A Technical Manual for Vegetation Monitoring

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Acknowledgements

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Contents

1 Introduction

The Concise Oxford dictionary gives two relevant meanings for monitoring. The first is 'tropical lizard of the genus *Varanus*, supposed to give warning of crocodiles', the other is 'to maintain regular surveillance'. The first meaning suggests that monitoring may have something to do with detecting danger and the second simply encourages us to keep watching. It is the second meaning that is increasingly used as an alternative to responding to threats to biological values in the face of change. Of course, monitoring need not only involve detecting something wrong. Monitoring is about detecting change and responding to it in a way that favours a desired outcome. In the context of this manual monitoring means 'to maintain regular surveillance in order to detect change and to respond to change in a fashion that favours the maintenance or enhancement of the subject's predicament'.

Monitoring projects usually take one of three forms:

- Monitoring the impact of a change in the environment. For example, monitoring the impact of a wildfire, a change in the local hydrology, or a development.
- Monitoring the impact of a management treatment. For example monitoring the impact of an ecological burn, a particular grazing regime, or the use of fertiliser.
- Monitoring changes in plant populations or communities over time. For example, monitoring a population of rare plants in a particular location.

Monitoring projects typically take many years to complete because they need to observe responses or changes over a number of seasons. Most government conservation agencies have a rapid turnover of project staff and many long-term monitoring projects are never finished because incoming staff have different work priorities and/or are not fully aware of the design and methods of the project. Developing rigorous and standardised monitoring projects will allow incoming staff to complete the monitoring and management commitments made by earlier staff.

1.1 Why should we monitor?

Monitoring allows land managers to evaluate the effectiveness of their management actions and to develop more appropriate management practices. If the responses of plants and vegetation to management actions are not monitored nothing can be learnt about the effectiveness of the actions and any improvements in management practices will be ad hoc at best. In contrast, monitoring enables land managers to systematically measure the responses of plants and vegetation to a management action and to determine whether or not it has been effective. This allows them to progressively modify their management practices until they are achieving the best result possible.

Monitoring projects require considerable resources and planning. Therefore, they should be undertaken only when they are likely to improve the management of conservation values.

1.2 Scope of the manual

Effective monitoring involves a commitment to conducting reliable and systematic measurements and responding to those measurements with appropriate management actions. This can only be achieved if the design of the monitoring project is relevant and scientifically rigorous. Therefore, the purpose of this manual is to equip you with the understanding and skills necessary to design and carry out simple but scientifically rigorous monitoring projects.

The manual is primarily intended to be a tool box for ecologists but it is hoped that it will also be used by field managers, private land owners and volunteers. Sections 1–5 are designed to give anybody involved in a monitoring project an overview of the principles and processes of designing monitoring projects. The rest of the manual is intended for trained ecologists so it is written in the technical language of ecologists.

Section 2 discusses the Nature Conservation Branch's Monitoring Program and the protocol that has been developed to standardise the design and implementation of monitoring projects conducted within that program.

Section 3 outlines a framework for designing monitoring projects.

Sections 4–5 describe two monitoring techniques that can be used by people who are not trained ecologists.

Sections 6–14 outline a range of specialised monitoring techniques used by ecologists.

Designing a new project requires consideration of the issues covered in the manual. Monitoring projects should be designed by professional ecologists who should also undertake the analysis of the results to ensure that their interpretation leads to the most appropriate management response being recommended. Statistical advice should always be sought once a monitoring question has been determined and the sampling strategy and analysis designed. Trained field assistants and volunteers should be able to set up and undertake some of the field methods described.

2 Monitoring Program Protocol

The Nature Conservation Branch (NCB) has developed a protocol for developing and conducting monitoring projects that form part of its Monitoring Program.

2.1 Aim of the protocol

At the program level, the protocol has been developed to facilitate implementation of the NCB's Monitoring Program. Use of the protocol will ensure that all monitoring projects are designed and conducted using common standards, procedures and methods. This will maximise their chances of success and ensure that the limited resources of the NCB are used for maximum benefit. It will also ensure that all the individual monitoring projects are integrated into one coherent program.

At a project level, the protocol has been developed to provide you with a framework for designing and conducting an effective and worthwhile monitoring project. It outlines the principles that underpin a best practice project and describes the processes involved in developing and undertaking a project that is scientifically rigorous, statistically simple, time and cost efficient, and relevant to management.

2.2 Protocol

The protocol sets out the procedures you should take when developing and implementing your monitoring project to ensure it meets the standards required by the NCB's Monitoring Program. A flow chart of the protocol is shown in Figure 1.1.

In developing and implementing a monitoring project you should:

- read the NCB's Monitoring Policy
- read the NCB's Monitoring Manual
- using the project proforma, prepare a project proposal that meets the best practice principles and the assessment criteria set out in the NCB's Monitoring Manual
- submit the project proposal to the Senior Botanist
- using the field and spreadsheet proformas, determine the details of the methods to be used incorporating the best practice principles and standards set out in the NCB's Monitoring Manual
- submit the methods proposal to the Senior Botanist
- have the project and methods proposals peer reviewed
- establish the project
- conduct the project
- write the report
- review the project and feed the information gained into adaptive management
- implement the appropriate management response or action.

2.3 Best practice principles

The specific attributes and techniques of a monitoring project will be determined by its objectives, scale and resources. Nevertheless, there are a number of principles that underpin all best practice projects. Therefore, the following best practice principles (Anzecc 1999) should be incorporated into the design of all projects that form part of the NCB's Monitoring Program:

- establish the need for the monitoring project

Structure of the Monitoring Program

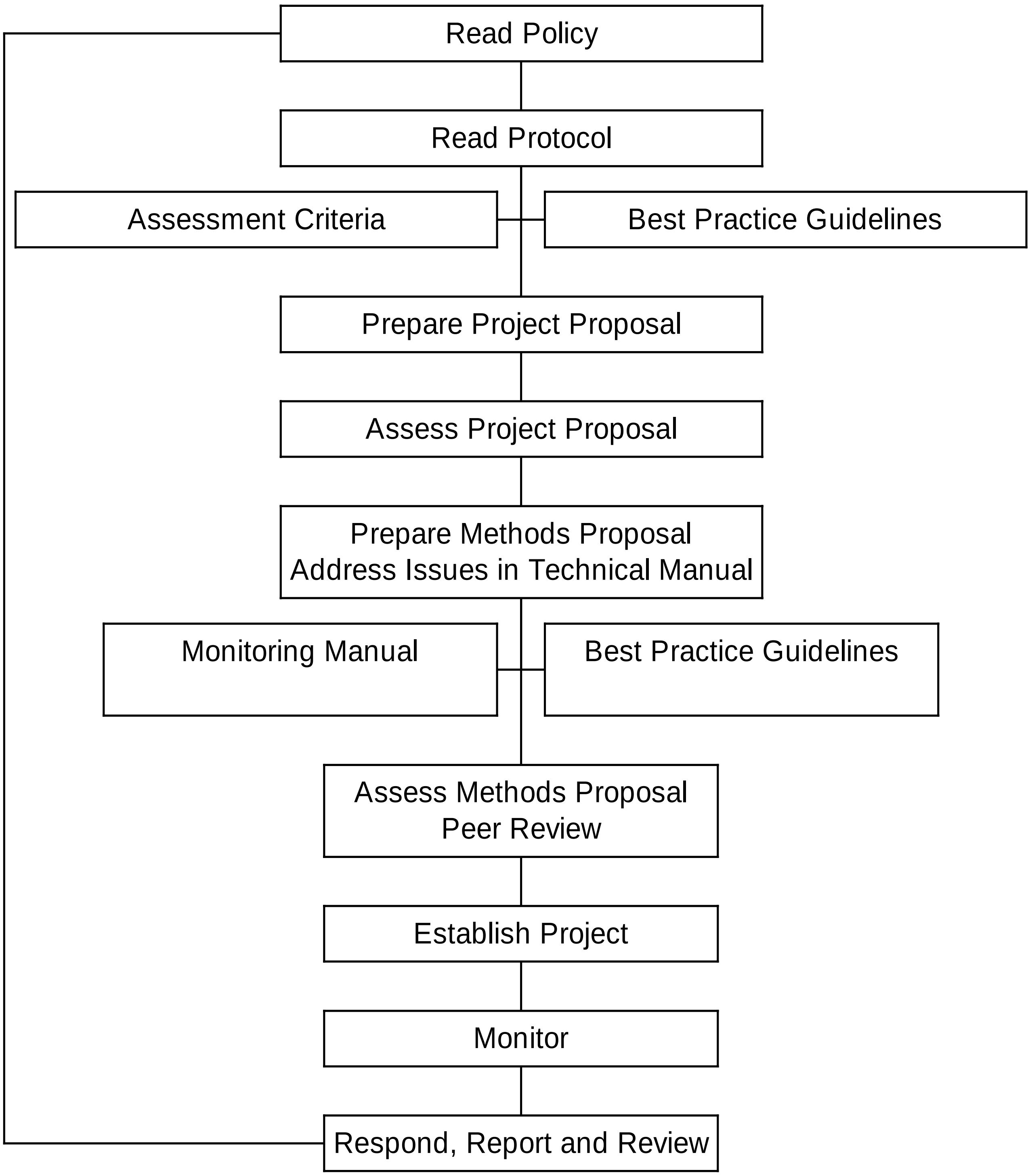


Figure 1.1: A flow chart showing the structure and protocol of the NCB's Monitoring Program.

- be committed to the project for its entire anticipated life
- be committed to incorporating the results of the project into management actions
- have clearly defined and achievable objectives
- comply with agreed standards, guidelines or protocols for sampling methods, data collation, data storage, information sharing, and have agreed definitions for the attributes and terms used
- be committed to collecting agreed core data
- have a basic understanding of the ecological characteristics of the plant species / community / impacts being measured
- have a knowledge of the relevant natural and anthropogenic disturbances
- have checked that no existing data is available
- have a robust method that allows for uncertainty (as far as possible)
- have a sampling strategy that is robust and repeatable and is independent of the person doing the sampling
- be committed to sampling the full range of variability needed to meet the objectives
- include feedback loops and mechanisms to incorporate the outcomes of the monitoring into policy and adaptive management
- be committed to appropriately disseminating the information gained.

2.4 Assessment process

All project and methods proposals that form part of the NCB's Monitoring Program will undergo the following assessment process before being accepted into the program:

- The Senior Botanist will assess the proposals according to the Monitoring Program's assessment criteria in consultation with the proponent. Modifications can be made at this time to help it meet the assessment criteria.
- A recommendation will be made to the relevant Section Manager. If the project is accepted the proponent will enter the details in the Monitoring Program's register.
- Each section will audit the projects for which it is responsible during the annual section planning procedure and judge which projects will receive ongoing support. Judgement should be made against the original assessment criteria, the standard of implementation, and the preliminary results.

2.5 Assessment criteria

All project proposals will be assessed using the following assessment criteria:

- clearly identifies what is to be monitored
- gives clear reasons why monitoring is needed
- identifies any obligations to monitor, eg an action of a recovery plan being implemented under contract
- provides an indication of the conservation priority of the subject
- identifies all the resources needed to complete the project, particularly the financial costs
- identifies what management practices might be changed
- demonstrates the commitment of the stakeholders to changing their management practices if the project identifies such a need
- estimates the likelihood of success in maintaining or improving the predicament of the plant species / community / impacts being measured.

3 Designing the Project

This section provides a framework for designing monitoring projects. It includes a checklist of the tasks involved and a discussion of the main issues to be considered when designing a project.

3.1 Project proposal

The following list is a checklist of the tasks that need to be done in order to complete a project proposal:

- identify who will take responsibility for the project
- identify the property or location of the project
- identify the site(s) to be monitored
- identify the land manager/owner responsible for the site(s) and get their permission
- identify what is to be monitored
- identify why monitoring is needed
- identify the conservation priority of the plant species/community/impact being measured
- identify the resources needed
- determine how much funding is available
- identify what management practice might be changed
- get the commitment of stakeholders to changing their management practices if the project identifies such a need
- identify the likelihood of success in maintaining or improving the predicament of the plant species/community/impacts being measured
- set the monitoring question
- determine the treatments to be used
- determine the threshold that will trigger a management response
- determine the method(s) to be used
- determine the frequency of monitoring
- determine the analysis to be used
- discuss your design and analysis with a statistician
- decide where the data and back up data will be stored
- complete the decision support system flow chart.

3.1.1 Setting the monitoring question

When Alice encounters the Cheshire Cat in Wonderland, she asks,
"Would you tell me, please, which way I ought to walk from here?"

That depends a good deal on where you want to get to," said the Cat.

I don't much care – as long as I get somewhere," said Alice.

Then it doesn't matter which way you walk," said the Cat.

Lewis Carroll

Monitoring presents a 'wonderland' situation for us — if you don't know what you want to know then it doesn't matter what you measure or how and when you measure it. However, if you have a specific monitoring question then there is a clear line of enquiry you need to follow to find the answer.

The data you need to collect will be determined by the monitoring question(s) you ask. Therefore, setting the right question is vital to the success of the project so it should be done carefully to make sure the answer is directly related to the management action being considered.

One way to pose a monitoring question is to:

- Think about what you want to know. State the question in terms of the subject (ie plant species/community/impact being measured), the treatment proposed (ie variable being measured), and what you expect will be affected by the treatment. For example, will the understorey of the grassy woodland change if the grazing regime is altered?
- Incorporate the variables you want to measure into the monitoring question. For example, will the abundance of native legumes increase if grazing is shifted from summer to winter?

This simple question will be complicated enough to answer without exploring any further issues. However, additional questions can be accommodated in a single project if the necessary data can be collected from the same quadrats. For example, will the structure of the woodland change under a winter grazing regime?

Therefore, in this case, the monitoring questions are set as:

- Will the abundance of native legumes in the woodland understorey increase under a winter grazing regime?
- Will the winter grazing regime change the structure of the woodland?

3.1.2 Methods to use and data to collect

The method(s) you select will depend on the monitoring question, the scale of the project, and the resources available. Sections 4–14 of this manual describe the methods commonly used in monitoring projects. You may need to talk to an experienced ecologist or refer to ecological texts (Krebs 2000) in order to decide which method is the most suitable for your project.

Change is a normal part of all ecosystems because all things ecological are dynamic. You need to understand the nature of the changes that may occur in an ecosystem and the management response needs to be based on a change that is perceived as undesirable for the plant species/community/impact being monitored.

Although the questions asked in monitoring projects are many and varied, ecosystem health is a common element in all monitoring projects. To determine the health of an ecosystem vital signs known as ‘ecological indicators’ are usually measured. For example, the population dynamics of a selected species may give indications about the structure and function of the whole community. Use of this ecological indicator means that not everything about the community has to be measured. However, what we measure should have certain characteristics if it is to be a good indicator. For example, it should:

- have dynamics that parallel the ecosystem
- have dynamics that are easily attributable to natural cycles or anthropogenic stresses
- be numerous and have a widespread distribution
- be sensitive to disturbance
- be able to be accurately and precisely estimated
- not be prohibitively costly to measure
- cause minimal environmental impact when measured
- have measurable results that are repeatable by different people.

Ideally, the parameters or thresholds of natural variation in the ecosystem need to be determined. Establishing the thresholds of natural variation can take many years and are known as baseline data. Often the pattern of natural variation has been destroyed because of the land management practices used. Indeed, it may be the impact of these practices that has brought us to monitoring a particular situation. In such cases we need to make decisions about which thresholds of variation are acceptable and which are not. In these circumstances we are designing the landscape or habitat or population to meet certain ecological criteria such as minimum population size or density. The thresholds of these criteria have an ecological purpose. For example, the threshold may be the minimum population size needed to buffer a population of rare plants against fluctuations that may threaten its existence. Alternatively, it may be the maximum forest fuel load possible to ensure that the intensity of an unplanned fire does not cause extinction of a threatened species. We monitor to detect when thresholds have been broken.

Detecting change, however, is not the end point of monitoring. If the resources used in monitoring are to be used effectively then a considered management response must be implemented to re-establish the plant species / community / impact to within the thresholds of natural variation.

Your monitoring question will determine the data you need to answer it. Do not waste time and money collecting redundant data, ie data not needed to answer the question. Collect only the data you need to answer your monitoring question.

When thinking about the data you will need to collect, identify any variables you will need to calculate and make sure you collect the data needed to do the calculations. For example, if you want to know the species richness you will need to know the number of species present, and if you want to know the species density you will need to know how many species are present in each quadrat.

To answer the two questions set in Section 3.1.1 you will need:

- a species list from each strata (this will include the legumes)
- a measure of the species abundance from each strata (eg frequency or density)
- a measure of the height and cover from each strata.

Several other design considerations will affect the accuracy and precision of your estimates and hence the power of your analysis. To maximise your chances of correctly identifying a significant treatment effect or change you will need to maximise the size of the treatment effect by minimising data error, reducing variability, and choosing variables that are strong indicators of change.

Vegetation cover is a good example of a variable that can introduce variation and error into your data depending on how and when it is estimated and who estimates it. Vegetation cover will vary or appear to vary during the year so it needs to be estimated at the same time each year — not only in the same season each year but also at the same time in relation to other factors, such as the time since grazing.

On the other hand, for perennials, frequency is an absolute measure that does not vary much during the year or between consecutive years. For annuals, the frequency or density is likely to be an accurate measure of the variation in abundance if it is measured at the same time each year. Although errors in counts can still be made, variability between different people’s counts or repeated counts is likely to be low.

3.1.3 Project proforma

The project proforma shown in Table 3.1 has been designed to help you gather the information needed for your project proposal. The completed proforma will used by the Senior Botanist to assess your project proposal.

Table 3.1: A project proforma containing the fields that are mandatory for a monitoring project.

Project title				**Project leader**		
Date						
Tenure			**Land manager**			
Who knows the location and details of this project?						
Monitoring question?						
Treatment(s)?						
Date applied			Location of datum			
			Easting	Northing		
Number and size of quadrats						
	Number	Size	Number	Size	Number	Size
Control						
Treatment						
Distribution of quadrats						
Random	How and why stratified?			How and why systematic?		
Arrangement of quadrats (diagram: include distances and directions to numbered quadrat marker pegs). For transects, specify whether quadrats are to left or right of transect line.						
Re-measurement (annual, 5 years?)						
Where is the data stored?						
Where are back up data?						
What is it stored on?						
Description of intended analysis						
Name of the statistician who looked at the design						
Description of the anticipated trigger for a management response						
**Attach the decision support system to this hardcopy						

3.1.4 Decision support system (DSS)

All project proposals must be accompanied by a decision support system (DSS) flow chart. The DSS outlines the scenarios you envisage will result from the monitoring project. It facilitates future management by setting out a plan of action for responding to the results of the monitoring project.

An example of a decision support system is shown in Figure 3.1. It shows the scenarios likely to result from a project monitoring a species to see if it is threatened by extinction. The actions on the left hand side show the actions that should be taken if the species abundance is found to be declining to below the threshold necessary for the species survival. The actions on the right hand side show the actions that should be taken if the species is found to be abundant but there is the risk of an unplanned fire that could threaten the survival of the species.

The decision support system should include details of:

- response variables and thresholds
- management actions
- authority
- timing
- resources.

The response variables are the variables you have chosen to measure as the indicators of change.

A threshold should be set for each response variable. The threshold is the limit beyond which a management response will be implemented. The threshold can be percentage change or an absolute value.

The management actions proposed should be practical and aimed at returning the response variable to values within the limits of the threshold or beginning a regeneration process.

If no treatment is being applied as part of the monitoring project the management action may be the application of a treatment for which the response is well understood. For example, if species richness has been measured to decline after 20 years since fire, the application of an ecological burn may be warranted.

The application of a management action may require certain biophysical conditions to prevail. The decision support system should guide the consideration of those conditions. For example:

- if seedling regeneration is less successful after a fire when the subsequent season is dry, check the long-term forecast
- if seedling regeneration is limited by the supply of seed, check for the presence and viability of seed.

Any authority that is necessary to undertake the desired management response should be recorded — for example, if a fire permit will be required.

If a management response will need co-ordination of people and resources this should be incorporated into the DSS — for example, the names and addresses of participants and the location of any equipment.

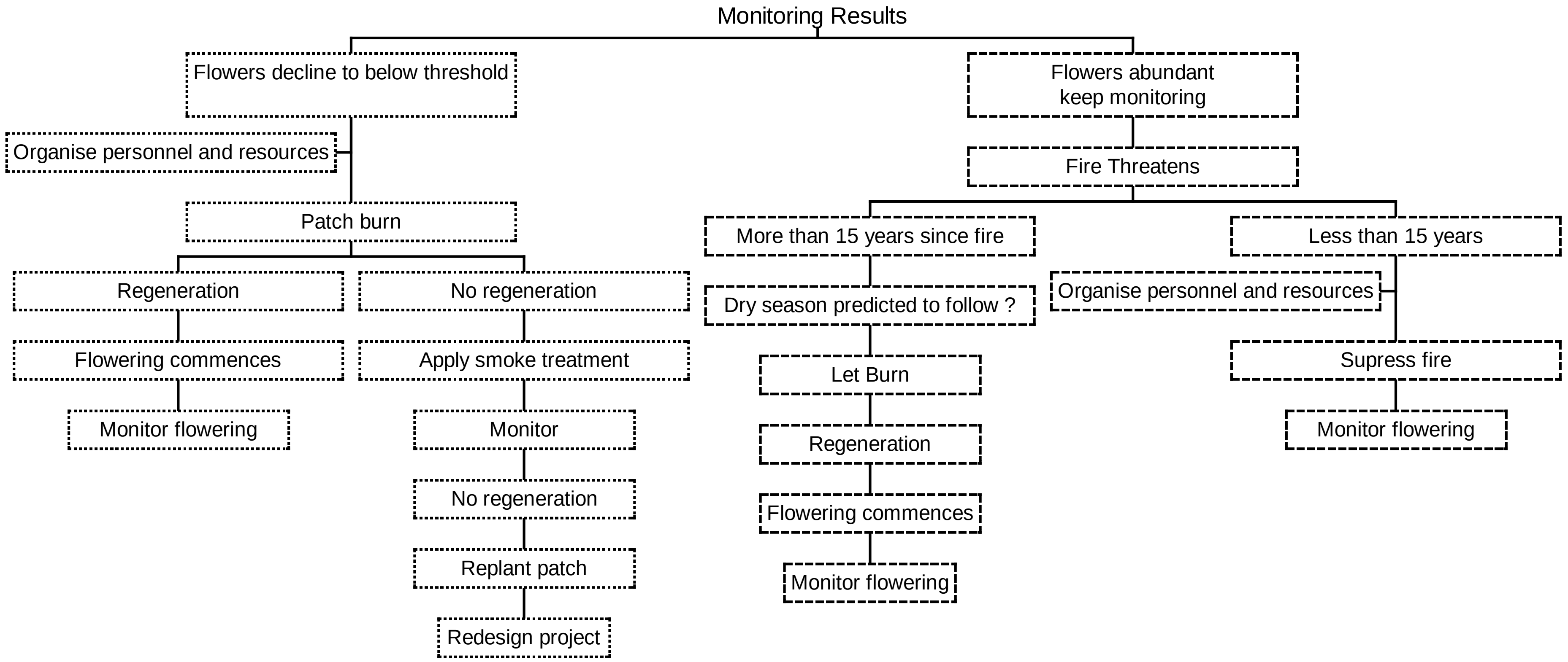


Figure 3.1 A flow chart of the Decision Support System indicating the flow of logic following the results of monitoring. The decision tree follows two scenarios, 1. declining numbers of flowers and 2. threat of unplanned fire.

3.2 Methods proposal

The methods proposal describes the technical details of the methods you will use to carry out your project. For example, the number of replicates and controls, the size and distribution of the quadrats, and how you will estimate your variables.

3.2.1 Field and spreadsheet proformas

The field proforma will be used when you collect your field data. It contains fields for information about the biophysical characteristics of the monitoring site, the species variables being measured, and any other information relevant to your project. Table 3.2 shows an example of a field proforma.

The spreadsheet or data proforma is used for organising the data from the field proforma so that it can be easily analysed or entered into a computer for analysis. Table 3.3 shows the spreadsheet proforma derived from the field proforma shown in Table 3.2. Usually, some of the fields in the spreadsheet will be the same as those in the associated field proforma and some will be for calculations derived from the other fields.

Designing the field proforma so it has the same fields as the spreadsheet proforma where appropriate means that transcribing data will be easier and less likely to produce errors. If the spreadsheet proforma is computer based and calculations are necessary the relevant formulae can be embedded into the spreadsheet so the calculations are completed as the data are entered. This will eliminate the possibility of making calculation errors.

The information on your field and spreadsheet proformas will be used by the Senior Botanist to assess your methods proposal.

Table 3.2: An example of a field proforma that can be cross-referenced to the project proforma and design. The data fields reflect the fields in the spreadsheet proforma to be used for summarising the data and analysis. (For details of Braun-Blanquet cover classes see Section 15.)

<table>
<tr><td colspan="2">Project title</td><td colspan="3">Project leader</td><td>Date</td></tr>
<tr><td colspan="2">Easting</td><td colspan="2">Northing</td><td colspan="2">Recorder</td></tr>
<tr><td colspan="4">Quadrat stratum Canopy-all species over 4 m tall.</td><td colspan="2" rowspan="10">Notes: Dolerite boulder field under E. delegatensis forest. Oldgrowth. The patch is about 100 ha with cleared agricultural land adjacent to the east and plantation E. nitens to the west.</td></tr>
<tr><td>Size</td><td colspan="2">Number</td><td>Treat/control</td></tr>
<tr><td>20 x 20 m</td><td colspan="2">1 of 8</td><td>Control</td></tr>
<tr><td>Aspect deg</td><td colspan="2">Slope %</td><td>Altitude (m)</td></tr>
<tr><td>130</td><td colspan="2">12</td><td>600</td></tr>
<tr><td></td><td colspan="3">Cover (Braun-Blanquet)</td></tr>
<tr><td>Geology</td><td>Rock</td><td>Bare</td><td>Litter</td></tr>
<tr><td>Dolerite</td><td>5</td><td>4</td><td>3</td></tr>
<tr><td></td><td></td><td></td><td></td></tr>
</table>

Species	Cover	Count	Height (m)	
A. dealbata	4	3	6	
E. delegatensis	4	5	35	
E. dalrympleana	4	3	35	
H. lissosperma	1	1	4	
B. salicina	1	1	4	
L. lanigerum	3	3	5	

Table 3.3: An example of the proforma spreadsheet derived from the field proforma in Table 3.2. Columns 2–4 (cover, count and height) are for the variables recorded on the field proforma. Columns 5–7 are for the calculated variables (frequency, density and relative density) that have been derived from columns 2–4.

Species	Cover (1)	Count (1)	Height (1)	Frequency (%)	Density (ha)	Relative density
A. dealbata	4	3	6	100	81.25	9.56
E. delegatensis	4	5	35	100	150	17.65
E. dalrympleana	4	3	35	100	87.5	10.29
H. lissosperma	1	10	4	100	231.25	27.94
B. salicina	1	7	4	100	162.5	19.12
L. lanigerum	3	8	5	75	175	15.44

4 Photo Point Monitoring

Photo point monitoring is a cheap but effective monitoring technique that can be used by land managers and volunteers who are not trained ecologists.

A photo point is a point from which a series of photographs is taken of a particular subject (ie a plant species / community / impact) to record any changes that are occurring. In its simplest form it can involve taking a single photograph of a plant community in a fenced-off paddock once a year. At the more sophisticated end of the spectrum it may involve satellite imagery. Satellite imagery has been used to monitor and map large-scale land clearing and the spread of drought.

Photo point monitoring can be used to monitor change in a plant species or community or compliance with a particular management regime. With some imagination and appropriate design it may also be used to monitor fuel loads and grazing intensity. It can also be used to illustrate the impact of changes that have been measured. For example, the progress of regenerating trees beneath a woodland canopy.

Photographs taken from a photo point can be very important in monitoring because they provide an accurate record of the changes that have occurred in the subject over time. As a result they can be powerful tools for showing that a significant change has or has not occurred.

4.1 Establishing photo points

Setting up a photo point needs careful consideration to make sure that you select the most appropriate site and set it up properly. You may need the advice of an ecologist.

Before setting up your photo point make sure that you:

- select a site that is typical of the vegetation type you want to monitor
- ensure that the change you are monitoring can be monitored using photographs
- ensure that the growth of any intervening vegetation will not obscure the subject (ie plant species / community / impact) being monitored in future photographs
- if possible, choose a south-facing photo point to avoid sun glare.

Use the following directions to set up a photo point:

- At the point from which you will take your photographs, hammer a dropper into the ground so the top is 1.4–1.6 m above ground level. This dropper is referred to as the marker peg. It should be labelled with a numbered metal tag.
- Hammer a metal peg into the ground 10–20 m from the marker peg along the direct line of sight between the marker peg and the plant species / community / impact being photographed. This peg is referred to as the sighter peg. The height of the sighter peg will depend on the subject being photographed but it should be tall enough to be seen easily from the marker peg throughout the monitoring project. The distance of the sighter peg from the marker peg may need to be adjusted if the ground is sloping. If the ground slopes down from the marker peg to the sighter peg, the sighter peg may need to be closer. If the ground slopes up from the marker peg to the sighter peg, the sighter peg may need to be further away.
- A third peg can be hammered into the ground about 50 m from the sighter peg along and beyond the direct line of sight of the subject being measured. It will be used to help you point the camera in the right direction so your photographs are taken along the same line of sight. The height of the peg will depend on the vegetation being monitored but make sure it will be tall enough to be seen when you take your photographs in future years. You may need to adjust the distance of the peg from the marker peg to suit the future density of the vegetation. For example, you may need to place it further away if the vegetation is likely to grow significantly.

- Additional poles can be placed along the line of sight or along the edge of the quadrats being monitored to help you measure the distance and height of the subject being monitored. These poles are to referred to as ranging poles.

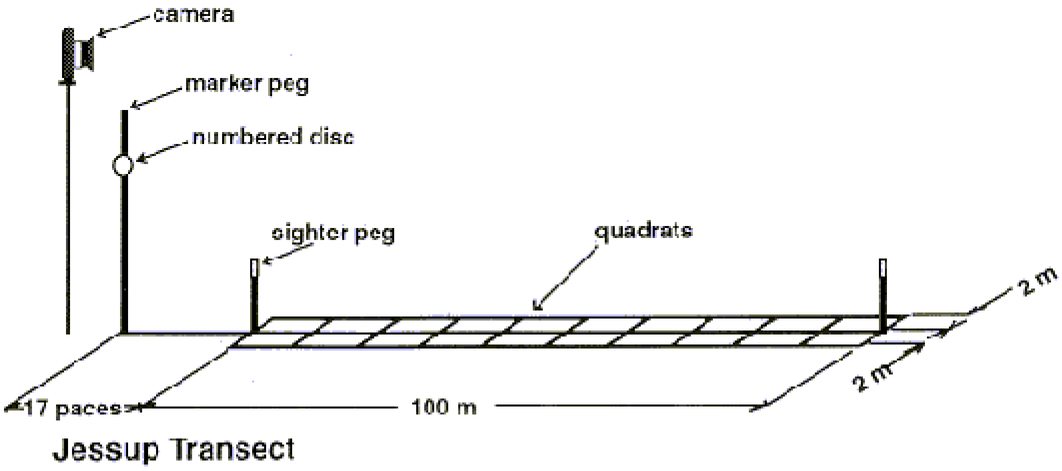


Figure 4.1: A diagram of a photo point site including an associated transect (after Department of Natural Resources, SA 1997, <http://www.rangelands.sa.gov.au/photopoints.html>).

4.2 Using photo points

The main purpose of photo point monitoring is to provide a reliable and accurate record of the plant species/community/impact being monitored. However, it is all too easy to forget which photograph was taken from which photo point and when it was taken. This problem can be overcome by hanging a data board containing the relevant information on the sighter peg. The information will then appear on the photograph itself.

The following information should appear on the data board:

- project title
- location of the site
- number of the photo point
- photographer
- date
- time.

When you take your photograph make sure that you:

- take the photograph from the marker peg
- focus on the sighter peg
- use a camera lens of the same specification each time
- use the same film type and speed each time
- use a shutter speed of between 125 and 250
- take the photograph at as close to the same date and time of day as possible each time
- take least two exposures of each photo-frame.

The technique described above is well suited to situations where the photo point monitoring is done in conjunction with monitoring of a transect. If the photo point is not associated with monitoring of a transect or quadrats you will need to record the following information on the field proforma:

- easting and northing
- description of the site location
- layout of the photo points
- condition of the site
- vegetation types present (ask an ecologist if necessary)
- estimate of the canopy cover at the site
- a line intersect species list (see Section 10 Transects).

5 Rapid Diversity Assessment

Rapid diversity assessment is a reasonably reliable technique that can be used to monitor the composition of vegetation relatively quickly and easily. It is used when a quick assessment needs to be made but strict scientific rigour is not needed.

The technique can be useful if you want to measure the response of a patch of vegetation to a new stock management regime such as cell grazing or if you want to monitor the species composition and richness of two sites with different fire frequencies.

Rapid diversity assessments are designed to be undertaken by non-ecologists. However, if you are not a trained ecologist you may need help to identify which species you should use as the species indicators.

5.1 Method

Before beginning your rapid diversity assessment you will need to make a poster of photographs of all the plants likely to be found at the site. The photographs should include a range of grasses, lilies, woody species, peas, herbs and weeds. The species chosen should be those species, including any weeds, that occur at the site or could be expected to occur if the condition of the vegetation improves or declines. The selected species should be arranged into categories or strata (grasses, rushes, herbs / ground cover, shrubs, etc) that reflect the structural layers present at the site and be separated into native and weed species. It is important that the species selected be good indicators of change. Peas are particularly important because being nitrogen fixers they are good indicators of health and should be included where possible in the structural layers. Arranging the species into structural layers can also give you an indication of whether the species are expanding or contracting from one vegetation layer to another over time.

The technique is based on the time meander search method. This involves meandering over a defined area and collecting or recording all the species found until you have spent a predetermined amount of time unsuccessfully searching for another new species. You may need to experiment in order to decide what length of unsuccessful searching time is reasonable, but 5 or 10 minutes of unfruitful searching may be adequate. When you have finished searching, identify and classify your plants into the various categories or strata by comparing them with the photographs on the poster. Identify any new species that do not appear on the poster if you wish. Record the presence or absence of species on a table similar to that shown in Table 5.1.

5.2 Analysis

In order to make sense of the information you have gathered you will need to do a few simple calculations. Record the following calculations on your table:

- Count the number of native and introduced species in each class.
- Total the scores of native and introduced species in each class to give the total number of species in each class.
- Total all the class scores to give the total number of species, total number of native species, and total number of introduced species.

5.3 Interpretation

Comparing your totals from year to year will give you an accurate impression of the way the species composition and diversity of the vegetation is changing over time. It will also indicate if species are expanding or contracting from one stratum to another.

The following are positive changes in the vegetation:

- an increase in diversity as a result of an increased number of native species
- a decrease in diversity as a result of a decreased number of weed species
- the same level of diversity as a result of an increased number of native species and a decreased number of weed species.
- the contraction of a weed species from one stratum to a lower stratum.

The following are negative changes in the vegetation:

- a decrease in diversity as a result of a decreased number of native species
- an increase in diversity as a result of an increased number of weed species
- the same level of diversity as a result of a decreased number of native species and an increased number of weed species.
- the expansion of a weed species from one stratum to a higher stratum.

The length of time you take to do the survey each year and the area you cover by the time you finish may reveal useful information. This information may augment the data you have collected and enable you to draw stronger conclusions from the data.

Table 5.1: The species groups and the number of native and introduced species in each group in two years at one site (artificial data).

Group (Yr 1)	**Species (Yr 1)**									**Total**	**Nat**	**Int**
Grasses	Nat. sp 1	Nat. sp 2	Nat. sp 3	Nat. sp 4	Nat. sp 5	Int. sp 1	Int. sp 2	Int. sp 3	Int. sp 4	5	3	2
Gramminoid/ rushes	Nat. sp 1	Nat. sp 2	Nat. sp 3	Nat. sp 4	Nat. sp 5	Int. sp 1	Int. sp 2	Int. sp 3	Int. sp 4	3	2	1
Herbs and ground cover 0.0-0.1 m	Nat. sp 1	Nat. sp 2	Nat. sp 3	Nat. sp 4	Nat. sp 5	Int. sp 1	Int. sp 2	Int. sp 3	Int. sp 4	4	4	0
Small shrubs 0.1-0.5 m	Nat. sp 1	Nat. sp 2	Nat. sp 3	Nat. sp 4	Nat. sp 5	Int. sp 1	Int. sp 2	Int. sp 3	Int. sp 4	7	5	2
Shrubs 0.5-3.0 m	Nat. sp 1	Nat. sp 2	Nat. sp 3	Nat. sp 4	Nat. sp 5	Int. sp 1	Int. sp 2	Int. sp 3	Int. sp 4	6	5	1
Totals										**25**	**19**	**6**

Group (Yr 2)	**Species (Yr 2)**									**Total**	**Nat**	**Int**
Grasses	Nat. sp 1	Nat. sp 2	Nat. sp 3	Nat. sp 4	Nat. sp 5	Int. sp 1	Int. sp 2	Int. sp 3	Int. sp 4	4	3	1
Gramminoid/ rushes	Nat. sp 1	Nat. sp 2	Nat. sp 3	Nat. sp 4	Nat. sp 5	Int. sp 1	Int. sp 2	Int. sp 3	Int. sp 4	4	2	2
Herbs and ground cover 0.0-0.1 m	Nat. sp 1	Nat. sp 2	Nat. sp 3	Nat. sp 4	Nat. sp 5	Int. sp 1	Int. sp 2	Int. sp 3	Int. sp 4	5	5	0
Small shrubs 0.1-0.5 m	Nat. sp 1	Nat. sp 2	Nat. sp 3	Nat. sp 4	Nat. sp 5	Int. sp 1	Int. sp 2	Int. sp 3	Int. sp 4	8	7	1
Shrubs 0.5-3.0 m	Nat. sp 1	Nat. sp 2	Nat. sp 3	Nat. sp 4	Nat. sp 5	Int. sp 1	Int. sp 2	Int. sp 3	Int. sp 4	8	8	0
Totals										**29**	**25**	**4**

Nat = Native species

Int = Introduced species

Table 5.2 Summary of the data in Table 5.1 indicating the difference between years in the total number of species, the number of natives and the number of introduced species.

Group	Total (Yr 1)	Nat	Int	Total (Yr 2)	Nat	Int	Differ-ence (Yrs)	Native	Intro
Grasses	5	3	2	4	3	1	-1	0	-1
Gramminoid rushes	3	2	1	4	2	2	1	0	1
Herbs and ground cover 0.0-0.1 m	4	4	0	5	5	0	1	1	0
Small shrubs 0.1-0.5 m	7	5	2	8	7	1	1	2	-1
Shrubs 0.5-3.0 m	6	5	1	8	8	0	2	3	-1
Totals	**25**	**19**	**6**	**29**	**25**	**4**	**6**	**6**	**-2**

Nat = Native species

Int = Introduced species

Grasses

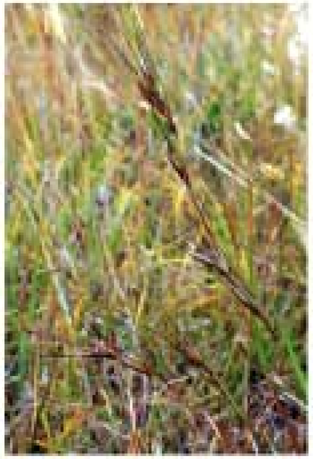
Total	Native Species	Introduced Species

Native

Poa spp.

Austrodanthonia sp.
Wallaby Grass

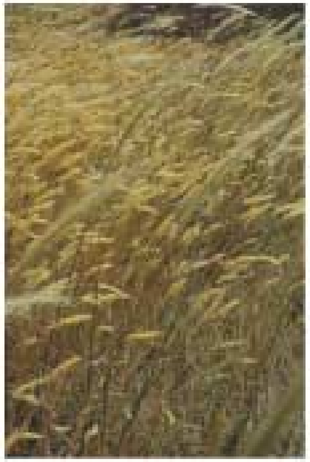
Austrostipa spp.
Spear Grass



Themeda triandra
Kangeroo Grass

Introduced

Holcus lanatus
Fog Grass



Anthoxantham odoratum
Sweet Vernal

Nassella trichotoma
Serrated Tussock

Shown here circled
in red next to Poa

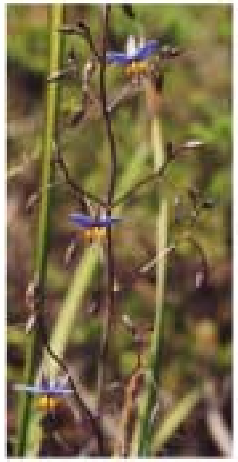
Gramminoid/rushes

Total	Native Species	Introduced Species

Native

Lomandra longifolia
Sagg

Diplarrena moraea
Flag Iris



Dianella revoluta

Lepidosperma laterale

Introduced

Herbs and Ground Cover 0.0-0.1 m

Total

Native Species

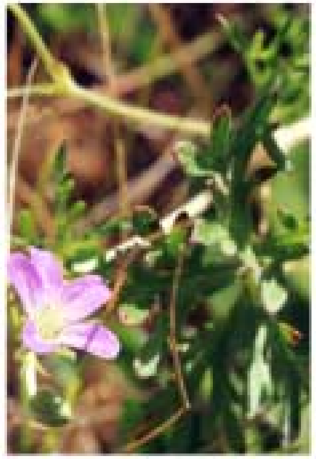
Introduced Species

Native

Gonocarpus tetragynus

Goodenia lanata
Native Primrose

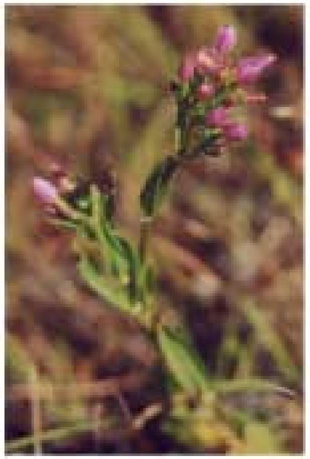
Bossiaea prostrata



Geranium sp.
Native Geranium

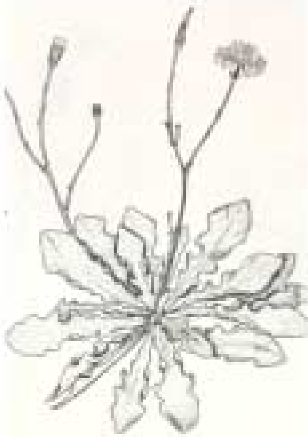
Viola sp.
Native Violet

Introduced



Centuarim erythraea
Common Centaury

Cirsium vulgare
Thistle



Hypocharis radicata
Cat's Ear

Trifolium sp.
Clover

Small Shrubs 0.1-0.5m

Total | Native Species | Introduced Species

Native

Poranthera microphylla

Pultenaea humilis
Dwarf Bush Pea

Hibbertia fasiculata
Guinea Flower

Pultenaea pedunculata

Leucopogon virgatus

Introduced

Ulex europaeus
Gorse

Erica lusitanica
Erica

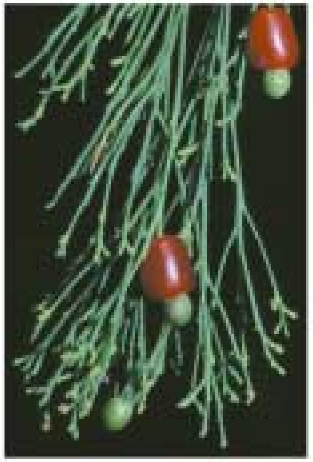
Cytisus scoparius
Broom

Shrubs 0.5-3.0 m

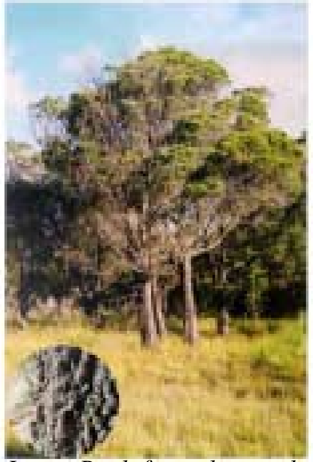
Total	Native Species	Introduced Species

Native

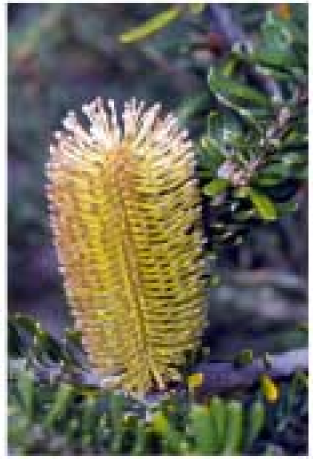
Acacia dealbata
Silver Wattle



Exocarpus cuppressiformes
Native Cherry



Inset: Bark from the trunk
Allocasuarina littoralis
Bull Oak



Banksia marginata
Honeysuckle

Introduced

Ulex europaeus
Gorse

6 Mapping the Extent of Vegetation

Vegetation mapping is a useful monitoring tool when a change in the extent of a particular type of vegetation is anticipated. Mapped units can be compared over time to reveal changes in:

- the extent and rate of spread of *Phytophthora*
- the expansion or contraction of a weed infestation
- the extent of a threatened species
- the extent of an endangered community.

Mapping methods vary widely and depend on the scale of the subject being mapped and the level of accuracy needed. For example, satellite images are useful for mapping the extent of vegetation when monitoring vegetation clearance at the regional, national or global scale. However, any mapping done at a national scale would not usually be accurate enough to be useful in a small-scale project.

Mapping from aerial photography can be very precise but the accuracy of the final product depends on the scale of the original photograph and the scale of the map on to which the information is transferred. For example, if you transfer a vegetation boundary from a 1:25 000 photograph to a 1:100 000 map and mark it with a 1 mm pencil line the width of the mapped boundary of the vegetation unit will increase from 25 m to 100 m. The usefulness of mapping at this scale also depends on the size of the units being mapped. A 100 m wide boundary is of little use when mapping areas less than 1 ha in size.

Mapping vegetation from the ground by drawing the vegetation boundaries on a map can be extremely accurate if undertaken properly. This scale of mapping is useful for mapping:

1. The local distribution of *Phytophthora*-affected vegetation. *Phytophthora* mapping is useful for comparing the distribution and rate of spread in areas under different management regimes.
2. Relatively small infestations of weeds. Weeds mapping is particularly useful for planning a weed management strategy, including estimating the timing and cost of control.
3. The occupied habitat of a threatened species.
4. Endangered community monitoring and critical habitat mapping where habitats cannot be discriminated using aerial photography.

6.1 Mapping method

1. Locate all the occurrences of the subject in the monitoring area.
   a. Use a search grid of an appropriate scale, that is, one that is larger than the size of a typical patch of vegetation but not so large that you will miss some. Place the grid over the map of the area and search along the grid lines.
   b. Put in a semi-permanent peg, tape or other marker and determine the precise location with a GPS and record it on a proforma.
2. After completing your reconnaissance you will have a better idea of the scale of the distribution and the scale of the detailed mapping task.
3. Return to each patch and estimate or measure the area it covers.
4. Draw the patch on the area map using measurements to get the scale correct.
5. Estimate the abundance of any target species (weed or threatened species) using Braun-Blanquet cover classes (See Section 15).
6. The calculation below will give you an estimate of the upper limit of the area occupied.

Estimate of cover = the sum of (cover in each patch x upper bound of the Braun-Blanquet cover class for each patch).

Use this estimate for calculating time, herbicide volume and cost. From the calculations and the totals in the proforma you can see that the actual area of cover is less than the area the patches occupy.

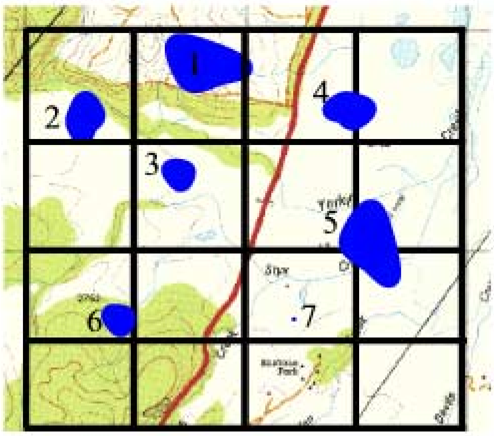


Figure 6.1 Seven patches of a weed mapped at 1:25 000 scale from a 500 m search grid.

Table 6.1: Calculation of the total area covered by the weed mapped in Figure 6.1.

Target weed	**Map**	**Easting: Northing**		**Date**
		Description of area		
Patch number	**Extent ***	**Cover %**	**Cover area**	**Cover % native**
1	62 500	100	62 500	
2	31 250	75	23 400	
3	15 625	50	7 800	
4	31 250	25	7 800	
5	62 500	5	3 100	
6	15 625	1	156	
7	(1)	(1)	1	
Total	**21.9 ha**		**10.5 ha**	

* The area occupied by the patch regardless of cover.

Estimate of cover calculation:

EC = (62 500 x 1)+(31 250 x .75)+(15 625 x .5)+(31 250 x .25)+(62 500 x .05)+(15 625 x .01)+1
=(62 500+23 400+7.800+7.800+3 100+156+1)
=104 807 m^2
=10.5 ha

7 Procedures

7.1 Determining quadrat size, number and distribution

7.1.1 Quadrat size

A method for determining sampling quadrat size is described by Mueller-Dombois and Ellenberg (1974) which considers the rate of addition of species to the species list as the quadrat size is increased. It is also discussed in many other ecological texts (eg Krebs 2000).

If the quadrat is to be used for frequency counts and if more than one or two species of interest have a frequency of 100% the size of the quadrat should be reduced. This will reduce the probability of a species being recorded in every quadrat.

Table 7.1: Recommended range of quadrat sizes in m^2 for frequency counts of different strata and ecosystems.

Stratum	Ecosystem	Quadrat size (m^2)
Moss layer	Peatland, mossbed, rainforest	0.01–0.1
Herb layer	Grassland, moorland	1–2
Low shrubs	Shrubland, heathland	4–16
Tall shrubs	Shrubland, forest	16–25
Trees	Forest, woodland	100–1 ha

The size you choose may be best determined by whether you are most interested in sampling the representative species composition (larger) or the spacing of the individuals when quantitative analysis is desired (smaller).

Several practical matters also need to be considered when determining your quadrat size:

1. Can you evaluate the quadrat without significantly disturbing the vegetation? Small quadrats may not need to be entered while large quadrats may be able to sustain the impact.
2. Does the sample in the quadrat adequately describe the vegetation being monitored? Consider the scale of variation (obvious patches, etc) and the species accumulation curve.
3. Can the species attributes (eg counts) be accurately sampled in the quadrat? A smaller quadrat may improve data accuracy and sample precision.

7.1.2 Replication in experimental design

Adequate replication of the treatment and control units will ensure that the results will not be biased by the characteristics of a particular part of the site. In other words, it will ensure that the physical and biological variation of the site is sampled adequately (see Section 7.1.9 Sample strategy: Random, systematic or stratified) so it does not mask any changes due to the treatment.

The replication of measures allows you to determine the mean and establish the variation around that mean. The variation is expressed as the variance, standard deviation (square root of the variance) or standard error.

Replication helps to ensure that the changes you measure are real. However, to do so you must also satisfy the assumptions of the standard statistical tests, including having:

- independent samples, ie the location and content of one quadrat does not influence the content of another
- randomly distributed quadrats, ie no preconceived or other bias or control determines where the quadrats are established.

7.1.3 Pseudoreplication

Pseudoreplication is defined as the use of statistics to test for treatment effects when the treatments are not replicated or the replicates are not independent.

The spatial applicability of the data depends on the scale over which the experiment is carried out and whether the treatments and experimental controls are randomly allocated. If the measurements are made at a single site the conclusions made cannot be generalised and apply only to the site monitored. Replication at a single study site is known as pseudoreplication. The results are valid only for the site.

If two sites are measured, one being a control and the other being a treatment, the experiment is not replicated. The replication problem is not overcome by having numerous quadrats at each site — the experiment would still be pseudoreplicated.

However, if a number of different sites are monitored and treatment and control quadrats are randomly allocated to the sites then conclusions can be drawn about the conservation outcomes in the type of vegetation that was monitored. (See Hurlbert 1984 for a discussion relevant to the design of monitoring projects.)

7.1.4 Number of quadrats

It is worth spending time determining the number of quadrats needed to give a precise estimate. The precision of the estimate is important for detecting any change due to the treatment. If the estimate is imprecise the power of the analysis will be low (see below) and only a very large change will be detectable. In these circumstances it may be very difficult or impossible to do anything meaningful with the data.

The formula for calculating the required number of quadrats to be measured repeatedly is:

$n = SE\ s^2/d^2$

where:

n is the number of quadrats
SE = sd/sqrt n
s^2 is the variance of the sample at a particular time (the variance is the standard deviation squared)
d^2 is the squared percentage change that your sample needs to be able to detect (expressed as a difference in density). For example, if the estimated mean density is 6 individuals/quadrat and you want to detect a 10% change then $d = 0.6$ and $d^2 = 0.36$.

Example of evaluating precision of estimates versus number of quadrats

After collecting data from 50 quadrats in *Epacris barbata* heath, we can calculate the number of quadrats needed to detect a change in *Epacris barbata* density of ±10% and ±20%. The calculation indicates that the 50 quadrats is more than enough to allow us to detect a change of 20%. If we want to detect a change of 10% we need to increase the number of quadrats to at least 78. However, future precision will also be affected by the future variability in the data. In practice, the number of quadrats may be determined by the resources available.

In this example the mean number of individuals for the 50 quadrats was 5.32 and the standard error was 0.75, so the sample variance is 29.

With 10% precision

n = $(0.75 \times 29) / (5.32 \times 0.1)^2 = 21.75 / 0.28$

78 quadrats

With 20% precision

n = $(0.75 \times 29) / (5.32 \times 0.2)^2 = 21.75 / 1.13$

19 quadrats

7.1.5 Calculating the statistical power of the monitoring design

Statistical power is the probability that a statistical test will correctly yield statistical significance if there is a treatment effect. Power analysis is very useful for indicating the size of the change the analysis can detect.

A monitoring design that has a low power has a greater chance of not identifying a change when it has occurred. Hence, project designers need to take account of the power in order to maximise the probability of detecting any difference. It is like choosing the magnification on a microscope, a more powerful design and test will allow you to detect a smaller difference. (See Burgman & Lindenmayer 1998 for a discussion.)

Power is related to alpha, effect size and sample size in the treatment. There is no convention as to the minimum acceptable level of power in a statistical test. The calculation of statistical power has been summarised graphically (Figure 7.1) and in tables (Burgmann *et al.* 1998). To estimate the power from the tables the sample size and effect size must be known. The effect size is the ratio of the differences between the treatment means and the pooled standard deviation. This is not difficult to calculate using the summary statistics powers of programs such as Excel.

$$ES = \frac{\text{Mean 1} - \text{Mean 2}}{\text{Pooled standard deviation}}$$

$$\text{Eg. } ES = \frac{12 - 8}{2.4} = 1.6$$

In this example the effect size is 1.6, which is a relatively large treatment effect. A small treatment effect may be in the order of 0.1. Inadequate designs may not be able to detect small treatment effects because of their lack of power.

GPOWER is a computer program that calculates the statistical power for you. It is a valuable tool for calculating the power of a design after you have collected the data, or beforehand using an estimate of the expected size of the treatment effect. It is available at <http://www.psychologie.uni-trier.de:8000/projects/gpower.html>.

Most experiments are dramatically underpowered, often being less than 50%. In other words, they have less than a 50% chance of detecting the expected treatment effect. The statistical power can be increased by:

- increasing the treatment effect
  - choosing maximally responsive variables
  - choosing valid measures of change rather than poor surrogates
  - reducing measurement error
  - reducing subject heterogeneity
    - using blocks, pairs and/or ANOVA
    - using ANCOVA (analysis of co-variance)
- increasing sample size
- adjusting alpha from 0.05 to 0.1 or even to 0.2.

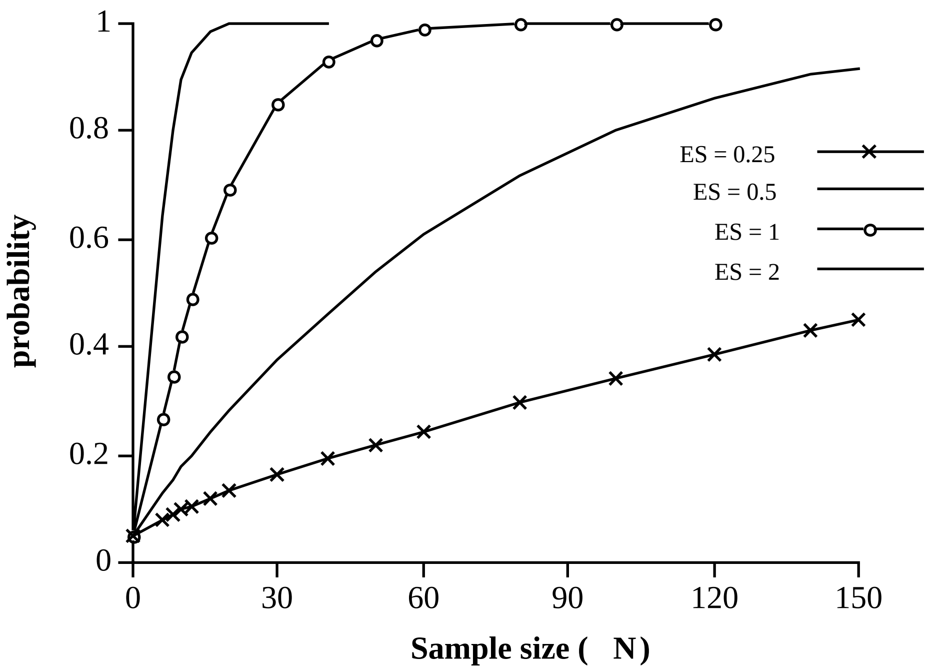


Figure 7.1: The probability of detecting a true difference between two populations of the magnitude indicated (effect size 0.25 to 2), based on random samples of size N (from Burgman *et al.* 1998).

7.1.6 Preparing a species accumulation curve

A species accumulation curve (Figure 7.2) is a useful tool for determining the number of quadrats needed to sample a single stratum of a plant community.

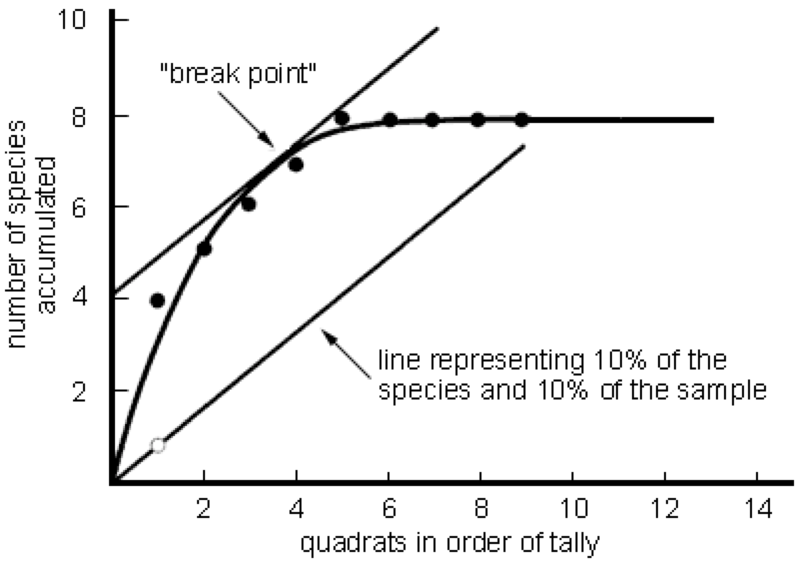


Figure 7.2: Preparing a species accumulation curve for determining the minimum number of quadrats needed to sample a stratum of vegetation (after Roberts-Pichette & Gilespie 1999).

The accumulated number of species counted in successive quadrats is on the Y axis and the number of quadrats is on the X axis. When the points are joined the curve characteristically rises

abruptly initially because many new species are added with each new quadrat. It then levels off as fewer species are added with each additional quadrat.
As added effort yields fewer new species the need for data about the additional species must be weighed against the effort required to get the data. Sampling is sufficient when no or very few species are added with each successive quadrat — that is some time after the curve starts to flatten. The minimum number of quadrats needed may be estimated by referring to the 'break point' where the curve starts to flatten.

For canopy trees the recommended minimum number of 20 m x 20 m quadrats is three over the break point. Tally a few quadrats before preparing a species accumulation curve. If you are below the minimum number needed, tally another two to five quadrats and prepare a new curve. Repeat the process until the minimum number of quadrats is reached. These data are sufficient to describe the community. However, the number of quadrats indicated by the species accumulation curve is not an indication of the number needed to accurately estimate density and abundance, etc (See Section 7.1.4 Number of quadrats and Section 7.1.5 Calculating the statistical power of the monitoring design.)

7.1.7 Quadrat shape

Quadrat shape is of no consequence for sampling accuracy and precision (Kurlow 1966). However, quadrat number, distribution and size are most important.

7.1.8 Quadrat distribution: Randomisation techniques

To determine the locations of the quadrats within the community use a random selection method. One method is to prepare a rough map of the area and draw a line along one side. Randomly select two or more points along this line where the base stakes will be placed. Draw a perpendicular line from each of the base stakes and randomly select the required number of locations along it (Figure 7.3).

Alternatively, randomly preselect two or more points in the stand and hammer in the base stakes. From these points quadrat locations can be determined by randomly selecting points on a compass star centred on the point (Figure 7.3). The distance the quadrats should be set apart for independence will depend upon the quadrat size and the characteristics of the vegetation.

Use a table of random numbers to select the points along the perpendicular or radiating lines. Each point represents the location of a corner of a quadrat. The quadrat should be set to the right-hand side of the line as a standard to aid relocation. Set a stake at each point and drive it in firmly.

A series of lines could be established in this way with a permanent base stake being placed at the origin of each line or at the centre of the compass star arrangement. Be sure to record how the quadrats are distributed in relation to the base stakes. You should include the direction and distance to a consistent corner, eg north. It is even more important to record the location of the base stakes from a datum that can easily be found. The datum may be a considerable distance from the base stakes. For example, it may be a roadside post, a very large boulder or a very obvious large tree. Use a GPS to pinpoint the datum.

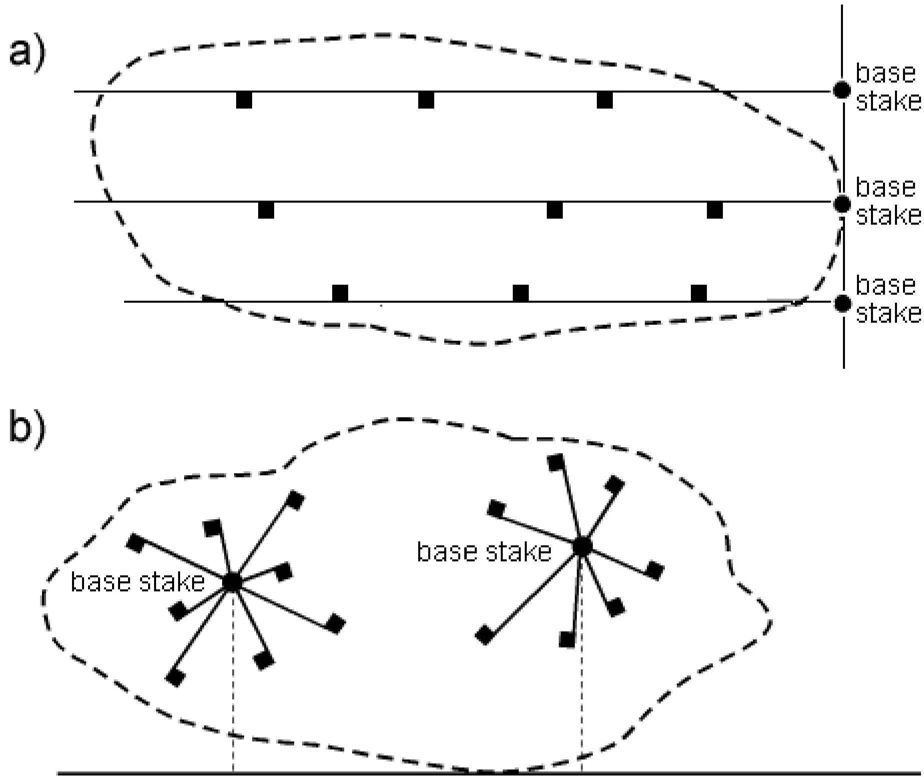


Figure 7.3: Two plans for locating 1 m x 1 m quadrats in a grassland community (after Roberts-Pichette & Gilespie 1999).

a. Three randomly selected lines crossing the community from the base stakes with randomly selected 1 m x 1 m quadrats located along it.

b. Two randomly selected locations for the base stakes from which randomly distributed arms of random length radiate with a 1 m x 1 m quadrat at each tip.

7.1.9 Sample strategy: Random, systematic or stratified random

Consider the need for and the relative merits of random, systematic or stratified sampling and match the strategy to the distribution of the subject and the nature of the landscape you are monitoring.

- Adequate **random sampling** allows generalisations to be made about the vegetation of the area but does not allow particular situations or communities to be targeted and may miss or under-sample them. It is suited to subjects that are distributed with no apparent pattern throughout the study area.
- **Systematic sampling** usually involves using a grid, transect or other system of organisation. For example, it may involve measuring one quadrat out of every ten in a grid. The data may not be sound for statistical analysis because they may not be independent. The independence of the quadrats should be tested for spatial autocorrelation, ie the plants and conditions in one quadrat may be affecting the plants or conditions in another quadrat.
- **Stratified random sampling** involves dividing an area into zones that are ecologically meaningful strata. This will allow a better coverage of the variation using less quadrats. It may also be used to limit the variation in any one stratum — whichever is deemed to be best suited for the task. Quadrats should be randomly distributed within the strata.

7.1.10 Paired samples

When treatments or impacts can be paired with similar quadrats that have not been treated the power of the analysis is increased because the variance is reduced. Situations suited to pairing of samples include treatment effects, such as weed control, and impact effects. If each sample of each pair is independent the Mann-Whitney test should be used to test for any differences. If the samples of each pair are not independent, eg the pair is time 1 versus time 2, the Wilcoxon signed rank test should be used.

7.2 Establishing quadrats

7.2.1 Equipment

Gathering all the equipment necessary to establish quadrats and take the initial measurements requires careful planning. A complete tool kit can save unnecessary return visits or last minute modifications to the design that may cause problems later.

Table 7.2: Essential equipment for establishing quadrats.

Biodegradable flagging tape, two colours
Clinometer
Compass
Camera
Field proforma
First aid kit
Geographic Positioning System
Grid 1m grid 100 squares
Map (1:25 000)
Metal label marker
Metal labels
Metal mallet
Pencils
Pliers
Resealable plastic bags for plant collection
Rubber erasers
Slide hammer
Steel posts
Steel pegs
Steel wire
Sticky paper labels for plastic bags
Tape measures: 5 m, 10m, 20m and 50 m

7.2.2 Method

Team: Minimum of three people.

Time: 15 mins for a basic 5 m or 20 m quadrat.

2 hours for a 20 m quadrat with 2 nested 5 m quadrats and 8 nested 1 m quadrats.

Method: If the site is sloping orientate the quadrat so it is parallel to the slope. If the site is flat orientate it so the corners point to the compass points. The pegs can then be orientated as N, S, E and W. Drive a peg firmly into the ground at the northern point A and another at the intended square side length away at point B. Get two people to attach measuring tapes to pegs A and B and move to the approximate positions of points C and D, crossing their tapes near the centre of the quadrat (Figure 7.4). The third person directs the others until the tapes cross at exactly half the diagonal distance between the opposite corners — this will be equidistant for each tape (2.83 m for a 2 m quadrat and 3.53 m for a 5 m quadrat). Mark this point as the quadrat's centre.

Mark each corner peg with the quadrat number and the appropriate letter. Line A-D is the base reference line. Mark the northern peg as A and make it distinctive from the others to aid orientation for remeasurement.

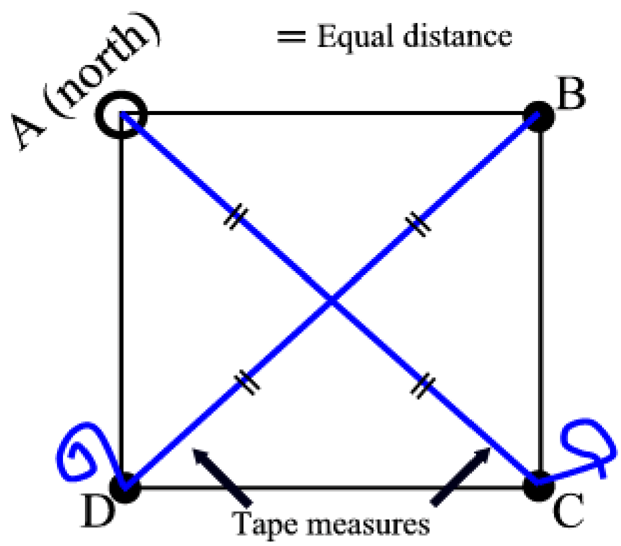


Figure 7.4: Establishing a quadrat using tape measures to produce a square.

7.2.3 Relocating quadrats

If a quadrat is to be revisited it must be easy to find. Remember that vegetation grows and in 20 years even one metre tall pegs may be difficult to relocate. Give future workers every chance of relocating them. Sometimes you may need to trade off visibility and secrecy if vandalism may occur. Regardless of the visibility the main marker post of a quadrat should be relocatable using a compass and tape from an obvious and fixed datum. However, this is becoming less important as GPS becomes more commonplace and accurate. Sketch the layout of the quadrats to scale and indicate the angles and distances to the marker pegs from the datum as well as the easting and northing of the datum and/or quadrat.

Once a quadrat has been relocated it is often difficult to determine the position of the marker peg in relation to the orientation of the quadrat. Make sure the marker peg can be distinguished from the other corner pegs by fixing a metal tag with the quadrat number to it. **The marker peg should be larger than the other pegs and be placed in the northern corner**.

Sketch the quadrat and indicate all the pegs and measurements of the quadrat. This is part of the design and should be included on the field proforma. It may be useful to indicate obvious objects such as burnt tree stumps, tracks, fences and large boulders on the sketch to make relocating easier. Make sure the site description and layout is recorded on or is attached to the field proforma and the location of the proforma is recorded in the program register.

7.2.4 Making slope correction

On uneven or sloping ground the distance between the corner quadrat stakes must be adjusted to take account of the slope. The distance on a flat surface between two corner stakes situated on a slope is always greater than the corresponding horizontal distance (Figure 7.5). The purpose of this correction is to ensure that each quadrat contains the same horizontal area. This is important for large quadrats in a stratified sample where one stratum is on a significant slope and another is not. The correction will help to ensure that any difference detected is due to the treatment and is not enhanced or diminished by any measurement error.

The simplest way to correct for slope is to hold a tape measure horizontally along h_1 (Figure 7.5) and to use a plumb-bob to indicate the point on the ground directly below the end at A. This point will be the lower limit of the quadrat.

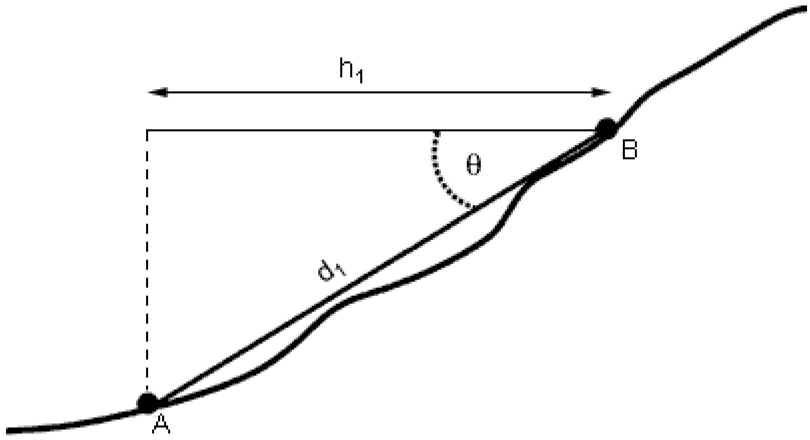


Figure 7.5: Slope correction. The distance between two points measured along a slope is always greater than the corresponding horizontal distance. On sloping ground the 20 m interval between the stakes must be extended by a factor corresponding to the degree of slope (after Roberts-Pichette & Gillespie 1999).

8 Sampling Designs

8.1 Introduction

Vegetation formations, such as grasslands, forests and alpine shrublands, differ both in the species they support, and in the structure of the community. Tasmania's vegetation includes communities dominated by trees, shrubs, grasses and/or sedges. In our descriptions we refer to these communities as, for example, shrubby forests, grassy woodlands or grasslands. It is implicit in this typology that formations can co-occur so grasslands and shrublands may be found under forest canopies. In a forest the different formations are called strata. The lower strata include regenerating species of the strata above them.

Differences in species richness, frequency and density of species between strata mean that different quadrat sizes are needed for the different strata. The quadrats can be used singularly or in combination to accommodate more than one stratum in, for example, a forest.

The following sections outline designs for the selection and arrangement of quadrats in three vegetation strata: the forest canopy, the shrub layer of forests and non-forests, and the ground cover of all vegetation formations. The quadrat sizes used are 1 ha, 20 m x 20 m, 5 m x 5 m, and 1 m x 1 m. Those less than 1 ha are referred to as 20 m, 5 m and 1 m quadrats respectively. Ways of nesting the different quadrat sizes in order to sample all the strata are shown. Other quadrat sizes can be used to accommodate specific needs or limitations but the rationale for the number and arrangement of quadrats will remain the same.

These designs assume that landscape stratification is not required. If stratification of the area is required the designs should be applied to each landscape stratum separately.

8.2 Experimental design

Ecological measures, such as native species abundance, vary naturally over time and between sites. By using a robust experimental design you can confidently distinguish between changes in the composition and structure of the vegetation that are a response to the management or treatment, and changes that occur naturally over time and between sites.

The essential requirements of a robust experimental design are having treatment controls, using a random and independent arrangement of quadrats, having adequate replication of quadrats, and using representative experimental units. Treatments and experimental controls should be allocated by:

- pairing experimental units (quadrats, blocks or sites) that are similar in terms of environment and the species present, then
- randomly designating one as the treatment and one as the experimental control.

If experimental units cannot be paired then it is especially important that they are distributed to cover the range of vegetation types in which the treatment will occur.

The following designs are robust for the situations indicated.

8.3 Design options

The options for an experimental design revolve around a consideration of how the treatments are applied to the sites and the nature of the sites (whether numerous, similar or single sites). The best option depends on a combination of the following factors:

- whether the subject occurs in a large enough part of a site at an adequate density
- for weed control, whether you are willing to leave uncontrolled quadrats throughout a site, or whether you would prefer to set up large blocks as treatment or experimental control areas, or whether it is best to leave entire sites uncontrolled
- whether the species or community occurs at many sites
- whether you want to generalise the results widely, eg make conclusions about the response of species richness to the removal of domestic grazing in grassy systems generally
- whether you want to restrict the applicability of the results to a particular site, eg examine the recovery rates of *Sphagnum* moss after mining in the Central Highlands.

8.3.1 Single site

- Randomly select the locations for the treatment and control quadrats and apply the treatment to the treatment quadrats. This will allow you to detect the effectiveness of the treatment. If similar treatment and control quadrats are paired the experiment results will be more powerful. This design is known as a BACI design (before/after, control/impact design) (Stewart-Oaten *et al.* 1986).

or

- Set up randomly located independent quadrats and measure the vegetation in all the quadrats before treatment and at set times following treatment. This has no experimental control so no hypothesis can be tested. Statistical differences can be determined in the time series.

The results from these designs cannot be generalised to all other sites because the data are collected from a single site.

8.3.2 Multiple sites

- Randomly locate the quadrats throughout the sites and randomly allocate the treatment and control quadrats.

or

- Select pairs of similar sites and randomly select one of each pair to be the treatment quadrat and other to be the control quadrat.

The results from these options are general and can be extrapolated to other areas of similar vegetation.

8.3.3 Blocks at one or several sites

- Subdivide the sites into blocks.
- Pair the blocks with similar vegetation types.
- Randomly allocate each block as a treatment or experimental control.

or

- Establish equal numbers of quadrats in each of the blocks before treatment.
- Measure the vegetation in all the quadrats before treatment and at set times following treatment.

8.3.4 Replication

Quadrats

Use an equal number of treatment and experimental control quadrats having calculated the number needed for the required power. (See Section 7.1.5 Calculating the statistical power of the monitoring design.)

Blocks

Use at least three blocks per treatment and an equal number of experimental control blocks per treatment.

Sites

Use at least four sites per treatment and an equal number of experimental control sites per treatment.

9 Quadrat Designs

9.1 Ground cover

Regardless of the vegetation formation, long-term monitoring of ground cover species composition will help to differentiate between variation in the baseline population and variation caused by longer-term environmental and management changes. Monitoring of the ground vegetation stratum in forests will give an indication of the future forest dynamics.

The monitoring of rare plant species, many of which are herbaceous, and invasive weeds occurs in this stratum. Information about the structure and composition of this stratum is important for management decisions that will affect the flora and fauna habitat structure.

9.1.1 Quadrat size

The recommended quadrat size for monitoring ground vegetation is 1 m.

The number of quadrats necessary to adequately characterise the species composition of a particular community is probably less than 30 for most Tasmanian situations but project or site limitations may reduce this number. Determine the number of quadrats needed by setting up a number of permanent quadrats, preparing a species accumulation curve, and adding quadrats as necessary. Alternatively, do a quicker unmarked survey to collect data for the species accumulation curve.

The advantage of the first method is that it is faster but you may be under-prepared for the task. The second method allows for alternative project design and preparation for field work.

9.1.2 Quadrat arrangement

The 1 m quadrats can be set up independently or nested within larger quadrats. Their arrangement will vary depending on the nature of the project and the other strata being sampled.

One metre quadrats may be arranged as follows:

- randomly distributed throughout a community or within a 1 ha quadrat
- nested in 5 m quadrats
- nested in 20 m quadrats.

A disadvantage of nesting is that the changes measured may be due to the impact of the people monitoring rather than the treatment being considered. Therefore, the arrangement of 1 m quadrats must be carefully considered because of the damage the people measuring could do to the vegetation in the larger quadrat in which they are nested. If measuring is to be done more than once a year the nested quadrats should be established along the sides of the larger quadrats.

9.1.3 Independent 1 m quadrats

Choose a randomisation technique and set up the quadrats.

9.1.4 1 m quadrats nested in 5 m quadrats

The recommended distance between 1 m quadrats is 5 m. However, this would allow only one 1 m quadrat to be nested in each 5 m quadrat. If more 1 m quadrats are added to the nest in a 5 m quadrat the independence of the 1 m quadrats may be compromised so the effect of this on the rigour of the design needs to be considered (consider spatial autocorrelation). No more than four 1 m quadrats should be nested in a 5 m quadrat and the distance between them should be maximised. The presence of tree stems may affect the location of the 1 m quadrats.

Opportunities for randomisation will be limited but this is less important if the 5 m x 5 m quadrats have been randomly located. The random distribution of any additional 1 m quadrats outside the 5 m quadrats will be statistically sound.

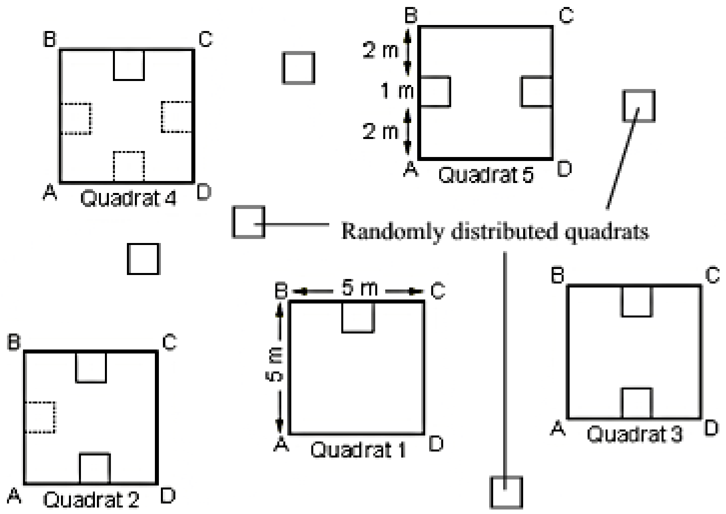


Figure 9.1: Layout of 1 m quadrats nested in randomly distributed 5 m quadrats. All 5 m quadrats should be at least 15 m apart. The dotted lines show possible arrangements for additional 1 m quadrats within the 5 m quadrats plus additional randomly located 1 m quadrats outside the 5 m quadrats (after Roberts-Pichette & Gilespie 1999).

9.1.5 1 m quadrats nested in 20 m quadrats

Randomly select the 20 m quadrats that will nest the 1 m quadrats. Randomly select the edge (A-D, A-B, B-C or C-D) for the 1 m quadrats. Set up four (or fewer if obstructed by tree stems) 1 m quadrats between the stakes set 5 m from the relevant corners of the 20 m quadrat, leaving a minimum of one metre between each quadrat (Figure 9.2). The layout can be done in conjunction with nested 5 m shrub layer quadrats or it can be independent of them.

This arrangement will give four 1 m quadrats along one side of a 20 m quadrat (if no trees or other obstructions get in the way). Five 20 m stand-alone quadrats would give up to twenty 1 m quadrats. If necessary, select a second side of the 20 m quadrats for additional 1 m quadrats.

9.1.6 Quadrats nested in a one hectare quadrat

If possible the 1 m quadrats should be staked and flagged before the 5 m and/or 20 m quadrats are surveyed so damage to the ground cover in the 1 m quadrats can be avoided. Arrange the quadrats along the two outside borders of quadrats 07, 09, 17 and 19 (Figure 9.2).

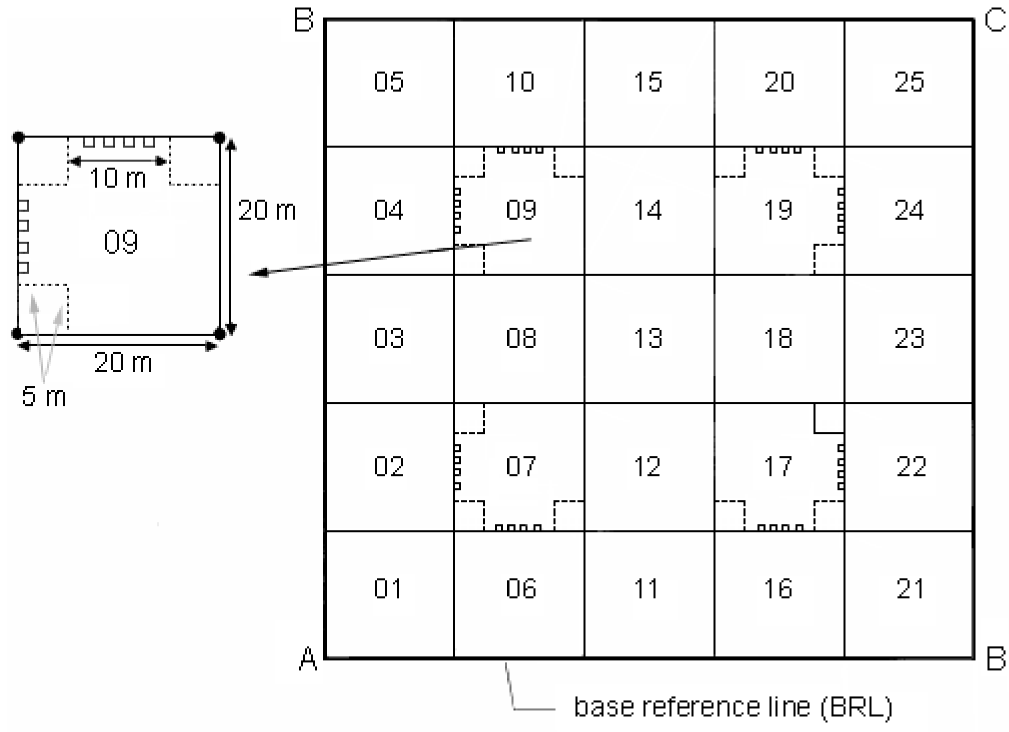


Figure 9.2: Layout of 1 m quadrats nested in a 1 hectare quadrat independently of the 5 m quadrats. A maximum of four 1 m quadrats should be laid out along a side, spaced at least 1 m apart (avoiding tree trunks), and starting no less than 6 m from a corner. Leave a minimum of 1 m between each 1 m quadrat. This will give a maximum of thirty-two 1 m quadrats in each 1 hectare quadrat. If this number is insufficient additional 1 m quadrats could be established along the outside borders of quadrats 08, 12, 14 and 18 (after Roberts-Pichette & Gilespie 1999).

9.2 Shrub layer

Woody species 1–4 m in height and less than 10 cm diameter at breast height (dbh) are included in the shrub stratum. The maximum height or diameter class should be selected to suit the task. For example, if most of the individuals of one species of even age are between 3 and 4 m in height but the dbh varies between 5 and 15 cm it would be sensible to include them in the same stratum by setting the max height at 4 m and ignoring the dbh.

In forest communities monitoring of small trees and shrubs can give information on the rates of growth and mortality of sapling species and the replacement rates of canopy species. Monitoring can also provide data about the influence of the canopy on the rates of recruitment of seedlings in the understorey, data on the species confined to the lower forest strata, and data for predicting how the structure of the upper forest strata is likely to change in the future.

In non-forest communities data from the shrub layer should give insights into the dynamics of any woody vegetation patches. The establishment or control of invasive weed species may also be tracked. Detailed shrub layer data are also important when monitoring or managing priority fauna species in forest and non-forest communities.

9.2.1 Quadrat size

Five metre quadrats are recommended for this stratum.

9.2.2 Number of quadrats

- Use the methods described in Sections 7.1.4 (Number of quadrats) and 7.1.5 (Calculating the statistical power of the monitoring design) to calculate the number of quadrats needed to give the required precision for an estimated variable.
- Ten quadrats are recommended to characterise the shrub layer.

9.2.3 Quadrat arrangement

Quadrat arrangements for the shrub stratum will differ with the type of plant community being monitored. In forest ecosystems nested or independent quadrats are recommended but in non-forest communities independent quadrats are recommended.

9.2.4 Forest ecosystems

It is assumed that the shrubs and small trees in forest ecosystems will be monitored in conjunction with canopy-tree monitoring. In wet forests it is preferable that the small-tree and shrub quadrats be independent rather than nested because trampling can be very damaging to the ground cover and dense shrub vegetation. In dry forests or forests with sparse shrub and ground cover the quadrats can be nested in 1 ha or 20 m quadrats. Because 5 m quadrats will have to be trampled it is worth thinking about monitoring before the ground cover dries so the ground cover is more resilient to disturbance by trampling.

The 5 m quadrats may be:

a. randomly distributed and independent of a 1 ha quadrat
b. nested in one or more randomly selected corners of the independent 20 m quadrats
c. nested in randomly selected corners of the randomly selected 20 m quadrats which are subsets of a 1 ha quadrat

For situation (a) locate the 5 m quadrats independently at least 15 m apart and in the same community type as any other quadrats in the design.

For situations (b) and (c) nest the 5 m quadrats in the independent 20 m quadrats or a 1 ha quadrat (Figures 9.1 and 9.2). Randomly select the 20 m quadrats and then randomly select a corner of the chosen quadrat. Reject any 5 m quadrat that is not a minimum of 15 m from another quadrat of the same size (ie they must not be in adjacent corners).

If the species accumulation curve indicates that more 5 m quadrats are needed than the number of 20 m quadrats select diagonally opposite corners to ensure the 5 m quadrats are 15 m apart.

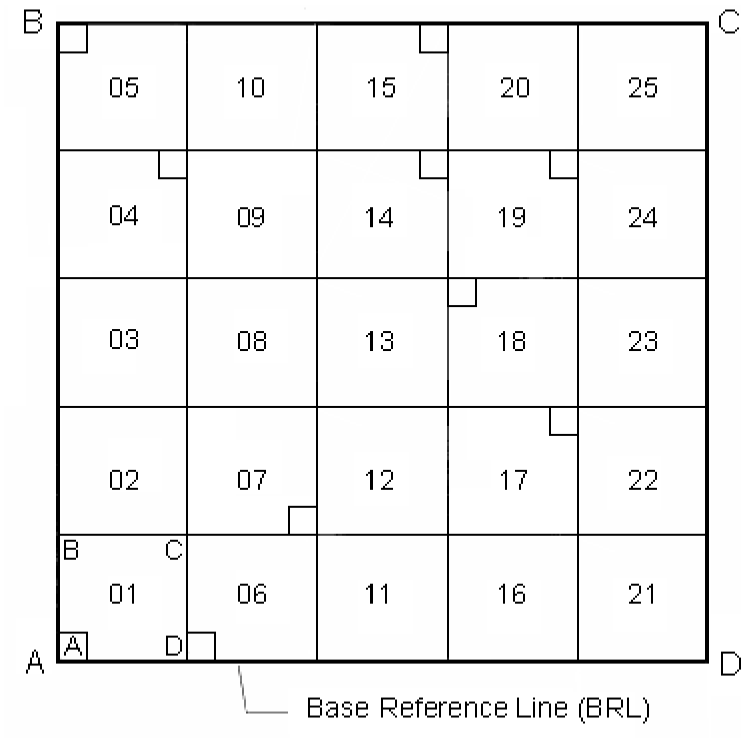


Figure 9.3: Plan of a 1 ha quadrat showing the positions of 5 m quadrats nested in ten randomly selected 20 m quadrats (after Roberts-Pichette & Gilespie 1999).

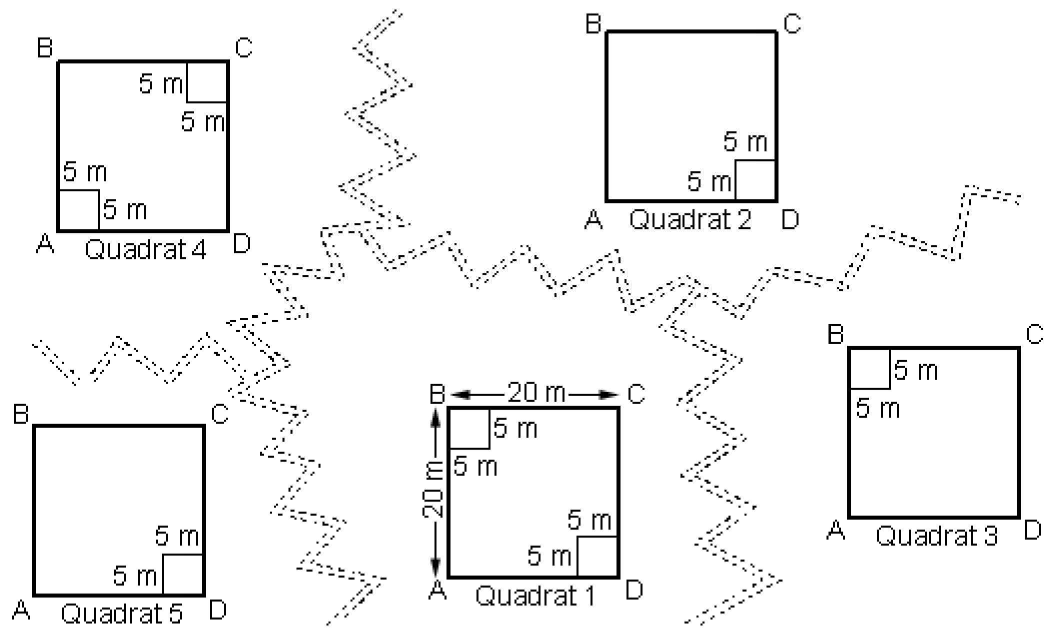


Figure 9.4: Layout for 5 m quadrats nested in randomly selected corners of 20 m quadrats. The broken lines indicate that the distance between the quadrats is not to scale (after Roberts-Pichette & Gilespie 1999).

9.2.5 Non-forest ecosystems

Determine the limits of the community being monitored. Randomly selected locations for the independent 5 m quadrats are recommended.

1. Locate the quadrats at a distance from the stand's edge which is equivalent to at least three times the height of the canopy of the shrubs or small trees being measured.
2. If this is not possible because the stand is small or irregular the quadrats must be placed at a distance which is at least equivalent to the height of the canopy from the stand's edge.
3. Ensure the quadrats are independent.

On a scaled map of the community overlay a square grid of a scale appropriate to the scale of the map. As an example, for a grassland ecosystem of about eight hectares with stands of shrubs and small trees draw a grid 400 m long by 200 m wide and assign three-digit numbers to the grid lines on the X and Y axes (Figure 9.5).

From a table of random numbers based on the units of the X and Y axes select and record the cross points on the grid that satisfy the conditions outlined above. Each cross point becomes the centre of a quadrat.

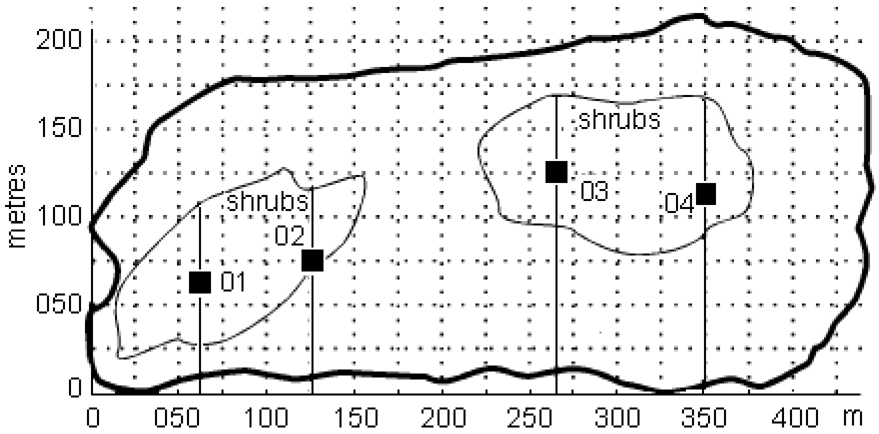


Figure 9.5: A map of a grassland with two patches of shrubs and small trees overlaid with a grid. The locations of four randomly selected 5 m stand-alone quadrats (not to scale) are shown. Locations 01, 03 and 04 would be accepted but 02 would be rejected (after Roberts-Pichette & Gilespie 1999).

9.3 Canopy trees

9.3.1 Stand selection

On closer examination a forest stand may have considerable patchy variation within it. The size and variability will affect the number of quadrats needed to adequately sample it. The variation may be stratified according to a sensible landscape variable such as drainage, altitude or aspect. Alternatively, the patch may be mapped and each mapping unit sampled independently. Not all units need to be sampled though this will depend on the monitoring question.

The full scope of the design will indicate what quadrat sizes need to be used. If the understorey strata are to be studied using nested quadrats their arrangement should be determined before any surveying begins. Early consideration of the sensitivity of the ground layer to disturbance will assist in designing a sensible nested or other arrangement of the quadrats. Attention to this factor during the planning process will increase the likelihood that the changes observed are the result of the environment or management and not the effects of the people collecting the data. Experience has shown that this point cannot be over-emphasised.

The number of 20 m quadrats is often determined by the time and resources available compared to the size of the stand. The designer should determine the number of quadrats needed in the light of the goals of the monitoring program, statistical advice and the species accumulation curve.

In Tasmania 20 m quadrats are recommended, with a minimum of about five quadrats in any one stand. A species accumulation curve can be used to help decide if this number is adequate for characterising the floristics. However, statistical power and other monitoring or research objectives may indicate that more quadrats are needed than the species accumulation curve suggests.

9.3.2 Quadrat arrangement

All quadrats should be randomly distributed in the chosen stand to reduce bias. Occasionally, the quadrat locations may be selected for specific or subjective purposes. If so, document the reasons for the location, number and arrangement of quadrats. In selecting the location for each 20 m quadrat several underlying principles should be observed:

a. Twenty-metre quadrats should be located at a distance from the non-forest stand edge that is equivalent to the height of the canopy in order to exclude any external environmental effects that may create edge effects.
b. In riparian forests where the trees occupy bands 60–200 m in width and the trees are the object of the study rather than the vegetation gradient 20 m quadrats should be established more or less parallel to the watercourse. When the band is less than 60 m in width the use of transects is recommended.
c. Avoid setting up quadrats that include atypical (for the stand) major vegetation gradients or sharp ecological discontinuities such as a small lake, field or river.
d. Avoid locations where roads or trails cross the quadrat unless the impact of the use of the trail is the object of monitoring. If used make sure the reason is documented.

One method for randomly selecting quadrat locations is to prepare a map of the stand and overlay it with a grid of an appropriate scale (Figure 9.6), rejecting any that do not meet the conditions outlined above. Each selected cross point becomes the centre of a monitoring quadrat.

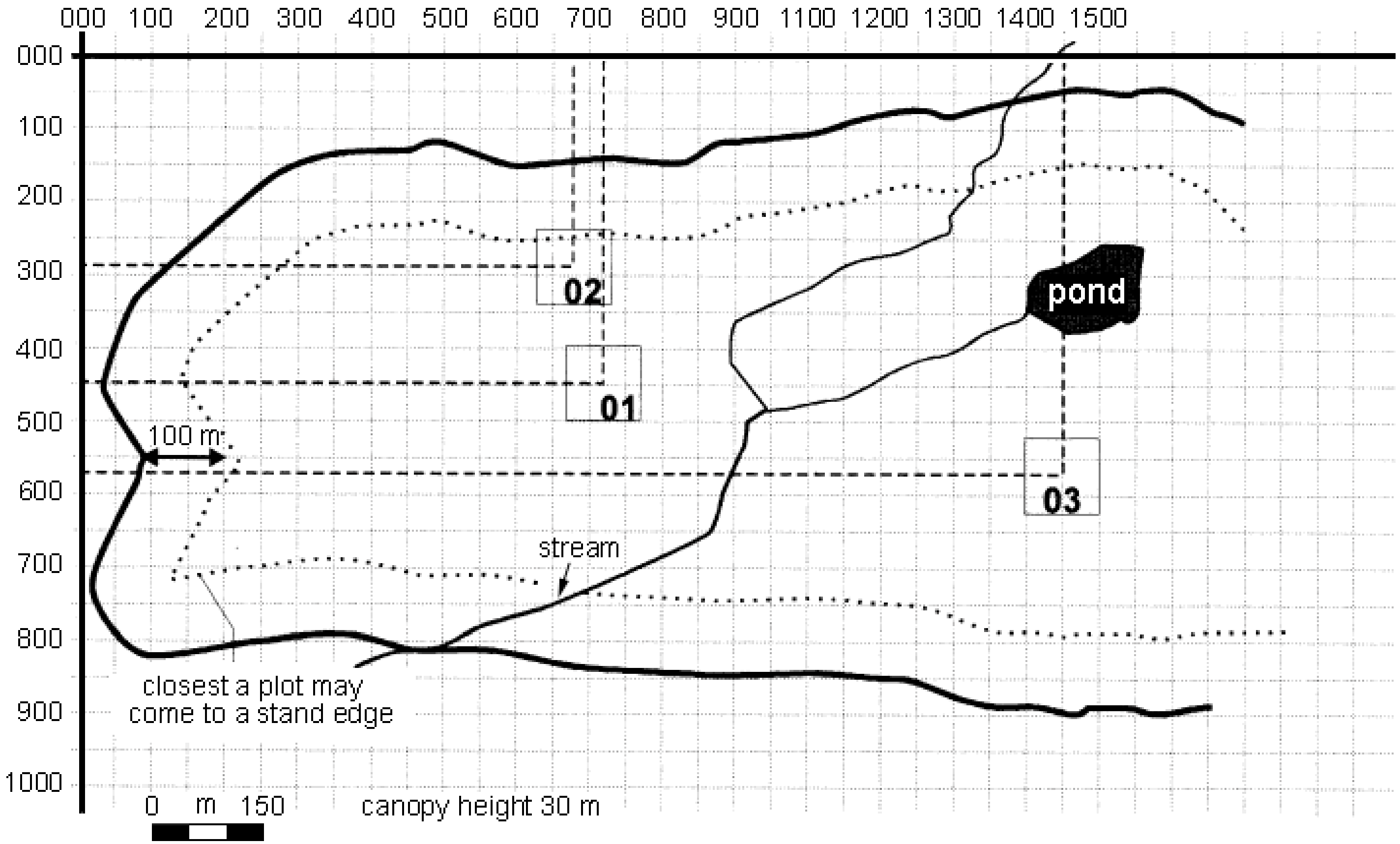


Figure 9.6: A map of a forest stand overlaid by a grid of horizontal and vertical lines. Randomly selected co-ordinates for 01 and 03 would be acceptable but those for 02 would be rejected.

10 Transects

Transects are useful when gradients are evident in the vegetation. Examples of places where transects would be appropriate are ecotones such as between heath and forest, through a riparian zone, or across a break in slope or fire boundary. They can also be used to illustrate impacts, although paired quadrats may be more appropriate.

Transects are an example of systematic sampling where data are collected at fixed intervals along a line or from contiguous or discontinuous quadrats. For example, you might use a transect to show the changes in plant species across the edge of remnant vegetation following clearing or to investigate the effects on species composition of a pollutant leaking from a septic tank.

10.1 Line transects

Line transects are used when you want to illustrate the changes in a plant community along a gradient or linear pattern. They can usually be completed fairly quickly though this depends on the data you collect.

A transect line can be made by laying a tape measure along the gradient of the area you want to study. The tape measure should be pulled tight and fixed. Its position should be carefully considered to be certain it is aligned along the strongest gradient. If it is incorrectly placed the results may be confusing.

The species touching the line can be recorded along the entire length of the line or at each marked point. If the slope is also measured it can be included in the profile diagram.

Line transects do not produce as much information on the relative densities of the individual species as belt transects. A line transect tells you what is present at the sample points but it does not give you much information about how much is present. If detailed density information is required a belt transect should be carried out.

Results

The results that can be reported from a line transect include:

- a change in the species dominance along the transect
- a transition in the species composition along the transect
- zones along the transect showing that some plants are common to all the zones and others are common to only one
- the ranges of individual plant species
- the dominant species in each zone can be tabulated.

The results can be illustrated using graphs and tables, particularly bar charts and histograms. These can be designed to include change over time when the transects have been remeasured.

The diagram below (Figure 10.1) shows the ranges of eleven of the most important species occurring along a continuous line transect across an ecotone between dry forest and swamp. The chart clearly illustrates the plant zonation patterns across the ecotone. It also illustrates how the boundaries of the zones become blurred when certain species overlap and occur in more than one zone. This is a useful way of clearly visualising the changes taking place along the line. It enables the patterns of zonation in the species along the line to be identified. It is useful to use photo points to augment your line transect as it gives you an additional record of any changes.

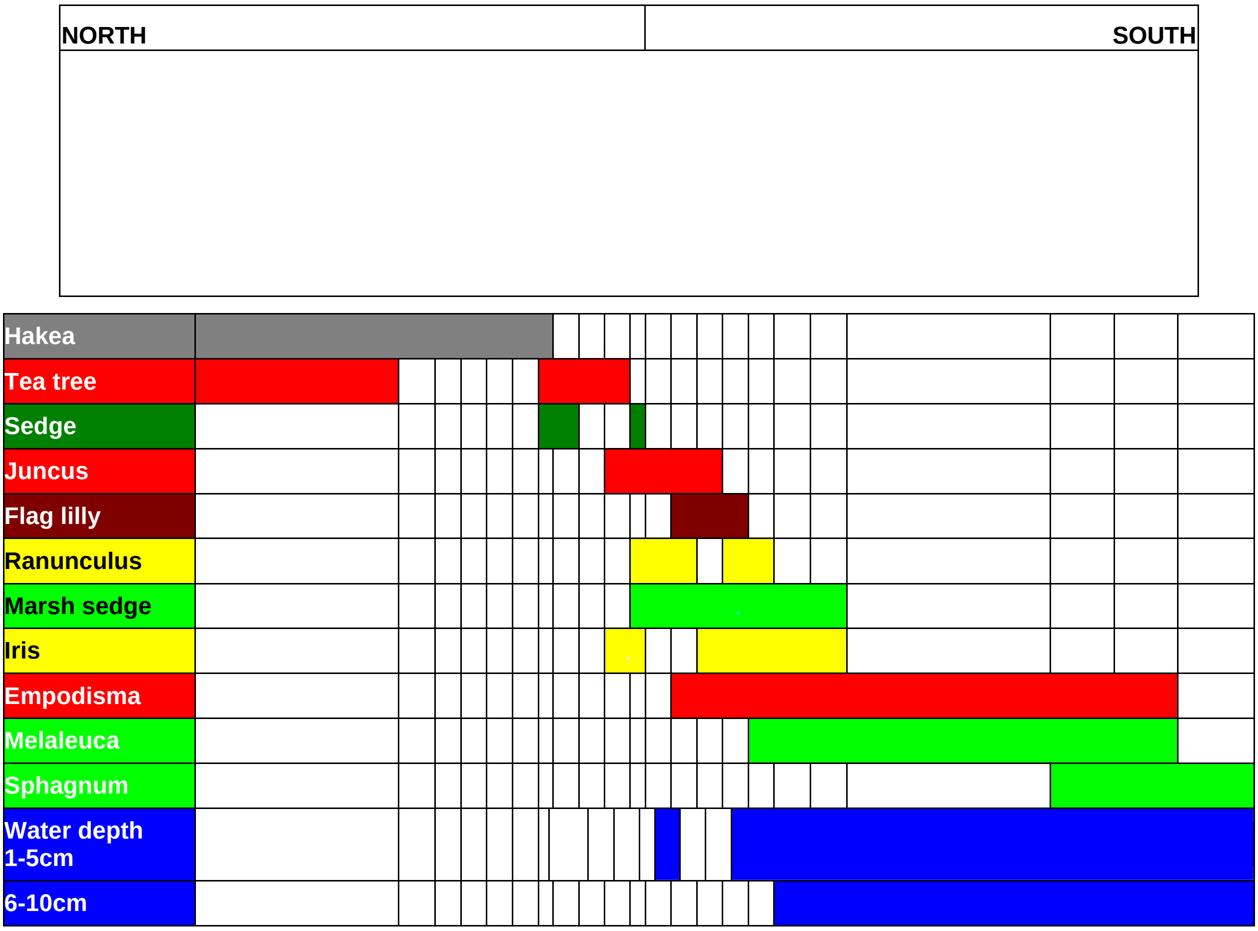


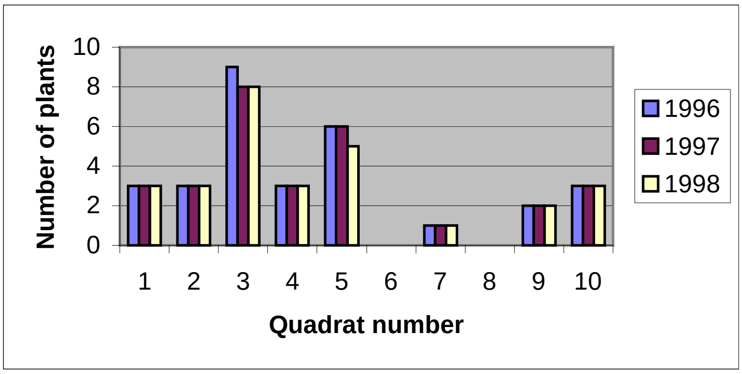
Figure 10.1 The distribution of 11 species along a continuous line transect across an ecotone between dry forest and swamp. The data is displayed using colour blocks for different species. (Adapted from OWWT 1999.)

10.2 Belt transects

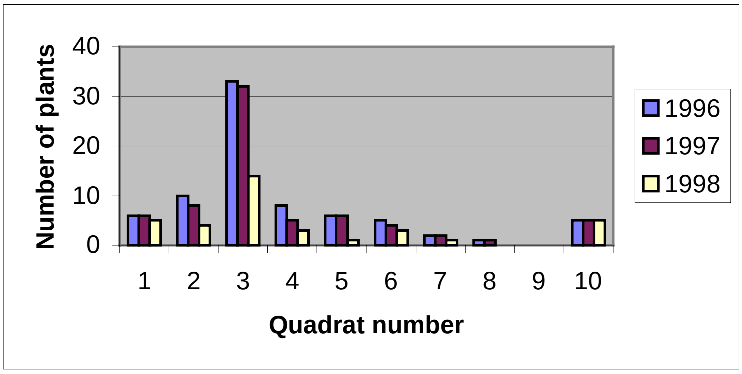
Placing quadrats on either side of an ecotone will not be sufficient to detect change early so a closely spaced series of quadrats or a set of contiguous quadrats in a transect will be needed. The quadrats should extend from one side of the ecotone, through it, to the other side. The number needed will depend on the spatial scale of the ecotone. The transects should be aligned with the gradient.

The quadrat size should be consistent with that needed for measuring canopy trees, shrubs or ground cover. You should use at least three transects for descriptive purposes and you need to consider replication and the use of controls if an impact is being measured. Statistical advice should be sought at this point.

Belt transects are similar to line transects but they give more information on the abundance of species. Lay the transect line across the area to be surveyed and place a quadrat at the first marked point along the line. Identify the plants in the quadrat and estimate or determine their abundance. The height of the plants in the quadrat can also be recorded. An example of the results that can be obtained from a belt transect survey is shown in Figure 10.2.



a.



b.

Figure 10.2. Belt transect data showing the number of *Epacris barbata* plants in ten quadrats over 3 years in a) one control and b) one treatment transect after the introduction of *Phytophthora cinnamomi*.

10.3 Advantages and disadvantages of transects

Transect data is useful to illustrate variation along gradients and change over time.

Continuous line transects are efficient over long distances when individual plants are sparsely distributed along the line. For example, on sand dunes or when recording species that are dispersed.

The data from quadrats along contiguous belt transects may not be independent and may not be suitable for statistical analysis.

If the plant cover is dense line transects are very time consuming to survey over long distances.

If separating individuals of a species is a problem, such as grasses or mosses, avoid continuous line transects.

If a particular area is not suitable for a continuous line transect an interrupted line transect may be suitable. This method records the individuals that touch nominated points along the line, for example every one metre mark. It can be done more quickly over long distances. Its disadvantage is that many of the species present may be overlooked if the interval selected is too large. To illustrate this problem, the number of species recorded on two line transects using three different methods is shown in Table 10.1. Both interrupted line transects using an interval of two metres missed more than 60% of the species present. It is important to remember that the most suitable method will depend on the habitat being investigated and the purpose of the survey.

Table 10.1: An example of the number of species recorded along two line transects.

No. of species recorded	Line transect 1	Line transect 2
Continuous	29	36
Every metre	16	19
Every two metres	10	12

11 Estimating Population Size

When estimating population size the aim is to obtain an estimate that is both accurate and precise. Short of counting *every* individual no survey will be absolutely precise. However, an accurate estimate and indication of the likely error can be obtained if adequate sampling is used.

The number of plants in a population can be easily estimated by counting the number of plants in a series of randomly distributed quadrats of known size and extrapolating the mean density to a measured area of occupied habitat. The number of samples (quadrats) required will vary with the size of the habitat, the variation in plant density, and the precision required of the estimate. It may be necessary to use a stratified random sampling technique if the landscape varies along a gradient.

Once the size of a population has been accurately estimated the size can be monitored for fluctuations. To detect fluctuations in a population's size the change must be greater than the error associated with the original estimate. Adequate sampling and careful counting will minimise the error so relatively small changes can be detected. (See Keith 2000 for methods.)

If quadrats are used in transects it is important to determine whether the density data are spatially autocorrelated. That is, whether the density of plants in one quadrat affects the density in a neighbouring quadrat. Rather than reducing efficiency by measuring quadrats that may be autocorrelated and have to be rejected later, it may be better to use randomly distributed quadrats rather than transects.

The size of the quadrat should take account of the feasibility of accurately counting all the individuals in it. A grid may be useful where the plants are small and very dense. The quadrat should be large enough to contain a significant number of plants and few or no empty quadrats. Excessive zero values indicate the occupied habitat is patchy, unsuitable habitat has been included, or the quadrat is too small. In the first two situations the location of the quadrats should be reconsidered. As a rule of thumb no more than about 20 plants should occur in a single quadrat or in a grid square within a quadrat otherwise significant measurement error may occur.

A practical way of determining the adequacy of the sampling intensity is to chart the mean density and stop sampling when additional quadrats result in only a minimal change to the mean and standard error. As the sample size (number of quadrats) increases the mean and standard error become more robust due to the amount of data accumulated (Figure 11.1).

Permanent quadrats, transects or non-permanent quadrats can be used. The advantages of using non-permanent quadrats are that no quadrats need to be established, marked and relocated, and shifts in the location of plants can be accounted for. Theoretically, a second independent survey (at the same time) should give an estimate that is not significantly different from the first. However, by measuring the same quadrats you get a more precise estimate of change over time. This is because it is likely that the variability of the change in density over time will be less than the variation in density throughout the monitoring area at one time. For example, if you established 100 quadrats to estimate the density at one point in time you would only need to resample 70 quadrats to measure the change in density to the same level of precision (eg ±20%).

If you establish new quadrats to measure a change in density you will need 40% more quadrats to get the same precision for a density estimate at one time. For example, if you establish 100 quadrats to estimate density you will need 140 newly established quadrats to measure a change in density to the same level of precision.

Another advantage of permanent quadrats is that individual plants can be marked and any number of attributes can be measured and monitored, including recruitment, mortality, number of flowers and rate of growth. The collation of these data constitutes a demographic census. A demographic census is recommended for monitoring populations of single species because it allows you to estimate population size, describe the health of the population and predict future changes.

An example:

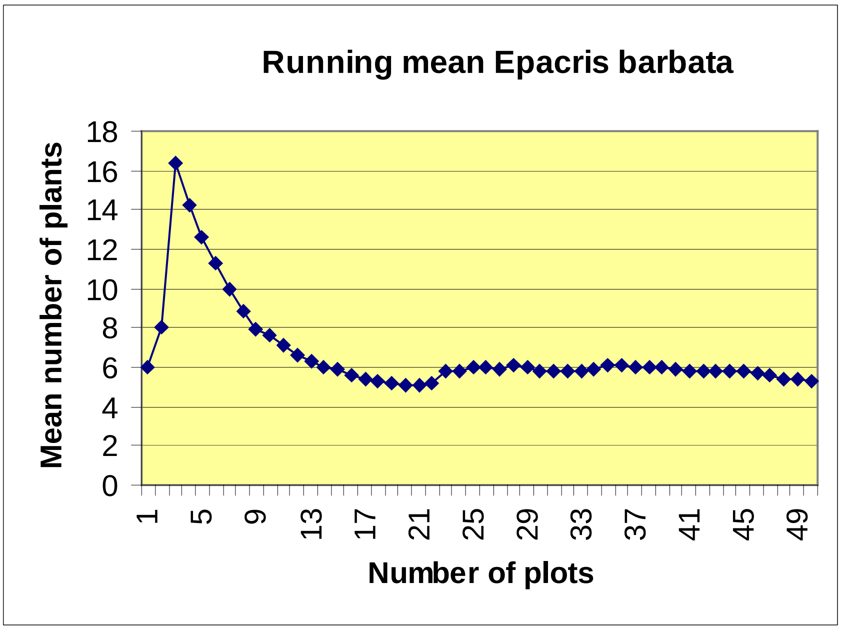


Figure 11.1: Graph of the running mean number of plants in successively counted 2 x 2 m quadrats for *Epacris barbata* at Freycinet Peninsula in 1996.

Figure 11.1 shows the results of calculating the mean number of plants in fifty 2 m x 2 m quadrats after counting each successive quadrat. The mean stabilised at 6 plants per quadrat after 25 quadrats but decreased to 5 plants after 46 quadrats. This was a gradual decline but only whole numbers are shown in the diagram.

From these data the population size (P) can be estimated using the formulae:

P = D x Ao

where:

D = mean density in the sample quadrats
Ao = area of occupancy of entire population expressed as a multiple of the quadrat area

P= 5 x (60 000/2)
P = 5 x 30 000
P = 150 000

Because this is an estimate we need to indicate the variance around the estimated values. The variance is calculated using the lognormal distribution of the data:

V = (1-As/Ao) x Vd x Ao^2

where:

As = area sampled
Ao = area of occupancy of entire population expressed as a multiple of the quadrat area
Vd = variance in plant density

(1-100/60 000) x 0.00149 x $(60\ 000)^2$
= 59 302

The population estimate is 150 000 ± 59 302

Because of the large variance around the estimate of population size it would be difficult to determine whether the population was fluctuating by repeating the count from time to time and comparing the estimates. Repeatedly remeasuring permanent quadrats is the best way to measure a decrease or increase in a population. Even then adequate random sampling is needed and an indication of the power of the analysis is important in order to understand the size of the fluctuation the analysis is capable of detecting.

Since most monitoring projects do not have long-term data that show the cycles of population fluctuation, detecting a decline in the size of a population needs to be considered in the light of other ecological information gained from the population census. Such evidence may include plant condition, the proportion of flowering plants, and the age class distribution. For example, a decline in a population due to a fall in the numbers in the smallest mature age class may indicate density dependent thinning rather than a decline due to the loss of mature individuals from a population below carrying capacity.

12 Ecological Burning

Biologists often prescribe burning patches of bush for habitat management. Ecological burning may be carried out to benefit entire plant communities or a particular plant or animal species. There are many factors involved in prescribing ecological burns and a body of literature outlines the general principles of fire history and behaviour, and the fire requirements of the Australian flora and fauna (eg Gill *et. al* 1981; Fensham 1992; Marsden-Smedley *et al* 1997). One of the most important questions that must be answered for a prescribed burn is when to burn? To answer this question we need to consider the general principles in the context of the site specific parameters.

The question of when to burn has three components. First, at what frequency should we burn? Second, at what time of the year or in what season should we burn? Third, on what day should we burn? The first two components should be answered by the person prescribing the burn. The third component should be answered by the person conducting the burn.

It is important that the person conducting the burn understands the relationship between soil heating and soil moisture because it will affect the choice of day to burn. The soil moisture will affect the temperature the soil reaches during the fire and hence the level of seed germination (Burrows 1999; Bradstock & Auld 1995).

In the following discussion we will explore the role of monitoring and how it can be used to answer the first component of the question: the correct frequency of burning.

Fire interacts with vegetation in a cycle that produces an ecological outcome. The outcome differs according to the variables acting in the cycle. The major components of the cycle influencing the outcome are the soil seedbank of the species or community, the population growth or decline of the species or community, the fuel load that develops over time, and the fire intensity (Figure 12.1). Seasonal conditions also act on the cycle but are beyond our control. The variables we can attempt to control are the timing and frequency of fire and the soil moisture content. We need to monitor the variables in the fire cycle to develop a prescription that will induce the ecological outcome we want.

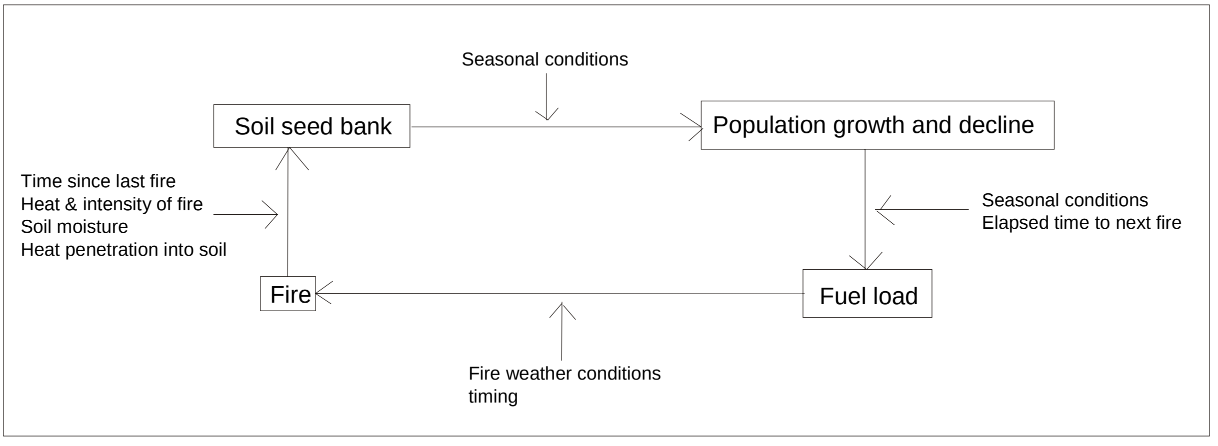


Figure 12.1: Interactions between physical, climatic and biological parameters in a fire ecology cycle.

12.1 Monitoring

There are two elements to a monitoring project: the short-term task of collecting baseline data and the longer-term tasks of monitoring. Both need to be designed before the baseline data is collected. The baseline data is important to establish the likely fire behaviour and the likely ecological outcome in response to the initial prescribed burn and to give a reference point for long-term monitoring.

Baseline information

- time since last fire
- current fuel load
- actual fire intensity
- plant population information
- soil seedbank information
- current and projected weather information
- fauna population information (if relevant).

Long-term monitoring program variables

- regular measurements of fuel load (annually would usually suffice)
- population growth or decline (frequency will depend on the species or community).

12.2 Measuring variables

12.2.1 Time since fire

The last fire can be determined by contacting the local fire authority or land manager or by determining the time since fire by counting *Banksia* nodes or annual growth rings of tea tree, *Leptospermum* spp (Brown & Podger 1982; Marsden-Smedley *et. al* 1999).

12.2.2 Fuel loads

The fuel load can be determined in one of three ways. Measuring fuel loads from first principles is a good method for baseline data whereas a surrogate method is good for annual monitoring. Two surrogate measures are suggested below but these methods are accurate only for the areas suggested. If a surrogate method is used for places outside these areas or for different vegetation types it needs to be calibrated for the site.

For dry forests in south-east Tasmania the fuel load can be estimated by using the method of Bresnehan (1998). This involves determining the time since fire, canopy type, rainfall class, tree density class and leaf litter depth. These inputs can be used to determine the fuel load using tables calibrated from the former variables.

For areas in the immediate environs of Hobart the method of Fensham (1992) can be used. This method uses an equation:

$W_t = W_{ss}(1\text{-}e^{-kt}) + 1.92(e^{-kt})$

where:

W_t = weight at time t (years since fire, measured in tonnes/hectare)
W_{ss} = a constant equal to the amount of fuel under steady state conditions
k = a constant equal to the proportion of litter that decomposes
t = time since fire (years).

This paper has a table with the values of W_{ss} and k for a range of forest types in the Hobart area.

The other option is to measure the fuel loads from first principles. Collect the fine fuels (up to 6 mm diameter) from the site by sampling a columnar quadrat 1 m^2 and up to 2.5 m above the ground. Place the fuels in a paper or hessian bag and dry the bag at 105°C for 24 hours (Bresnehan 1998).

12.2.3 Fire intensity

The intensity of the fire can be estimated from the flame heights and the rates of spread observed on the day of the fire (Bresnehan 1998).

12.2.4 Plant populations

(See Section 11 Estimating Population Size.) Keith (2000) describes methods for surveying threatened plant populations that would be useful for any plant population. If the plant population is still alive when the burn is prescribed it is easy to set up the monitoring plots before the fire. Use materials that will withstand fire to mark out the plot boundaries. Star pickets will withstand fire but small galvanised stakes rust away very quickly after fire. Do not make the plot size too big as trampling within the plot during annual surveys will seriously affect the results. A belt transect of 1 m^2 quadrats is a good size for small to medium size shrubs, herbs, etc as the scorer can see all the plants while leaning over the plot boundary. Quadrats of 2 m^2 are too large and result in damage to the plants when they grow and obscure the smaller plants.

It is difficult to set up monitoring plots if there are no live plants left when the fire is prescribed. Suitable habitat can be difficult to identify once the area has been burnt and searching for plants can become almost impossible. In these cases identify the suitable habitat and set up a reference point within the habitat patch before burning. Put the reference stake at one corner or in the centre of the patch and estimate the extent of the suitable habitat from the stake. This will give a more defined area in which to search for any regenerating plants. When the regenerating plants are found establish the long-term plots.

12.2.5 Soil seedbank

Soil seedbanks can be assessed by collecting soil cores and applying germination treatments to them (Lynch, 1993; Marsden-Smedley *et al* 1997).

12.2.6 Meteorological data

If you are planning to carry out an ecological burn it is probably best not to do it if there is a possibility of drought in the following season. Meteorologists cannot accurately say when and how severe a drought might be but they can make predictions and this is the best you can hope for. The Bureau of Meteorology's website <http://www.bom.gov.au/> has a page called 'Seasonal Outlooks' that gives the chances of exceeding the median rainfall for the next three months. Other pages give weekly or monthly rainfall bulletins from selected gauges. Other data can be purchased from the Bureau. The other more expensive option is to install an automatic weather station that can be downloaded to a computer.

12.3 Developing prescriptions

Developing a prescription for ecological burning depends on the subject you want to manipulate. The *Bushcare Tool Kit* includes general prescriptions for various vegetation types (Kirkpatrick & Gilfedder 1999). The parameters that govern fire behaviour must be estimated to ensure the fire can be controlled and applied at the desired intensity. A skilled fire crew should be employed to undertake the burn.

A thorough understanding of the ecology of a species is needed before ecological manipulation of the species or its habitat. In particular, the state of its seedbank and the response of mature plants to the proposed fire intensity need to be known. Inappropriate timing and intensity of an ecological burn to promote regeneration in a senescent population may result in further decline of the species and exhaustion of its seedbank. Reliable data and expert opinion should be obtained before deciding to burn.

13 Handling, Analysing and Interpreting Data

13.1 Introduction

Meaningful analysis and interpretation of monitoring data depends on collecting the appropriate data using a sound experimental design. Even if accurate data have been collected the accuracy of the data can be compromised if sound handling techniques are not used. The analysis of well organised and error-free data should be a step-by-step procedure that produces readily interpreted results.

The following steps are a guide to handling and analysing your data:

1. Collect the data on a field proforma.
2. Enter and store the data on a spreadsheet proforma. This is best done as soon as possible after the data has been collected so any anomalies can be clarified. The data should be checked against the field proforma for errors, preferably by a second person. Checking is particularly important as data entry errors can reduce the accuracy of your analysis.
3. Get to know your data by analysing it graphically.
4. Summarise the data for each variable (eg density of the plant species).
5. Estimate the variability and precision of the data (standard deviation, range and standard error).
6. Statistically analyse the data to test for any change between years or between treatments. Do the statistical power analysis.
7. Interpret the significance tests in terms of:
   - relationship to the threshold
   - effectiveness of the management or treatment
   - obligation to continued monitoring.

13.2 Data handling and storage

13.2.1 Data collection

The project proforma should be completed. It should record all the information needed to repeat the monitoring independently.

The data should be recorded on the field proforma designed for the project. The field proforma should record all the data relevant to the monitoring program, the project and the site. Beyond these data you can customise the proforma to record the specific data needed for the project.

The layout of the data on the field proforma should be similar to that on the spreadsheet proforma and/or should allow easy transfer to the computer package to be used for the analysis. This will reduce the likelihood of making errors while transcribing and make it easier to check for any errors.

13.2.2 Data entry and storage

It is important to transfer your collected data from the field proforma to the spreadsheet proforma or computer spreadsheet as soon as possible. Failure to do this will increase the likelihood of making errors because as time passes it will become more difficult to remember what the notes and scribbles on your field proforma really mean.

The following standard entry format should be used:

- put each variable in a separate column
- put each remeasurement in a separate column
- put experimental units in separate rows
- **never** have multiple fields in one column
- name the spreadsheet meaningfully
- store a copy of the data on the latest portable storage device, for example a CD
- make a hard copy
- record the location of the data and the hard copy on the Monitoring Program's register.

13.3 Analysing data

13.3.1 Graphical analysis

The first stage of data analysis is displaying the data graphically. This exercise may reveal informative trends and other patterns and may confirm your expectations or raise additional questions. 'Additional' because the questions you intend to answer should be clearly stated in the project design. Having an idea of the distribution of the data through graphical analysis will facilitate the interpretation of statistical comparisons later.

- Consider the best way to display the data — simple is best.
- Separately display each of the standard variables you have calculated.
- Histograms are appropriate for displaying cumulative data such as frequency or basal area but they are not appropriate for displaying means.
- Histograms can be constructed to display the data before and after treatment, the differences between treatments, and time series data.
- Pie charts are useful for percentage data
- Time-series curves are suited to seasonal and annual changes.
- Means should be displayed as points bounded by an estimate of the standard error.

13.3.2 Summarising the data

Calculate the summary statistics for each variable, such as species richness or abundance.

If the experimental units are:

- quadrats, calculate the summary statistics for the treatment and control quadrats separately
- blocks, calculate the summary statistics for all quadrats within each block
- sites, calculate the summary statistics for all quadrats at each site.

If all the sites or blocks have a similar physical and biotic character calculate the summary statistics for:

- all treatment sites or blocks combined
- all experimental control sites or blocks combined.

The data in Table 13.1 allow you to make a preliminary description of what has happened in the quadrats between the two years. This is a useful exercise in getting to know your data. For example, the data indicate that the total number of plants has declined from 266 to 216. The average number of plants in each quadrat has declined by about 1 per quadrat. The variability and precision of the data improved marginally in the second year indicating that the treatment effect has been fairly consistent across the quadrats. If the treatment effect had been patchy the variability and precision of the data would probably have decreased.

Table 13.1 Statistics from 50 quadrats summarising the abundance of *Epacris barbata* in 1996 and 1997.

Summary statistic	1996	1997
Sample size	50.00	50.00
Mean	5.32	4.32
Standard error	0.77	0.69
Confidence level (95.0%)	1.55	1.38
Median	4.00	3.00
Standard deviation	5.44	4.85
Sample variance	29.57	23.53
Range	33.00	32.00
Minimum	0.00	0.00
Maximum	33.00	32.00
Sum	**266.00**	**216.00**

13.3.3 Estimating variability and precision

For data collected in quadrats or transects:

1. Estimate the means of the variables of interest, eg density or cover before and after treatment for:
   - treatments
   - controls.
2. Estimate the variability (standard deviations and maximum and minimum values) of each of the variables:
   - before treatment data
   - after treatment data
   - change data.
3. Estimate the precision and reliability (standard error) of the means for:
   - before treatment data
   - after treatment data
   - change data.

The statistical significance of any measured change in the population means may be tested using these data.

Large standard deviations and large differences between the minimum and maximum values indicate high variability. High variability may occur in the measures before treatments are applied throughout the area or it may be due to variability in the post-treatment measures indicating that the treatment did not affect the measure evenly throughout the area. One way of reducing data variability is to stratify the sample.

A large standard error and wide confidence interval indicate that the calculated mean has a low precision. Data that are imprecise make detecting change more difficult. Not detecting a change in imprecise data does not necessarily mean that biologically meaningful change has not occurred. If the data are imprecise:

- improve your monitoring by increasing the number of quadrats or transects to decrease the standard error and improve precision.
- stop monitoring if the effort required to make valid conclusions exceeds the resources.

13.4 Statistical analysis of vegetation change

13.4.1 Tests of significance

A test of significance helps to determine whether the change in the vegetation is likely to be the result of the management applied or is likely to be variation due to another cause.

13.4.2 Magnitude of change

If it is assumed that a treatment will bring about a significant change in the structure and/or composition of the vegetation you will be more interested in the magnitude of the change (with an indication of the likely accuracy of the results).

The magnitude of the change can be calculated with confidence intervals about the mean of each variable, eg density of a species.

The main tool for testing the significance of the data is the t-test. The t-test is designed to detect whether an observed difference between two means is greater than what you would expect to see from any two data sets collected from the area had no treatment been applied.

To compare changes between treatment and control quadrats over time a two-way ANOVA with a covariate should be used. The covariate will allow the effect of time to be taken into consideration.

If the data are not normally distributed then non-parametric equivalents (Mann-Whitney or Wilcoxon) should be used. Use Wilcoxon for paired data and Mann-Whitney for unpaired data.

For comparisons between the mean change in treatments and the mean change in experimental controls use independent t-tests. If the experimental units are paired use paired t-tests.

For comparing mean values between treatments and experimental controls at a single time, use an independent t-test. If the experimental units are paired use paired t-tests but be aware that it will not test your hypothesis.

The application of these tests to the data is straight forward in Excel. The summary statistics described above can also be calculated easily using Excel. However, it worth calculating the statistics yourself so you become more familiar with the data. Knowing the data will help you to detect errors and recognise unexpected results.

13.4.3 Limitations of significance tests

If we measure the difference between the treatments and controls before treatment and compare it to the difference after treatment we can measure the treatment effect and thus have a valid test of the effectiveness of the treatment.

If no difference is found between the means of the treatments and the experimental controls, it does not necessarily mean that no difference exists. (See Section 7.1.5 Calculating the statistical power of the monitoring design.)

The biologically effective change is what is meaningful and caution is warranted where the variables are prone to measurement error. For example, if percentage cover has been used the apparent change must be at least 20% before it can be assumed to represent change other than that caused by normal seasonal fluctuations or measurement error.

Being aware of these problems enables you to deal with them or at least be aware of the limitations of your data. For example, if no difference is found between the means of the treatments and the experimental controls but you observed that the quadrats contained different species of different densities after treatment you should not necessarily accept that there is no difference. You should not interpret statistical tests in isolation from your ecological and biological understanding of the sites and the species.

13.5 Interpreting data: Using the data to evaluate change

For each year of monitoring analyse the data to determine if the thresholds or decision triggers have been met or if a statistically significant change has occurred. For example, whether a 25% reduction in density has occurred or if a new grazing regime has resulted in significantly more regeneration of the canopy trees.

If a threshold indicating a critical change has been broken, the planned management response should be implemented. However, if the plan was made before any data were collected and analysed, remain open to the possibility that the management response may need to be reconsidered after the data has been analysed, in the light of your improved ecological understanding.

Remember that although ecological management principles have been derived from many studies they are not scientific laws and the actual management prescription may need to differ from place to place in order to achieve the desired outcome.

In cases where no threshold has been set but a statistically significant change has been measured the quality of that change should be evaluated and responded to. The response will be to ameliorate the impact by modifying the treatment (management practice) or promote the impact by continuing the treatment.

Some responses to treatment are not continuous. For example, an ecological burn may trigger a pulse of tree regeneration as a single cohort of seedlings rather than continuous population growth over some years. In such cases there is no need to reapply the treatment. If the treatment failed to promote adequate regeneration the treatment needs to be reconsidered in the light of the factors that may have limited its effectiveness. Such factors may be climatic, due to competition or due to poor application of the treatment.

A decision support system is a very useful tool for helping decision-making following interpretation of the results and implementation of the management response.

13.6 Presenting results

In many instances it will be necessary to convince non-scientists with an interest in your project to support implementation of the relevant management actions or continuation of the project. Whether the support is financial or political it may be vital to the success of the project. One way to increase your chances of support is to have everyone understand the results of the monitoring.

At this point statistical rigour can move to the background and the focus should be on illustrating the outcome and its implications for the conservation value being considered. The graphical analysis undertaken as step 1 of the data analysis will be useful here. Reconsider the graphical analysis in the light of the statistical results because it may now be possible to give a clearer interpretation.

Provided you have a rigorous design and a valid analysis behind you, simplifying the data to focus people’s minds on the salient points can be very useful. This may include ‘cleaning’ the data to emphasise your salient points.

- Remove the outliers that can be explained and rejected.
- Present significantly different values in different colours rather than with standard errors.
- Refrain from presenting tables of data.
- Use meaningful names for the treatments, variables and sites being discussed and use them in your illustration captions. For example, use words like herbicide, number of plants killed and Mt Elephant instead of codes like H1, % mort and Site 1.
- Explain the data and illustration comprehensively in the caption.

13.7 Suggestions for advanced ecological packages

A number of software packages have been designed specifically for ecological projects. They include advanced analytical procedures that will take considerable time to understand if you are not experienced with them. All the packages include classification and ordination procedures. The ease with which the data can be entered, stored and retrieved is an important consideration with any package.

The two packages most commonly used are PATN and PC-ORD. PATN is the older of the two packages and is not as complete or user friendly as the Windows-driven PC-ORD. The latter includes the latest versions of the ordination software that make the results more consistent than those previously available.

PC-ORD is a Windows-based program that performs multivariate analysis of ecological data. In addition to utilities for transforming data and managing files, it offers many ordination and classification techniques not available in the major statistical packages. PC-ORD includes NMS, DECORANA and TWINSPAN and is designed for professional ecologists. It is not a basic data analysis tool but rather it requires a good understanding of the data, techniques and ecology to produce sensible results.

The advantage of PC-ORD compared to the older ecological packages is that it is in a Windows format, is well supported, has the latest versions and corrections to statistical techniques, and the ordination and classification capabilities are easy to use.

The package includes many of the basic statistical procedures referred to in this manual, including descriptive statistics, diversity indices and species area curves. Its other features include graphics, data modifications, matrix operations, import/export file, Bray-Curtis (polar) ordination, correspondence analysis, Mantel test, outlier analysis, non-metric multidimensional scaling, principal components analysis, species lists and user written tools.

PC-ORD can be viewed at <http://www.ptinet.net/~mjm/pcordwin.htm>.

14 Costing Projects

Monitoring is expensive! Calculating the cost of a monitoring project is a sobering task. Nevertheless, it is a task that needs to be done if resources are to be responsibly and appropriately committed. Costing and designing a project is similar in purpose to developing a business plan. It is at the project's planning stage that you can determine the financial resources needed. If the project cannot be financially supported it should not proceed.

Estimating the costs of monitoring can help to focus your efforts on the most important monitoring tasks. It can also discourage you from using monitoring as a compromise that allows a change in land use which is likely to threaten a conservation value.

The cost of establishing a monitoring project is generally less than half the total cost of the project, even in a project designed to run for only two years. A realistic idea of the duration of the project is needed before you can accurately forecast the total cost.

14.1.1 Quadrat costs

Table 14.1 outlines the costs associated with a project in a forested ecosystem. The project uses a nested quadrat design of six 20 m quadrats with three nested 5 m quadrats and six nested 1 m quadrats. The design has three treatment and three control nests. The design is the minimum needed for comparing a treatment and a control in a forested ecosystem. More quadrats may be needed depending on the variability of the vegetation. The costs are estimated in $Aus for the year 2001 and the rate of $40 per hour for labour is based on a project officer's salary plus associated full cost recovery (it is likely to be conservative). Some of the estimated times will vary depending on the nature of the vegetation, its accessibility, and the skills of the people involved.

In this example the costs can be summarised as being approximately 50% for establishment and associated support costs, 30% for a single remeasurement, and 20% for the analysis and write up. Clearly the number of times the project is to be remeasured will affect the proportions so the establishment costs will be a smaller proportion of the total cost if more remeasurements are done. In this example the establishment cost falls to about 12% after five years. Projects should be designed to include the minimum number of remeasurements necessary to answer the questions being asked.

Table 14.1: Costs of establishing a site in a forested ecosystem indicating the number of people required, time to establish and measure the quadrats in the left column, total people minutes, the $ rate per hour, cost for one quadrat, total number of quadrats in the design, total number of hours needed in the field and total cost.

	People	Time to establish	Time to measure	Rate ($)	Cost ($)	Total quadrats	Field hours	Total cost ($)
Establishment								
20 x 20 quadrats	3	20	20	40	80	6	4	480
5 x 5 quadrats	2	10	15	40	33	18	7.5	600
1 x 1 quadrats	2	5	20	40	33	36	15	1 200
Total						**60**	**26.5**	**2 280**
Other costs								
Design (hrs)		4		40				160
Vehicle days		4		90				360
Accomm days		9		120				1 080
Plant id (hrs)		4		40				160
Quadrat materials								400
Total								**2 160**
Treatment								
Burn or							1 day	3 000
Herbicide or							1 ha	1 000
Fence							1 km	3 000
Data entry (1)		6		40				240
Remeasure (occasions)		1						3 000
Data entry (2)		6		40				240
Analysis (hrs)		8		40				320
Write up (hrs)		16		40				640
Total								**4 440**
Grand Total								**11 880**
Each additional year								**4 200**

14.1.2 Photo point costs

Table 14.2: Costs of establishing three photo points at a site in a forest or woodland. The estimate is based on establishing photo points at four sites in a day, assuming they are about 30 minutes travel apart.

	People	Time to establish	Rate ($)	Cost ($)	Number	Field hours	Total cost ($)
Establishment							
Photo point	2	30	40	40	3	1.5	120
Travel to next site	2	30	40	40		0.5	40
Other costs							
Vehicle				20			20
Materials				25			25
Total per site							**205**

15 Appendix 1. Basic Definitions and Calculated Variables

The definitions, formulae and instructions set out below are basic and often prerequisite for the establishment, collation and initial analysis of data collected from monitoring quadrats.

Abundance

The total number of individuals of a species in the area of the sample.

Basal area

The cross-sectional area of tree stems. Calculated for each individual from the diameter at breast height (1.3 m) and summed for the sample.

Braun-Blanquet cover classes

These classes are usually estimated and have been determined to be reasonably repeatable absolute measures. The classes are usually:

1 = solitary and less than 1% cover

2 = few with less than 1% cover

3= 1–5% cover

4 = 5–25% cover

5 = 25–50% cover

6 = 50–75% cover

7 = >75% cover.

In ecological texts the solitary and few cover classes have been represented by non-numeric characters. However, when using computers we cannot use the classes R and + because they are not numbers and they do not go into the number fields of databases. It is important to maintain the discrimination of very low covers so the system used here includes the fields 1 through to 7. When comparing your data with data collected under other systems the data should be transformed to the appropriate classes.

Crown separation ratio

This is a visual estimate of the plant cover. It is the average distance between the crowns divided by the average size of the crown. In the field this involves visualising how many crowns of a given plant species can be fitted into the distance to the nearest neighbour of that species on average over the site. The method could be modified for use with photo points so the separation is measured in the horizontal plane. The data can be classed to suit the structure of the vegetation. An example is shown in Table 15.1.

Table 15.1: Possible descriptions of crown separation ratios at a site.

Class	Term	CSR	Description
1	Isolated plants	>20	Isolated plants
2	Very sparse	5–20	Well spaced
3	Sparse	1–4	Clearly spaced
4	Dense	0.5–0.9	Clear separation
5	Closed	0–0.9	Touching to overlapping

Density

The average number of individuals of a species per unit area.

$$D = \frac{\text{number of individuals in the sample}}{\text{total area of sample } (m^2)}$$

Dominance

The area a species occupies in a stand (basal area or cover can be used) per unit area. Note that in Australia (and North America) dominance is defined by the height of the species, the tallest being the dominant species. Where two or more species are in the tallest stratum the basal area or cover can be used to determine the dominant species, the remaining species are co-dominant. Sub-dominant species occur in a stratum below the dominant species.

$$\text{Dominance} = \frac{\text{basal area or cover of individual species in the sample } (m^2)}{\text{total area of the sample } (m^2)}$$

Experimental unit

A defined area over which a treatment or experimental control is set up. They include quadrats, blocks and sites.

Experimental controls

An experimental control is an experimental unit in which no treatment is applied and to which treated experimental units are compared.

Where time is not the treatment, experimental controls are required because the structure and composition of vegetation changes with time, and this change needs to be isolated from that brought about by the application of the treatment.

Importance value

An index made up of relative density, relative dominance and relative frequency that profiles the structural role of a species in a stand. It is useful for making comparisons among stands in reference to species composition and stand structure.

IV = relative density + relative dominance + relative frequency (See below for relative measures.)

Lognormal distribution

This distribution allows confidence limits to be calculated when the lower limit cannot be less than zero, eg the confidence interval about a population size estimate. Each value in the distribution can be calculated with a function in Excel written as = lognormal (x,mean,sd) (Keith 2000).

Percentage frequency

The distribution of a species through a stand, ie the percentage of quadrats in the sample area in which a given species occurs.

$$F = \frac{\text{number of quadrats in which a species occurs}}{\text{total number of quadrats in the sample}} \times 100$$

Population size estimate

$$\text{Mean density per unit area} \times \frac{\text{area of occupancy}}{\text{unit area}}$$

Population structure

The number of individuals of a species in a defined size or age class.

Relative density

The density of one species relative to all species in the sample.

$$RD = \frac{\text{number of individuals of a species in the sample}}{\text{total number of individuals of all species in the sample}} \times 100$$

Relative dominance

The area a species occupies in a stand (basal area is used for trees) as a percentage of the total area occupied by all species.

$$RDom = \frac{\text{basal area of a species } (m^2)}{\text{total basal area of all species } (m^2)} \times 100$$

Relative frequency

The distribution of one species relative to the distribution of all species.

$$Rfrequency = \frac{\text{frequency of a species in a sample}}{\text{total frequency of all species in the sample}} \times 100$$

Species richness

The number of species in a defined area, eg a quadrat of any known size.

Species diversity

The number of species and the number of individuals of each species calculated as an index. The Shannon-Weiner is the most often used measure of diversity where pi is the proportion of individuals of species I in the community, and there are S species present.

Diversity = $- \Sigma^{s}_{i=1} p_i \log p_i$

The index ranges from 0 (1 species present to Log S). See Rosenzwieg (1995) and Burgman and Lindenmayer (1998).

Simpsons Index uses the same parameters but indicates the probability of detecting at random two individuals of the same species.

Diversity = $- \Sigma^{s}_{i=1} p^2_i$

Treatment

The method applied to test a response compared to an experimental unit not treated by the method. Examples of treatments include herbicide treatment of weeds, grazing intensity and application of fire. Time is also regarded as a treatment.

16 Appendix 2. Monitoring Private Forests Reserves

16.1 Introduction

The Private Forests Reserves System (PFRS) will require monitoring to facilitate the adaptive management process necessary to manage the forested ecosystems in perpetuity. Unlike most reserve systems the PFRS is on privately-owned land in an agricultural landscape. In many instances the PFRS will continue to be grazed by sheep and / or cattle and may have limited firewood and timber harvesting within it. The operations plans that guide the management of the PFRS contain untested management prescriptions. They usually differ between reserves but are based on a set of prescriptive management guidelines aimed at maintaining or enhancing the condition of the reserves The application of the prescriptions in the long term needs to be monitored and where necessary the prescriptions adjusted to ensure the management goals are met.

Although it is beyond the resources of the PFRS program to monitor every reserve in the PFRS in a rigorous and scientific manner there is a need to audit all reserves. The audit process should monitor the condition of the reserve and compliance with the operations plan. The aim of the following proposal is to recommend an approach and provide an estimate of the scale and cost of a monitoring program suitable for the PFRS.

16.2 Approach

The 50 forest types that may be represented in the PFRS Program can be classified into grassy forests, heathy forests, shrubby forests and wet forests. These types will form the basis of the monitoring effort.

The recommended approach is to collect a comprehensive data set that describes each of the above forest classes (from reserves or other forests) and represents the range of conditions that currently exist. The number of sites necessary to obtain data that provides an acceptable surrogate measure of condition would need to be determined during data collection but may be in the order of 50 or more sites.

A survey of the 50 or more sites would reveal the nature of forests in good and poor condition. From those data a number of parameters that correlate strongly with an index of condition could be identified. Those parameters could provide surrogate indicators of condition for each of the forest classes. The surrogates should be robust and incorporate a level of uncertainty.

The surrogates should be calibrated with data from 10–20 permanent monitoring sites that are remeasured periodically (5 years). The result would be a surrogate measure that is an acceptably sensitive gauge of the condition of other forests in the reserve system. If a reserve inspection showed that the surrogate measure had fallen below a certain level the condition would be deemed unacceptable. For example, greater than 75% of the ground should be covered by native grasses.

The 50 or more sites would be surveyed once with non-permanent quadrats. The 10–20 permanent sites would be monitored every 5 years while 20% of the remaining sites would be monitored annually using surrogate measures, thus ensuring that each site is monitored every 5 years. The costing assumes 200 reserves each dominated by a single forest type.

The costs of a 20 year program in $Aus for the year 2001 are estimated in Table 16.1. The costs are likely to be conservative.

16.3 Design and cost

Table 16.1: Indicates an example of the scale of the design and attendant costs. Costs include labour and office support @ $40 per hr, vehicle @ $90 per day, travel costs @ $120 per day, materials @ $100 per permanent site and reporting time.

	Quadrat size	Quadrat size	Quadrat size	People	Approx cost
50 Survey sites					
Temporary sites	3 (20 x 20)	9 (5 x 5)	24 (1 x 1)	2	57 000
10 Permanent sites, detailed survey	3 (20 x 20)	9 (5 x 5)	24 (1 x 1)	3	13 290
3 Photo points					2 050
Total costs (3 remeasures)					72 340
190 Audit sites, 40 pa				1	
3 Photo points at 40 sites (establish)				2	8 200
Remeasure pa				1	4 000
40 Surrogate surveys pa	20 (20 x 20)			1	12 000
Vehicle/travel				1 or 2	3 000
Audit costs pa					27 200
Total audit costs					**$408 000**
Grand total					**$480 340**

16.4 Schedule

Table 16.2: Indicates the number of sites and a time schedule for each aspect of the monitoring task.

	Number of sites	Start	Complete
Baseline data	50 plus	2001	2002
Permanent sites			
Establishment	10	2002	2002
Remeasure	10	2007	2012, 2016
Surrogate monitoring			
Establish	40 pa	2001	2005
Remeasure	40 pa	2002	2016

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