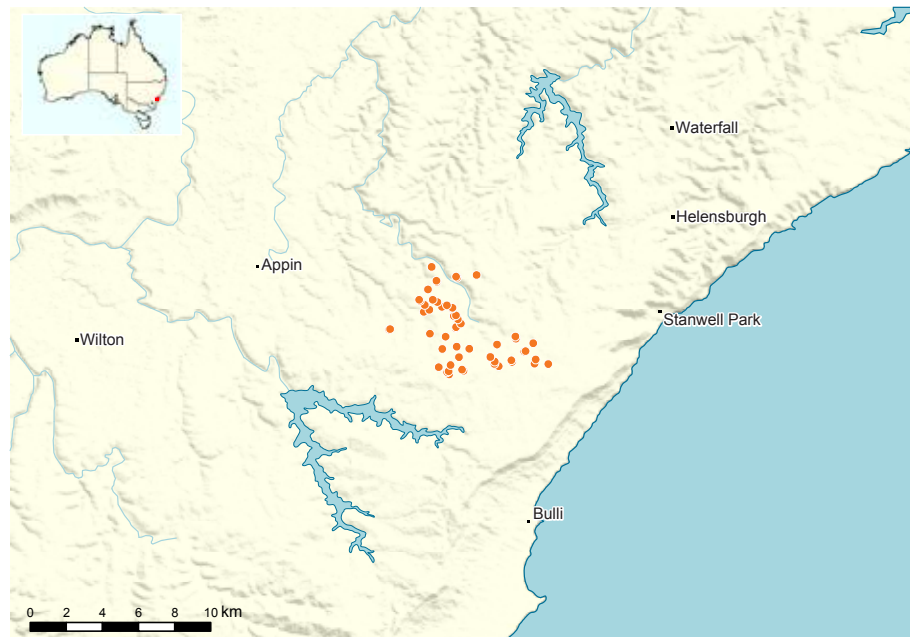


**Plot Leader:**

David Keith

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School of Biological, Earth and Environmental Sciences  
University of New South Wales, Sydney 2052

Email: david.keith@unsw.edu.au



## Location of Upland Heath Swamps Plot Network

Photo (opposite page): Upland swamp, D Keith

## Objective

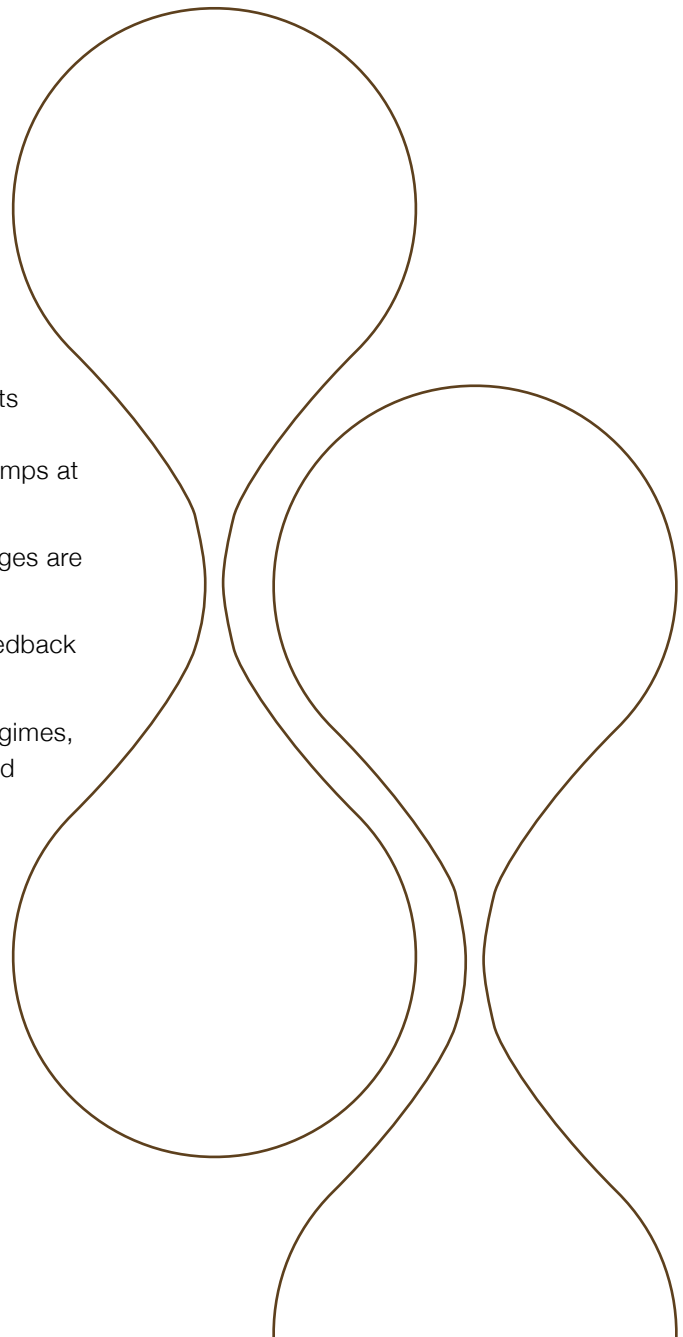
To improve understanding of the roles of climate, substrate and fire regimes in the dynamics and persistence of upland swamps and their biodiversity.

## Research goals

- An improved understanding of factors that control change in upland swamps, their biodiversity and hydrological functions at site and landscape scales.
- An improved capacity to predict the responses of upland swamps, their biodiversity and hydrological functions to future climate change, fire regimes and underground mining.
- An improved basis for developing management strategies aimed at conservation of upland swamps, their biodiversity and hydrological functions.
- A set of indicators and methods for assessing, managing and monitoring change in upland swamps.
- An extensive high-resolution, plot-based and spatial inventory of vegetation, fire history, soil properties and hydrology over decadal timescales.

## Research questions

- How do environmental moisture gradients structure the diversity of heath and sedge/land vegetation within upland swamps at local and regional scales?
- What structural and compositional changes are occurring in upland swamps?
- What is the nature of covariation and feedback between vegetation and soil properties?
- What are the effects of alternative fire regimes, and how can responses be characterised by trends in functional groups of species?
- What models of ecosystem dynamics best explain and predict changes in upland swamps and their biota in response to changing climate and fire regimes?





**Table 10.1 Upland Heath Swamps Plot Network summary table**

<b>Ecosystem</b>	Sydney coastal upland swamp
<b>General location</b>	Dharawal National Park
<b>Other custodian(s) and/or partners</b>	NSW National Parks and Wildlife Service
<b>Disturbance type</b>	Fire regimes
<b>Data type (fauna/flora/vegetation structure)</b>	Soil moisture, flora, vegetation structure
<b>No. of plots</b>	54
<b>Plot size</b>	0.00075 ha
<b>Start year</b>	1983
<b>Temporal revisit</b>	Every 5 years or after fires

## Specific data collection protocols

Sampling of vegetation is stratified along the soil moisture gradient and across the range of structural variability in the vegetation. Thus, three categories of soil moisture and three categories of vegetation structure (based on the height and form of shrubs) are sampled in a factorial design at 60 sites in upland swamps scattered throughout the study area (Keith & Myerscough 1993).

Each sample site is a belt transect of 60 contiguous 0.5 m × 0.5 m quadrats in which presence/absence of all vascular plant taxa are recorded (based on whether they were overhanging the quadrats) and tallied to give a frequency out of 60. The sites were originally sampled in 1983, marked in the field by two wooden stakes at either end of the transect and plotted on a 1:10 000 aerial photograph. By 2004, it was possible to relocate 54 of the 60 original transects and, of these, at least one of the original markers was found for 20 transects. During the intervening years, some of the wooden markers had been consumed by fires, but based on the annotated aerial photograph, field notes and detailed recollections of the original observer (David Keith), transects were confidently re-established within approximately 10 m of their original location. These formed the basis for establishing permanent swamp monitoring sites, which are now marked in the field at the positions of quadrats 1 and 30 with steel star pickets, extending approximately 1.5 m above the ground surface and located on the Map Grid of Australia (Geodectic Datum of Australia) using a GPS.

Exploration and subsampling of the 1983 data showed that the floristic relationships between the 60 sites could be adequately retrieved if species frequencies were calculated from a sample of 30 quadrats within each transect (correlation of association matrices based on 60 and 30 quadrats yielded Mantel's  $R > 0.95$ ). Therefore, only the first 30 quadrats of each transect were resampled in 2004 (Keith et al. 2007). Vegetation sampling was repeated in 2009–10 and 2014. The next census is scheduled for 2019 or within 12 months of the next bushfire, whichever occurs first.

At each sampling time, 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 (Keith & Myerscough 1993). Light intensity was measured with a light meter (LI-COR, Lincoln, NE, USA; model LI-250) 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. Light penetration through the vegetation canopy is calculated by taking the natural logarithm of the ratio of light intensity at ground level to that of direct sunlight above the vegetation canopy.

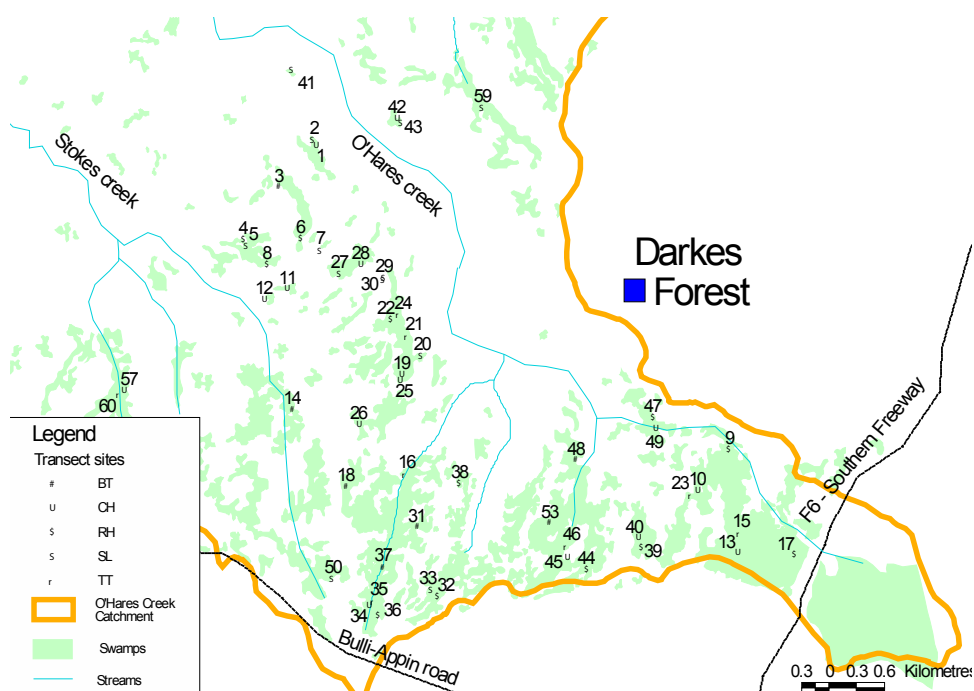
Duplicate samples of surface soils (0–7-cm depth) are collected from a stratified random subsample of transects from the nine combinations of the moisture-by-vegetation structure strata for analysis of exchangeable cations (potassium, sodium, magnesium, calcium, aluminium, manganese), pH, electrical conductivity, water content, loss on ignition, total phosphorus, total iron and nitrate. Cation exchange capacity was determined by the silver-thiourea method, pH was determined using 1:2 calcium chloride extract, electrical conductivity and nitrate are determined in 1:5 water solution, total phosphorus and iron are determined using hydrogen chloride digests, loss on ignition is gravimetrically determined at 55 °C, and water content is determined by moisture lost on drying the sample. Light penetration and soil data are gathered from the same transects that were selected in 1983 (Keith & Myerscough 1993).



Photo: Berin Mackenzie at work in the upland swamp, D Keith

The fire history from the mid-1960s to the present was compiled from records and maps held by the Sydney Catchment Authority and the National Parks and Wildlife Service, including wildfires and prescribed burns (Keith et al. 2006). Since 1982, fire occurrences have been verified by personal observations (David Keith). Spatial distributions of upland swamp vegetation was interpreted visually from aerial photography taken in 1960 and 1998, and the data were digitally captured and stored.

Hydrological climate variables are monitored at Bureau of Meteorology and Sydney Catchment Authority facilities at Darkes Forest (precipitation since 1890) and Cataract Dam (precipitation since 1920 and pan evaporation since 1969), respectively, adjacent to and within 5 km of the study area. Between 15 June and 6 July 2013, three automatic weather stations were installed across the regional precipitation gradient within the study area. These are located at GDA 34°15'03.94"S 50°54'50.36"E (Site A), 34°15'27.0"S 150°52'46.3"E (Site B) and 34°12'05.4"S 150°50'20.6"E (Site C). 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 40 cm below the surface at 30-minute intervals.



**Figure 10.1** Location of monitoring transects in five upland swamp plant communities, as defined by Keith and Myerscough (1993) that occur across five local soil moisture gradients

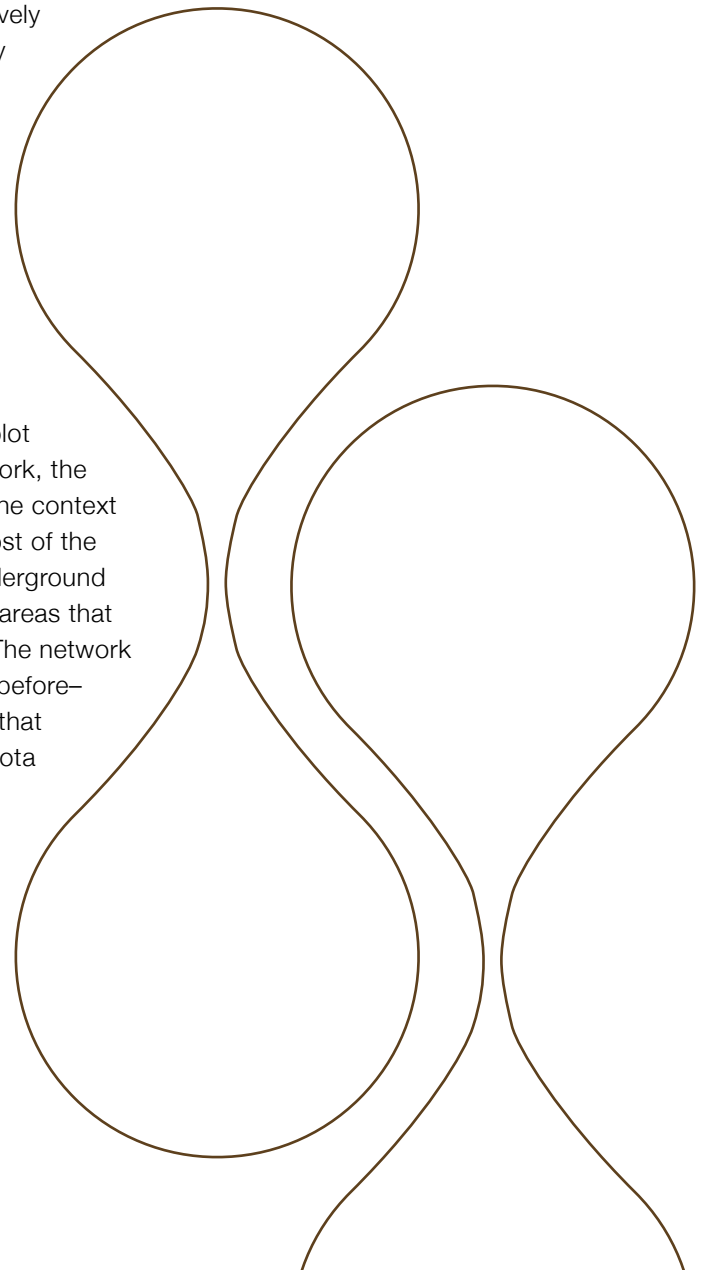
## If I had my time again

The Upland Heath Swamps Plot Network began simply out of curiosity. It actually started out of a third-year student project. I was so intrigued by the patterns in these fascinating systems that no one seemed to have worked on in any botanical depth, that I went back in my spare time to investigate further, establishing some plots. As a new graduate, my employer at the NSW Herbarium encouraged me to develop my interest. In time and with discussions with my former lecturers, it turned into a PhD project, which was when the main questions began to crystallise and a proper sampling design was settled. The first census was incredibly intensive and likely over the top for what was needed. The enthusiasm of youth proved hard to match in subsequent censuses when limited resources forced a rethink of the sampling intensity.

An important aspect of adaptive monitoring is to think carefully and laterally about how new questions and opportunities can be incorporated without interrupting the 'golden thread'. In this plot network, analyses of early trends and patterns in the data showed us that we could reduce the sampling effort by recording half as many subplots (30 cf. 60) in the same total number of plots to calculate a species frequency score for each transect and still retain 95% of the information on the compositional relationships between samples. This helped us sustain monitoring over time as available resources contracted, but we could not have been confident about the information lost if we had not sampled intensively during the first census and carried out exploratory subsampling analyses on the resulting data. Calibration of any new or adapted methods is essential.

At the time the study began, underground coal mining was just beginning to emerge and climate change was yet to emerge as an environmental issue for the persistence of upland swamps. The sampling design was fortuitously stratified along a regional rainfall gradient for other reasons, and this enabled the plot network to examine, within a mechanistic framework, the responses to climate change as they play out in the context of a time series of background data. Although most of the plot network is within reserves excluded from underground mining, it would have been good to replicate it in areas that were slated for future mining back in the 1980s. The network could still be expanded in this way to establish a before-after control-impact design to investigate effects that long-term changes in groundwater have on the biota of these unique ecosystems.

Bringing upland heath swamps into LTERN has helped us take advantage of new technologies in hydrological and soil monitoring to examine the relationship between vegetation and those factors at much greater resolution than was possible before. In hindsight, it would be great to have collected that kind of environmental





covariable data much earlier. Even if we had, the technology has changed so much that it would surely have generated some interesting calibration challenges.

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Keith DA & Tozer MG (2012). Vegetation dynamics in coastal heathlands of the Sydney Basin. *Proceedings of the Linnean Society of New South Wales* 134:B181–B197.







# 11 Woodland Restoration Plot Network

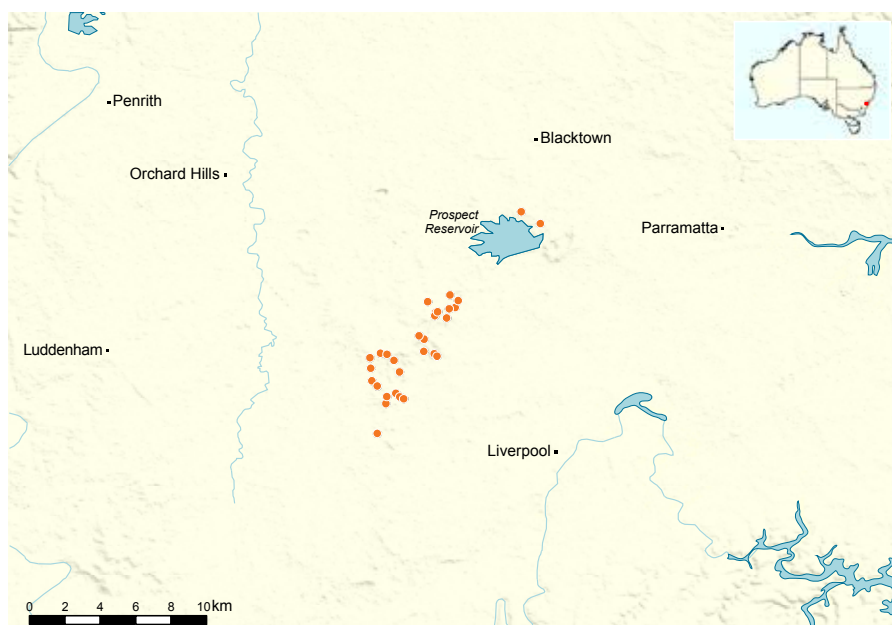


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## Location of Woodland Restoration Plot Network

Photo (opposite page): Woodland restoration, D Keith

## Objective

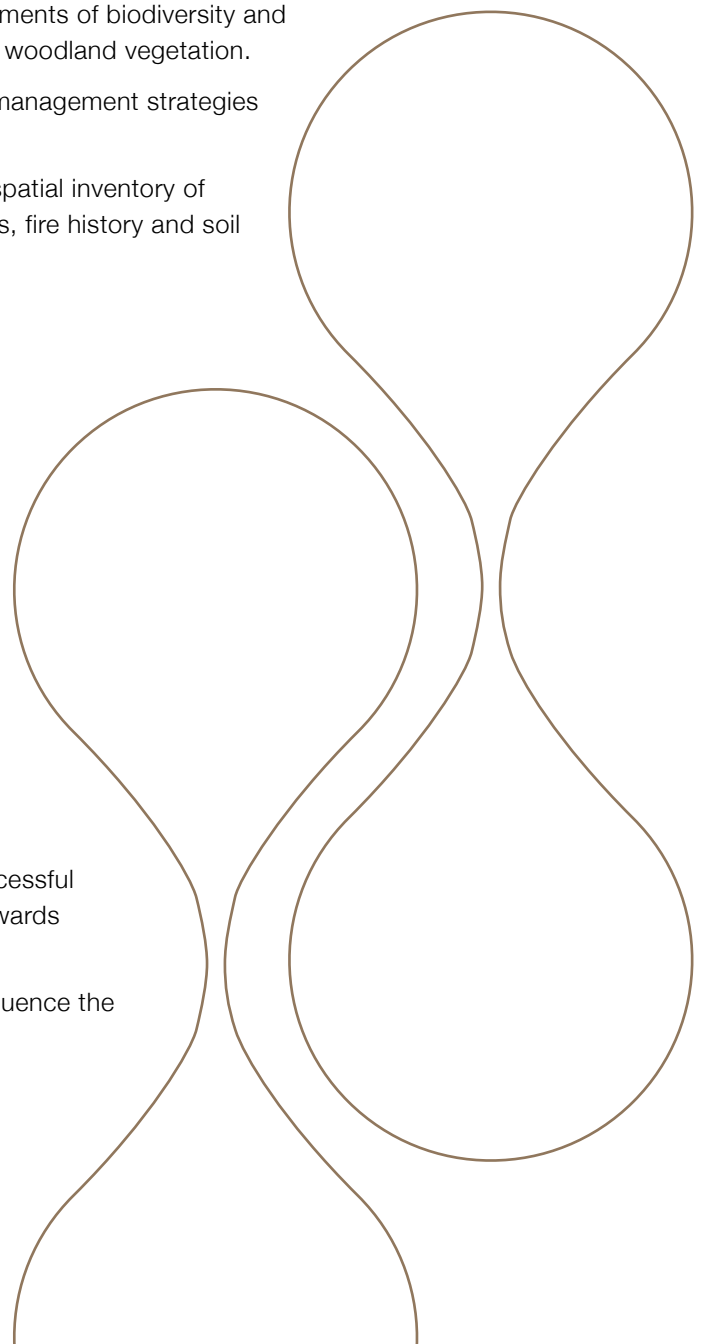
To develop robust methods for evaluating the success of native woodland restoration on retired agricultural land and apply them to a major restoration project of an endangered ecological community. The plot network aims to determine whether the composition and structure of restoration plantings undertaken between 1992 and 2002 are on a trajectory from abandoned exotic pasture towards comparatively undisturbed remnant vegetation. The data gathered will inform future restoration efforts.

## Research goals

- Improved methods and indicators for evaluating success of woodland restoration on retired agricultural land.
- An improved capacity to predict the suitability of retired agricultural land for woodland restoration projects.
- An improved understanding of problematic elements of biodiversity and ecological lags in the development of restored woodland vegetation.
- An improved basis for developing restoration management strategies with a high likelihood of success.
- An extensive high-resolution, plot-based and spatial inventory of vegetation, avian and invertebrate communities, fire history and soil properties over decadal timescales.

## Research questions

- What are appropriate methods and metrics for detecting change in the biodiversity values of restoration plantings?
- What is the pace and direction of temporal trajectories in woodland structural features, and composition of plant, invertebrate and avian communities within restoration plantings?
- What ecological traits differentiate native species that respond positively to restoration treatments and those that fail to respond?
- What site features enhance the chance of successful woodland restoration (i.e. rapid trajectories towards reference states)?
- How do alternative management strategies influence the pace and direction of restoration trajectories?





**Table 11.1 Woodland Restoration Plot Network summary table**

<b>Ecosystem</b>	Woodland
<b>General location</b>	Cumberland Plain, western Sydney
<b>Other custodian(s) and/or partners</b>	Western Sydney Parklands (Western Sydney Regional Park)
<b>Disturbance type</b>	Historic clearing, current grazing
<b>Data type (fauna/flora/vegetation structure)</b>	Vegetation structure, flora, fauna, soil
<b>No. of plots</b>	30
<b>Plot size</b>	0.1 ha
<b>Start year</b>	1992
<b>Temporal revisit</b>	Every 3–4 years since 2001

## Specific data collection protocols

The study site is located on retired farmland that includes a mosaic of restored vegetation (native plantings) of varying ages juxtaposed with patches of remnant vegetation and untreated, abandoned pasture. During their period of pastoral management (before 1990), the sites have been grazed by cattle, fertilised and planted with exotic pasture grasses, particularly *Phalaris* species. Through this management, native ground flora has been displaced to varying degrees across the study area. All sites were originally woodland before agricultural development about 200 years ago.

Restoration projects commenced in the area in 1992 with a stated goal of 're-establishment of native vegetation' (Perkins 1997). The restoration plantings were carried out in a pattern designed to connect remnant patches of woodland, which were also the primary sources of seed for tubestock. To evaluate success against the above goal, we therefore identified the remnants as suitable reference sites to which the restored sites were expected to increase their resemblance in composition and structure over time. Disturbance resulting from past agricultural practices in the area have affected remnant patches to varying degrees, but these were the best available examples of native woodland in the region. Untreated pasture is defined as a control from which restored sites are expected to become increasingly dissimilar in species composition and vegetation structure with time.

The restoration process was initiated with weed control and the exclusion of livestock (J Christie, Greening Australia, pers. comm.). All sites were slashed and sprayed with glyphosate before planting. Twenty-six indigenous tree and shrub species, propagated to tubestock from local seed sources, were planted mechanically in rows after the pasture began to break down. The mix of planted species varied across the landscape, the aim being to match species with soils and topographic positions occupied by their wild populations. All plants were weed matted with a recycled paper disc and surrounded by a protective plastic sleeve. Maintenance sprays of glyphosate were applied in spring and autumn for 2–3 years after planting, to reduce competition from weeds in the

vicinity of plants. To reduce the risk of fire, mechanical slashing was carried out among the plantings and hazard reduction fires were lit in areas surrounding plantings at approximately annual intervals. Since the late 1990s, cattle have been reintroduced into the southern areas of plantings, but fencing has been constructed to exclude livestock from some restoration areas and remnants (D Williams, Greening Australia, pers. comm.). Cattle continue to be excluded from the northern areas of plantings.

The study landscape therefore comprises a mosaic of patches, including untreated pastures, remnant woodlands with various histories of past disturbance and a chronosequence of restoration plantings dating from 1992 to 2002 (Figure 11.1).

The aims of the study design were to sample management treatments (untreated pasture, the chronosequence of restored vegetation and remnant woodland) across four primary locations within the Western Sydney Parklands (Hoxton Park, Plough and Harrow, Horsley Park and Prospect Reservoir). A fully randomised orthogonal sampling design was not possible because all management treatments were not represented at each of the four primary locations. Sample sites representing different management treatments were therefore situated haphazardly within patches (Figure 11.1), to sample areas with similar topography (upper and mid-slopes) and minimise environmental variation that may potentially confound management effects. The first set of vegetation surveys were completed in 2001 (25 sites), with repeat surveys of new haphazardly selected sites to sample the same patch types in 2004 (54 sites), 2005–06 (20 sites) and 2012 (30 sites). The total number of sites varied between surveys depending on available resources, but the proportional stratification among patch types and ages remained the same. Invertebrates were sampled in late 2002 and 2009. Soils were sampled in 2010 by collaborators at the University of Western Sydney. A survey of avifauna commenced in 2013.



Photo: Galahs, C MacGregor

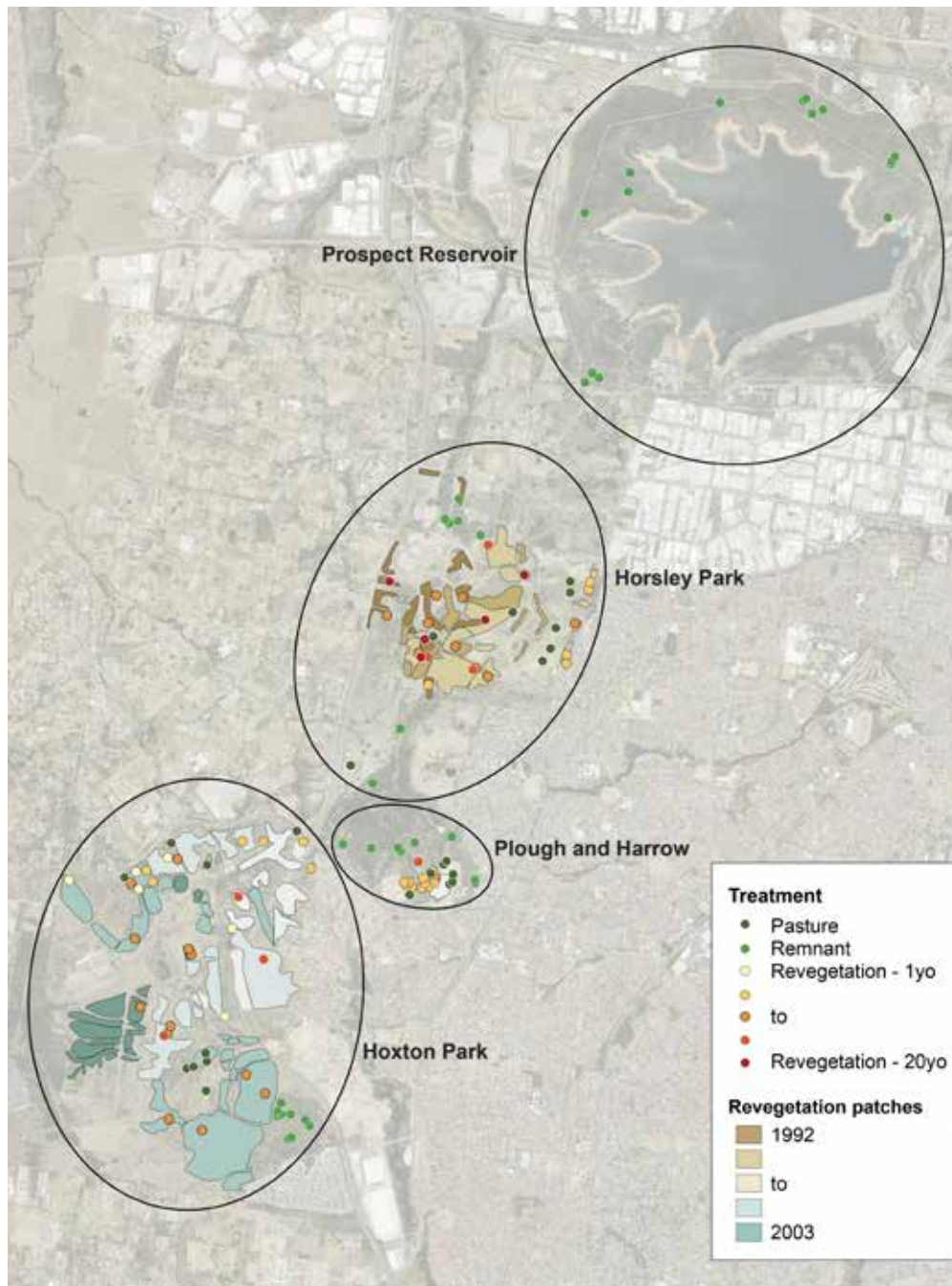
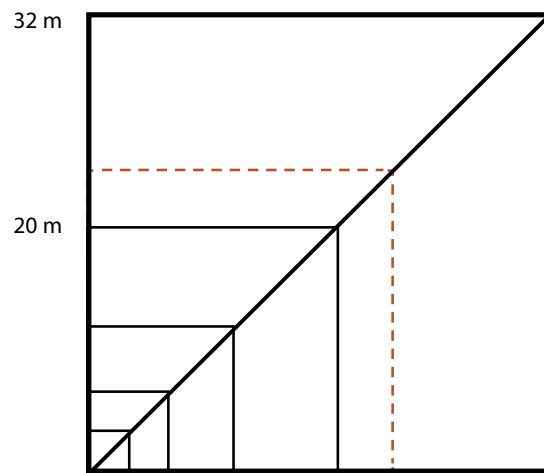


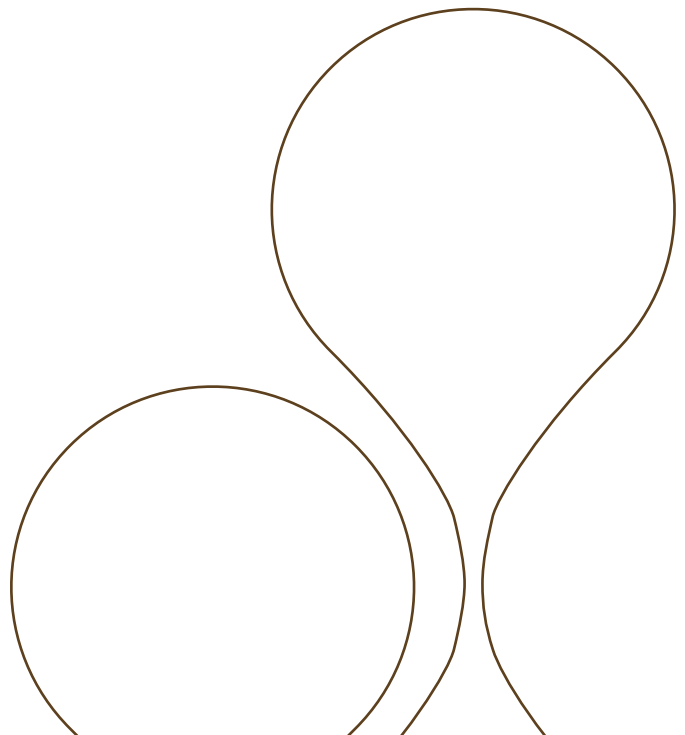
Figure 11.1 Study landscape for the Woodland Restoration plot network, with sample locations for 2012

## Floristics

Plant species composition is recorded using the frequency score method (Wilkins et al. 2003), in which complete species lists are compiled in each of six nested square subplots. Subplot dimensions are successively doubled from 1 m to 2 m, 4 m, 8 m, 16 m and 32 m. All six subplots have a common corner marked with a star picket (Figure 11.2). Only species rooted in the additional area of each subplot are recorded (i.e. excluding records from smaller nested subplots). A frequency score is computed for each species by counting the number of subquadrats in which it occurs. Planted and wild occurrences of the same species are recorded separately. In addition, a species list with Braun–Blanquet cover-abundance estimates (8-point scale; Table 11.2) is recorded in a 20 m × 20 m plot inserted within the nested sequence of subplots (see Tozer et al. [2010] for sampling methods).



**Figure 11.2** Layout of survey subplots: six to calculate species frequency scores and a 20 m × 20 m subplot for Braun–Blanquet cover-abundance estimates





**Table 11.2** Cover-abundance score using a modified Braun–Blanquet scale

Cover score	Percentage cover
1	Rare, few individuals (three or less) present cover <5%
2	Occasional and <5%
3	Common (consistent throughout site) and <5%
4	Very common (consistent throughout site) and <5%
5	Cover >5% and <25%
6	Cover >25% and <50%
7	Cover >50% and <75%
8	Cover >75%

Average height and cover of each vegetation stratum are visually estimated to assess vegetation structure in the four quadrants of each 20 m × 20 m plot. The abundance of each species is estimated. Patches of recruitment through suckering have a count for individual stems because of difficulties in determining an individual—for example, a single acacia plant may be counted as multiple stems. Where the species is a sprawling ground cover (e.g. *Dichondra*, *Desmodium*), an estimate of rooting nodes is taken. Percentage cover of bare ground and leaf litter, and environmental covariables, including aspect, slope, soil texture and grid location, are also recorded.

### Invertebrates

Ants are sampled with pitfall traps (Lomov et al. 2009). Each sampling plot is a 15 m × 15 m grid of five pitfall traps (one at each corner with one trap in the centre of the grid). Traps consist of 150-mL plastic containers (40-mm internal diameter) sunk in the ground flush with the surface and filled with 50 mL of 100% ethylene glycol. All traps are set up at least five days before opening them to minimise ‘digging-in’ effects (Greenslade 1973). The traps are operated for 14 days. Species are identified to their actual species group, or identified to genus and assigned a species number. The voucher specimens are deposited in the entomology collection of the Australian Museum.

### Avifauna

Bird species are sampled during a spring sampling period and a winter sampling period, using a point count method (Pyke & Recher 1984). Point count stations are located within the centre of the 20 m × 20 m floristic plots described above. After a one minute settling time, an observer surveys the area surrounding the station for 20 minutes. The species (and the sex and age if appropriate), method (visual or auditory), time (0–3, 3–5, 5–10, 10–15, 15–20 minutes), stratum (canopy, upper understorey, mid-understorey, lower understorey, ground), distance (<10, 10–20, 20–30, 30 m) and orientation (N, NE, E, SE, S, SW, W, NW) from observer, and activity type, is recorded for the birds detected. Flyovers, juveniles and flushes are recorded separately. Each of the stations

are surveyed a minimum of six times by two independent observers between sunrise and 10.00 am 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 and precipitation), presence of flowering or fruiting plants, and an estimate of ambient noise is also recorded. Surveys are not conducted on days of rain (more than a drizzle), high wind or fog.

### Environmental data

Soil sampling methods are described in Fitzgerald (2009). Access to the data requires the author's permission.

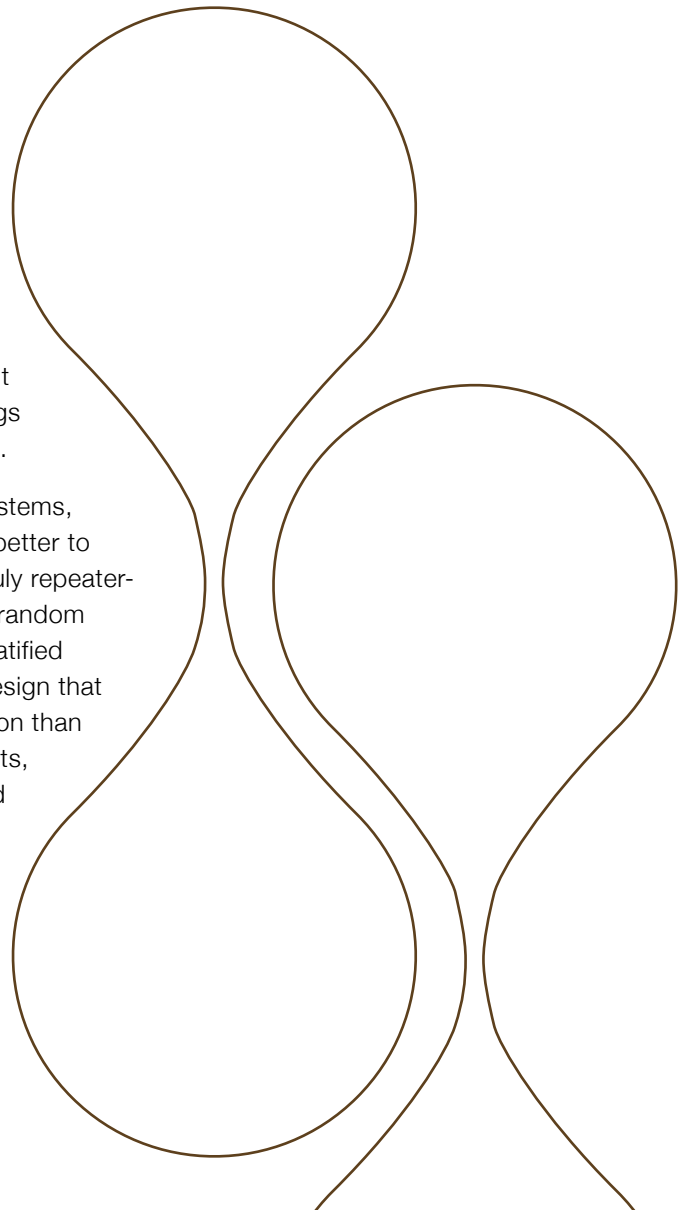
Precipitation and pan evaporation are monitored daily at Prospect Reservoir (Sydney Catchment Authority), and precipitation and temperature are monitored at nearby suburban Bureau of Meteorology stations.

### If I had my time again

The woodland restoration network began as a student project in early 2001. There had been so much interest and enthusiasm in the past decade around restoring native woodlands with tree planting on retired agricultural land that we wanted to know how these newly established ecosystems were developing into the kind of native systems that had been supplanted by land use changes more than a century earlier. The student project was planned as a one-off survey with a space-for-time substitution design across plantings of different age. A few years after that project, we were awarded a Linkage Grant to explore the mechanisms of response. As part of that project, a new student measured a new random sample of the plantings chronosequence, and a long-term study began.

Woodland understories are temporally noisy systems, so I often wonder whether it would have been better to establish permanent plots in the plantings (a truly repeater-measures design) as opposed to taking a new random sample at each census. On the other hand, stratified random resampling is a statistically powerful design that surely gives us a stronger basis for generalisation than a fixed set of plots. Given the counter-arguments, I am not sure I would change the design if I had my time again.

Although there is some evidence (and much more inference!) that much of the 'noise' in woodland ground layers is likely related to seasonal and inter-annual variations in



weather, it would be great to have explored changes at that temporal resolution with more frequent observations. This would provide a powerful framework for teasing out directional change from fluctuations, but would require a substantial boost in resources.

Land use legacies seem to be very important in the response of these kinds of systems. Sadly, spatially explicit records of fertiliser applications, temporal variations in stocking rates, locations of salt licks and so on were never recorded (and still aren't) across most of the Australian rural landscape.

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# 12 Mallee Plot Network



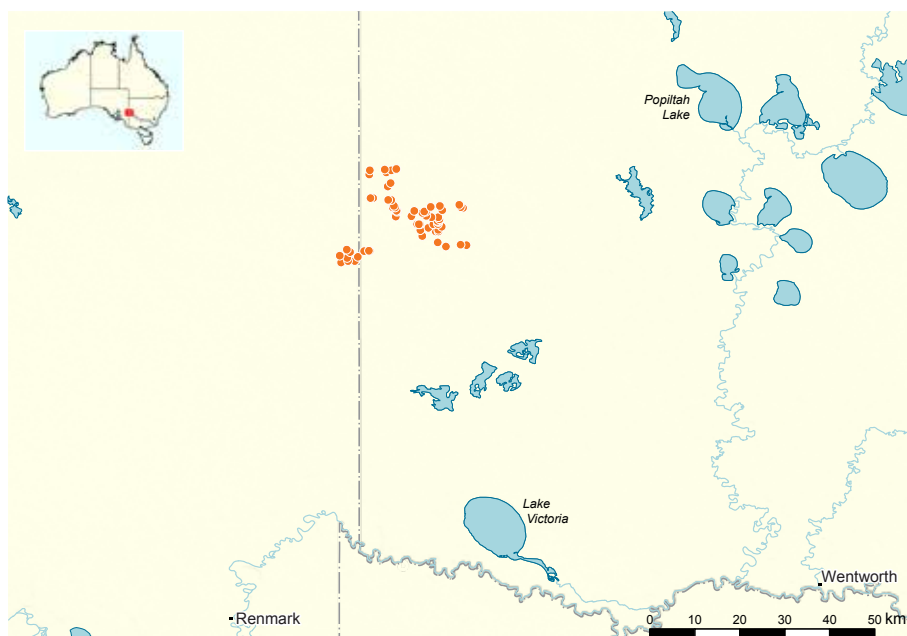
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UNSW



## Location of Mallee Plot Network

Photo (opposite page): Mallee plots, D Keith

## Objective

This plot network incorporates a landscape-scale experiment that 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 timescales. The data gathered are used within an adaptive management framework to inform options for achieving conservation objectives.

## Research goals

- Design of ecological investigations that permit systematic probing of casual agents under a range of conditions and over appropriate timescales.
- Establishment of ecological baselines that can be used for surveillance monitoring and detection of surprise responses to rare events or 'unknown unknowns'.
- Contributions to ecological theory, ensuring that long-term ecological research contributes cost-effectively to understanding causes and effects of ecosystem change.
- Flexibility in data collection to allow additional permutations of the core factors (fire, grazing and climate) to be examined as opportunities arise and as understanding of salient processes develop. For example, further sites were added in 2010 and 2011 to sample responses in rare high-rainfall years.
- Establishment of a rigorous comparative experimental design to assess the outcomes of management actions in an adaptive framework.
- Provision of data on multiple alternative management options related to the frequency, season, severity and size of fires, and the control or exclusion of different herbivore species across a number of years that span a range of environmental conditions.
- Contribution of data and time to maintain field research infrastructure and accessible data management systems to allow for multidisciplinary collaborations.
- Improved methods and indicators for evaluating management regimes of mallee vegetation.
- An extensive high-resolution, plot-based and spatial inventory of mallee vegetation, herbivory and fire history over a decadal timescale.



## Research questions

- How do fire regimes, herbivory and rainfall influence mallee vegetation dynamics? This will provide context to the research questions about mechanisms of change.
- Does plant diversity decline with long intervals between successive fires?
- How long does it take mallee trees and shrub species to accumulate seed banks after fire?
- How closely does species composition of soil seed banks resemble that of standing vegetation?
- How do survivorship and fecundity of different plant species vary with time since fire?
- How are differential responses to fire between plant species related to their life history traits?
- Do different herbivore species have contrasting effects on standing vegetation?
- How does herbivore activity vary with time since fire?
- How does fire size affect post-fire herbivory by vertebrates?
- Can varied vegetation responses to different fires be explained by inter-annual variation in rainfall?
- How does variability in fire events and climate affect seedling recruitment?
- How does soil moisture vary with temperature and antecedent rainfall?

**Table 12.1 Mallee Plot Network summary table**

<b>Ecosystem</b>	Sand dune spinifex mallee
<b>General location</b>	Tarawi Nature Reserve, Scotia Sanctuary, Danggali Conservation Park
<b>Other custodian(s) and/or partners</b>	Nature Reserve; Sanctuary, National Park
<b>Disturbance type</b>	Fire regimes, grazing regimes, climatic variation
<b>Data type (fauna/flora/vegetation structure)</b>	Vegetation structure, fire occurrence and severity, fauna
<b>No. of plots</b>	53
<b>Plot size</b>	0.2 ha
<b>Start year</b>	1996
<b>Temporal revisit</b>	Staggered; annual for 3 years, then decadal

## Specific data collection protocols

### Study area and landscape

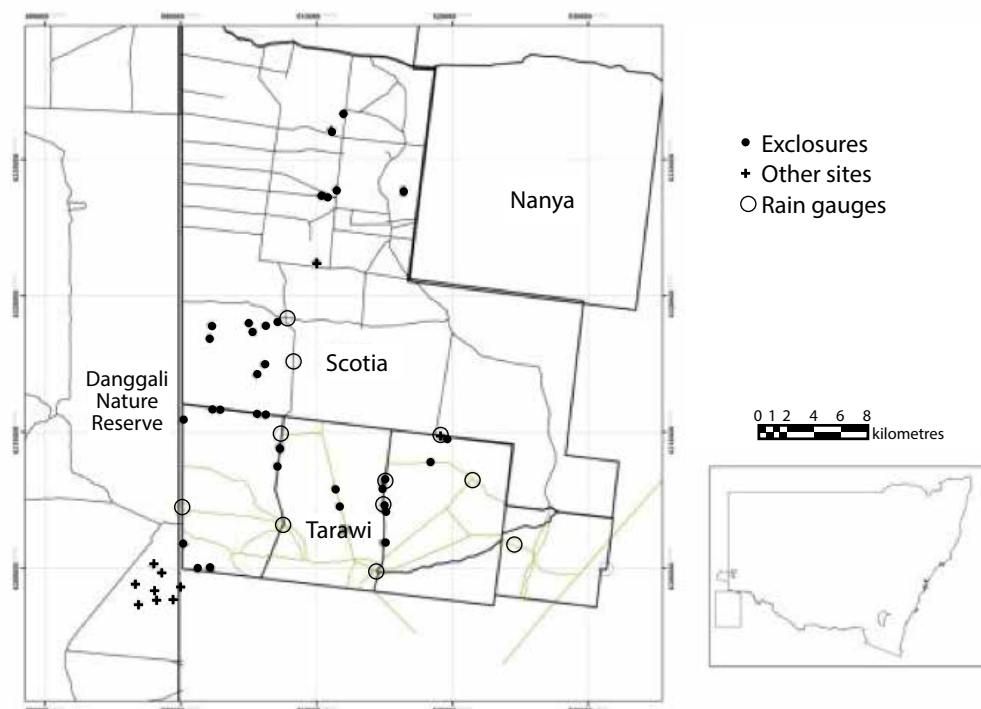
The study is located in the red aeolian sand dunefield landscape of the Scotia district within Tarawi Nature Reserve (33.44°S 141.16°E), Scotia Wildlife Sanctuary (33°17'S 141°05'E) and Dangali Conservation Park (33°22'S 140°45'E) in south-western New South Wales and adjacent areas of South Australia (Figure 12.1). The study area sits on the south-eastern edge of the Australian arid zone and is close to the arid limits of distribution of the mallee woodland biome, which stretches across the temperate semi-arid belt of southern Australia (Noble 1984). Mallee woodlands typically occur in regions receiving rainfall of 200–500 mm per year. From 1940 to 2010, mean annual rainfall at Tarawi Homestead was approximately 240 mm (data summary courtesy of John Warren, Tarawi Nature Reserve).

In the Scotia district and its surrounding region, mallee woodlands occur within a landscape mosaic that includes patches of woodland dominated by *Casuarina pauper* (belah) and shrublands dominated by *Maireana sedifolia* and *M. pyramidata* (bluebush) (Westbrooke et al. 1998). These latter vegetation types occur on gently undulating sandplains with a calcareous crust not far below the soil surface. In contrast, mallee woodlands dominate transverse east–west oriented dunefields. The dunes are characterised by deep, red sandy loams dominated by *Eucalyptus socialis* (pointed mallee), *E. dumosa* and *E. costata*—occasionally with *Callitris verrucosa*—with a mixed understorey of hummock grasses and shrubs, and a largely ephemeral ground layer of tussock grasses and forbs. The intervening swales have finer-textured red loams and generally support a wider range of eucalypts including *E. oleosa* and *E. gracilis*, but *C. verrucosa* is absent. Their understoreys typically include a higher density and diversity of shrubs but lack hummock grasses, and the ground layer is typically sparse. Detailed descriptions of vegetation and landscapes are included in Westbrooke et al. (1998).



Photo: Mallee plot post-fire, D Keith





**Figure 12.1** Location of experimental sites within Tarawi Nature Reserve, Scotia Wildlife Sanctuary and Danggali Nature Reserve study area

This study focuses on vegetation dynamics on dune crests and upper slopes, primarily because resources are insufficient to sample across the full catenary sequence of dunes and swales. Study of fire in swale landforms is problematic because these are rarely flammable under prescribed fire conditions due to the absence of hummock grasses, which augment lateral fuel connectivity and thus promote fire spread on the dune crests and slopes.

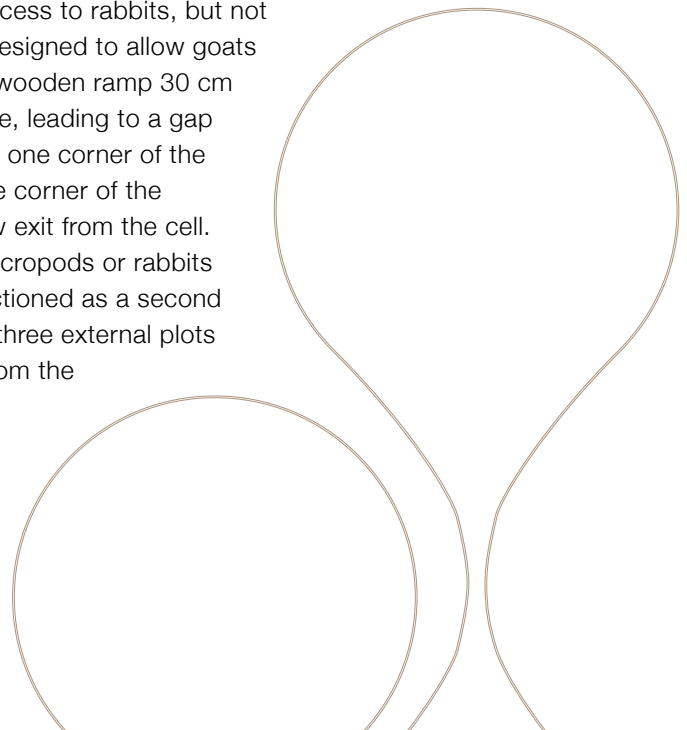
### Experimental sites and treatments

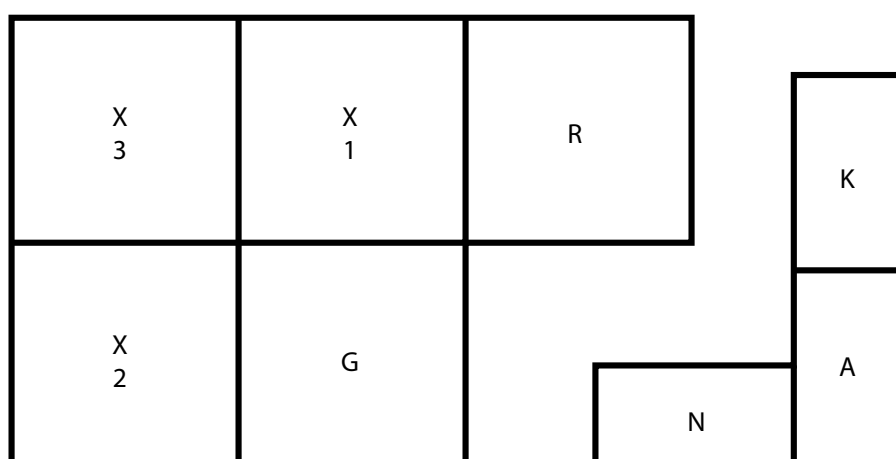
Between 1996 and 2011, 53 experimental sites were established on dune crests and upper slopes, of which 29 are located in Tarawi Nature Reserve, 16 are in Scotia Sanctuary and 8 are in Danggali Conservation Park (Figure 12.1). In Tarawi, each site is marked with a steel sign on an adjacent access track. These include four pilot sites established during 1996–98, when the design of herbivore exclosures was developed.

All but one of the 53 sites (1998/CON1) has been burnt since 1995, either in prescribed fires (33 sites) or wildfires (19 sites). Prescribed fires varied in area from 1–70 ha, whereas wildfires varied in area from 70 ha to 3000 ha. Prescribed fires were implemented in 2000, 2001, 2003, 2005, 2006, 2009, 2010 and 2011. The 33 sites sampling prescribed fires were stratified across this chronosequence, with four sites sampled in each burn year except 2005 (five sites), 2009 and 2010 (two sites each), and 2011 (eight sites). For each burn year, the sites were stratified between locations with different prior fire histories; half had previously been long unburnt (1917 or earlier) and half had been unburnt for 20–30 years (1979–84). However, the four sites sampling prescribed burns in Scotia in 2010 only sampled a single fire history.

When new sites to be burnt in prescribed fires are established, three surveys are undertaken in successive years at the time of treatment. These sites are initially marked out and surveyed 1–3 months before burning treatment (pre-fire survey). They are fenced to exclude all vertebrate herbivores, usually within 1–3 months after burning treatment. A second survey (post-fire survey) is carried out approximately one year after the first survey. Within 1–2 months after the second survey, fences are modified to allow selected herbivores access to compartments of the exclosures (see details below). During the second survey, additional plots are recorded outside the exclosures where herbivores have continual access to the vegetation before and after burning. A third survey (post-grazing survey) is carried out within and outside the exclosures approximately one year after the second survey. Pre-fire surveys could not be carried out at any sites burnt in wildfires or the four sites burnt in prescribed fires during 2010 in Scotia Sanctuary. The eight sites in Danggali were not fenced to exclude herbivores and, consequently, only one post-fire, post-grazing survey was carried out, equivalent to the surveys of the external plots on the third annual visit to the other sites.

Grazing exclosures were constructed at all sites except those in Danggali and the Scotia sites burnt in 2009 and 2010. The latter site was within the Scotia stage 1 fenced area, from which goats and rabbits had been eliminated, kangaroos were at low densities and in which bilbies, numbats, burrowing bettongs and bridled nail-tail wallabies had been introduced (T Cathcart, Australian Wildlife Conservancy, pers. comm.). The design of all exclosures constructed since 2000 (inclusive) followed the layout in Figure 12.2. Each comprised five contiguous fenced cells 15 m square. Initially all five cells were closed to all vertebrate herbivores for approximately one year after construction. The basic fence design comprised treated pine posts at each corner, four star pickets along each side, with two droppers per panel between pickets supporting a 1.8-m-tall sheep mesh wire fence with chicken mesh covering the lower 0.6 m of the vertical fall and turned outward at ground level to a 0.6-m lateral apron. After being surveyed at the end of this period, the fences of each cell were modified to allow selective access to different combinations of vertebrate herbivores, as shown in Figure 12.3. One cell was retained in an unmodified state as a total exclusion treatment (none plot). In a second cell, the chicken wire mesh was removed from two sides, leaving a gap of 0.6 m beneath the sheep wire mesh and allowing access to macropods, goats and rabbits (all plot). In a third cell, the sheep mesh was removed from two sides leaving a 0.6-m-high chicken mesh fence, allowing access to macropods but not goats or rabbits (kangaroo plot). In a fourth cell, the mesh apron was lifted and pinned to the fence, leaving a 10-cm gap at the base of the 1.8-m-high fence, allowing access to rabbits, but not macropods or goats (rabbit plot). The fifth cell was designed to allow goats access, but not macropods or rabbits (goat plot). A wooden ramp 30 cm wide was constructed on the outside of the exclosure, leading to a gap in the upper part of the fence 1.2 m above ground in one corner of the plot. A similar ramp was constructed on the opposite corner of the cell, but with the ramp installed on the inside to allow exit from the cell. Subsequent scat counts indicated that no goats, macropods or rabbits accessed this cell, so that in practice goat plots functioned as a second total exclusion treatment (cf. none plot). In addition, three external plots 13 m × 7.5 m were established outside and 7.5 m from the exclosure fence, where all vertebrate herbivores had continual access to the vegetation before and after burning treatment.





A = all in, unrestricted access; G = goat entry; K = kangaroo entry only; N = none in, total exclusion; R = rabbit entry only; X1–X3 = unrestricted access

**Figure 12.2 Standard layout of grazing exclosures at each site**

Goat entry was facilitated using wooden ramps, but this has proven ineffective and no goats entered these cells, which therefore replicates the total exclusion treatment. Each of the cells K, A, N, R and G were closed to all herbivores for one year after fire, and then opened to the respective herbivores. Plots X1–X3 remained unfenced throughout, allowing continuous access to all herbivores.

The standard exclosure layout was not followed at the four pilot sites established before 2000. T1996/1 had a single-celled exclosure comprising a 1.8-m fence with a 0.6-m ground apron to exclude all vertebrate herbivores (none plot). T1997/1, T1997/2 and T1998/CON1 comprised four cells as described above for the none, all, kangaroo and rabbit plots, except that all vertebrates were initially excluded using an electric fence constructed 2 m outside the perimeter of the exclosure fence and powered by 12-volt batteries. The electric perimeter fences were dismantled 1.5–2.5 years after construction, to allow access to the respective herbivores.

Collectively, the experiment established a set of sites that represented a chronosequence of fire ages crossed with different grazing treatments and measured sequentially before and after implementation of the treatments. In addition to the sequence of three surveys carried out during establishment of the plots, an additional contemporaneous survey took place from spring 2011 to summer 2013 across all sites except those in Danggali. The sampling order was stratified by year of establishment and burn history.

### Response variables and sampling protocol

The density (number of individuals per unit area) of each vascular plant species is recorded in every plot. That is, both the five 15 m × 15 m fenced plots and the three 13 m × 7.5 m unfenced external plots. The total counts made in each plot are aided by informally dividing each plot up into segments for logistical purposes only. Counts of each species are partitioned into live reproductive plants, live non-reproductive established plants, fire-killed established plants, plants that had emerged as seedlings or resprouted after fire and subsequently died, live seedlings less than two years of age, and dead seedlings.

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 are visually estimated in each exclusion and external plot. These currently include hummock grass height (10 randomly selected individuals per plot), 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.

Seedling cohorts of *Eucalyptus* and *Callitris* that emerged after fires in 1996, 1997, 2005 and 2006 were marked with uniquely numbered metal tags and monitored for survival, growth and reproduction in subsequent years.



Photo: D Keith

**Figure 12.3 Example of cellular exclosure fencing, allowing selective access to different mammalian herbivores**


Site T2005/5 at the third census, two years after burn treatment and one year after exclosures were opened to allow selective herbivore access. A plot (right foreground) has negligible cover of tussock grasses and shows soil disturbance from numerous footprints of goats and kangaroos, K plot (left foreground) has an open cover of tussock grasses, R plot (right background) has a very sparse cover of tussock grasses, and N plot (left background) has abundant tussock grasses and other ground layer plants. G plot is obscured from view (far left background).

### Environmental monitoring

Automatic weather stations were established at Tarawi Homestead and Scotia Sanctuary homestead in 1994. They record precipitation, temperature, relative humidity, and wind speed and direction. Previously, rainfall records had been maintained since 1941 by a visually monitored rain gauge. Four additional visually monitored 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 Sanctuary in September 2007.

In May 2011, monitoring tubes for soil moisture probes were installed at intervals along two transects extending across the catenary sequence from swale to swale across a dune crest. Tubes were installed in each swale, on the dune crest and on the upper





and lower flanks on each side of the dune. Soil moisture is monitored at monthly intervals at depths of 100, 200, 300, 400, 600 and 1000 cm below the soil surface at monthly intervals using a PR2/6 Profile Probe manufactured by Delta-T Devices Ltd.

## If I had my time again

The Mallee Plot Network was one that arose directly from an approach to researchers by conservation managers. The early motivation was to resolve a problem about fire management in a newly established nature reserve on a former sheep station: when should all the old and possibly decaying mallee be burnt? In the course of resolving that question, new ones rapidly emerged involving interactions between fires, herbivore activity and rainfall variability. The flexibility to adapt our sampling design with new additions and calibrated modifications has been crucial to addressing the expanded context of conservation management in the mallee.

This plot network, like others in remote locations, demonstrates the value of staff continuity and champions. It is fortunate that one of the managers and two scientists involved in initiation of the project remain involved some 17 years later. On-site land management staff were critical to the success and husbandry of the plots and their treatments, which has become a major challenge since the retirement of a key staff member and speaks volumes about the virtues of extending retirement age beyond 72 years.

One of the lessons learnt from long-term ecological research in the mallee is the critical importance of environmental covariables. These help to explain trends and anomalous changes, and can be crucial in generating hypotheses for testing in manipulative experiments and adaptive monitoring. Long-term rainfall data proved critical to the interpretation of long-term monitoring results in the Mallee Plot Network. Some of this has been collected from manually read gauges, so it was crucial to maintain regular checks of the instruments, and to curate and secure the data. More recently, LTERN support has enabled us to start monitoring soil moisture to give finer resolution and more proximal insights into ecosystem responses to rainfall events. If we had our time again, we would have started taking these measurements earlier in the study.

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# Conclusion—long-term ecological research: critical elements and reflections

This manual documents and describes the objectives of the LTERN Facility, the questions being examined and the field methods being used. We have published this information to inform environmental professionals and others of the detail involved in long-term monitoring—so they can use it to inform their own ecological monitoring initiatives. Protocols outlined in this manual have evolved over time to achieve specific objectives aimed at understanding ecosystem changes in different ecological communities; they are likely to be useful in other monitoring efforts of similar environments. We also summarise critical elements needed to maintain long-term monitoring initiatives, and we provide some reflections from researchers that have successfully designed, implemented and maintained long-term ecological research.

## Critical elements: people and funding

The procedures outlined in this manual depend on infrastructure provided through initiatives like LTERN, which is a program supported by the Australian Government National Collaborative Research Infrastructure Strategy. The fundamental *infrastructure* requirement, however, is having skilled people in the field rather than expensive equipment. Effective ecological monitoring of ecosystems is reliant on trained, highly skilled people. It takes statisticians, biologists, data managers and strong leadership to deliver an ecological monitoring program. However, recruiting people with relevant skills is an ever-increasing challenge because critical skills are not always taught sufficiently to undergraduates, and a lack of job security makes retention of technical staff difficult.

Over the past few decades, the number of people with field experience has declined. The resulting lack of field identification skills, particularly of flora and invertebrates, and a poorer knowledge of ecological sampling and statistical inference will lead to a shortage of trained people who are ready or willing to participate in ecological monitoring or to train those who need this knowledge in the future. This trend has occurred worldwide over the past few decades (see, for example, Ens et al. 2014; Greene 2005; Noss 1996).

In addition, LTERN Plot Leaders, and other Australian researchers, face enormous difficulty in maintaining continuity of staff (and thus their field-based projects) due to limited access to ongoing funding. This is, in part, because long-term ecological monitoring requires repeated access to conventional short-term scientific research funding, which is very difficult. This difficulty is amplified by an emphasis in western science on ‘innovation’ and new discoveries. This fixation with ‘new’ can undermine real advances that take time, consistency and persistence (Lindenmayer & Likens 2010, 2011). That said, the delivery of a strategic priority<sup>7</sup> that is critical to a healthy, sustainable and prosperous Australia *should not be contingent on* individual researchers

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7 [www.science.gov.au/scienceGov/news/Pages/PrioritisingAustraliasFuture.aspx](http://www.science.gov.au/scienceGov/news/Pages/PrioritisingAustraliasFuture.aspx)

being able to repeatedly secure short-term (3–5 year) research funding under the current funding ethos in Australia. Instead, separate, long-term and stable funding is needed to underpin such research priorities. This will secure monitoring programs, such as those in LTERN, that are delivering on their stated purposes, and will continue to do so if they are able to endure.

## Reflections: methodological stability and adaptive monitoring

In developing this manual for a broader public audience, certain themes kept arising from plot network leaders. Many of the LTERN plot networks were not devised with the intent of being monitored long term. Most Plot Leaders did not predict that their plot networks would continue to be maintained and monitored for 10–30 years or longer.

One of the fundamental aspects of maintaining a long-term research program is ensuring that field methods stay the same. Although there is an interest in new technologies that could be incorporated into our network, there is an inherent problem of trying to analyse/interpret the data generated from new methods with long-term data collected using other methods. Technological advances, therefore, can only be employed to—*complement not substitute*—traditional methods employed at the sites.

While having skilled people in long-term ecological research is the most important element of our infrastructure, LTERN also embraces new technologies where appropriate. For example, the Desert Ecology Plot Network (Section 9) is now using remote cameras to detect wildlife and GPS tags to track the movements of larger predator species. But these are being used to complement the ongoing plot-based observations—not replace them (Greenville et al. 2014). This is because, while they provide valuable enhancements to the monitoring, they do not detect several target species. For example, positive identification of species from camera trap images is problematic because they fail to differentiate subtle morphological traits, such as the shape of the footpads in mammals. GPS animal tracking is problematic because the cost is prohibitive and not useful for small-bodied species. A recent review by Kays et al. (2015) shows that around 65% of mammal species and 70% of bird species still cannot be tracked as they move, because their body weights are too small for tags to be attached without interference. We therefore continue with the on-the-ground plot-based observations, and trial or use additional technologies only where appropriate to complement traditional methods.

The use of tried and trusted methods does, however, need to be balanced against the need for adaptive monitoring. An important aspect of adaptive monitoring is to think carefully and laterally about how new questions and opportunities can be incorporated without interrupting the core purpose, and by retaining the essential data collection. In the Upland Heath Swamps Plot Network (Section 10), for example, analyses of early trends and patterns in the data showed us that we could reduce our sampling effort by recording data from half the original number of subplots (30 cf. 60) to calculate a species frequency score for each transect and still retain 95% of the information on the compositional relationships between samples. This helped us sustain monitoring over time as available resources contracted. However, we could not have been confident about the information lost if we had not sampled intensively during the initial sets



of surveys and conducted exploratory subsampling analyses on the resulting data. Calibration of new or adapted methods is essential.

One of the lessons learnt from long-term ecological research is the critical importance of collecting site or plot-based data on environmental variables. These data can be used as covariates in analyses to help explain trends and anomalous changes, and can be crucial in generating hypotheses for testing in manipulative experiments and adaptive monitoring. Long-term rainfall data proved critical to the interpretation of long-term monitoring results in the Mallee Plot Network (Section 12) and in the Desert Ecology Plot Network (Section 9).

If you are reading this guide with the purpose of developing your own long-term research program, we hope you find it informative. Remember to keep your methods simple and robust to change. And take particular note of the advice sections at the end of each network's section, because these have been designed with a focus on 'if I had my time over again'.

## Feedback and further information

If you would like to learn more about LTERN's activities and the lessons we have learnt, you can download our booklet *Making ecological monitoring successful: insights and lessons from the Long Term Ecological Research Network* (Burns et al 2004).

If you have found this manual of interest then please let us know via our LTERN Office mailbox: [ltern@anu.edu.au](mailto:ltern@anu.edu.au).



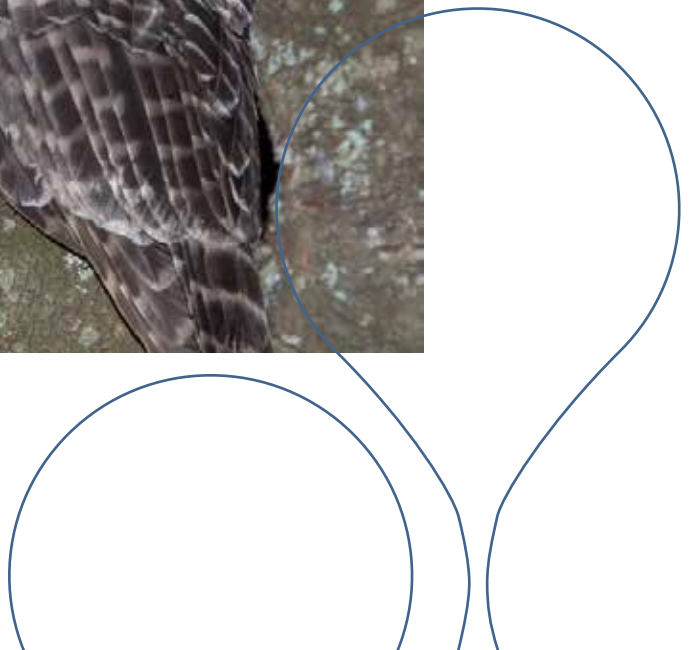
Photo: Juvenile Long-nosed bandicoot, C MacGregor

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Photo: Powerful owl, R Jackson





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