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Box–Ironbark Ecological Thinning Trial
Integrated Analysis and Projected Changes

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FOREWORD

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Executive summary

In 2002, Parks Victoria established a management-scale experiment to examine the effectiveness and feasibility of ecological thinning as a means for restoring Victoria's Box–Ironbark forests. The Box–Ironbark Ecological Thinning Trial (the Trial) took an adaptive experimental management approach to investigate how ecological thinning may be used to restore a greater diversity of habitat types to the Box–Ironbark landscape and therefore allow improved functioning and persistence of key communities and species populations.

The Trial was implemented in four Parks Victoria reserves (the Sites) in the Box–Ironbark region of central Victoria (Castlemaine Diggings National Heritage Park, Pilchers Bridge Nature Conservation Reserve, Spring Plains Nature Conservation Reserve and Paddys Ranges State Park). At each Site, treatments with varied rates of tree removal and retained patchiness (Control, Isolated Patchy 1 and Patchy 2) were implemented in 30-ha Plots. Within these Plots, three coarse-woody-debris manipulations were applied: 100% removal; 50% retention; and 100% retention of bole material.

As part of the Trial, a research and monitoring program (Phase 1), focusing on forest structure, selected biodiversity elements and habitat features, was established to examine the impacts that ecological thinning and the different experimental treatments had on key components of Box–Ironbark forests. This report documents the experimental design, the pre- and post-thinning monitoring results of selected biodiversity and habitat attributes across all Sites and discusses the implications of these results and their potential future trajectories. As the Trial used an adaptive experimental approach, changes or additions to the ongoing monitoring design to enhance outcomes are also discussed.

Before ecological thinning commenced, Plots were dominated by high numbers of coppice-generated trees (up to approximately 1500 stems per hectare). Less than 3% of trees were considered large (>60 cm diameter) and only 3% were hollow-bearing, implying limited availability of habitat for a number of threatened fauna. Pre-thinning, Plots contained very small amounts of coarse woody debris, particularly large pieces (>10 cm diameter).

As a result of ecological thinning, stem density was significantly reduced and mean stem diameter increased. Coarse woody debris increased across all thinned Plots, including significant increases in large pieces of coarse woody debris. Changes to other habitat features post thinning, including fine debris, were measurably higher than pre-thinning values. Vegetation responses to thinning included increased herb and tussock-grass cover and more profuse flowering of herbs and shrubs. There was also a decrease in perennial-shrub cover and an initial, probably temporary, increase in annual weed grasses. Among vertebrate fauna, thinning affected the occurrence of some diurnal birds as well as some other vertebrate groups. Species richness was greater among bird assemblages after thinning, although this may have been influenced by the timing of surveys. Understorey birds were strong contributors to this result, responding favourably to the greater complexity of ground-layer habitats brought about by the addition of coarse woody debris. Bat activity was greater in Plots after thinning. Other vertebrates, including terrestrial and arboreal mammals, appeared to remain stable or displayed positive responses. Ground invertebrate assemblages were dominated by ants in species richness and total abundance, which in turn were dominated by a small number of opportunistic ant species which responded positively to disturbance associated with thinning.

The results presented in this report document the pre-thinning conditions and initial post-thinning conditions and provide a benchmark for the ongoing monitoring of the Trial. These results have been used to predict the future trajectories of biodiversity and habitat features for the Trial. As such, this report will make an important contribution to the future management of Victoria's Box–Ironbark parks and reserves system.

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1 BOX–IRONBARK ECOSYSTEMS

In 2002, Parks Victoria established a management-scale experiment (the Trial) to examine the effectiveness and feasibility of ecological thinning as a means for restoring Victoria's Box–Ironbark forests. The Trial took an adaptive experimental management approach (Johnson 1999) to investigate how ecological thinning may be used to restore key habitat components to the Box–Ironbark landscape and, therefore, allow improved functioning and persistence of key communities and species populations.

This report brings together initial findings from the Trial, detailing the short-term outcomes that have occurred due to the thinning operation. While many of the long-term outcomes of ecological thinning in Box–Ironbark forests will take decades to understand, this report provides important information and comparisons between the pre- and post-thinning environment. This report documents the baseline conditions before and after ecological thinning and uses scientific methods to describe the immediate responses of flora, fauna and key habitat features. This information is used to predict the trajectory of these responses in the longer term to assist both management and long-term monitoring of Trial outcomes.

A companion report to this report is the *Box–Ironbark Ecological Thinning Trial Field Guide: Documentation of Methods and Monitoring Framework* (Pigott *et al.* In Press), which provides a more thorough and descriptive coverage of the design, methods and thinning techniques used in the Trial. A more succinct discussion of these topics is provided by Pigott *et al.* 2010.

1.1 The Box–Ironbark Landscape

In Victoria, Box–Ironbark forests typically occur north of the Great Dividing Range, occupying the inland slopes that extend out to the Northern Plains. They occur from Chiltern in the east to Stawell in the west. Undulating rises and low hills characterise the topography of the Box–Ironbark region, with altitude ranging from 150–400 m above sea level. Soils are typically shallow and stony, and have low fertility (particularly on rises). The mean annual rainfall of the region ranges from 400 mm (in the north-west) to 700 mm (north-east) (Bureau of Meteorology data).

While generally referred to as Box–Ironbark forests (herein and elsewhere), these forests are composed of a number of distinct floristic communities within approximately 25 recognised ecological vegetation classes (EVCs; Muir *et al.* 1995). These EVCs include Box–Ironbark Forest, Sandstone-rise Broombush, Gravelly-sediment Mallee, Heathy Woodland, Low-rise Grassy Woodland, Creekline Grassy Woodland, Heathy Dry Forest, Grassy Dry Forest and Granitic Hills Woodland (Muir *et al.* 1995). Box–Ironbark Forest and Heathy Dry Forest are the most extensive EVCs across the region.

Box–Ironbark Forest EVC extends across the northern and central parts of the region, occurring on gently undulating rises to low hills (Muir *et al.* 1995). This EVC comprises open forests dominated by Red Ironbark *Eucalyptus tricarpa* and Grey Box *E. microcarpa*, with Yellow Gum *E. leucoxylon* on moister sites and drainage lines, and Red Box *E. polyanthemos* occupying drier slopes. An open shrubby understorey is typical, including Golden Wattle *Acacia pycnantha*, Gold-dust Wattle *A. acinacea*, Twiggy Bush-pea *Pultenea largiflorens* and Drooping Cassinia *Cassinia arcuata*. The ground layer is generally sparse and includes species such as Black-anther Flax-lily *Dianella revoluta*, Wattle Mat-rush *Lomandra filiformis*, Grey Tussock-grass *Poa sieberiana* and Bristly Wallaby-grass *Austrodanthonia setacea*.

Heathy Dry Forest EVC occurs on upper slopes and ridge tops. The low, open forest is dominated by Red Stringybark *E. macrorhyncha* and Red Box. This EVC has a characteristic dense, heathy understorey composed of Daphne Heath *Brachyloma daphnoides*, Drooping Cassinia and Cat's Claw Grevillea *Grevillea alpina*. A grassy ground layer is typical, and includes Grey Tussock-grass, Silvertop Wallaby-grass *Joycea pallida*, Black-anther Flax-lily and Cranberry Heath *Astroloma humifusum*.

Box–Ironbark ecosystems support a distinct and diverse flora and fauna. For many species in the region, these ecosystems provide the stronghold in their distribution as a result of their close association with Box–Ironbark habitats.

1.2 Pre-European Composition and Structure of Box–Ironbark Forests

Based on limited accounts gleaned from observations of early explorers and settlers, it is generally accepted that Box–Ironbark forests were typically composed of large, widely-spaced trees with a grassy to shrubby understorey (Newman 1961; Calder *et al.* 1994). Some authors have indicated that tree density in these forests was believed to be around 30 large trees (>60 cm DBH dDameter at Breast Height) per hectare, including trees up to 1520 cm DBH (Newman 1961), but it is likely that densities would have varied across the landscape. Natural patchiness would be expected as a result of factors such as soil fertility, fire history and topographic position (gullies versus ridges).

1.3 Contemporary Composition and Structure of Box–Ironbark Forests

Since European settlement, the Box–Ironbark forests have been extensively cleared for agriculture, mining, timber harvesting and urban settlement (e.g. major regional centres such as Bendigo, Ararat, Stawell and Maryborough). This has contributed to a severe reduction in the extent and quality of Box–Ironbark forests (Muir *et al.* 1995; ECC 2001). It is estimated that about 15% of the cover of Box–Ironbark forests and woodlands at the time of European settlement remains, albeit in a modified structure (Traill 1993; ECC 1997).

Timber harvesting has been extensive in Box–Ironbark forests, and most areas have been completely cleared or cut-over since European settlement. By the early 1900s, most areas had already been cut-over three or four times (Newman 1961), and regrowth from these trees has been intensively managed for timber and firewood production. Vast tracts of Box–Ironbark forest standing today are dominated by high densities of small trees, many as multi-stemmed coppice forms (Traill 1993). The substantial change in forest structure and loss of large, old trees has significant implications for wildlife dependent on mature trees for nectar, hollows and provision of coarse woody debris (Traill 1991; Soderquist 1999). Further, the Box–Ironbark region has been the major source of Victoria's firewood supply over many decades, and in most areas standing and fallen dead timber is scarce due to firewood collection (Tzaros 2005).

1.4 Ecological Management of Box–Ironbark Forests

In October 2002, the Victorian Government passed the National Parks (Box-Ironbark and Other Parks) Bill to increase the number of Box–Ironbark parks and reserves and significantly enhance the conservation of Victoria's remaining Box–Ironbark forests and woodlands. In managing these parks and reserves, Parks Victoria is required to develop and implement an Ecological Management Strategy (EMS). The focus of the EMS is to create a system that more closely resembles the state of Box–Ironbark forests and woodlands pre-European settlement, and to address a broad range of landscape and biodiversity elements such as pest plants and animals, land degradation and fire. Specifically, the primary aim of the EMS is to maintain a mosaic of Box–Ironbark forest types that support a diversity of habitats to provide long-term protection for the fauna and flora that characterise the system and maintain its function.

The basis of the objectives of the EMS originates from historic accounts that suggest the Box–Ironbark forests and woodlands once comprised a mosaic consisting predominantly of large, mature and widely-spaced eucalypts, interspersed with patches of younger trees, diverse understorey shrubs and herbs, and a complex layer of coarse woody debris. This is far removed from the substantially modified contemporary state, with Box–Ironbark forest now generally composed of high densities of small trees of uniform age, with few large trees in the landscape. For habitat, biodiversity and conservation purposes, there is an ecological need to maximise the number of large trees present in the Box–Ironbark landscape without compromising other habitat values (ECC 2001).

Ecological thinning is the first management technique to be trialled under the EMS. The Trial is taking an adaptive experimental management approach to investigate how ecological thinning may be used to expedite the development of older-growth characteristics and restore a greater diversity of habitat components to the landscape and, therefore, allow improved functioning and persistence of key communities and species populations.

A purpose of the Trial is to apply different methods of ecological thinning (and associated works) to Box–Ironbark forests and examine the impacts of these methods on biodiversity, forest structure and habitat values. In general terms, ecological thinning aims to:

- reduce the density of existing trees to accelerate growth of retained trees; and
- re-create the ‘spaced’ or ‘patchy’ nature of Box–Ironbark forests that occurred in parts of the landscape before European settlement.

1.5 Box–Ironbark Ecological Thinning Trial Research and Monitoring

A research and monitoring program focusing on forest structure, selected biodiversity elements and habitat features was established to examine the impacts of ecological thinning and different experimental treatments on key components of Box–Ironbark forests. The Trial is a long-term project with many results not expected for at least a decade. Consequently, the Trial is being conducted in two phases:

- **Phase 1**: Design and establishment of the experiment, implementation of experimental treatments (ecological thinning and woody-debris removal), pre-thinning and initial post-thinning monitoring of selected biodiversity and habitat attributes across all Sites, analysis and reporting of results.
- **Phase 2**: On-going monitoring, evaluation and reporting to examine the longer-term implications of ecological thinning.

This report documents Phase 1 of the Trial. The projects and their broad aims for this phase are summarised in Table 1.

Table 1. Research and monitoring projects for the Box–Ironbark ecological-thinning Trial.

Project and theme	Broad aim
Forest Mensuration (forest structure)	Monitor and describe changes in composition and structure of canopy trees (i.e. density and basal area)
Key Fauna Habitat (habitat features)	Monitor and describe changes in forest habitat values (e.g. tree-hollows or leaf litter)
Floristic Survey (biodiversity indicators)	Monitor and describe changes in richness and composition of understorey flora
Selected vertebrates (biodiversity indicators)	Monitor and describe changes in species richness and numbers of selected vertebrates (birds, mammals)
Selected invertebrates (biodiversity indicators)	Monitor and describe changes in species richness and numbers of selected invertebrates (ants, spiders)

The individual project aims and objectives are expanded on in the *Objectives and Methods* section.

Plate 1. Typical contemporary Box–Ironbark forest structure, dominated by high densities of relatively small stems.

2 OBJECTIVES AND METHODS

2.1 Experimental Design

The experimental design for the project was developed by Parks Victoria in consultation with a Scientific Reference Group (Pigott, Wright & Varcoe 2009). The experimental design included four Sites, each having four 30-ha Plots subject to a single thinning treatment (i.e. three thinning treatments plus a control). In each Plot, nine 1-ha Sub-plots were established to which three different felled-timber removal treatments were applied (two removal treatments plus a control). In brief, a single tree felling treatment was applied which involved the selection of stems for retention, and the felling of the remaining tree stems. Selection of stems for retention was conducted in accordance with the three thinning treatments described below.

A detailed description of the methods used in the Trial and how they were developed is presented in Pigott *et al*. (In Press).

2.1.1 Study Sites

Sites were selected for the Trial based on the following criteria:

- they supported EVCs that were common throughout the Box–Ironbark ecosystem;
- they contained a range of landscape positions and aspects;
- they were buffered, where practicable, by untreated forest (to reduce susceptibility to edge effects); and
- there was suitable vehicle access and they were relatively close to a Parks Victoria/Department of Sustainability and Environment work centre.

The four Sites in central Victoria were:

- Castlemaine Diggings National Heritage Park
- Spring Plains Nature Conservation Reserve
- Paddys Ranges State Park
- Pilchers Bridge Nature Conservation Reserve

The four sites were all located south of the regional government centre at Bendigo and the work centre at Castlemaine (Figure 1).

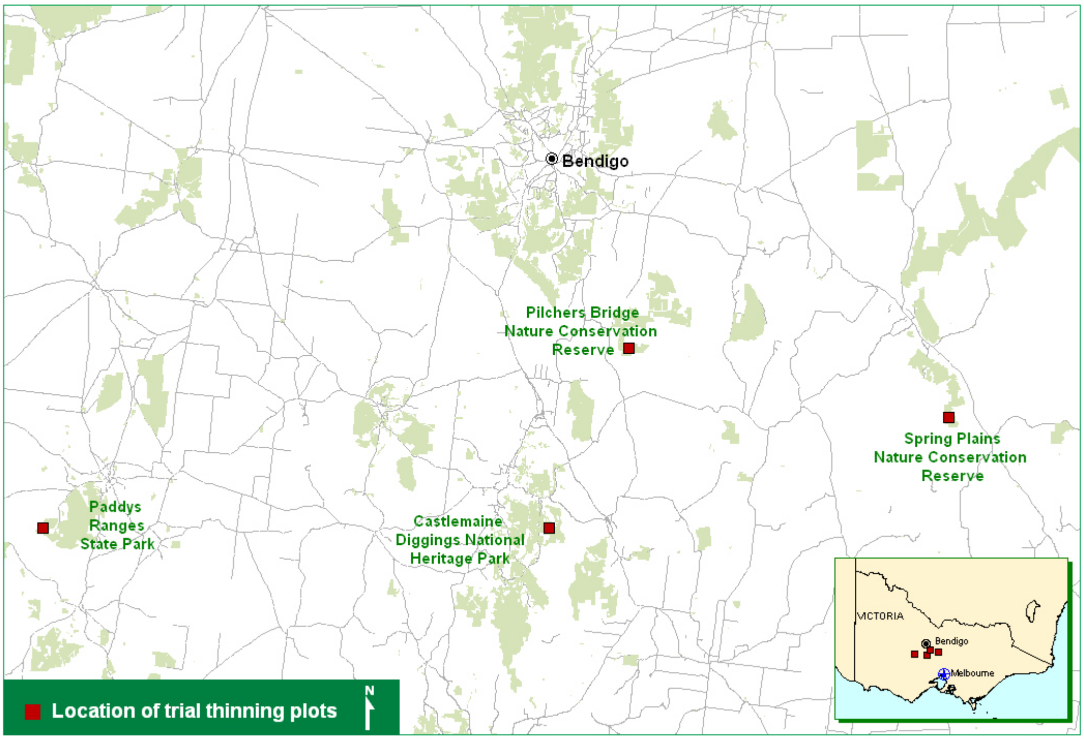

Figure 1. Regional map showing locations of Box–Ironbark ecological-thinning trial Sites in four parks and reserves south of Bendigo, central Victoria. All reserves in the study area are shown in green.

2.1.2 Plots

A series of Plots which had undergone different treatments (the Plots) was designed to investigate forest thinning with an emphasis on habitat management rather than timber production (Pigott *et al.* 2010). Table 2 outlines the distribution of experimental units across the four Sites.

Table 2. Number of Plots and Sub-plots at each Site selected for the Trial, including the major EVC sampled**.**

Site	EVC	Sites	Plots	Sub-plots
Castlemaine Diggings NHP	HDF	1	4	36
Spring Plains NCR	HDF	1	4	36
Paddys Ranges SP	BIF	1	4	36
Pilchers Bridge NCR	BIF/HDF	1	4	36
Total		4	16	144

HDF = Heathy Dry Forest; BIF = Box–Ironbark Forest

The different types of thinning, focusing on the density and spatial arrangement of retained trees, were intended to reflect conventional forestry practice, albeit with a focus on habitat trees rather than production, as well as exploring a new conservation-oriented approach to forest management. Based on these patterns, the treatments have been termed 'Control', 'Isolated', 'Patchy 1' and 'Patchy 2' (Table 3).

Table 3. Descriptions of stem density and patch retention at the four ecological-thinning treatments in the Box–Ironbark ecological-thinning Trial (taken from Pigott *et al.* In Press).

Treatment	Procedure
Control	No thinning treatment is applied (i.e. no trees are cut or removed)
Isolated	**Density**: Trees selected for retention to establish a predetermined density considered to represent moderate density. **Pattern of retention**: All stems (within the estimated 'zone of influence' of the selected stem) are felled to a basal area equivalent to 50% pre-thinning status. None of the experimental area is retained unthinned.
Patchy 1	**Density**: Trees selected for retention to establish a predetermined density considered to represent low density. **Pattern of retention**: Patchy, with stems retained to a level of 25% of pre-thinning basal area after thinning (as for Isolated); 10% of experimental area is retained unthinned.
Patchy 2	**Density:** Trees selected for retention to establish a predetermined density considered to represent moderate density. **Pattern of retention**: Patchy, with stems retained to a level of 50% of pre-thinning basal area after thinning (as for Isolated); 25% of experimental area is retained unthinned

Because a different thinning treatment was applied to each Plot at each Site, there were four replicates of each treatment across the study area, amounting to 120 hectares under each treatment condition.

During the ecological-thinning operation, tree size and habitat value were the main considerations in the selection of trees for retention. Patchy 1 treatment was the most open of the ecological-thinning treatments, with a stem reduction of 75% but retention of 10% of area in unthinned patches.

2.1.3 Sub-plots

Within each Plot, nine 1-ha Sub-plots (100 m × 100 m) were randomly selected to monitor some structural features at a finer scale. At this level, felled bole component of coarse woody debris was manipulated to examine the effects that three retention levels had on ecosystem function and habitat diversity in the post-thinning environment (see Pigott *et al.* 2010). The three Sub-plot treatments all retained felled head material on site and the bole material retained was manipulated as follows:

- Removal of 100% woody-debris (predominantly felled bole material >6cm);
- Removal of 50% of woody-debris;
- No removal of woody-debris.

These Sub-plot treatments are replicated three times within each Plot, but not in the Control.

2.1.4 Within Sub-plot Sampling

Within each Sub-plot, three 60-m transects (herein termed ‘permanent transects’) were arranged in a standard design to enable assessment of ground cover, coarse woody debris and floristic components. Transects were parallel, running east–west, and spaced 25 m apart. The layout of a standard Sub-plot is shown in (Figure 2).

The ends of each permanent transect were permanently marked with a steel dropper (approximately 1 m high). The standardised layout ensured that the transect layout could be readily reconstructed in the event that any of the permanent markers were removed. In some instances, where tracks interfered with transect layout, it was necessary to modify the standard Sub-plot set-up.

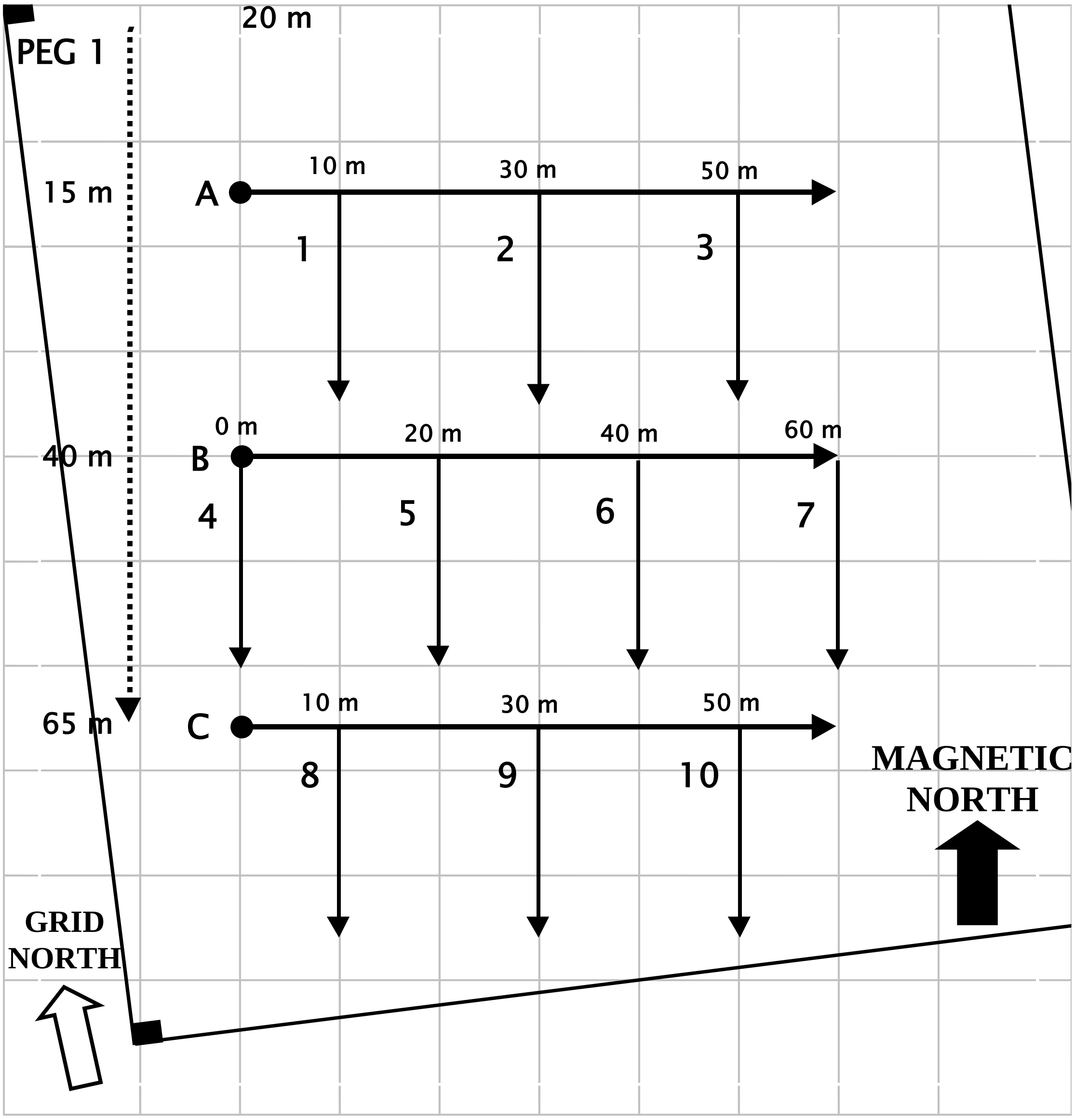

Figure 2. Arrangement of permanent transects in Sub-plots to sample coarse woody debris, ground cover and floristic components, including measurements from the boundary of the Sub-plot.

Solid, horizontal arrows (A, B, C) show the location of 60-m permanent transects, while solid, vertical arrows (1 to 10) show the location of the ten unmarked 20-m measurement transects along which floristic measurements were taken. Note that the transects were laid out using a grid based on magnetic north, but the boundaries of the Sub-plot (black border) were based on the Australian Map Grid 1966.

2.1.5 Site Infrastructure

Each Sub-plot was permanently marked using a steel post positioned at the north-western corner (Figure 2). The location of the Sub-plot was recorded from this corner using a GPS unit.

Within each Sub-plot, the three 60-m sampling transects used for floristic and key habitat assessments, described below, were permanently marked by steel posts at each end.

2.2 Sampling Methods

2.2.1 Tree Mensuration

The tree mensuration project was established to provide a basis for monitoring the effect of ecological-thinning treatments on the structure of the forest ecosystems by measuring tree characteristics including stand density, species composition and size (i.e. stem diameter).

The Triangular Tessellation Technique (TTT) (Ward 1991) was selected as the most appropriate method of sampling forest structure for the Trial because of its accuracy in estimating stand density over large forest areas. Points were selected using standard guidelines for native eucalypt forest surveys (Dignan & Fagg 1997). For example, as the survey area was less than 100 ha, points were selected at 50-m intervals along a set of transects spaced 100 m apart (these were different transects to the permanent transects in the Sub-plots described above). The TTT is based on selecting the three trees closest to the sample point and measuring the sides of the triangle formed by them. Based on the guidelines for native eucalypt forest (Dignan & Fagg 1997), approximately two point samples per hectare were required, resulting in 50–60 samples per Plot, which equated to 150–180 trees per Plot. The unique spatial relationship of the trees in each sample allows for accurate calculation of density for a given area (Pigott *et al*. In Press).

In addition to ‘distance-to-nearest-neighbour’, the following information was recorded for each sampled tree:

- species of *Eucalyptus*;
- diameter at breast height (DBH);
- number and type of tree hollows (i.e. base, bole and canopy; see Palmer *et al.* 2008).

DBH was recorded to enable calculation of basal area for standardisation purposes. Basal area (the area of tree stems) is a commonly used silviculture measure of timber volume as it is easily measured in the field (McEvoy 2004). The density of tree species was also calculated for each Plot (the proportional frequency of the species was multiplied by the mean density estimate).

Calculation of basal area for all Plots used stem-density estimates with DBHOB for each point sample. The point samples were then averaged to provide a mean basal area for each Plot. To provide an alternate field measurement, an optical reading of basal area was also recorded at each tree sample location using a commercially available dendrometer (Gibson *et al*. 2008). Further descriptions of pre- and post-treatment survey methods (including mathematical formulae) used to calculate stand density and basal area are described in Pigott *et al*. (In Press).

2.2.2 Canopy Openness

Through October–December 2008, following implementation of thinning treatments, canopy openness was quantified using stratified photo points within Sub-plots. Along each permanent transect canopy images were captured directly above at 10-m intervals (n = 7 per permanent transect, 21 per Sub-plot), commencing at 0 m through to 60 m. Canopy images were captured using a Canon EOS40D digital camera with a Sigma EX circular fisheye lens 4.5 mm 1:2.8 DC HSM (Gibson *et al.* 2009). At each photopoint, a tripod was set at an approximate height of 1 m and oriented to magnetic north. The lens was stabilised in a horizontal plane using a bubble level. Canopy images were captured only under suitable environmental conditions, including clear sky and absence of direct sunlight.

Canopy images were analysed using GLA (Gap Light Analysis) version 2 (Frazer *et al*. 1999). This measured the representation of ‘sky’ and ‘non-sky’ pixels in each image. This provided a quantitative and accurate assessment of the amount of the image that was ‘covered’ by the tree canopy, and therefore a measure of canopy openness.

2.2.3 Key Fauna Habitat

The key fauna habitat monitoring project examined the effects of the various thinning treatments on forest structure by using techniques that measure the key faunal habitat features related to ground cover, as well as the distribution and abundance of hollows and coarse woody debris. Variables measured included litter depth, composition of ground cover (measured as percentage cover of leaf, fine litter (<1 cm diameter), coarse litter (>1 cm diameter), bare ground, bryophytes, rocks and animal scats), amount and size-class distribution of coarse woody debris and number and dimensions of tree hollows.

2.2.3.1 Hollows

The number and dimensions of observed tree hollows were recorded in trees measured in TTT surveys (see Palmer *et al*. 2008; Pigott *et al*. In Press). All observations of hollows, including estimations of their entrance diameter, were ground-based. Approximately 150 trees were assessed per Plot in the TTT surveys, with the following information recorded for each tree:

- species;
- DBHOB (mm);
- hollow type (base, trunk or canopy); and
- hollow entrance dimensions (height [mm] and width [mm]).

Approximately 50 triangular tessellation point samples (three trees each) were assessed for hollows within each Plot.

2.2.3.2 Coarse Woody Debris

Coarse woody debris was defined as all woody debris >1 cm wide. The distribution of coarse woody debris was measured along each permanent transect (Figure 2) by recording the diameter (i.e. width) of each contact of coarse woody debris with a tape laid along the length of the 60-m transect. The distribution of coarse woody debris was recorded in 10-m sections for each transect. Therefore, a total transect length of 180 m was used to measure coarse woody debris in each Sub-plot.

A measure of the volume of coarse woody debris (V) was calculated using the formula:

$$V = (\pi^2/8L) \times \sum d^2$$

where π = 3.14159265; L = length of the transect sampling line; d = diameter of each piece at point of measurement.

2.2.3.3 Litter Depth

Litter depth was measured using a 20-cm diameter litter disk at sampling stations positioned at 5-m intervals from 0–60 m along each permanent transect (Figure 2). This sampling equated to 12 sampling stations per transect; therefore a total of 36 litter depth measures were gathered per Sub-plot.

2.2.3.4 Ground-Cover Components

Along each permanent transect, ground-cover components were sampled at 5-m intervals from 0–60 m using the same sampling stations used to measure litter depth. A 50-cm frame containing 10 pins with 50-mm spacing was used to record contacts with ground-cover components at each of these intervals. The composition of ground cover was classified into eight components:

- plant (included any attached part of a living plant);
- bare ground;
- rock;
- mosses (bryophytes) and lichen;
- leaf litter;
- fine litter (<1 cm diameter);
- coarse litter (>1 cm diameter; includes coarse woody debris and detached bark); and
- scats (i.e. macrofauna faeces).

For each transect 12 frames totalling 120 contacts were gathered, totalling 360 contacts per Sub-plot.

2.2.4 Floristics

The floristics project examined the effects of the various treatments on the composition and structure of understorey flora using techniques that assessed the species and cover of vegetation life formlife forms. Variables measured included floristic composition and the cover proportion of understorey life formlife forms, including annual and perennial grasses, annual and perennial herbs, coppice, perennial shrubs, perennial sub-shrubs, perennial tufted herbs and tree recruits.

2.2.4.1 Floristic Composition and life form Cover

Floristic composition and life form cover were assessed using ten standardised 20-m transects (herein termed 'measurement transects') set perpendicular (i.e. north–south) to the three permanent transects within each Sub-plot (Figure 2). All transects remained within the Sub-plot and a buffer was maintained to reduce any possible edge effects (Figure 2). The measurement transects were not permanently marked, and their relocation relied on their known distance along the three permanent transects.

Projected foliage cover of dominant understorey species (mostly small shrubs and tussock grasses) was determined using the point quadrat technique along each measurement transect. Vegetation that touched a vertically-held steel pin (1 m long, 4 mm diameter) was recorded at 20-cm intervals, resulting in 100 points per measurement transect, with each 'hit' being equivalent to 1% cover. Shrubs taller than the steel pin were generally in low abundance, but where such a shrub was encountered the observer estimated whether the pin, if projected directly upwards, would contact its foliage. Eucalypt saplings were included in the survey if they were <2 m tall to allow determination of recruitment events. Coppice regrowth on eucalypt stumps, a consequence of thinning, was also recorded for assessment and monitoring. A brief search was then undertaken for any understorey species within 1 m on either side of the transect that had not previously detected by the point-quadrat method, and these were allocated a nominal value of 0.5% cover. This effectively resulted in 10 measurement transects of 40 m^2, giving a total sampling area of 400 m^2 within each Sub-plot.

The total number of contacts for each species along each measurement transect were summed, and recorded as percent foliage cover. The mean of all 10 measurement transects was then calculated to derive floristic community data at Sub-plot level.

Pre-thinning surveys commenced in March 2004 and were completed by September 2004 (Table 1), so that most surveys were undertaken in autumn and winter, when many annual or perennial herbs were no longer visible, or were difficult to identify; Spring Plains NCR was the only site surveyed in spring. Nonetheless, the dominant shrubs and tussock-forming species that contributed most to overall structure were present and identifiable regardless of season.

Post-thinning surveys commenced in spring 2005 and were completed by spring 2007 (Table 4). Most Sites were surveyed around a year after thinning operations had been completed at that Site, although time constraints meant that Patchy 1 and Patchy 2 treatments at Castlemaine Diggings NHP and Patchy 2 treatment at Spring Plains NCR were surveyed only 3–6 months after thinning.

Table 4. Completion dates for thinning operations, and pre- and post-thinning understorey surveys in each treatment.

Treatment	Thinning completed	Pre-thinning survey		Post-thinning survey	
	Date	**Date**	**Season**	**Date**	**Season**
CDNHP Control	n/a	Apr 2004	autumn	Oct 2005	spring
CDNHP Isolated	Aug 2004	Mar 2004	autumn	Oct 2005	spring
CDNHP Patchy 1	May 2007	Mar 2004	autumn	Oct 2007	spring
CDNHP Patchy 2	Jul 2007	Apr 2004	autumn	Oct 2007	spring
PBNCR Control	n/a	Aug 2004	winter	Oct 2006	spring
PBNCR Isolated	Mar 2005	Aug 2004	winter	Oct 2006	spring
PBNCR Patchy 1	Oct 2005	Aug 2004	winter	Oct 2006	spring
PBNCR Patchy 2	Oct 2006	Aug 2004	winter	Oct 2007	spring
PRSP Control	n/a	Jun 2004	winter	Oct 2005	spring
PRSP Isolated	Sep 2004	Jul 2004	winter	Oct 2005	spring
PRSP Patchy 1	Dec 2005	May 2004	autumn	Oct 2006	spring
PRSP Patchy 2	Jul 2006	May 2004	autumn	Oct 2007	spring
SPNCR Control	n/a	Sep 2004	spring	Oct 2006	spring
SPNCR Isolated	Nov 2005	Sep 2004	spring	Oct 2006	spring
SPNCR Patchy 1	Sep 2006	Sep 2004	spring	Oct 2007	spring
SPNCR Patchy 2	Apr 2007	Sep 2004	spring	Oct 2007	spring

CDNHP = Castlemaine Diggings NHP; SPNCR = Spring Plains NCR; PRSP = Paddys Ranges SP; PBNCR = Pilchers Bridge NCR.

2.2.5 Ecosystem Function: Selected Vertebrates

The faunal groups studied to assess the effects of ecological thinning comprise diurnal birds, nocturnal birds, terrestrial mammals, arboreal mammals and nocturnal mammals. Birds and mammals were chosen for this study because they are easily recorded, most are likely to reveal changes in population abundance, and their ecology and habitat requirements are generally well-known. Some data from an independent Honours project at the University of Ballarat (Olsen 2010), which investigated the occurrence of reptiles at selected Sites after thinning, was also included to provide additional insights, though this was not part of monitoring project.

The fauna-survey techniques used in this study were expressly developed for sampling birds and mammals, and are well-established and regularly employed by field biologists. Each of the standard survey techniques described below was used during the sampling periods in each Plot at each Site. The techniques of diurnal-bird census, owl call-playback, hair-tube survey, spotlight survey and ultrasonic bat detection were incorporated into each survey of each treatment, though the scale at which they were employed varied (see below).

In this report, nomenclature follows: Van Dyck & Strahan (2008) — mammals; Christidis & Boles (2008) — birds; and Wilson & Swan (2008) and Cogger (2000) — herpetofauna (reptiles and amphibians). Scientific names for all vertebrate taxa recorded during surveys are presented in Appendix 1.

2.2.5.1 Diurnal Bird Surveys

Surveys for diurnal birds were carried out using a standardised area search: every Sub-plot was searched once for 20 minutes. Therefore, for each Plot, results were pooled from nine replicate surveys during both pre- and post-thinning surveys.

During each search the observer moved through the selected Sub-plot at a constant rate and recorded the presence (and, where possible, number) of all birds seen or heard within the designated search area. Birds observed or heard outside of the Sub-plot were also recorded, although the use of these data in analyses was limited. Searches were conducted during suitable weather between dawn and 16:00 in all parts of each Site; high temperatures in the afternoon were avoided. The visitation order of Sub-plots within each Plot was randomised, but all Sub-plots were surveyed on the same day. Pre-thinning diurnal-bird surveys were conducted between February and May 2004; post-thinning diurnal-bird surveys were conducted between October 2005 and January 2008.

2.2.5.2 Owl-call Playback

During call-playback surveys, taped calls of five nocturnal bird species (Powerful Owl, Barking Owl, Southern Boobook, Sooty Owl *Tyto tenebricosa* and Masked Owl *T. novaehollandiae*) were amplified and played between 21:00 and 01:00 within a Plot to elicit a response from animals that potentially occur in the Plot or in adjacent areas. Where possible, call playback was conducted during optimal weather. To minimise the effect that playback might have on nearby Plots, different Plots at the same Site were not surveyed on the same night. All birds and mammals that responded to the taped calls were recorded.

A total of 19 call-playback sessions was conducted across all Sites before thinning operations, and 28 sessions post thinning (Table 5). Pre-thinning call-playback surveys were conducted between February and May 2004; post-thinning call-playback surveys were conducted between October 2005 and January 2008.

Table 5. Number of call-playback sessions conducted at each Site during both pre- and post-thinning surveys.

	Control		**Isolated**		**Patchy 1**		**Patchy 2**	
Site	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Castlemaine Diggings NHP	2	1	1	2	1	1	1	1
Paddys Ranges SP	2	2	1	1	2	1	1	1
Pilchers Bridge NCR	2	3	2	4	-	1	-	1
Spring Plains NCR	-	4	3	1	-	3	1	1
Total	**6**	**10**	**7**	**8**	**3**	**6**	**3**	**4**

2.2.5.3 Spotlight surveys

Multiple spotlight surveys were conducted in different Sub-plots of each Plot during both pre- and post-thinning surveys. During each spotlight survey the observer moved through a fixed area (100 m × 50 m) along the approximate mid-line of the Sub-plot for 20 minutes, searching the ground and trees, and recording the numbers of vertebrates seen or heard. The visitation order for Sub-plots at a Plot was randomised on each night.

A total of 90 spotlight surveys were conducted across all Sites before thinning operations, and a total of 104 sessions after thinning (Table 6). Pre-thinning spotlight surveys were conducted between February and May 2004 and post-thinning spotlight surveys were conducted between October 2005 and January 2008.

Table 6. **Number of spotlight transects at each Site during both pre- and post-thinning surveys.**

Treatment	**Control**		**Isolated**		**Patchy 1**		**Patchy 2**	
Site	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Castlemaine Diggings NHP	5	4	4	6	5	6	4	3
Paddys Ranges SP	5	6	5	5	6	5	7	6
Pilchers Bridge NCR	12	11	5	14	9	8	6	4
Spring Plains NCR	3	8	5	4	3	5	6	9
Total	**25**	**29**	**19**	**29**	**23**	**24**	**23**	**22**

2.2.5.4 Hair-tube Surveys

Two types of hair-tubes were arranged alternately 10 m apart in a line through each of three Sub-plots in each Plot. Ten funnel-type hair-tubes (Faunatech Universal Hairfunnel or Handiglaze) were placed on the ground, and 10 small, tree-mounted hair-tubes (PVC piping) were attached to the trunks of the largest trees, approximately 2 m above the ground. This totalled 60 hair-tubes per Plot (i.e. 240 hair-tubes per Site). Hair-tubes were left *in situ* for approximately 2 weeks. The hair collected on the adhesive surfaces of the hair-tube during this time was identified to species (or genus) where possible by an experienced practitioner.

The same number of hair-tubes per Site was deployed during both pre- and post-thinning surveys between November and April.

2.2.5.5 Bat Echolocation

Anabat units (computerised bat echolocation call detectors) were positioned within Sub-plots, usually on successive nights within a Site or Plot during fine weather for both pre- and post-thinning surveys. Detectors were programmed to commence recording bat calls at dusk. Ultrasonic bat-call recordings were downloaded to a computer for electronic identification of species by *Anascheme*, call recognition software that identifies individual bat calls by means of their frequency and shape characteristics (Gibson & Lumsden 2003). This task was supported by visual analysis of bat calls by experienced staff. The identification of insectivorous echolocation calls is still a developing field and the refinement of techniques is ongoing. Identification rates are typically low; some calls can only be assigned to complexes of two or more species; and some Victorian species are more readily identifiable than others.

There were 81 bat detector-nights during pre-thinning surveys between October 2004 and April 2006 and 128 during post-thinning surveys between October 2006 and January 2008 (Table 7).

Table 7. Number of bat detector-nights at each Site during both pre- and post-thinning surveys.

Plot	**Control**		**Isolated**		**Patchy 1**		**Patchy 2**	
Site	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**	**Pre**	**Post**
Castlemaine Diggings NHP	4	3	4	3	4	10	4	8
Paddys Ranges SP	6	6	6	5		10		6
Pilchers Bridge NCR	5	9	4	9	5	11	5	10
Spring Plains NCR	9	12	3	7	6	9	6	10
Total	**24**	**30**	**17**	**24**	**15**	**40**	**15**	**34**

2.2.5.6 Incidental Observations

Incidental records of vertebrates from in and around Sites were also collected during the course of the project, and submitted to the DSE's Atlas of Victorian Wildlife database. These records were not included in any analyses.

2.2.5.7 Bias

Several sources of bias are recognised when surveying fauna, and these vary between species, habitats, seasons, weather conditions, observers and sampling techniques. An effort was made to minimise the effects of sampling biases by: standardising the methods and observers; accommodating temporal variability by randomising the sampling sequence (where logistically possible); restricting study sites to a single EVC (though Paddys Ranges SP is an exception); and generally conducting surveys during clement weather.

2.2.6 Invertebrate Indicators

The invertebrate indicators project examined the effects of the various experimental treatments on the ordinal composition of invertebrate assemblages, the genera and species composition of the ant assemblage and the structure of ant functional groups.

2.2.6.1 Invertebrate Sampling

Invertebrate sampling was conducted along the three permanent transects within each Sub-plot. Two sampling techniques were used initially: pitfall trapping for ground-active invertebrates; and vacuum sampling for shrub invertebrates. Vacuum sampling was discontinued after the pre-thinning samples because it involved much effort for little return; it was included initially to collect spiders and beetles, but few were found, and the samples comprised mainly flies.

Ten pitfall traps were used in each Sub-plot: three were placed equidistant on the outer two permanent transects (10 m, 30 m, 50 m); and four were placed equidistant along the middle permanent transect (0 m, 20 m, 40 m, 60 m), at intersection points along permanent transect used to establish measurement transects for floristic survey. Glass test tubes (1 cm in diameter) were used as pitfall traps. These were inserted into plastic sleeves that were hammered into the ground. The pitfall traps contained propylene glycol preservative. Traps operated for 1 week; see Table 8 for the dates of pitfall trapping. Samples were placed in 70% ethanol for storage.

Table 8. Dates of pre- and post-thinning invertebrate pitfall trapping during the Trial.

Site	Treatment	Pre-thinning dates	Post-thinning dates
Castlemaine Diggings NHP	Control	05–12 Mar 2004	16–23 Jan 2006
	Isolated	05–12 Mar 2004	16–23 Jan 2006
	Patchy1	29 Apr–06 May 2004	05–15 Nov 2007
	Patchy2	29 Apr–06 May 2004	05–15 Nov 2007
Paddys Ranges SP	Control	04–11 Aug 2004	28 Nov–05 Dec 2005
	Isolated	04–11 Aug 2004	28 Nov–05 Dec 2005
	Patchy1	21–28 Feb 2005	09–16 Oct 2007
	Patchy2	21–28 Feb 2005	09–16 Nov 2007
Spring Plains NCR	Control	10–17 Dec 2004	14–21 Nov 2006
	Isolated	10–17 Dec 2004	14–21 Nov 2006
	Patchy1	10–17 Dec 2004	05–12 Dec 2007
	Patchy2	10–17 Dec 2004	05–12 Dec 2007
Pilchers Bridge NCR	Control	07–14 Sep 2004	27 Nov–05 Dec 2006
	Isolated	07–14 Sep 2004	27 Nov–05 Dec 2006
	Patchy1	29 Mar–4 Apr 2005	02–09 Nov 2007
	Patchy2	29 Mar–4 Apr 2005	02–09 Nov 2007

Pitfall traps are biased towards ground-active invertebrates. Flying insects are sometimes collected, but the effectiveness of this technique in detecting this group varies. The invertebrates that were most amenable to pitfall trapping were scorpions (Scorpionida), spiders (Araneae), harvestmen (Opilionida), isopods (Isopodida), centipedes (Chilopoda), millipedes (Diplopoda), silverfish (Thysanura), cockroaches (Blattodea), earwigs (Dermaptera), crickets and grasshoppers (Orthoptera), booklice (Psocoptera), beetles (Coleoptera) and wingless Hymenoptera (mainly ants). Pitfall traps can collect a large number of flies (Diptera), but this may be due to their attraction to the preservatives in the traps. The number of invertebrates collected depends upon their level of activity, which can be stimulated by certain environmental factors. For example, higher temperatures generally result in greater invertebrate activity and greater trap success, while rain can stimulate activity among dormant stages (e.g. springtails [Collembola] are more abundant after rain).

Although pitfall trapping has a number of limitations, it is the most widely used invertebrate trapping method for the assessment of invertebrates in natural environments. It is simple, relatively inexpensive, collects many specimens and is inconspicuous (unlike some traps which attract attention and potential inference).

The main issues involved with pitfall trapping are: digging-in effects; the diameter of the traps; the number and configuration of traps; the use of a preservative; and the length of operation (Greenslade 1973; Ward *et al.* 2001; Neville & Yen 2007). In comparing test tubes (18 mm diameter) with plastic drinking cups (70 mm diameter), Borgelt & New (2005) found that the test tubes trapped a total of 25 ant species while the cups trapped 31 species (including the 25 species collected in test tubes). Further, traps were run for 2, 5, 7 and 14 days, and it was found that a high proportion of genera and species of ants was collected in the first 2 days; shorter sampling time still gave an adequate representation of local ant assemblages, but not all the rarer species were trapped (Borgelt & New 2006).

Ideally, pitfall traps should be open simultaneously when invertebrate activity is highest — normally spring and early summer. Unfortunately, this was impractical during the Trial because of the timing of Site set-up and the thinning operations, which were influenced by extrinsic factors.

2.2.6.2 Specimen Identification

All pre- and post-thinning pitfall trap samples were identified to order, and all ants identified to morphospecies. Larvae were left as ‘larvae’; they were either Diptera, Coleoptera, Lepidoptera or Hymenoptera.

2.3 Data analysis

2.3.1 Individual Monitoring Projects

For all analyses, a significance level of $p<0.05$ was employed unless stated otherwise. For some analyses, a more conservative significance level was used (e.g. $p<0.01$) to identify a significant result.

2.3.1.1 Univariate Analysis

To determine the effects of treatment (i.e. Control, Isolated, Patchy 1 or Patchy 2) and time (i.e. pre-thinning versus post-thinning) on biodiversity (e.g. floristic life forms) and habitat variables (e.g. ground cover, coarse woody debris, litter depth) analysis of variance (ANOVA) techniques were used.

Life form cover changes were analysed using a two-way ANOVA to determine the effects of treatment or time, and the interactions between treatment and time. The ANOVAs were performed separately for individual Sites and for combined data. The coarse-woody-debris retention treatments were ignored at this stage, as there had been insufficient time for the effects of the disturbance to settle down.

Potential changes in the extent (e.g. cover, frequency, number of hits, depth) of ground-cover components (e.g. fine litter, bare ground, rocks), litter and coarse woody debris after thinning were analysed using repeated measures ANOVA to determine the effects of treatment and time. The repeated measures ANOVAs were performed separately for individual Sites and combined data. In this design, Plots represented subjects, with Control, Isolated, Patchy 1 and Patchy 2 being fixed within-subject factors; Sub-plots within Plots were effectively random factors. Time represented trials, with two levels specified (pre- and post-thinning).

2.3.1.2 Multivariate Analysis

Multivariate techniques were used to analyse community-level differences for floristic and fauna assemblage data at the Plot scale.

To determine whether there were any differences in the floristic composition of vegetation communities, non-metric multidimensional scaling (NMDS) was used to produce ordinations of the floristic community data, as this has proved to be a robust technique for indirect gradient analysis (Minchin 1987). The ordinations commenced with a matrix of Bray-Curtis dissimilarities between all pairs of Sites, standardised by species maxima.

This ensured that the resulting ordinations were not dominated by those species with the highest cover. Species that occurred at only one Site were removed from the data set to reduce ‘noise’. All samples were then positioned onto a scatter diagram such that the relative distances between Sites were (as far as possible) in rank order with their dissimilarities.

Because the ordination uses rank order, not the actual dissimilarity values, the logic applied is of the form: A is closer to B than it is to C (Clarke 1993). Actual distances on the Plot are based on the minimum stress solution from 20 iterations. This stress is a measure of the total scatter about a line of best fit for a monotone regression of rank-order ordination distances against original rank-order dissimilarity values (Clarke 1993).

Vector fitting was then used as an additional descriptive tool to determine whether there were any directions across the Site ordination that were significantly correlated with particular variables. This technique, originally called rotational correlation, involves the rotation of the ordination co-ordinates until the designated site variable shows maximum linear correlation with the X-axis (Dargie 1984). The degrees of rotation required to maximise the correlation value determine the direction of the vector across the ordination. The significance of any correlation is determined by a random permutation procedure, sometimes called a Monte Carlo simulation (Hope 1968). Significant vectors were then examined to determine whether any of the variables showed logical relationships with other variables in ordination space.

NMDS was used to produce ordinations of the community data for different fauna groups (all vertebrates; diurnal birds; all birds; terrestrial mammals; bats). This technique is widely used for community data and has proved to be a robust technique for indirect gradient analysis (Minchin 1987). The ordinations commenced with a matrix of Bray-Curtis dissimilarities between all pairs of sites, based on binary data (i.e. presence or absence of taxa in the data-set). All samples were then positioned onto a scatter diagram such that the relative distances between sites were, as far as possible, in rank order with their dissimilarities. There was no transformation of the data.

The logic for the NMDS was the same as that used for floristics. In all cases, stress was <0.2 for the two-dimensional solutions and, given the preliminary nature of the data and the confounding effects of season and year, only these ordinations were calculated.

These ordinations are coarse and are calculated only on the presence of definite taxa (e.g. ‘probable’ hair identifications from hair-tube surveys were removed, as were multi-genera bat species complexes from the bat-call data). For most survey techniques the level of survey effort generally varied between Sites and between Plots; however, results were standardised for effort to compensate for this.

The NMDS multivariate approach was also used to assess forest mensuration data supported by Principal Components Analysis (PCA). For analysis of tree density, accuracy of the PCA output diagram was improved by removing data from Paddys Ranges SP because of known differences in EVCs (Gibson *et al.* 2008; Pigott *et al*. In Press). This allowed better interpretation of the variables influencing PCA axes 1 and 2.

2.3.2 Analysis of Integrated Project Data

To investigate the relationships and interactions among selected biodiversity variables and different habitat attributes (including forest structure), simple linear regression was used. Linear regression models were used to explain the relationship between the response variables (e.g. groups of birds that exhibit similar behaviour in terms of either foraging, nesting or migratory movements) and a series of ecologically meaningful predictor variables (e.g. geographical; treatment; habitat). This was used to determine the relationship between ecological-thinning outcomes (i.e. increased coarse woody debris; decreased stem density) and the response of biodiversity. An advantage of linear regression models is that they have the capacity to (with appropriate recognition of limitations) predict future trends based on changing scenarios (e.g. increased hollow abundance) using current data. This should prove useful in the ongoing monitoring and evaluation of the longer-term implications of the ecological thinning (Phase 2).

The linear-regression-models approach was based on the following assumptions:

- changes in one parameter as a result of the thinning treatment are likely to affect changes in other parameters;
- differences in those parameters between Sites should already exist, regardless of whether or not they have been thinned; thus,
- relationships between different parameters may already be evident in pre- or post-thinning data.

Regressions were performed separately for pre- and post-thinning surveys, and for combined data. This was under the assumption that relationships between different parameters should be stronger when the differences between sites are commensurately larger (e.g. after thinning). For example, initial analysis suggested that bat activity was higher when tree density was lower, but this was driven largely by the post-thinning data.

Predictor variables used for the linear regression models across project themes included: litter cover; litter depth; coarse woody debris <10 cm; coarse woody debris >10 cm; tree density; number of trees with hollows; understorey cover; understorey richness; shrub cover; and ant species richness.

For floristics, response variables included: understorey richness; orchid richness; and weed cover. Regressions involving tree density were at a Plot scale, with n = 32 (combined data) or n = 16 (pre- or post-thinning). All other regressions were at the Sub-plot level, with n = 288 (combined data) or n = 144 (pre- or post-thinning).

A wide range of variables was used to assess the response of vertebrates to ecological thinning. Avian response variables included: bird species richness; total bird abundance; number of foraging groups; number of nest groups; relative abundance and richness of each foraging, nest and migratory group (Appendix 2). For mammals variables included: total bat activity; *Vespadelus* activity; *Chalinolobus* activity; White-striped Freetail Bat activity; *Antechinus* activity; Brush-tailed Phascogale activity; mammal activity (tree tubes); mammal activity (ground tubes); native mammal activity (all hair tubes); native mammal richness (all hair tubes); and total arboreal mammals (spotlighting).

For invertebrates, the variables used included: order richness; scorpion individuals; Aranae individuals; psuedoscorpion individuals; Acarina individuals; Isopoda individuals; Chilopoda individuals; Dermaptera individuals; Coleoptera individuals; Diptera individuals; ant richness; ant abundance; Hymenoptera (non-ants) individuals; and larvae. These invertebrate variables were also related to bird-predictor variables, including: bird species richness; total bird individuals; and total bird insectivore individuals.

2.3.3 Data from Independent Projects

To help predict future effects of the Trial, some data from independent research carried out in the Box–Ironbark region were examined. The data investigated included: floristic and structural life form data; bird assemblage; and select fauna data. These data sets were provided by a range of organisations, including the Arthur Rylah Institute of Environmental Research (ARIER) and various universities.

For the floristics theme, some limited floristic and structural data from vegetation condition (i.e. Habitat Hectare assessment) research (Tolsma & Newell 2003) were also analysed using simple linear regression. These included floristic and structural data from 41 Grassy Dry Forest sites (from north-east of the Melbourne metropolitan area), and 85 Box–Ironbark Forest sites between Rushworth and St Arnaud. Comparable or similar data included: tree canopy cover; tree density; log length; litter cover; shrub cover; understorey cover; understorey richness; weed cover; and orchid richness.

A number of sources of additional vertebrate data were examined, including for bats and terrestrial mammals (ARIER, unpublished data), as well as birds (A.F. Bennett, unpublished data). Bats and terrestrial mammals had previously been surveyed at 35 Box–Ironbark sites in either Box–Ironbark Forest EVC (24 sites) or Heathy Dry Forest EVC (11 sites) (ARIER, unpublished data). A range of habitat variables were measured at these sites including: log volume; number of tree hollows; litter cover; tree density; and vegetation cover. The relationships between vertebrates and habitat variables were analysed using linear regression models. For birds, two sets of data were available. First, the bird assemblages occurring at 80 sites in the Box–Ironbark region in Victoria were analysed using an MDS ordination to interpret assemblage patterns between different EVCs. Second, the bird assemblages occurring at 31 sites at different geographic locations and within different age-class forests (young versus old) were analysed using an MDS ordination. To interpret the ordination, the pattern of sites based on geographic location and age-class of sites was examined. Basic habitat data from a subset of paired young and old sites in this study was analysed using paired t-tests to determine if there were any differences in habitat variables including logs, large trees, understorey cover and litter between the two age-classes.

3 RESEARCH AND MONITORING PROJECT OUTCOMES

This section of the report describes the outcomes of Phase 1 of the Trial for each of the projects. In each project the pre-thinning and initial post-thinning monitoring results of the selected biodiversity and habitat attributes across all Sites, Plots and Sub-plots (where used) are presented. In broad terms, the aims of the projects were to determine the effects of ecological thinning at various tree densities and, where appropriate, determine the effects of different woody-debris removal levels.

3.1 Forest Structure: Tree Mensuration

The implementation of tree thinning affects forest structure regardless of site condition because removal of trees modifies conditions of the surrounding environment. Considering this generality, it was important to evaluate whether treatment objectives had been met and to establish a baseline for monitoring these changes through time. Measures selected for these purposes were: species composition; stem density; basal area; and tree size-class distribution.

3.1.1 Effects of Thinning on Tree Composition and Structure

3.1.1.1 Species Composition

Seven species of eucalypts (*Eucalyptus*) were recorded during assessments of canopy composition at the Sites. Long-leaf Box *Eucalyptus goniocalyx*, Red Box and Red Stringybark were prominent at sites supporting Heathy Dry Forest EVC (Castlemaine Diggings NHP, Pilchers Bridge NCR and Spring Plains NCR). Associations of Grey Box, Red Ironbark, Red Box and Yellow Gum were variously present at Paddys Ranges SP, which supported Box–Ironbark Forest EVC. Small numbers of Yellow Box *Eucalyptus melliodora* occurred across all Sites.

The relative frequencies of the dominant species (as a percentage of the total) for each Plot following thinning are shown in Table 9. The relative frequencies of the dominant species for each Plot measured before thinning were mostly maintained after thinning.

Table 9. Percentage of total stem frequency of overstorey species recorded in post-thinning TTT Plot surveys (with relative change in parenthesis and most dominant species in each shaded).

Site	Treatment	GB	LLB	RB	RIB	RS	YB	YG
CDNHP	Control	3 (0)	36 (-1)	26 (+2)	0 (0)	35 (0)	0 (0)	0 (0)
	Isolated	0 (0)	24 (-10)	38 (+2)	0 (0)	38 (+9)	1 (0)	0 (0)
	Patchy1	0 (-1)	23 (-16)	22 (+13)	0 (0)	54 (+5)	1 (+1)	0 (0)
	Patchy2	0 (-2)	26 (-3)	26 (+8)	0 (-2)	48 (-1)	1 (+1)	0 (0)
SPNCR	Control	0 (0)	27 (-1)	31 (+3)	0 (0)	42 (-2)	1 (0)	0(0)
	Isolated	1 (+1)	14 (-1)	34 (+3)	0 (0)	50 (-3)	1 (0)	0 (0)
	Patchy1	0 (0)	25 (+4)	35 (+10)	0 (0)	37 (-13)	3 (-1)	0 (0)
	Patchy2	0 (-4)	33 (+9)	36 (+4)	0 (0)	32 (-7)	0 (-2)	0 (0)
PBNCR	Control	0 (-3)	19 (+4)	47 (+2)	0 (0)	34 (-3)	0 (0)	0 (0)
	Isolated	9 (+4)	16 (0)	42 (+18)	1 (+1)	32 (-23)	1 (+1)	0 (0)
	Patchy1	0 (-1)	28 (+3)	38 (+4)	0 (0)	29 (-17)	5 (+5)	0 (0)
	Patchy2	0 (0)	24 (-1)	34 (+5)	0 (0)	42 (-4)	0 (0)	0 (0)
PRSP	Control	27 (+3)	10 (-2)	33 (+2)	1 (0)	0 (0)	7 (+2)	22 (-2)
	Isolated	35 (-14)	3 (0)	11 (+6)	32 (+3)	7 (+2)	3 (+2)	9 (+1)
	Patchy1	16 (-8)	2 (-1)	7 (-6)	62 (+25)	4 (-10)	9 (+1)	0 (-1)
	Patchy2	56 (+24)	14 (-4)	1 (-4)	1 (0)	0 (+1)	5 (-17)	23 (+1)

CDNHP = Castlemaine Diggings NHP; SPNCR = Spring Plains NCR; PRSP = Paddys Ranges SP; PBNCR = Pilchers Bridge NCR. GB = Grey Box; LLB = Long-leaf Box; RB = Red Box; RIB = Red Ironbark; RS = Red Stringybark; YB = Yellow Box; YG = Yellow Gum.

Canopy tree species that were dominant during pre-treatment surveys mostly remained dominant following ecological thinning, though the proportions changed markedly in some Plots because thinning focussed on the removal of smaller stems. The dominant species (Long-leaf Box, Red Box and Red Stringybark) in Plots at Heathy Dry Forest Sites (Castlemaine Diggings NHP, Pilchers Bridge NCR and Spring Plains NCR) all coppiced after the main stems were felled, and if left unmanaged would regrow into multi-stemmed trees (Kellas 1991; ECC 1997).

A greater mix of tree species occurred at the Box–Ironbark Forest Site (Paddys Ranges SP), where the relative frequencies of canopy trees differed markedly to those observed at the Heathy Dry Forest Sites. Post-thinning changes also differed within and between Plots, although Grey Box remained the dominant species (by stem number) (Table 9). Each Plot had minor contributions from at least one additional species, but up to seven species occurred in some Plots (Table 9).

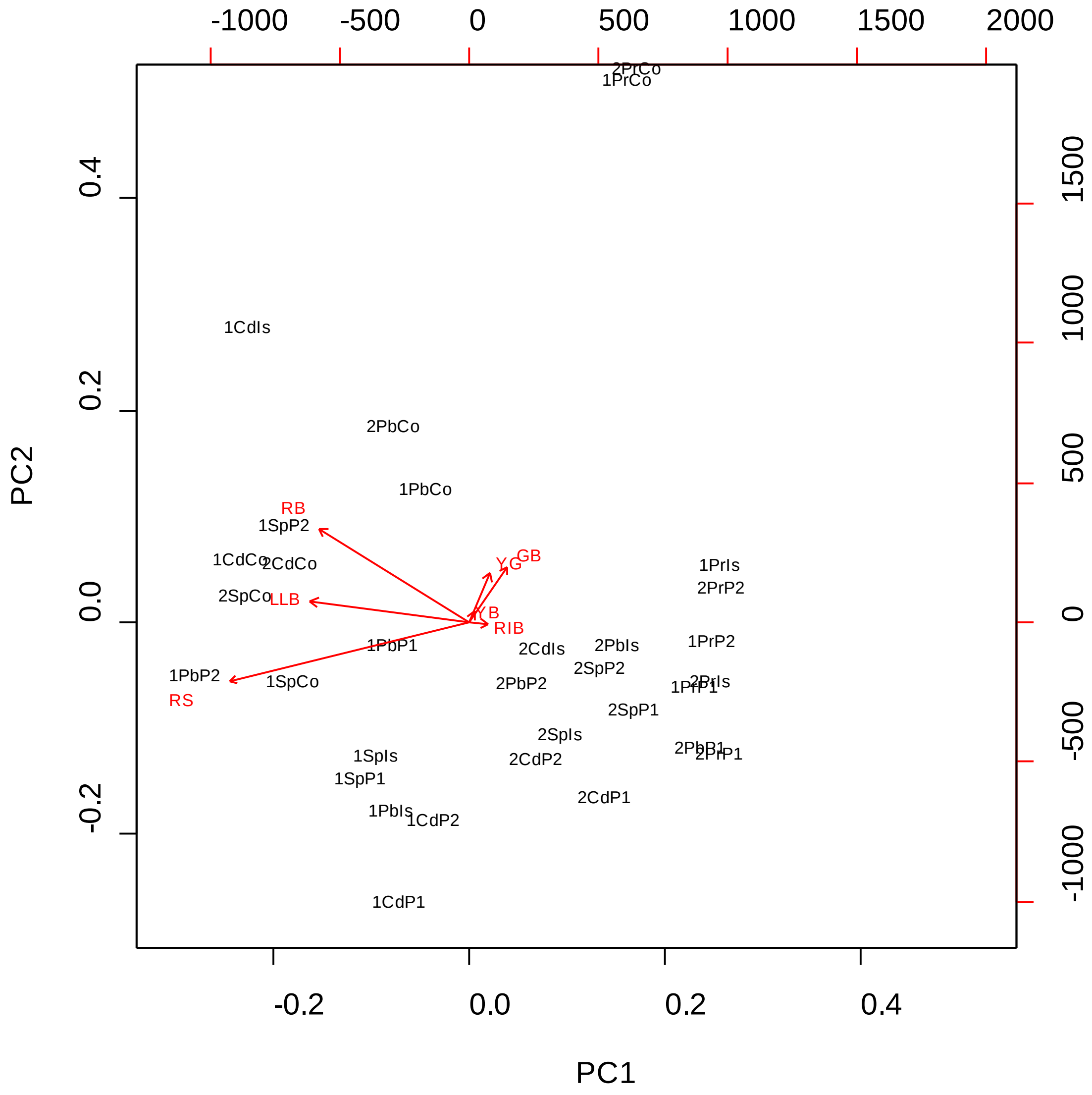

Figure 3. Principal components analysis of overstorey tree species density (all Sites).

Points starting with ‘1’ are pre-thinning, and those starting with ‘2’ are post thinning.
Cd = Castlemaine Diggings NHP; Sp = Spring Plain NCR; Pb = Pilchers Bridge NCR; Pr = Paddys Ranges SP. Plots: Co = Control; Is = Isolated; P1 = Patchy 1; P2 = Patchy 2. RS = Red Stringybark; RB = Red Box; LLB = Long-leaf Box; YG = Yellow Gum; RIB = Red Ironbark; GB = Grey Box; YB = Yellow Box.

All pre- and post-thinning stem-density data for Plots, including the proportion of eucalypt species, were analysed using principal components analysis (PCA). The output for this analysis showed that Sites were clustered according to species combinations (i.e. EVCs), with Plots at Paddys Ranges SP separated from other Sites (both pre- and post-thinning) (Figure 3) (Gibson *et al.* 2008). Separation of plots along the axes for this PCA diagram were stem density (Axis 1) and proportion of species occurrence (Axis 2). Red Stringybark with Long-leaved Box and Red Box appear to be important in Axis 2.

Variations in proportion of canopy species may help explain why pre- and post-thinning outcomes at Paddys Ranges SP (and to a lesser extent Castlemaine Diggings NHP pre-thinning) are placed as ‘outliers’ in Figure 3. Remaining Paddys Ranges SP Plots are located at the right of the central cluster, indicating differences in a combination of stem density and species composition (Figure 3).

In order to seek clarification of the relationships between stem density and species composition for the Heathy Dry Forest EVC Sites, a further PCA was carried out excluding the data from Paddys Ranges SP (Figure 4). As for the ‘all Site’ data, the primary principal component (Axis 1) was stem density and the second (Axis 2) was proportion of species occurrence. Again, Red Stringybark, with Long-leaved Box and Red Box, appear to be important in Axis 2.

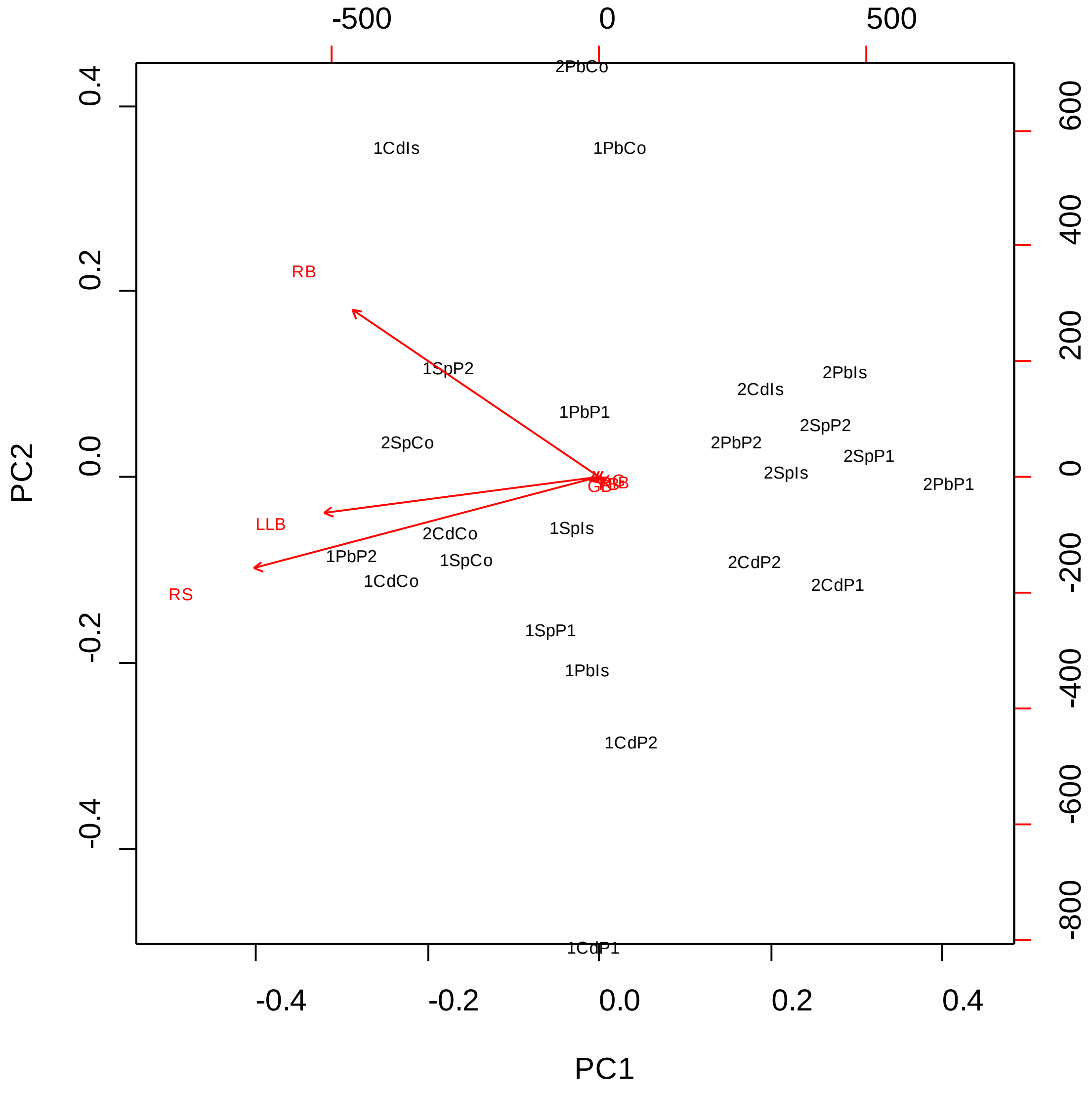

Figure 4. Principal components analysis of overstorey tree species density (all Sites excluding PRSP); abbreviations as for Figure 3.

3.1.1.2 Stem Density

Before ecological thinning, stem densities varied between both Plots and Sites (Table 10). Stem density was expected to vary due to a combination of geographical differences including topography, distance between sites and EVC, as well as different histories of disturbance, including fire and timber-harvesting. To account for initial differences in stem density between both Plots and Sites, change in stem densities after thinning were evaluated as percentage change (Figure 5).

Table 10. Mean stems per hectare derived from TTT surveys in Plots by Site.

Site	Treatment	Mean stems per hectare	
		Pre	Post
Castlemaine Diggings NHP	Control	1430	1286
	Isolated	1419	513
	Patchy1	889	319
	Patchy2	822	515
Spring Plains NCR	Control	1201	1349
	Isolated	925	436
	Patchy1	1010	264
	Patchy2	1319	361
Paddys Ranges SP	Control	888	904
	Isolated	469	226
	Patchy1	343	87
	Patchy2	253	300
Pilchers Bridge NCR	Control	883	964
	Isolated	917	341
	Patchy1	926	70
	Patchy2	1451	562

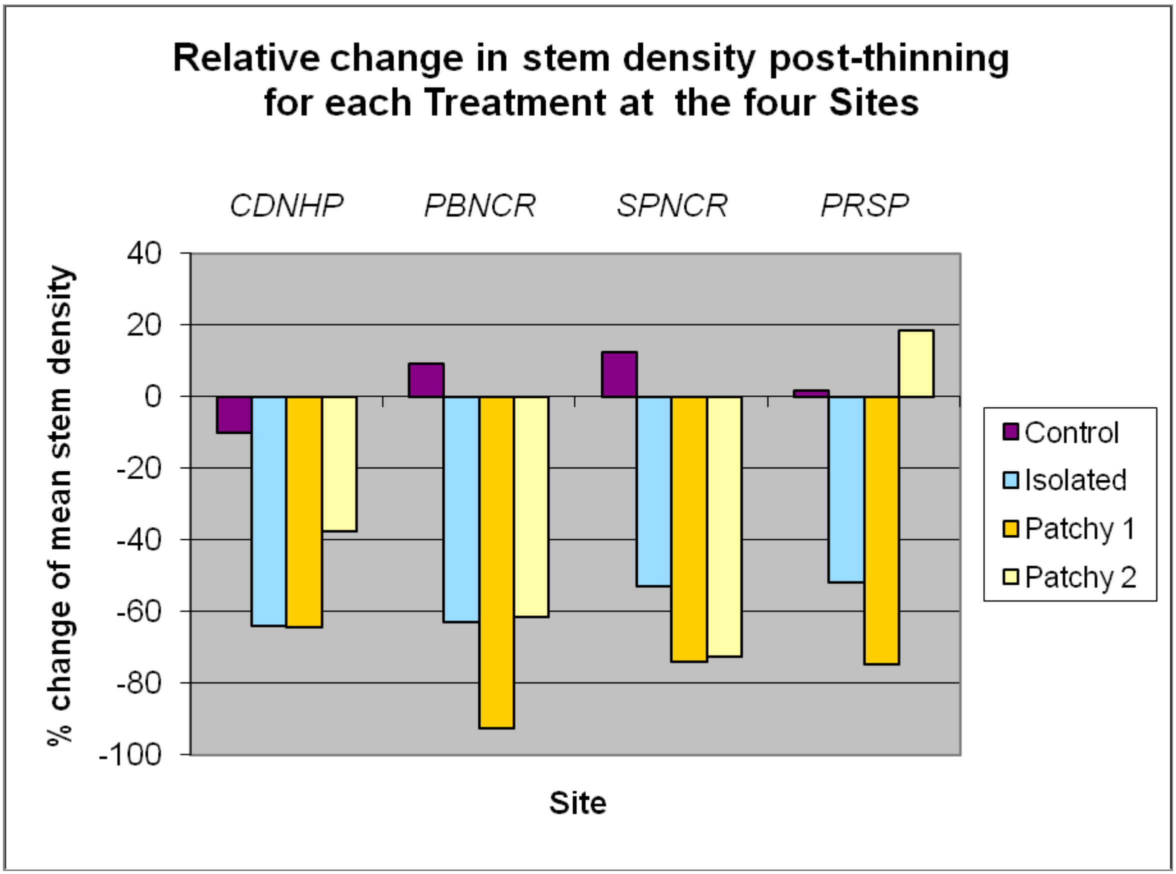

Figure 5. Percentage change in mean stem density following implementation of thinning Treatments at four Sites in the Trial.

The changes shown in Figure 5 were expected because reducing stem density was a key target of the Trial. Isolated treatment consistently led to a reduction in stem density of approximately 50–60%. Patchy 1 (*c*. 60–90%) and Patchy 2 Plots (*c*. 30–70% - see also discussion about Paddys Ranges SP Plot in Section 3.1.1.2) showed greater variation between Sites. Because of high variation in stem density within and between Plots and between Sites, as well as pre- and post-treatment Control estimates, these changed values cannot be considered across Plots or Sites and therefore do not identify regular patterns in the treatments applied. The post-thinning results effectively establish the new ecosystem baseline for forest structure at the Plot scale, independent of existing EVC Benchmarks established by the Department of Sustainability and Environment. This will be useful for ongoing monitoring of stem density following ecological thinning over longer time-scales.

It must be noted that the sampling techniques used to estimate stem density are likely to have implications for the results obtained. For example, the Patchy 2 Plot at Paddys Ranges SP showed a positive change in stem density following thinning, despite the obvious removal of stems across this Plot (Figure 5). An explanation for this could be that the sample size of 50 triplets of trees used post thinning (as for pre-thinning monitoring; see Pigott *et al.* In Press) may be insufficient to detect changes at the 30-ha scale.

3.1.1.3 Stem Diameter

There were was a clear positive change in mean stem diameter (i.e. increased DBHOB) for all treated Plots as a result of ecological thinning (Figure 6).

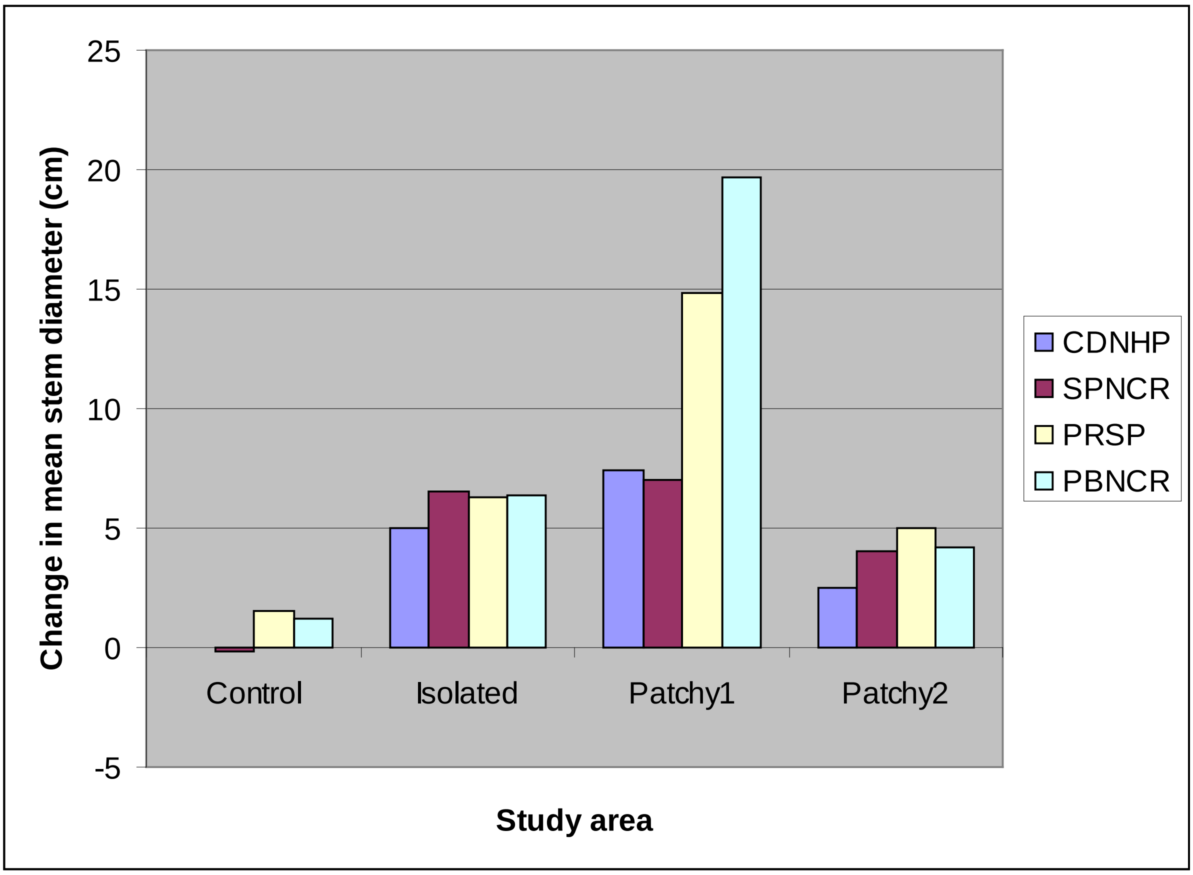

Figure 6. Change in mean stem diameter for thinning treatments at four Trial Sites.

Change in mean stem diameter grouped by treatment shows some consistency across sites in Isolated and Patchy 2 Plots but not for Patchy 1. This outcome is likely to be attributable to greater variability in retained trees where there is a 75% reduction of stems, as determined by basal measurements in the field (Gibson *et al.* 2008). It also reflects variations in the species mix and pre-thinning densities of canopy species, both being consequences of original EVC and the history of disturbance.

Generally, thinning resulted in an increase in mean stem diameter, but variation is high across Plots. At this early stage in the Trial this change cannot be considered a response to thinning, but instead is a direct result of the retention of larger trees during thinning operations. For example, Red Stringybark is a common component of the overstorey across Plots in Heathy Dry Forest. Following thinning, mean stem diameter of Red Stringybark increased in all Plots (Figure 7). The range of values recorded in each Plot shows a high amount of variation, making it difficult to extrapolate any trends for specific treatments. In support of the above inference regarding stem reduction, Patchy 1 treatment (75% reduction in stems) resulted in the greatest difference in mean stem diameter at most sites (Figure 7). The greatest change was evident at Pilchers Bridge

NCR Patchy 1 Plot; this corresponds with this Plot also having the greatest reduction in the number of stems.

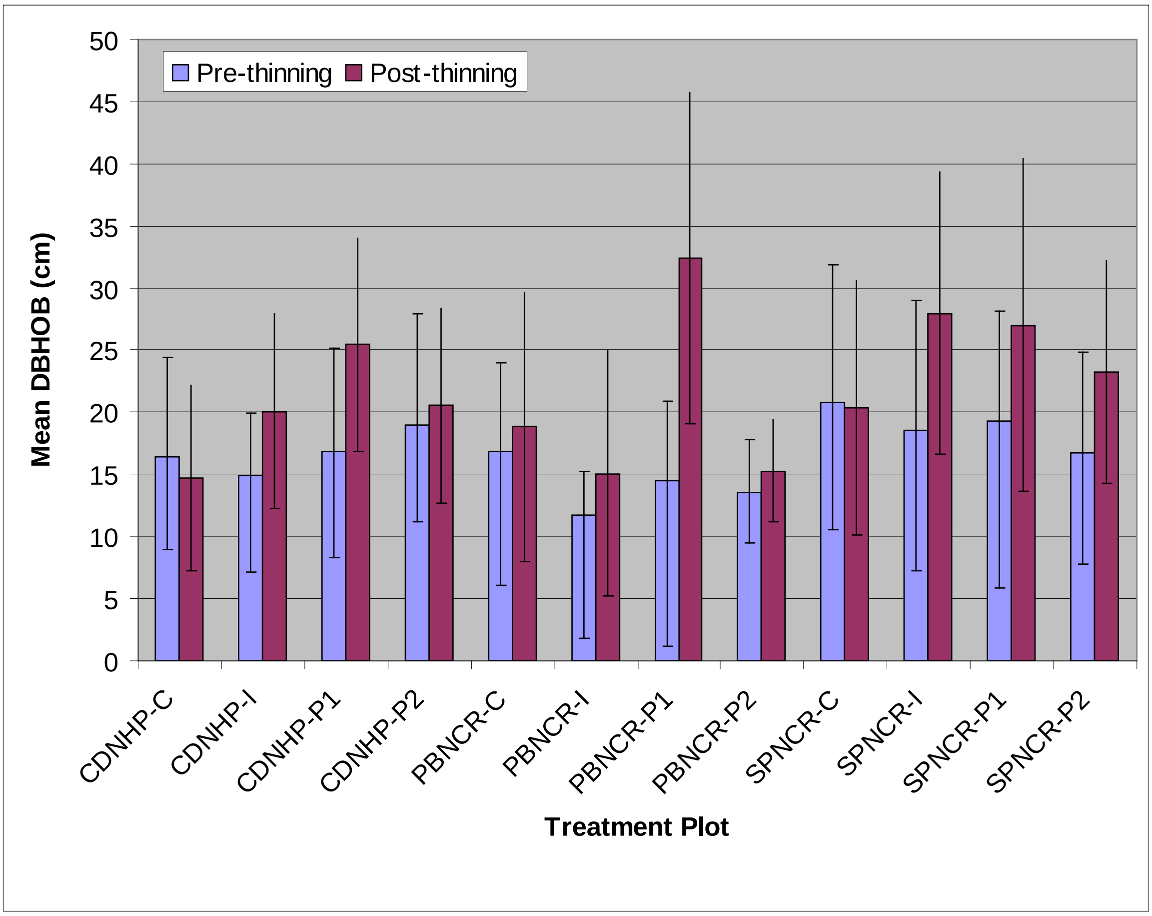

Figure 7. Mean stem diameter of Red Stringybark at Castlemaine Diggings NHP, Pilchers Bridge NCR and Spring Plains NCR Sites pre- and post thinning (error bars show range of DBHOB around the mean).

3.1.1.4 Basal Area

Post-thinning change in basal area of each Plot was calculated using TTT data from repeated surveys.

As expected, there was a measurable reduction in basal area for most treatments at all Sites, despite variation in numbers of stems removed (Figure 8). To address known differences for Sites, including geographic location and EVC (Gibson *et al.* 2008; Pigott *et al.* In Press), the change in basal area is considered separately for each Site.

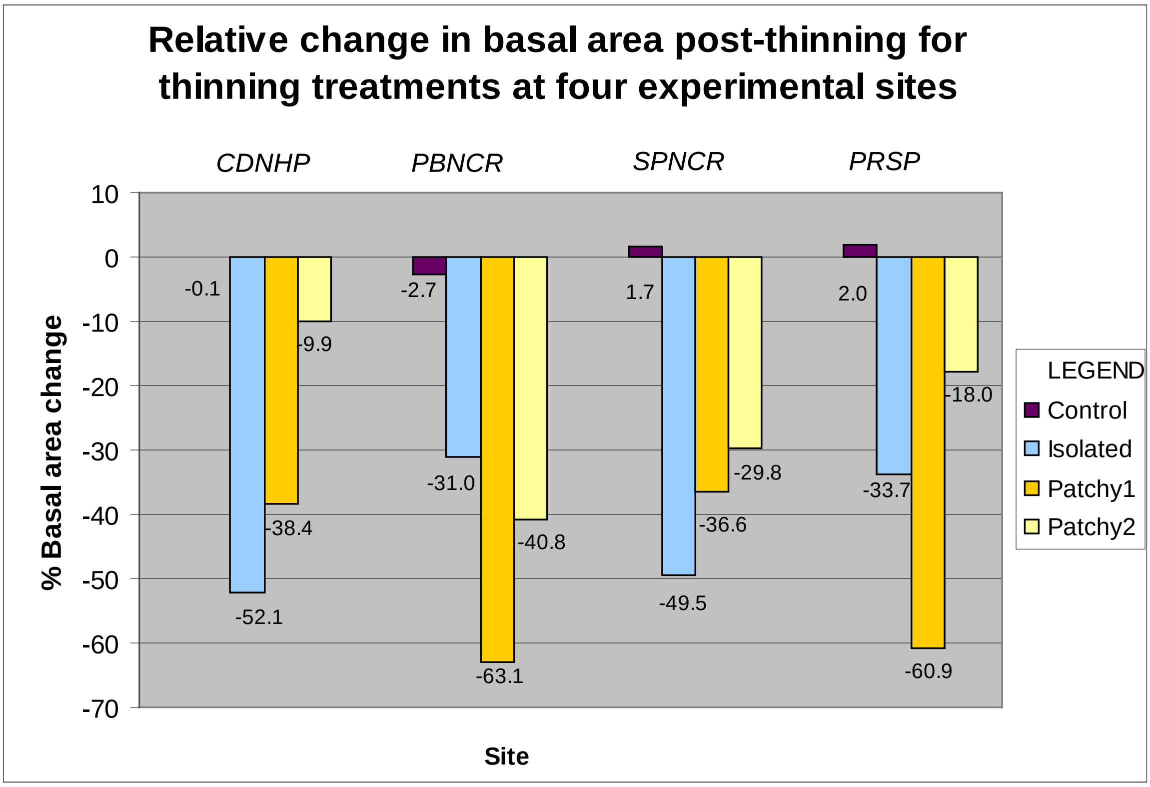

Figure 8. Relative change in mean basal area following implementation of thinning treatments at four Sites in the Trial.

Despite reductions in mean basal area, there were no clear trends in change of basal area at the Plot level following thinning, other than the expected outcome that thinning resulted in a reduction in basal area at treated Plots (Figure 8). Values for Control sites showed little change (Figure 8), unlike comparisons of some of the other variables (e.g. stem density). Across Plots, only some of the treatment prescriptions (i.e. specified levels of basal area reduction; see Table 3) were met. For example, only two Isolated Plots met prescribed level of basal area reduction, while all the Patchy 1 and Patchy 2 Plots fell short of their prescribed targets.

A factor contributing to lower thinning rates than were prescribed was probably the difference between the two methods used to estimate basal area. During thinning operations, estimates of basal area were made using a hand-held optical wedge, as per convention (Pigott *et al.* In Press). This technique is generally considered reliable when conducted by an experienced practitioner. However, in this study, when compared with TTT basal-area data (used for pre-thinning estimates), pre-thinning values at some

Control Plots indicated that the optical wedge technique did not provide a reliable estimate of basal area (Figure 9). This is important as the optical wedge technique was used to interpret the level of cutting required for treatment implementation in the field.

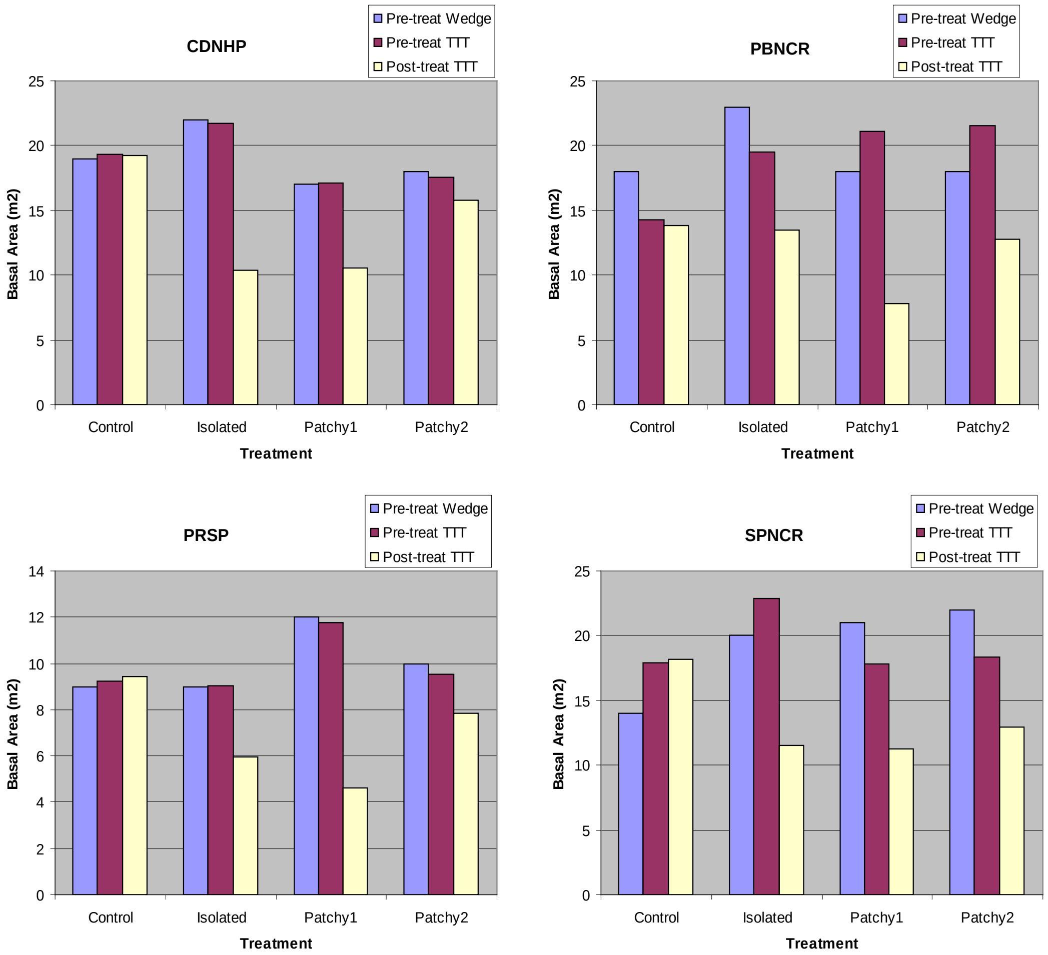

Figure 9. Comparisons between pre- and post-treatment basal area measurements for the four Trial Sites.

Other confounding factors were likely to contribute to the variable outcome shown in Figure 9. It is possible that an amount of variation exists due to the sampling method used. Post-thinning assessment of Plots may be an underestimate of actual basal area. The calculation of basal area relies on the distance measured between nearest neighbour trees in the 50 triplet samples combined with DBHOB for those trees. This distance measure in some Plots may be too long (in relation to diameter) for the formulae to accurately predict basal area across 30 ha. For example, in Patchy 2 Plots the target of 50% basal area reduction was applied only to the 75% of the Plot subject to thinning. This would account for the reduced total basal area observed in these Plots, but not for the large variation in these Plots across all Sites (Figure 9). Other anomalies were also observed, including the relatively large stem reduction (approximately 90% of stems) in the Patchy 1 Plot at Pilchers Bridge NCR which resulted in a 63% basal area reduction, still 12% short of the basal area target.

In the context of these factors, thinning Patchy 2 to *a priori* targets would have been easier to estimate in the field because fewer trees were required to be removed. The Isolated treatment may have been more consistently cut to prescription (whether or not meeting the required basal area) because it would have been a familiar method of cutting to the crew due to its similarities with silvicultural thinning. Variation in the Control estimates simply reflects error or the in-built variation associated with data collection.

Basal area will be a key indicator in the ongoing monitoring of the Trial, including in assessing the effects of ecological-thinning treatments. The TTT basal area data will provide an important benchmark against which to assess future change in forest structure.

3.2 Forest Structure: Key Fauna Habitat

The key fauna habitat features that were affected by the various experimental-thinning treatments were ground cover, litter structure, volume of coarse woody debris and availability of tree hollows. These features were assessed before experimental thinning and again 12–24 months after experimental thinning.

3.2.1 Tree Hollows

The availability of tree hollows for fauna in Box–Ironbark forests is extremely limited (Traill 1991, 1993; Soderquist 1999; Adkins *et al.* 2005), and this has been attributed to the loss of large trees from the Box–Ironbark landscape. Generally, in eucalypts there exists a positive correlation between the number of large old trees and the proportion of trees containing hollows, number of hollows per tree and the size of hollows (Lindenmayer *et al.* 1993). In Mugga Ironbark *Eucalyptus sideroxylon*-dominated forest in the Warby Range State Park in north-eastern Victoria, only 2% of sampled trees (n = 159 trees) contained hollows (Adkins *et al.* 2005). Similarly, in the Bendigo region, hollows occur most commonly in trees >60 cm DBH, with 42% of these trees containing hollows. Fewer than 1% of trees in the Box–Ironbark forest fall into this category, yet they account for a third of all hollows. Few trees of this size or greater were recorded during the Trial.

The proportion of trees that contained hollows in this study was variable and ranged from 1.3% (Patchy 2 at Paddys Ranges) to 21.4% (Patchy 1 at Spring Plains) (Table 11).

Table 11. Number of hollow-bearing trees in Plots measured during post-thinning TTT surveys.

The total number of trees assessed is shown in parentheses.

Treatment	Pilchers Bridge NCR	Castlemaine Diggings NHP	Spring Plains NCR	Paddys Ranges SP
Control	14 (146)	9 (146)	14 (120)	10 (148)
Isolated	3 (158)	4 (117)	5 (126)	2 (150)
Patchy1	13 (149)	5 (162)	27 (126)	2 (129)
Patchy2	9 (147)	7 (132)	12 (129)	2 (159)

The distribution of tree hollows varied between Sites and Plots. Spring Plains NCR supported the highest number of tree hollows, followed by Pilchers Bridge NCR, Castlemaine Diggings NHP and Paddys Ranges SP. Due to the low densities of large trees recorded at the Sites, it is considered that the number of tree hollows present would be significantly lower than that which occurred before European settlement (Traill 1991).

The low number of hollow-bearing trees recorded and total number of hollows (see Palmer *et al.* 2008) supports other assessments that have found a low availability of this crucial habitat feature in Box–Ironbark forests and woodlands (e.g. Soderquist 1999). As hollow-bearing trees were selected for retention in the Trial, post-thinning survey samples were more likely to contain a higher proportion of these trees than pre-thinning samples. These data were variable (by Site) but nevertheless supported the established relationship between tree size and number of hollows (Soderquist 1999).

The types of hollows present in the landscape reflect the shift in tree structure characters since European settlement, with today's forests dominated by immature trees, and the high proportion of base hollows is a characteristic feature of forests dominated by coppice stems (Soderquist 1999). Hollows at Castlemaine Diggings NHP and Paddys Ranges SP were dominated by base hollows, with few trunk hollows or canopy hollows present; there were no trunk or canopy hollows at Castlemaine Diggings NHP. Spring Plains NCR and Pilchers Bridge NCR supported higher overall numbers of hollows, including higher proportions of canopy hollows and trunk hollows, reflecting the greater number of trees in larger size-classes present at these Sites. A previous assessment of tree-hollow availability in Box–Ironbark forest found that canopy hollows occurred most commonly in trees >60 cm DBH, with 42% of these large trees bearing hollows (Soderquist 1999). Trees of <20 cm DBH effectively lacked hollows and those 20–40 cm DBH had few (Soderquist 1999).

Medium hollows (with entrance diameter 5–20 cm) and large hollows (entrance diameter >20 cm) were the most common tree-hollow size-classes at Spring Plains NCR, Pilchers Bridge NCR and Paddys Ranges SP; large hollows, and to a lesser extent medium hollows, were rare at Castlemaine Diggings NHP (Table 12). Soderquist (1999) found that the proportion of medium-sized tree hollows was not significantly different across tree size-classes.

Table 12 Number and size of hollows across treatments

Park	**Treatment**	**Hollow entrance dimension**			**Total**
		Small	**Medium**	**Large**	
Castlemaine Diggings NHP	Control	6	3	-	9
	Isolated	-	-	-	0
	Patchy 1	13	1	3	17
	Patchy 2	4	4	-	8
Spring Plains NCR	Control	9	8	8	25
	Isolated	-	2	6	8
	Patchy 1	3	8	18	29
	Patchy 2	13	14	18	46
Pilchers Bridge NCR	Control	9	6	16	31
	Isolated	3	1	13	17
	Patchy 1	-	2	7	9
	Patchy 2	2	3	11	16
Paddys Ranges SP	Control	4	2	6	12
	Isolated	-	-	6	6
	Patchy 1	7	1	5	13
	Patchy 2	5	3	7	15

* Hollow entrance smallest dimension: small = 2-5 cm^2, medium 5-10 cm^2, large 10-20 cm^2 & very large >20 cm^2 (after Soderquist 1999).

Hollow-bearing trees at Castlemaine Diggings NHP, Spring Plains NCR and Pilchers Bridge NCR were predominantly of three species: Long-leaf Box, Red Box and Red Stringybark. At Paddys Ranges SP, Grey Box was the major hollow-bearing tree, but Yellow Gum, Yellow Box and Red Ironbark also provided hollows (Table 13). These findings support those of Soderquist (1999), which identified ‘true boxes’ (Grey Box, Red Box and Yellow Box) as supporting the highest incidence of tree hollows in Box–Ironbark forest.

Table 13 Hollow distribution for tree species within treatments at all Sites.

Park	**Treatment**	**_Tree species*_**							
		LLB	**RB**	**RS**	**GB**	**YG**	**YB**	**RIB**	**_Unknown_**
Castlemaine Diggings NHP	Control	3	2	4	-	-	-	-	-
	Isolated	-	-	-	-	-	-	-	-
	Patchy 1	8	1	7	1	-	-	-	-
	Patchy 2	1	3	3	1	-	-	-	-
Spring Plains NCR	Control	9	9	2	-	-	-	-	*5*
	Isolated	3	2	3	-	-	-	-	-
	Patchy 1	18	4	7	-	-	-	-	-
	Patchy 2	17	19	9	-	-	-	-	-
Pilchers Bridge NCR	Control	9	19	3	-	-	-	-	-
	Isolated	2	5	8	2	-	-	-	-
	Patchy 1	4	2	2	1	-	-	-	-
	Patchy 2	2	11	3	-	-	-	-	-
Paddys Ranges SP	Control	2	3	-	3	3	1	-	-
	Isolated	-	-	-	5	-	-	1	-
	Patchy 1	-	2	-	4	-	1	5	*1*
	Patchy 2	3	-	-	11	1	-	-	-

* Tree species: LLB = Long-leaf Box *Eucalyptus goniocalyx*; RB = Red Box *E. polyanthemos*; RS = Red Stringybark *E. macrorhyncha*; GB = Grey Box *E. microcarpa*; YB = Yellow Gum *E. leucoxylon*; YB = Yellow Box *E. melliodora*; RIB = Red Ironbark *E. tricarpa*

3.2.2 Canopy Openness

Canopy cover was measured in the post-thinning environment. As expected, canopies were more open at treated Plots at all Sites (Figure 10). Compared to Control Plots, thinning resulted in a general shift (assuming Plots that were treated had comparable canopy openness to that registered for Control Plots post thinning) in canopy openness of 10–20%. There was a relatively consistent trend in canopy openness achieved between the three thinned treatments (Figure 10). Patchy 1 treatment resulted in a more open canopy, followed by the Isolated treatment, and Patchy 2 treatment resulted in lower canopy openness percentage, though, at Paddys Ranges SP, canopy openness in Patchy 2 was comparable with that in Patchy 1.

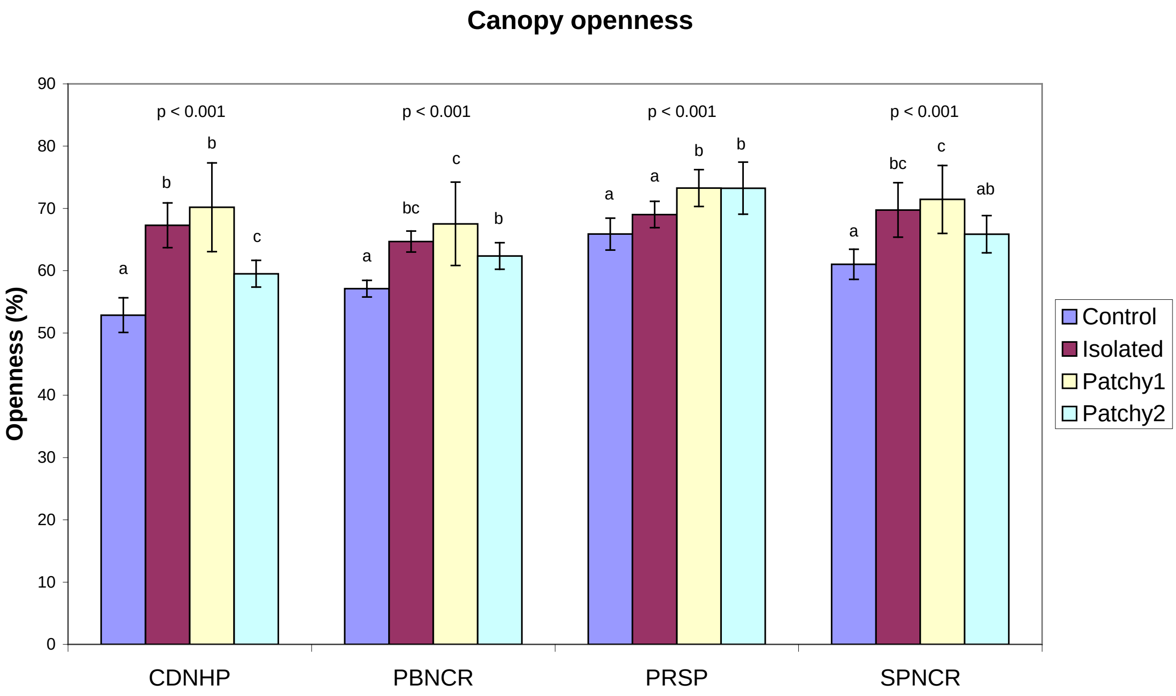

Figure 10. Average post-thinning canopy openness (%) across all Sites.

Error bars are standard errors. Measurements within Sub-plots were averaged and then the nine Subplots averaged again to calculate a treatment average. Significance values represent one-way ANOVA, calculated separately for each Site. Letters indicate homogenous subsets, based on Tukey's HSD post-hoc comparisons.

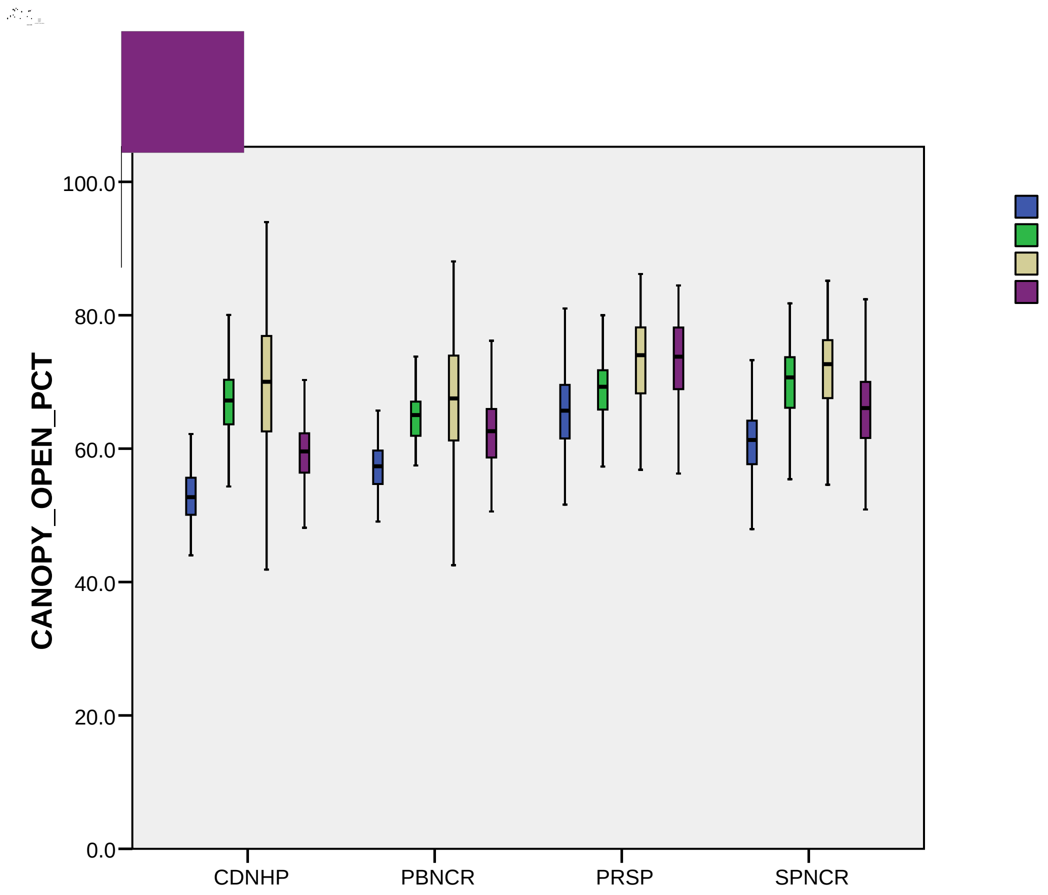

Figure 11. Variation in canopy openness (%) within each Plot post thinning.

Line represents the median. Box represents 25–75%. Circles represent outliers. Boxplots represent the median and 95% confidence limits.

Figure 11 shows the variation in canopy openness (%) within each Plot at each Site and provides a useful illustration of the patchiness of canopies between Plots. Treated Plots were characterised by greater variation in the 189 point assessments of canopy openness (i.e. canopy photograph using fish-eye lens) carried out. Patchy 1 treatment appeared to be particularly variable across Sites (Figure 11). In ecological terms, thinning is considered to have created a patchier canopy cover, different to the more homogenous and dense canopy layer observed at Control Plots (Figure 10, 11).

3.2.3 Coarse Woody Debris

Coarse woody debris has a major role in the structure and function of eucalypt forests, including Box–Ironbark forests, and is important for biodiversity (Laven & Mac Nally 1998; Mac Nally *et al.* 2002b; Manning *et al.* 2007). Large, old eucalypts produce the greatest amounts of coarse woody debris (Jacobs 1955), so it is probable that the absence of large, old trees and the dominance of smaller stems have contributed to a much lower production of coarse woody debris, particularly large logs, in Box–Ironbark forests (Laven & Mac Nally 1998).

The slow, natural accumulation of coarse woody debris in drier eucalypt forests in south-eastern Australia means experimental augmentation may be necessary to achieve biodiversity outcomes (Mac Nally *et al.* 2002b; Manning *et al.* 2007).

Before thinning, the size-distribution of coarse woody debris displayed a clear pattern of decreasing frequency with increasing diameter across all Plots and Sites. Coarse woody debris >10 cm diameter occurred sparsely. This general pattern was maintained post thinning after the addition of thinning debris, though there were significant increases in both large and small coarse woody debris (Table 14, 13; Figure 12, 13).

The use of the term ‘large coarse woody debris’ here is descriptive only and does not equate to what would be considered large pieces of coarse woody debris in an ecological sense in these forests. Large coarse woody debris in these forests is considered to have a diameter of >30 cm (see *EVC/Bioregion Benchmark for Vegetation Quality Assessment Goldfields bioregion EVC 20 Heathy Dry Forest* and *EVC 61 Box Ironbark Forest* for details of the natural conditions used as a benchmark for this EVC at http://www.dse.vic.gov.au/). Such pieces were virtually absent across all Sites, even after thinning. Although no log length measurements were recorded in this Trial, the amount of coarse woody debris in Plots post thinning is expected to be at least, and probably much higher than, the 20 m/0.1 ha applied as a benchmark in these forests to represent the average characteristics of a mature and apparently long-undisturbed state (see *EVC/Bioregion Benchmark for Vegetation Quality Assessment Goldfields bioregion EVC 20 Heathy Dry Forest* and *EVC 61 Box Ironbark Forest* at http://www.dse.vic.gov.au/).

There was almost no gain in coarse woody debris at Control Plots during the monitoring period (approximately 2.5 years); indeed, in some Plots a loss was recorded. This aligns with other studies in eucalypt forests, including River Red Gum (Mac Nally *et al.* 2002b) and gum-box grassy woodlands (Manning *et al.* 2007), which found the natural accumulation of coarse woody debris was extremely slow. Due to the history of use and disturbance in these landscapes (e.g. firewood collection and lack of large senescent trees contributing fallen branches) there is little coarse woody debris on the ground. As the accumulation of coarse woody debris is so slow in these systems, the active intervention through the Trial to increase coarse woody debris loads in these forests to address biodiversity concerns (e.g. Palmer 1998; Antos & Bennett 2008) is warranted.

Some caution is necessary when interpreting the amount of change in the volume of coarse woody debris after thinning. The declines in the volume of coarse woody debris registered in some Control Plots indicated that the sampling technique used was affected by measurement variability between observers. The use of the same fixed-line transects during both monitoring periods was expected to minimise variation due to sampling error. By scrutinising the raw data for the two monitoring periods it appears that much of the variation resulted from relatively large discrepancies in counting litter pieces <5 cm diameter (the tally of pieces in size-classes <5 cm was considerably less in post-thinning surveys) (Palmer *et al.* 2008). Figure 12 shows that some variation also occurred in the larger size-classes; this may have a more pronounced effect on the results given that large pieces of coarse woody debris could significantly inflate or deflate volume calculations. This variation between observers must be considered in these results and should be carefully monitored during future surveys.

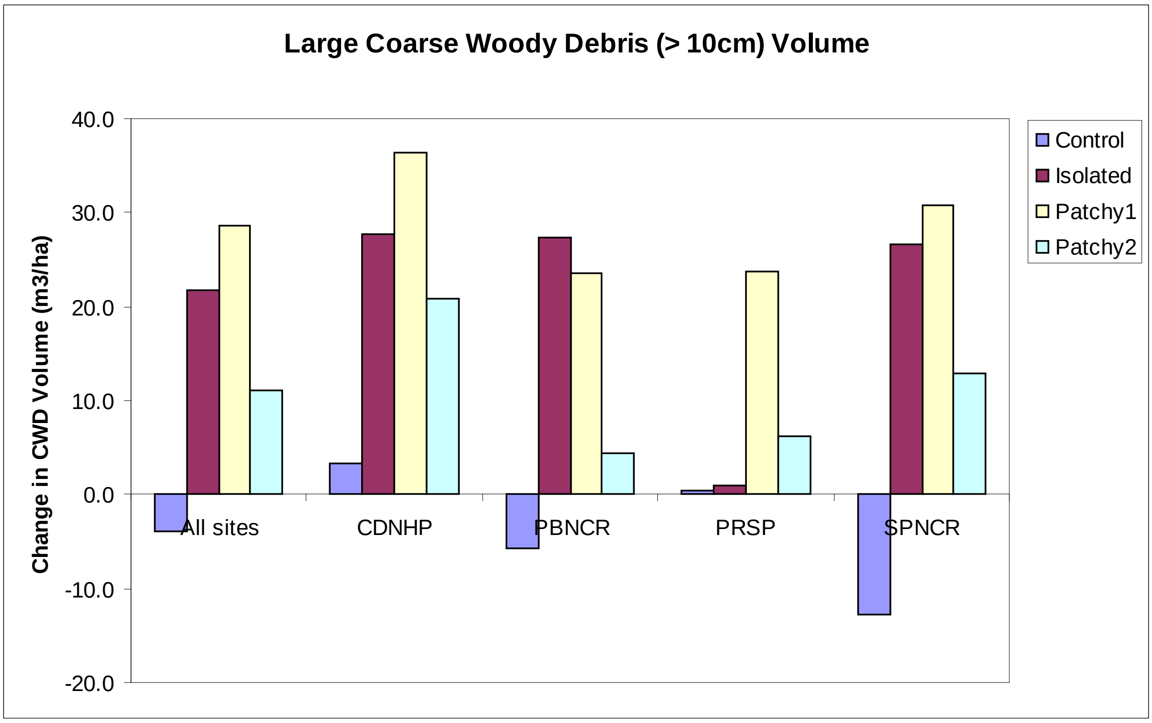

Figure 12. Change in mean large coarse woody debris (diameter >10 cm) volume within Plots across all Sites following ecological thinning.

Table 14..Changes in volume of large coarse woody debris (diameter >10 cm) after completion of ecological thinning (rmANOVA).

Values represent mean volume of coarse woody debris measured in m^3/ha at each Plot. Time refers to monitoring periods: 0 = pre-thinning, 1 = post-thinning. Significant results are presented in **bold**.

	Time	**Cont**	**Isol**	**P 1**	**P 2**	***Between subjects***	***Within subjects***	
						p (treat)	**p (time)**	**p (time*treat)**
All Sites	0	12.42	4.72	15.54	12.60	**<0.001**	**<0.001**	**<0.001**
	1	8.58	26.49	44.16	23.69			
Castlemaine Diggings NHP	0	1.32	1.86	3.99	12.68	**0.002**	**<0.001**	**0.005**
	1	4.98	29.64	40.38	33.58			
Pilchers Bridge NCR	0	19.11	4.97	20.98	14.31	0.098	**<0.001**	**0.002**
	1	13.40	32.40	44.52	18.65			
Paddys Ranges SP	0	5.96	1.27	13.72	7.88	**<0.001**	**<0.001**	**<0.001**
	1	6.38	7.16	37.44	14.09			
Spring Plains NCR	0	22.56	10.47	23.49	15.55	**0.028**	**0.002**	**0.004**
	1	9.72	37.10	54.29	28.45			

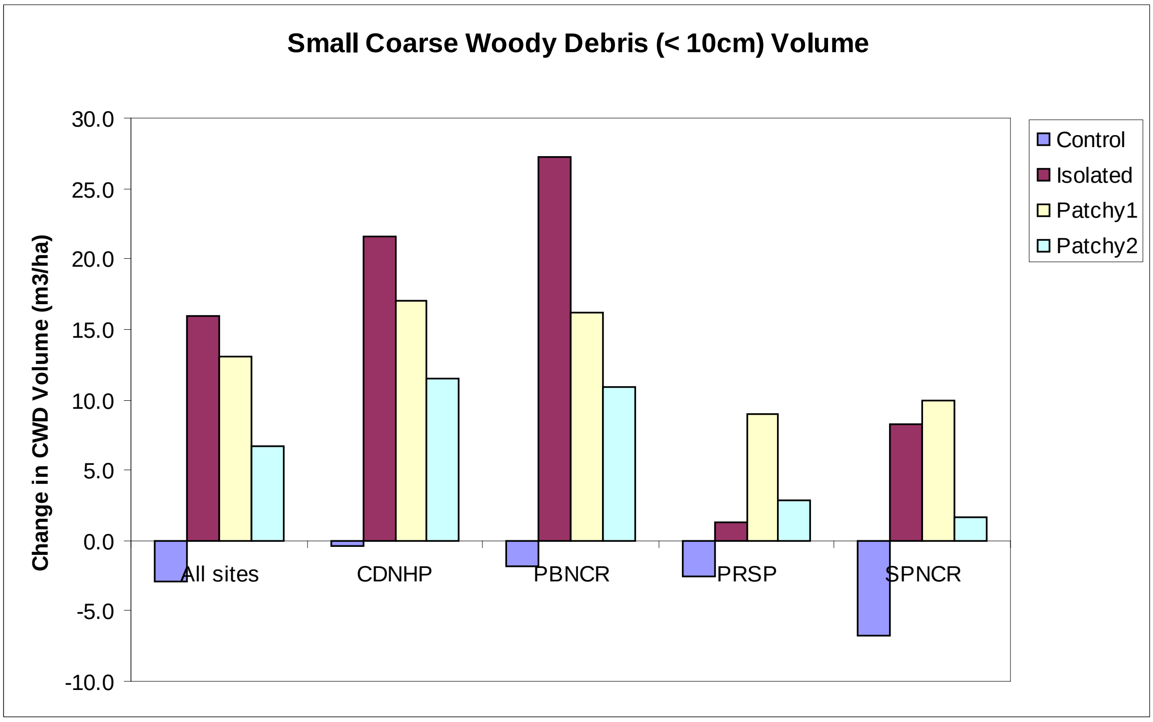

Figure 13. Change in mean small coarse woody debris (diameter <10 cm) volume within Plots across all Sites following ecological thinning.

Table 15. Changes in volume of small coarse woody debris (diameter <10 cm) after completion of ecological thinning (rmANOVA).

Values represent mean coarse woody debris volume measured in m^3/ha for each Plot. Time refers to monitoring periods: 0 = pre-thinning, 1 = post-thinning. Significant results are presented in **bold**.

	Time	Cont	Isol	P1	P2	Between subjects	Within subjects	
						p (treat)	p (time)	p (time*treat)
All Sites	0	9.18	7.52	9.29	9.89	**<0.001**	**<0.001**	**<0.001**
	1	6.28	23.51	22.34	16.63			
Castlemaine Diggings NHP	0	6.75	7.44	6.42	8.39	**<0.001**	**<0.001**	**<0.001**
	1	6.38	29.08	23.49	19.91			
Pilchers Bridge NCR	0	10.60	7.55	13.43	9.97	**<0.001**	**<0.001**	**<0.001**
	1	8.74	34.78	29.60	20.85			
Paddys Ranges SP	0	6.04	4.84	7.93	8.27	**<0.001**	**<0.001**	**<0.001**
	1	3.48	12.33	16.95	11.17			
Spring Plains NCR	0	12.99	10.23	9.40	12.92	**<0.001**	**<0.001**	**<0.001**
	1	6.21	18.45	19.32	14.57			

3.2.3 Litter Depth

At the Plot scale, mean litter depth was 17–35 mm in the pre-thinning environment, and 14–30 mm post-thinning. In another ecological study in Box–Ironbark forests, mean litter depth was significantly different between undisturbed sites (mean depth = 3.15±0.9 cm) and sites subject to intense grazing (mean depth = 1.72±0.1 cm) (Brown 2001).

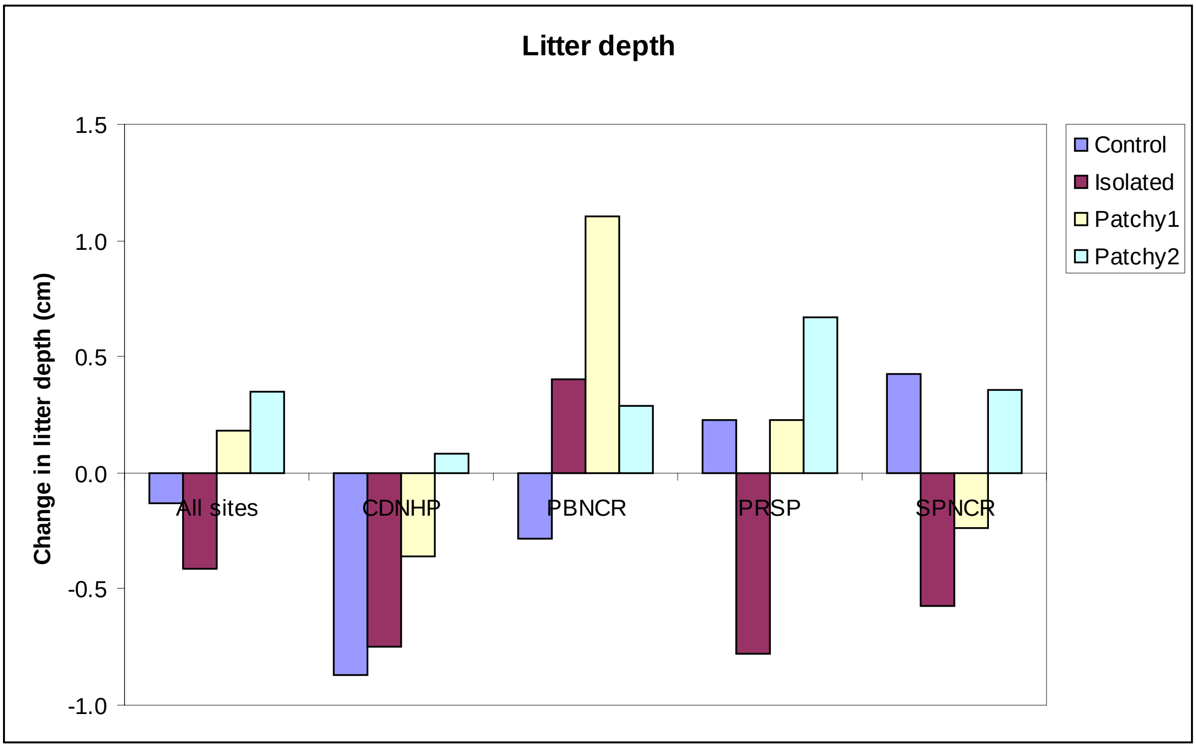

Figure 14. Change in mean litter depth (cm) within Plots across all Sites following ecological thinning.

Table 16. Changes in litter depth (cm) after thinning (rmANOVA).

Values represent mean litter depth (cm) for each Plot. Time refers to monitoring periods: 0 = pre-thinning, 1 = post-thinning. Significant results are presented in **bold**.

	Time	Cont	Isol	P 1	P 2	*Between subjects*	*Within subjects*	
						p (treat)	**p (time)**	**p (time*treat)**
All Sites	0	2.17	2.59	2.21	2.12	0.169	0.956	**<0.001**
	1	2.04	2.18	2.40	2.47			
Castlemaine Diggings NHP	0	3.06	3.59	3.12	2.79	0.061	**0.024**	**<0.001**
	1	2.19	2.84	2.77	2.88			
Pilchers Bridge NCR	0	2.00	2.04	1.85	1.93	**0.004**	**<0.001**	**<0.001**
	1	1.72	2.45	2.95	2.23			
Paddys Ranges SP	0	1.68	2.87	1.91	1.75	0.12	0.398	**<0.001**
	1	1.90	2.10	2.14	2.41			
Spring Plains NCR	0	1.89	1.97	1.96	1.99	**0.001**	0.908	**<0.001**
	1	2.32	1.40	1.72	2.35			

Though there were significant increases in litter depth in some Plots, the response of litter depth to the thinning operations varied and was not consistent between Sites or Plots (Table 14; Figure 14). For example, litter depth decreased in Patchy 1 Plots in Castlemaine Diggings NHP and Spring Plains NCR, but increased in Paddys Ranges SP and Pilchers Bridge NCR. Patchy 2 was the only treatment that displayed a consistent, unidirectional change across all Sites, with an increase in mean litter depth across Sites, ranging from 0.11 cm at Castlemaine Diggings NHP to 0.66 cm at Paddys Ranges SP. While it was difficult to attribute proportions of total litter due to natural fall and that due to the thinning debris at thinned Plots, much of the potential litter that resulted from thinning was retained on felled crowns (leaves and small branches) and tree boles (fibrous bark) and at this stage made limited contributions to the litter layer.

In a study of litter dynamics in wet Mountain Ash *Eucalyptus regnans* forest in southern Victoria (Ashton 1975), litter depth ranged from 2 to 9 cm in open, undisturbed parts of the forest floor and was relatively consistent across younger and mature stands, despite significant differences in decomposition rates between the stands. Therefore, given the annual cycling of litter in eucalypt forests, it might be expected that litter depth would remain fairly constant, or display subtle but relatively short-term changes in response to ecological thinning.

Although not assessed during the Trial, by opening up the forest structure, ecological thinning is likely to alter decomposition dynamics in the litter layer. The decomposition of litter is an ongoing process, but is generally higher in autumn and early winter. Ashton (1975) found that rates of decomposition in 'pole stands' of Mountain Ash in summer were much lower than those in mature forest, attributing this to the different microclimates of the two stands. By opening up the forest structure and reducing canopy cover it is likely that litter microclimates would be affected due to increased solar radiation, possibly leading to reduced litter decomposition rates in thinned Plots.

3.2.4 Ground Cover

A complex ground layer was considered a characteristic feature of historic Box–Ironbark forests (Tzaros 2005). Relatively undisturbed ground layers typically consist of a complex variety of fallen tree branches and logs (coarse woody debris), rocks, leaves, bark and small canopy branches (fine litter), and low vegetation including grasses, herbs and prostrate or small shrubs (Tzaros 2005). Reflecting a long history of disturbance, including timber removal, firewood collection and mining, the ground layer present at Sites before thinning displayed a high level of modification, including a simplified structure (e.g. reduced coarse woody debris, reduced ground layer vegetation cover).

Before ecological thinning, leaf litter and fine litter components generally accounted for 60–70% of ground cover at all Sites. Antos & Bennett (2005) recorded similarly high proportions of fine litter cover (70%) in Grey Box vegetation communities on Victoria's Northern Plains. Brown (2001) recorded significant differences between litter cover at disturbed (grazed) sites and undisturbed sites in Box–Ironbark communities, with disturbed sites having greater litter cover (mean = 60.84%) than undisturbed sites (mean = 49.89%). Mac Nally *et al.* (2000) also recorded differences in fine litter cover between gullies (mean = 42%) and ridge sites (mean = 52.3%) in Box–Ironbark forests.

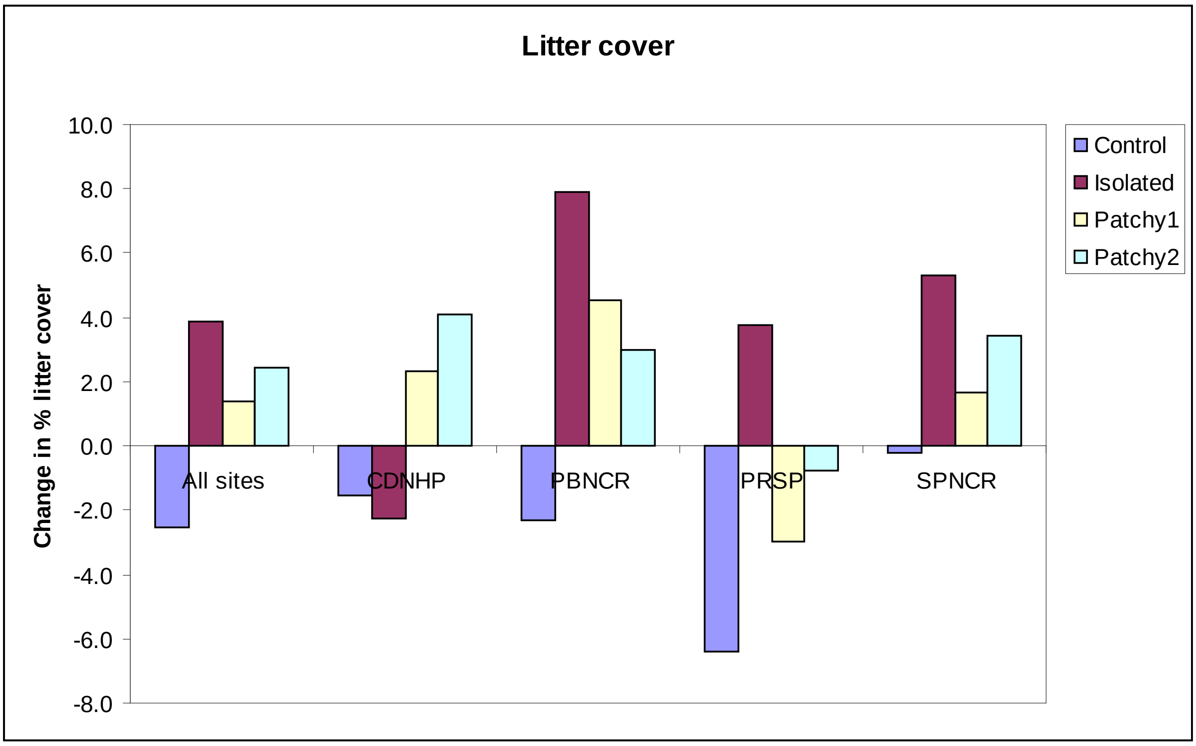

Figure 15. Change in mean litter cover (%) within treatments across all Sites after thinning.

Table 17. Changes in litter cover (%) after thinning (rmANOVA).

Values represent mean litter cover (leaf litter + fine litter touches) measured using point frames along permanent transects in each Plot. Time refers to monitoring periods: 0 = pre-thinning, 1 = post-thinning. Significant results are presented in **bold**.

	Time	**Cont**	**Isol**	**P1**	**P2**	***Between subjects***	***Within subjects***	
						p (treat)	**p (time)**	**p (time*treat)**
All Sites	0	0.76	0.72	0.76	0.77	**0.007**	**0.04**	**0.004**
	1	0.73	0.76	0.78	0.80			
Castlemaine Diggings NHP	0	0.76	0.77	0.75	0.76	0.661	0.601	0.236
	1	0.75	0.74	0.77	0.80			
Pilchers Bridge NCR	0	0.80	0.71	0.78	0.80	**0.007**	**0.009**	**0.033**
	1	0.77	0.79	0.83	0.83			
Paddys Ranges SP	0	0.68	0.70	0.78	0.75	**0.004**	0.159	0.023
	1	0.62	0.74	0.75	0.74			
Spring Plains NCR	0	0.79	0.71	0.75	0.79	0.086	0.061	0.493
	1	0.79	0.76	0.76	0.81			

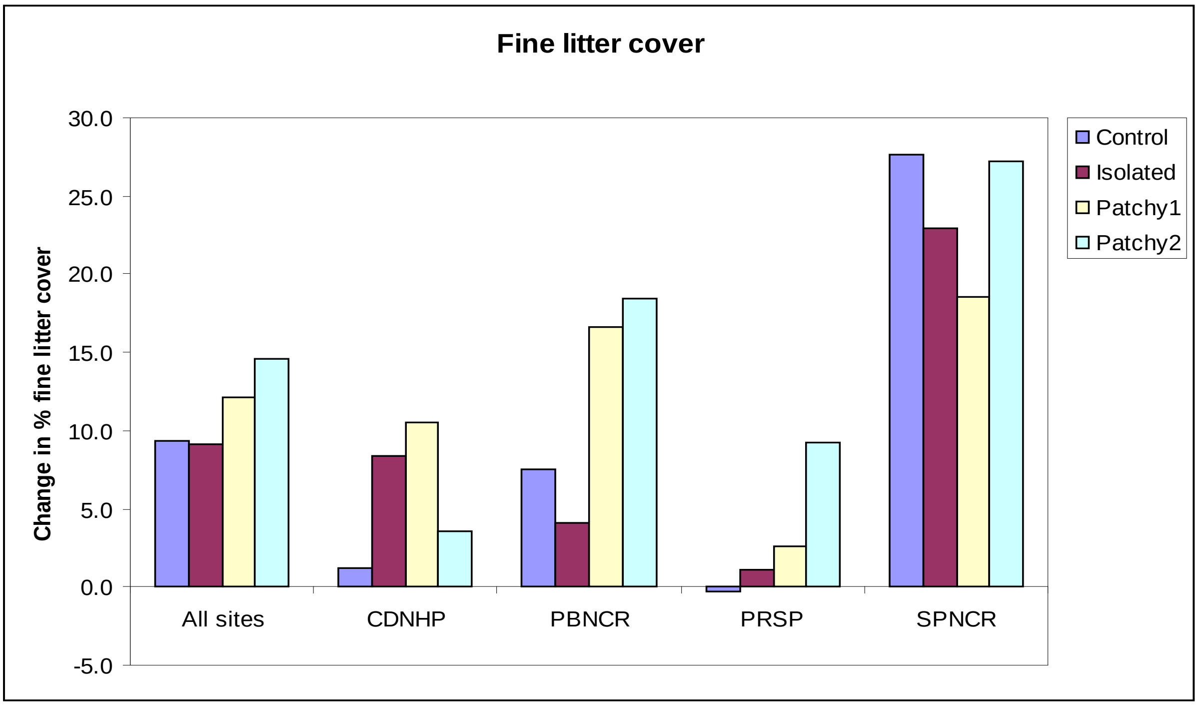

Figure 16. Change in fine-litter cover (%) within Plots across all Sites after thinning.

Table 18. Changes in fine-litter cover (%) after thinning (rmANOVA).

Values represent mean fine litter cover measured using point frames along permanent transects in each Plot. Time refers to monitoring periods: 0 = pre-thinning, 1 = post-thinning. Significant results are presented in **bold**.

	Time	**Cont**	**Isol**	**P1**	**P2**	***Between subjects***	***Within subjects***	
						p (treat)	**p (time)**	**p (time*treat)**
All Sites	0	0.33	0.31	0.36	0.34	**<0.001**	**<0.001**	0.15
	1	0.42	0.40	0.47	0.49			
Castlemaine Diggings NHP	0	0.30	0.31	0.34	0.33	**0.001**	**<0.001**	**0.03**
	1	0.31	0.36	0.45	0.37			
Pilchers Bridge NCR	0	0.32	0.27	0.30	0.29	**<0.001**	**<0.001**	**<0.001**
	1	0.39	0.31	0.46	0.47			
Paddys Ranges SP	0	0.42	0.37	0.47	0.46	**<0.001**	**0.032**	0.102
	1	0.42	0.38	0.50	0.55			
Spring Plains NCR	0	0.29	0.27	0.31	0.29	0.199	**<0.001**	0.088
	1	0.57	0.50	0.49	0.56			

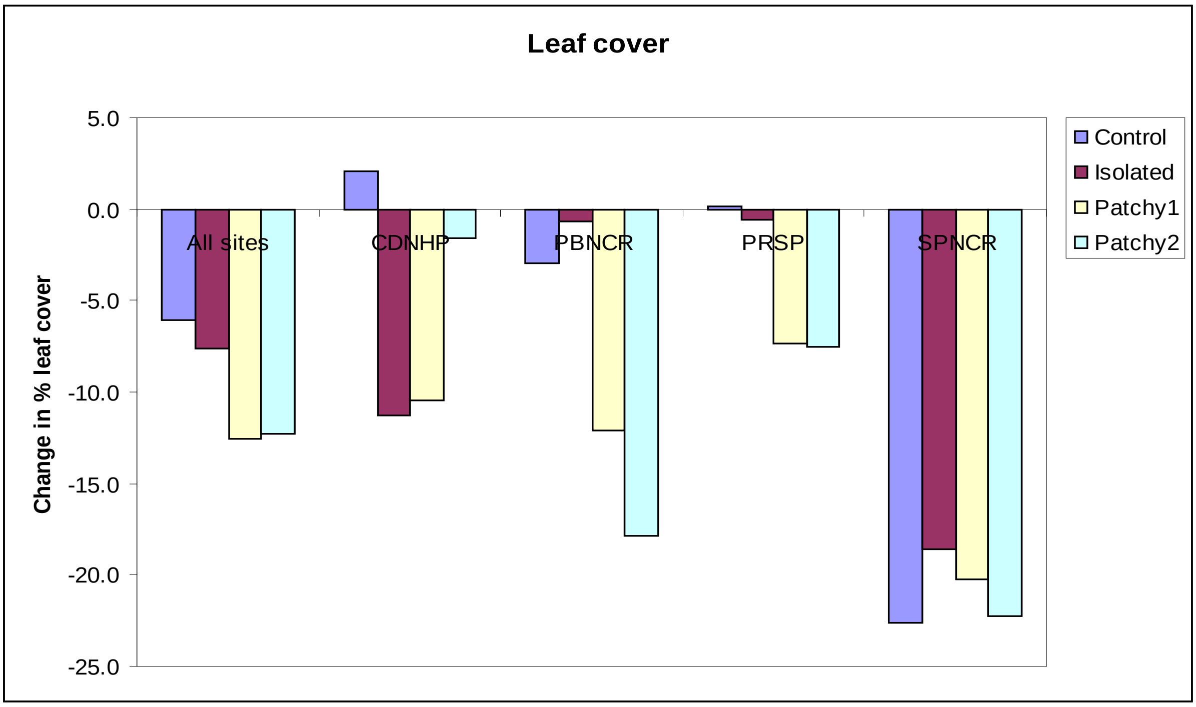

Figure 17. Change in leaf cover (%) within Plots across all Sites after thinning.

Table 19. Changes in leaf cover (%) after thinning (rmANOVA).

Values represent mean leaf cover measured using point frames along permanent transects in each Plot. Time refers to monitoring periods: 0 = pre-thinning, 1 = post-thinning. Significant results are presented in **bold**.

	Time	**Cont**	**Isol**	**P 1**	**P 2**	***Between subjects***	***Within subjects***	
						p (treat)	**p (time)**	**p (time*treat)**
All Sites	0	0.34	0.35	0.33	0.34	**0.030**	**<0.001**	**0.014**
	1	0.28	0.27	0.20	0.21			
Castlemaine Diggings NHP	0	0.38	0.36	0.33	0.35	**<0.001**	**<0.001**	**<0.001**
	1	0.40	0.25	0.23	0.33			
Pilchers Bridge NCR	0	0.38	0.36	0.38	0.42	0.237	**<0.001**	**<0.001**
	1	0.34	0.35	0.26	0.24			
Paddys Ranges SP	0	0.17	0.30	0.22	0.18	**<0.001**	**0.001**	**0.021**
	1	0.17	0.30	0.15	0.10			
Spring Plains NCR	0	0.41	0.35	0.37	0.39	0.422	**<0.001**	0.582
	1	0.18	0.17	0.16	0.17			

Litter cover (combined leaf and fine litter) generally increased after thinning, although there were minor decreases in some thinned Plots (Figure 15–17). Changes in litter cover after ecological thinning were significant across all Sub-plots and across Plots at Pilchers Bridge NCR (Table 17). The increase in litter cover appears to be an effect of the ecological thinning, as there was a uniform decrease in litter cover observed across all Control Plots. Following ecological thinning, leaf litter and fine-litter components continued to account for 60–75% of ground cover, with a shift towards a higher contribution by fine-litter components (Table 17, Table 18 and Table 19). After thinning, the fine-litter cover (as a component of litter) increased across most Plots and most Sites with a corresponding decrease in leaf cover (Figure 16, 17). Post-thinning assessment of changes in the ground-layer cover and structure were made in a localised environment where much of the felled crown material, and some bole material, remained intact, and was still raised (between 0.1 m and 1.5 m above the ground). This felled material is thought to have contributed little to ground cover at the time of assessment.

Studies in other eucalypt forest types (e.g. Mountain Ash forest) have shown leaf fall to generally make up the major component of litter addition. The addition of twigs and small branches (fine litter) contributes to about 25% of the total litter, but this is highly variable, being largely dependent on the incidence of high-wind events (Ashton 1975). In effect, the thinning operation led to a substantial input of fine-litter material in the Trial, resulting from the retention of felled tree crown material. The longevity of this habitat feature is not known, but is expected to be at least several years, with retention times expected to be longer for larger components of fine-litter material.

There was a general trend of slight increases in coarse-litter cover after thinning. Coarse-litter cover was around 10% in the pre-thinning environment. Following thinning, coarse-litter cover increased only slightly at treated Plots; this result was surprising, and needs to be considered in conjunction with the findings for coarse woody debris presented in Figure 18. Coarse-litter cover decreased across all Control Plots between the pre- and post-thinning surveys; these decreases were greater than the increases recorded in coarse-litter cover in thinned Plots. This change may not be 'real', and may be a reflection of measurement variability attributable to different observers. Nevertheless, it provides quantitative evidence of the slow rate of natural accumulation of coarse litter and coarse woody debris in Box–Ironbark forests. There were significant differences between Plots in coarse-litter cover at some Sites (Castlemaine Diggings NHP, Pilchers Bridge NCR and Paddys Ranges SP), but the gains in coarse-litter cover were not statistically significant for any Site after treatment (Table 20).

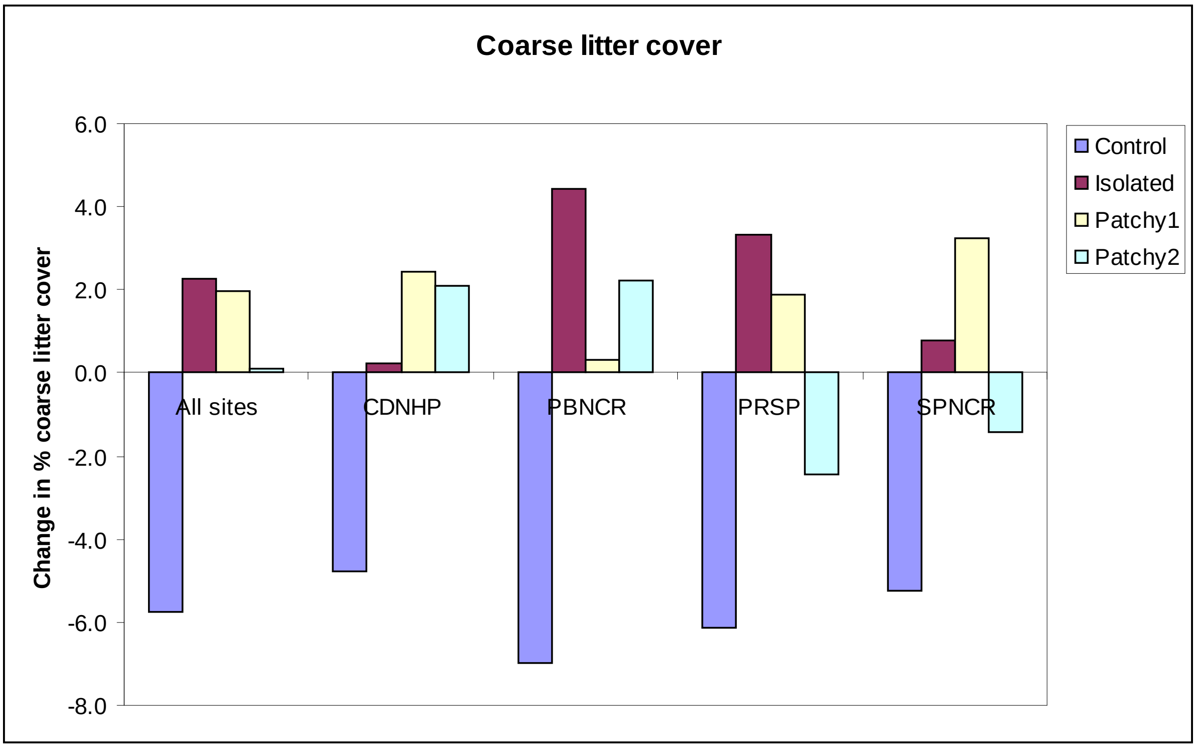

Figure 18. Change in coarse-litter cover (%) within Plots across all Sites after thinning.

Table 20. Changes in coarse-litter cover (%) after thinning (rmANOVA).

Values represent mean coarse-litter cover measured using point frames along permanent transects in each Plot. Time refers to monitoring periods: 0 = pre-thinning, 1 = post-thinning. Significant results are presented in **bold**.

	Time	Cont	Isol	P 1	P 2	***Between subjects***	***Within subjects***	
						p (treat)	**p (time)**	**p (time*treat)**
All Sites	0	0.09	0.07	0.08	0.10	**<0.001**	0.385	**<0.001**
	1	0.03	0.09	0.10	0.10			
Castlemaine Diggings NHP	0	0.08	0.09	0.07	0.08	**0.029**	0.993	**0.012**
	1	0.03	0.10	0.10	0.10			
Pilchers Bridge NCR	0	0.10	0.07	0.10	0.09	**0.039**	1.000	**<0.001**
	1	0.03	0.12	0.11	0.11			
Paddys Ranges SP	0	0.09	0.03	0.09	0.11	**<0.001**	0.259	**<0.001**
	1	0.03	0.06	0.11	0.08			
Spring Plains NCR	0	0.09	0.08	0.07	0.10	0.19	0.352	**0.002**
	1	0.04	0.09	0.11	0.09			

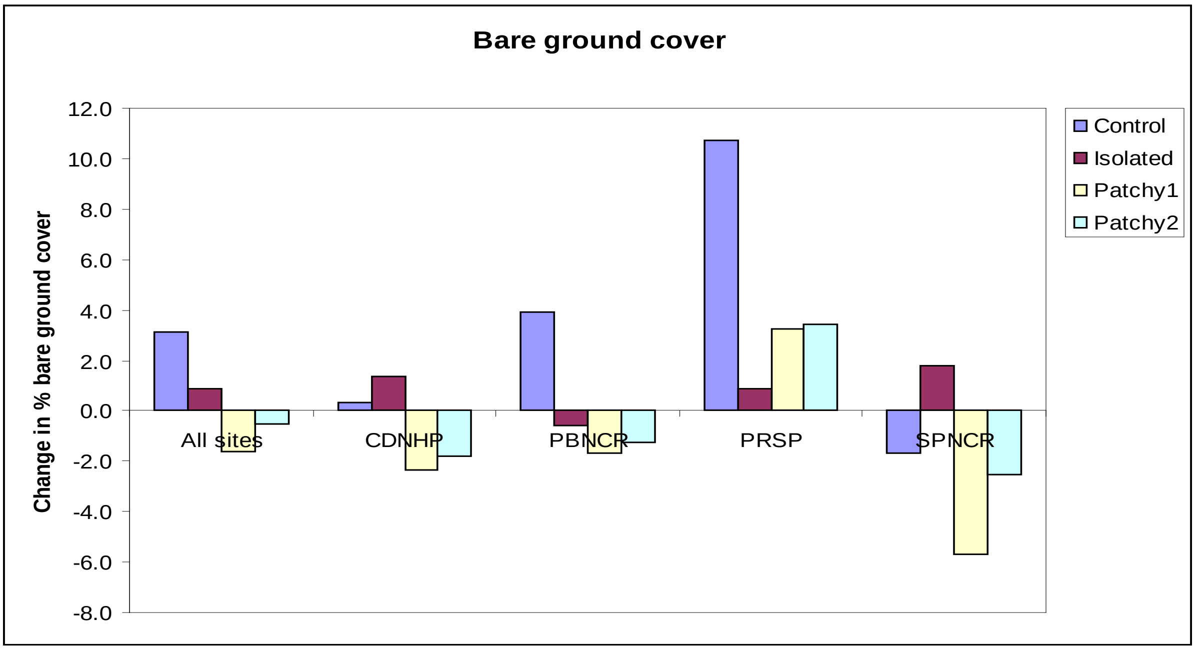

Figure 19. Change in bare-ground cover (%) within Plots across all Sites after thinning.

Table 21. Changes in bare-ground cover (%) after thinning (rmANOVA).

Values represent mean bare-ground cover measured using point frames along permanent transects in each Plot. Time refers to monitoring periods: 0 = pre-thinning, 1 = post-thinning. Significant results are presented in **bold**.

	Time	**Cont**	**Isol**	**P 1**	**P 2**	***Between subjects***	***Within subjects***	
						p (treat)	**p (time)**	**p (time*treat)**
All sites	0	0.09	0.07	0.08	0.10	0.141	0.361	**0.008**
	1	0.03	0.09	0.10	0.10			
Castlemaine Diggings NHP	0	0.07	0.05	0.06	0.05	0.40	0.424	0.273
	1	0.08	0.06	0.04	0.03			
Pilchers Bridge NCR	0	0.13	0.08	0.13	0.11	**0.039**	1.000	**.002**
	1	0.17	0.08	0.12	0.10			
Paddys Ranges SP	0	0.19	0.14	0.14	0.19	**0.002**	**<0.001**	**0.019**
	1	0.29	0.15	0.17	0.22			
Spring Plains NCR	0	0.06	0.07	0.11	0.05	**0.036**	**0.018**	**0.025**
	1	0.05	0.09	0.06	0.03			

Changes in the amount of bare ground after thinning were inconsistent at the Plot level and at the Site level (Figure 19). At Paddys Ranges SP there was a significant increase in bare-ground cover following thinning across all Plots, with the largest change being recorded in the Control Plots (Table 21). Bare-ground cover increased in three of the four Control Plots in the post-thinning environment. This indicates that changes may not be solely an effect of thinning, but are likely to also be a factor of timing of survey (i.e. seasonal effect) or presiding environmental conditions (such as a prolonged period of below-average rainfall).

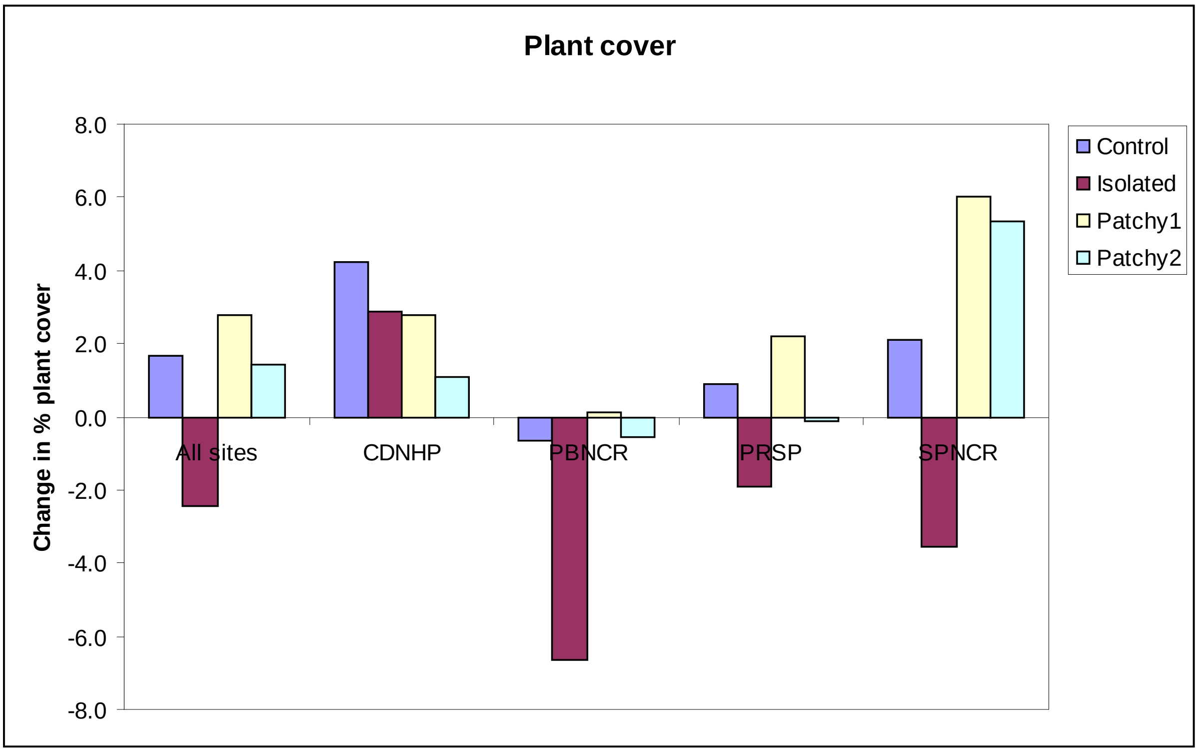

Figure 20. Change in plant cover (%) within Plots across all Sites after thinning.

Table 22. Changes in plant cover (%) after thinning (rmANOVA).

Values represent mean plant cover measured using point frames along permanent transects in each Plot. Time refers to monitoring periods: 0 = pre-thinning, 1 = post-thinning. Significant results are presented in **bold**.

	Time	Cont	Isol	P 1	P 2	*Between subjects*	*Within subjects*	
						p (treat)	p (time)	p (time*treat)
All Sites	0	0.04	0.10	0.05	0.04	**0.003**	0.26	**<0.001**
	1	0.06	0.07	0.07	0.06			
Castlemaine Diggings NHP	0	0.07	0.08	0.08	0.08	**0.001**	**0.003**	0.648
	1	0.11	0.11	0.11	0.09			
Pilchers Bridge NCR	0	0.02	0.13	0.02	0.02	**<0.001**	**<0.001**	<0.001
	1	0.01	0.06	0.02	0.02			
Paddys Ranges SP	0	0.03	0.05	0.02	0.02	0.181	0.370	**<0.001**
	1	0.04	0.03	0.04	0.02			
Spring Plains NCR	0	0.06	0.14	0.06	0.05	0.081	**0.007**	**0.002**
	1	0.08	0.10	0.12	0.10			

There were small increases in plant cover after thinning (Figure 20). These changes were not consistent between Plots or Sites. Plant cover increased in all Plots at Castlemaine Diggings NHP following treatment (Figure 20). More detailed discussions of plant-cover changes (life form based) are presented in the floristic section below.

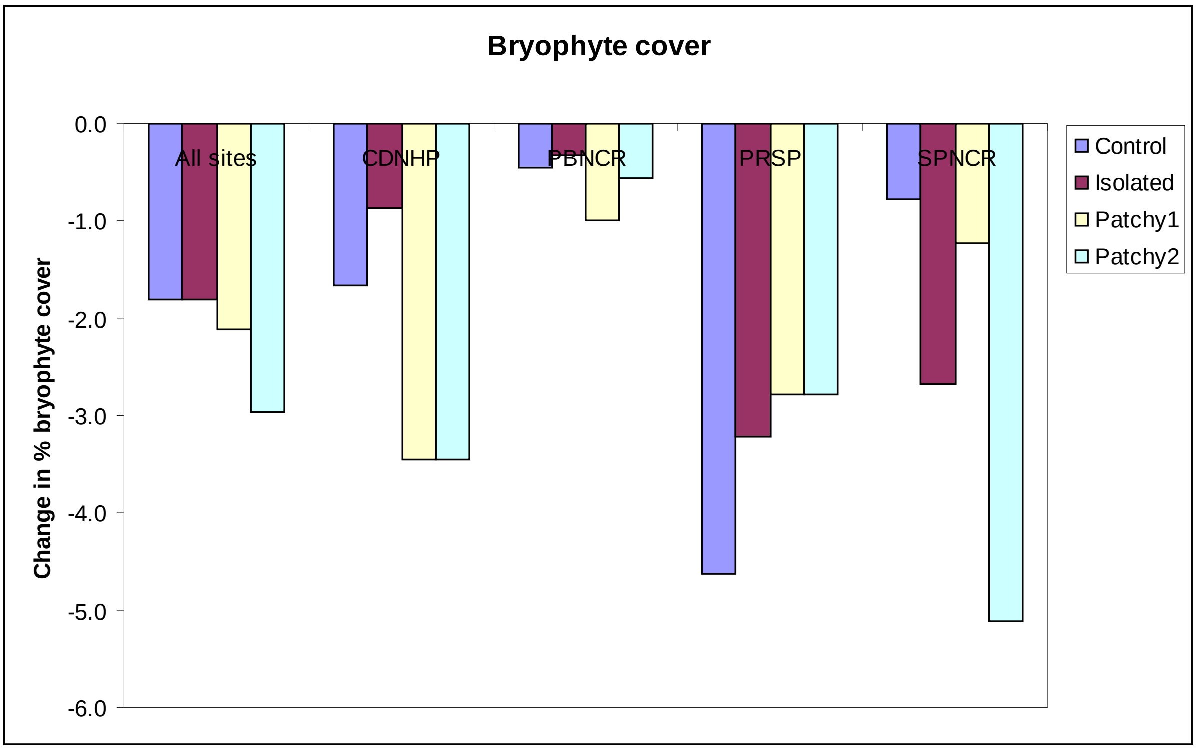

Figure 21. Change in bryophyte cover (%) within Plots across all Sites after thinning.

Table 23. Changes in bryophyte cover (%) after thinning (rmANOVA).

Values represent mean bryophyte cover measured using point frames along permanent transects for each Plot. Time refers to monitoring periods: 0 = pre-thinning, 1 = post-thinning. Significant results are presented in **bold**.

	Time	Cont	Isol	P 1	P 2	***Between subjects***	***Within subjects***	
						p (treat)	**p (time)**	**p (time*treat)**
All sites	0	0.05	0.06	0.04	0.05	**0.001**	**<0.001**	0.36
	1	0.03	0.04	0.02	0.02			
Castlemaine Diggings NHP	0	0.06	0.03	0.06	0.07	0.333	**<0.001**	0.211
	1	0.04	0.02	0.02	0.03			
Pilchers Bridge NCR	0	0.04	0.07	0.03	0.03	**<0.001**	0.222	0.961
	1	0.03	0.06	0.02	0.02			
Paddys Ranges SP	0	0.08	0.10	0.05	0.04	**<0.001**	**<0.001**	0.711
	1	0.03	0.07	0.02	0.01			
Spring Plains NCR	0	0.03	0.04	0.03	0.07	0.295	**<0.001**	**0.001**
	1	0.03	0.02	0.02	0.02			

Bryophyte cover decreased across all Plots and all Sites in the post-thinning environment (Figure 21), and was significant for all sites except Pilchers Bridge NCR (Table 23). The decrease was generally greatest in thinned Plots, but not always (e.g. Paddys Ranges SP). Bryophyte cover decreased in Control Plots at all Sites between pre- and post-thinning monitoring periods (Figure 21).

Increased light penetration and exposure to direct sunlight as a result of reduced canopy cover in thinned Plots would be expected to impact on bryophyte cover. Thinned forest areas have been found to support lower bryophyte cover due to reduction in shade cover, increased solar radiation and associated decreases in humidity (Ariyanti *et al.* 2008). There was also potential for impacts on bryophyte cover brought about by trampling and damage during the implementation of thinning works. The detectability and extent of bryophyte cover is likely to change seasonally; due to differences in the timing of post-thinning surveys, some of the variability and change in bryophyte cover may be attributed to seasonal effects.

3.2.5 Data Summary

Differences in key fauna habitats, including coarse woody debris, litter structure and ground cover, between pre- and post-thinning surveys were attributed to the effects of thinning, as well as to effects of sampling timing (i.e. possible seasonal effects). While the early effects of thinning on key fauna habitat components displayed high levels of variation, some general trends were apparent:

- thinning is considered to have created a patchier canopy cover, different to the more homogenous and dense canopy layer observed in Control Plots;
- coarse woody debris increased across all thinned Plots, including significant additions of large pieces of coarse woody debris which were scarce in the pre-thinning environment;
- litter cover generally increased post thinning; and
- bryophytes and lichens decreased across all Plots and Sites post thinning.

Other components, including bare-ground cover, plant cover and litter depth, showed high levels of variation across both Sites and Plots, and their immediate response to thinning was not clear.

Due to differences in the timing of post-thinning surveys, some of the variability and change in some components may be attributed to seasonal effects or environmental conditions. For example, the change in bryophyte cover could also have been influenced by the timing of post-thinning surveys which were mostly carried out during summer, when bryophyte cover is expected to be lower due to drier conditions. Likewise, increased areas of bare ground in the post-thinning environment could have been impacted by prolonged dry conditions between sampling periods. The potential for seasonal effects highlights the importance of accounting for these during future monitoring.

Post-thinning assessment of changes in the ground-layer cover and structure were made in a localised environment where much of the felled crown material and some bole material remained intact, and was still raised above the ground. Therefore, this felled material probably contributed little to ground cover at the time of assessment. It is likely that as this material becomes incorporated into the ground layer, detaching or collapsing to ground level 2–5 years post thinning, it will contribute to changes in ground-layer cover (e.g. more leaf cover) and structure (e.g. litter depth).

The manipulation of loads of coarse woody debris at the Sub-plot level proved difficult in practice and was inconsistently applied across Plots (Pigott *et al.* 2009). Biodiversity and habitat variables measured at the Sub-plot level (e.g. ground cover, coarse woody debris, floristics and birds) were subsequently not analysed at the Sub-plot treatment level. This meant that there was no differentiation of the effects of the different coarse-woody-debris removal treatments described in *Objectives and Methods*.

3.3 Forest Structure: Floristics

The canopy formed by overstorey trees in a forest has a major impact on the conditions experienced by plants at ground level or in subordinate strata, particularly through the interception of light and water and the complexities of competition. These effects depend to a large extent on the type of forest, as canopy density varies both spatially and temporally according to the overstorey species present (Stewart 1988; Belsky *et al.* 1989; Turton & Duff 1992; Rokich & Bell 1995; Messier *et al.* 1998; Kirkpatrick 1997) and aridity (Specht 1972; Specht & Morgan 1981).

Research has shown that the creation of gaps in the canopy by the removal of the overstorey leads to variable changes in the ambient environment in which understorey species exist. The degree of those changes depends largely on the size of the gap (Fahey & Puettmann 2008), but is also affected by the nature of the surrounding canopy, such as height and openness, as well as topography (Collins *et al.* 1985). Gaps or other areas without overstorey generally experience higher photosynthetically active radiation, higher maximum soil temperatures, higher minimum ground temperatures and lower water deficit than areas under canopy (Collins *et al.* 1985; Bowman & Kirkpatrick 1986b; Nunez & Bowman 1986; Belsky *et al.* 1989; Stoneman *et al.* 1994; Rokich & Bell 1995; Kirkpatrick 1997; Bauhus *et al.* 2001). In some savanna ecosystems, soils under canopy may have increased moisture and may also have higher levels of nutrients such as nitrogen and phosphorus (Vetaas 1992). Given the potential differences in ambient conditions between gaps and the surrounding canopy, it is expected that the creation of additional gaps by an imposed thinning program would elicit responses in the understorey vegetation.

Just as canopy gaps vary in size, shape and structure, plants also vary in their ability to respond to changed conditions (Collins *et al.* 1985). While some forest herbs are adapted to high-intensity light, others need low-intensity light to avoid inhibition of photosynthesis, and other herbaceous species display plasticity or flexibility, and are able to adjust both physiologically and physically to a wide range of light regimes (Collins *et al.* 1985). Changes in the intensity (amount) or quality (wavelengths) of light reaching the ground may affect germination, as seeds of some species require varying amounts of light for germination while seeds of other species require darkness (Rokich & Bell 1995). The variations in temperature, moisture and light in gaps in the canopy can affect photosynthesis and assimilation in forest herbs, influencing growth rates and form, and even allocation to sexual and asexual reproduction (Collins *et al.* 1985). Thus, the response of understorey species to changes in the canopy is expected to vary substantially, depending on complex interactions between the nature of the gaps in the canopy and the individual characteristics of those understorey species.

The responses of understorey vascular plant assemblages in Australian forests to treatments such as clear felling, fire or mining have been extensively studied. Similarly, the responses of understorey fodder plants to tree thinning, particularly changes in biomass production, have been well studied for pastoral management. However, far less research has been undertaken on the changes in the understorey brought about by overstorey thinning (as opposed to clearing) for silvicultural purposes, let alone for ecological purposes. Some exceptions include work relating to thinning in Silvertop Ash *Eucalyptus sieberi* forest (Bauhus *et al.* 2001; Peacock 2008), thinning of Mountain Ash forest (Peacock 2008) and unpublished preliminary reports for silvicultural projects in East Gippsland, Victoria (Griffiths & Muir 1991).

The canopies of eucalypt forests and woodlands are persistent (i.e. evergreen) but often open, with more light reaching the understorey than in many other forest types

(Kirkpatrick 1997), reducing the need for understorey plants to be shade-tolerant. Foliage cover tends to decline from humid to arid zones (Specht 1972; Specht & Morgan 1981). Box–Ironbark forest (and Heathy Dry forest) are both considered relatively dry (Muir *et al*. 1995) and open, and the understorey changes after increased light penetration might therefore be smaller, or substantially slower, than that those in denser forest types. Further, given the long history of disturbance, responses are likely to be strongly influenced by the composition of the extant vegetation in conjunction with the availability of propagules, such as in the soil-seed bank. Therefore, in Box–Ironbark forest, the response of the understorey to thinning is both largely unknown and difficult to predict. It is the broad aim of this adaptive management experiment to determine what changes in floristic composition and structure will occur.

The rate at which changes in understorey composition and abundance occur is largely unknown, but may be low. Given that the current data are derived from pre-thinning and immediate post-thinning surveys only, few meaningful changes are likely to be detected by the Trial, and results and predictions should be treated with caution. Nonetheless, the data gathered from these initial stages provide the baseline against which longer-term data may be compared and are sufficiently robust that meaningful changes should be detected as they occur.

3.3.1 Pre-thinning Site and Plot Comparisons

Initial visits suggested that there were differences between Sites, and even within some Sites, in terms of canopy or understorey floristics. This was confirmed by the pre-thinning survey data.

3.3.1.1 Overstorey

The composition of the forest canopy (from pre-thinning surveys in 2004) was relatively similar at Castlemaine Diggings NHP, Pilchers Bridge NCR and Spring Plains NCR (Figure 22), although Grey Box at Spring Plains NCR was restricted to three of the four Plots.

Paddys Ranges SP differed from all the other Sites, and no two Plots there had the same mix of canopy species (Figure 22). The only eucalypt species common to every Plot was Grey Box, and no other species was present in more than two Plots. The Control Plot contained only two eucalypt species: Grey Box and Red Box. These differences suggest that using data collected at Paddys Ranges SP to generate between-Site and between-Plot comparisons may be difficult at the community level. However, analysis at a species level is still possible, and useful.

	Treatment	Long-leaf Box	Red Stringybark	Red Box	Grey Box	Yellow Gum	Red Ironbark
Castlemaine	Control	■	■	■			
	Isolated	■	■	■			
	Patchy1	■	■	■			
	Patchy2	■	■	■			
Pilchers Bridge	Control	■	■	■			
	Isolated	■	■	■			
	Patchy1	■	■	■			
	Patchy2	■	■	■			
Spring Plains	Control	■	■	■			
	Isolated	■	■	■	■		
	Patchy1	■	■	■	■		
	Patchy2	■	■	■	■		
Paddys Ranges	Control			■	■		
	Isolated	■	■		■		■
	Patchy1		■		■	■	■
	Patchy2	■			■	■	

Figure 22. Eucalypt canopy species in each Plot at each Site.

3.3.1.2 Understorey

Pre-thinning survey data indicated that differences existed between Sites in terms of understorey floristic composition, although some of this was undoubtedly due to seasonal factors. Spring Plains NCR and Castlemaine Diggings NHP were similar to each other floristically, although not necessarily structurally, and all Plots within those Sites were similar to each other, allowing good future comparison at a community level. Pilchers Bridge NCR differed slightly from those Sites, and its Isolated Plot had more perennial grasses and fewer annual grasses than the other Plots. However, the understorey at Paddys Ranges SP was very different to the other Sites. For example, its mean understorey cover was 19%, and its shrub cover was 10%; in comparison, Spring Plains NCR had a mean understorey cover of 47% and shrub cover of 5%, and was dominated by perennial tussock grasses. These Sites are likely to have different edaphic factors and site history, and are likely to respond differently to thinning.

Differences in understorey composition between Plots at Paddys Ranges SP reflected the differences in canopy composition. The Isolated and Patchy 1 treatments were dominated by the same five species, in the same order (Figure 23). However, the Control and Patchy 2 Plots contained one or two different species in their top five, and they were ranked in a different order, which may confound future analyses of floristic change at the broader community level. Nonetheless, changes at a species level are likely to be similar across Sites and Plots, and the data from Paddys Ranges SP can still make an important contribution to our understanding of thinning responses.

	Joycea pallida	*Lomandra micrantha*	*Acacia pycnantha*	*Lomandra filiformis*	*Pultenaea largiflorens*	*Acacia acinacea*	*Acrotriche serrulata*	*Cassinia arcuata*
Control	1	2	3	4	5			
Isolated	2	4	1	5		3		
Patchy 1	2	4	1	5		3		
Patchy 2	2		1	4			3	5

Figure 23. Dominant understorey species within Plots at Paddys Ranges SP before thinning.

The number is the ranking of each species in terms of their percent cover (1 = highest).

3.3.2 Effects of Thinning on Life Form Cover

Preliminary analyses of the differences between pre- and post-thinning cover of the various life forms were confounded by the effects of season and year. The initial pre-thinning surveys were completed in 2004, with some assessments in autumn, some in winter and some in spring. Rainfall was low from November 2003 to May 2004 (Bureau of Meteorology data), and many of the dominant shrubs and tussock grasses showed signs of heavy browsing and grazing. All post-thinning assessments were undertaken in spring, but assessments were spread over 3 years (Table 4), with annual rainfall differing both within and between years. For example, total annual rainfall at Maryborough in 2005, 2006 and 2007 was 458 mm, 290 mm and 543 mm, respectively (Bureau of Meteorology data), which led to differences in spring growth, particularly of annual species.

Floristic surveys were also confounded by the slow breakdown of crown foliage in thinned Plots, with temporary (albeit patchy) obscuring or smothering of the ground layer. At Castlemaine Diggings NHP, for example, felled crowns retained leaves on the branches 3 years after thinning (Plate 1). Nonetheless, as these short-term effects of disturbance abate, it should be possible to differentiate the effects of the applied thinning treatments from this initial background variation.

Plate 2. Three years after completion of thinning, dead foliage and twigs on felled crowns still obscure the ground at Castlemaine Diggings NHP Isolated Sub-plot 7.

The following figures and tables show the immediate effects of the thinning treatments. Probability values for the effect of treatment, effect of year, and interaction between treatment and year have been shown to demonstrate the statistical methods employed for the Trial. However, in many cases, the results merely reflect the confounding effects of season and year, and they should be viewed with caution.

3.3.2.1 Annual Grasses

This category comprised mostly weeds, such as quaking-grass *Briza* and hair-grass *Aira*, and native annual grasses were poorly represented. Cover declined slightly in the Control Plots due to post-thinning surveys being undertaken in spring (at the start of their growth cycle) rather than autumn (Figure 24; Table 24), but cover increased (e.g. 1.5% to 3%) in some thinned treatments, especially in the Patchy 1 and Patchy 2 Plots at Spring Plains NCR, which were more recently disturbed and surveyed in the wetter 2007.

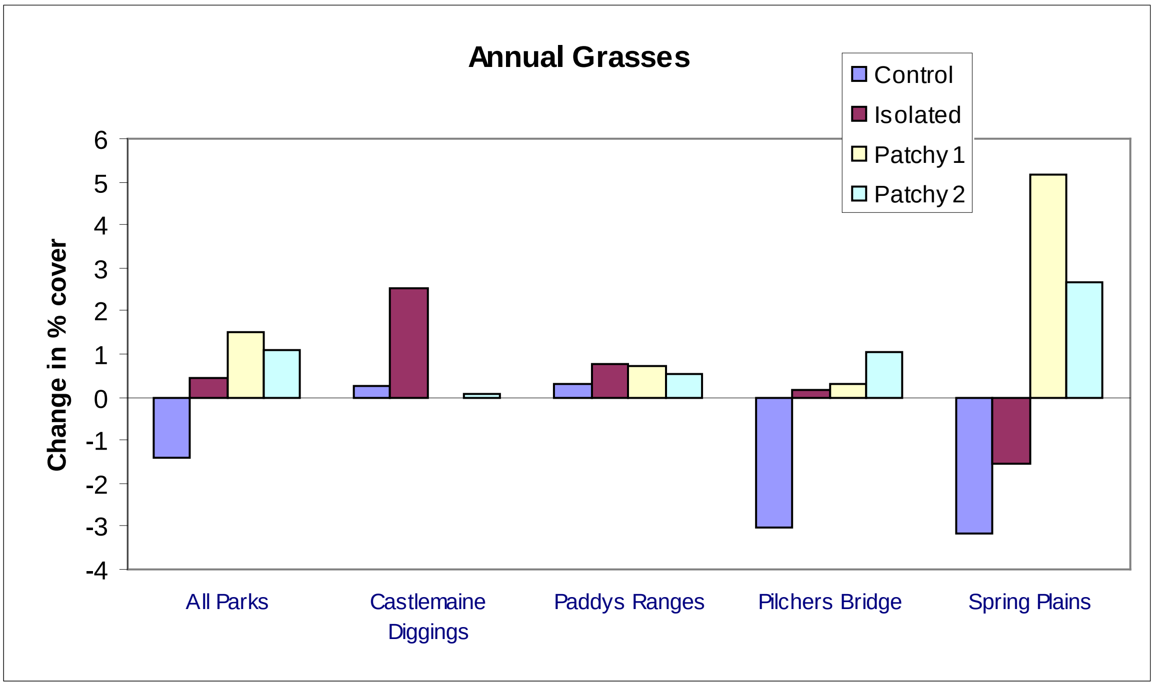

Figure 24. Changes in % cover of annual grasses after thinning.

Table 24. Changes in annual-grass cover after thinning (Two-way ANOVA).

	Time	Cont	Isol	P1	P2	p (time)	p (treat)	p (time*treat)
All sites	0	2.46	1.56	2.82	3.43	0.377	**<0.001**	0.138
	1	1.06	2.02	4.35	4.51		***	
Castlemaine Diggings NHP	0	0.77	1.46	0.40	1.02	0.014	**<0.001**	**0.005**
	1	1.02	3.97	0.38	1.10	*	***	**
Paddys Ranges SP	0	0.32	0.10	0.41	1.25	**<0.001**	**<0.001**	0.723
	1	0.64	0.85	1.11	1.79	***	***	
Pilchers Bridge NCR	0	3.89	0.26	5.33	0.91	0.519	**<0.001**	0.087
	1	0.88	0.41	5.62	1.96		***	
Spring Plains NCR	0	4.87	4.41	5.13	10.53	0.481	**<0.001**	**0.036**
	1	1.69	2.87	10.28	13.21		***	*

Weed grasses were most abundant in flat, low lying areas, or in and around piles of still-leafy woody debris on sloping ground. This suggested that these piles were acting as zones for the accumulation of water and nutrients, and with some increased shade (helping to reduce evapotranspiration) were providing suitable conditions for the rapid establishment of short-lived species such as Large Quaking-grass *Briza maxima* and hair-grass (Plate 3). These effects should settle down over time as attached foliage and smaller branches rot away, but should be monitored closely.

Plate 3. Quaking-grass and hair-grass infestation under thinning debris, Pilchers Bridge NCR, Patchy 1 Sub-plot 2.

3.3.2.2 Annual Herbs

In general, there was a slight increase in annual-herb cover, due to post-thinning surveys being undertaken at a more optimum time of year (Figure 25; Table 25). The increase was greater in thinned Plots than in Control Plots and may be an early indication of improved conditions for these annuals. However, small decreases in cover were noted in the Isolated Plot at Spring Plains NCR and in Control Plots at Pilchers Bridge NCR and Spring Plains NCR, where post-thinning surveys were completed in 2006, a drier year. Species that decreased at those Sites included small daisies, such as cudweed *Euchiton*, and *Crassula*.

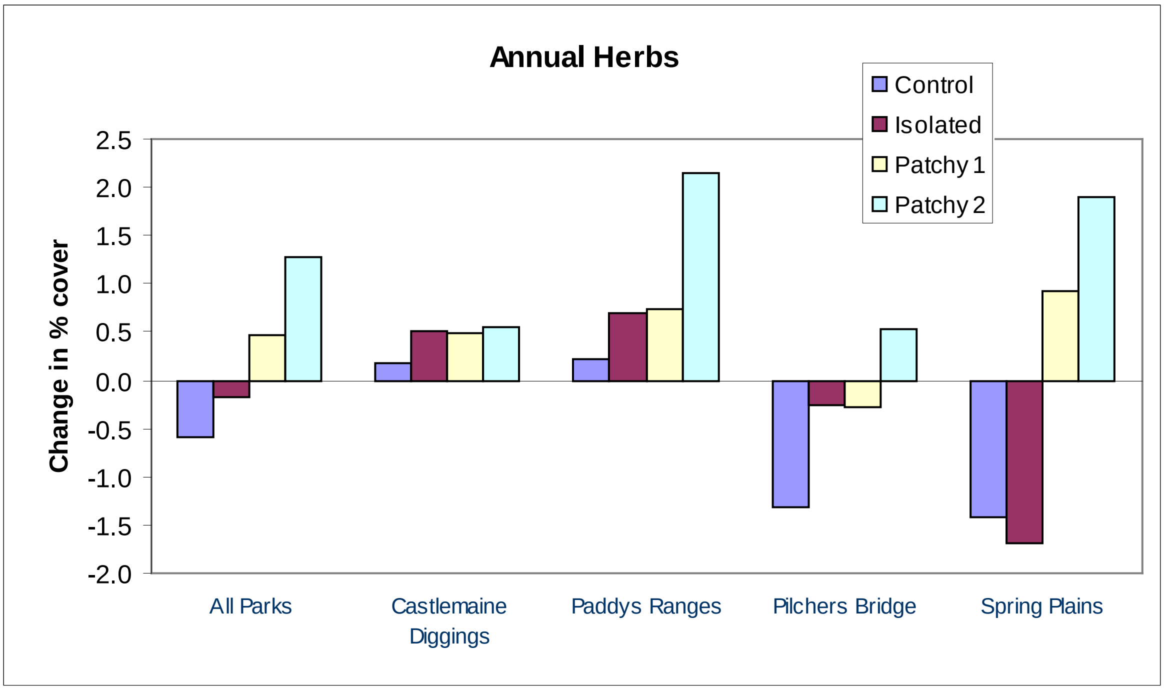

Figure 25. Changes in % cover of annual herbs after thinning.

Table 25. Changes in annual-herb cover after thinning (Two-way ANOVA).

	Time	Cont	Isol	P 1	P 2	p (time)	p (treat)	p (time*treat)
All Sites	0	0.80	0.62	0.69	0.54	**0.044**	**<0.001**	**<0.001**
	1	0.21	0.44	1.15	1.82	*	***	***
Castlemaine Diggings NHP	0	0.04	0.03	0.01	0.02	**<0.001**	0.089	**0.042**
	1	0.22	0.53	0.51	0.57	***		*
Paddys Ranges SP	0	0.17	0.22	0.19	0.39	**<0.001**	**<0.001**	**<0.001**
	1	0.40	0.92	0.93	2.55	***	***	***
Pilchers Bridge NCR	0	1.54	0.33	1.02	0.30	**0.007**	**<0.001**	**<0.001**
	1	0.22	0.08	0.74	0.83	**	***	***
Spring Plains NCR	0	1.43	1.92	1.52	1.44	0.824	**0.001**	**<0.001**
	1	0.01	0.24	2.44	3.34		**	***

3.3.2.3 Coppice Growth

Some increases in the cover of eucalypt coppice regrowth were measured in thinned Plots, especially in Isolated Plots where multi-stemmed trees were often stem-reduced rather than felled and killed (Figure 26; Table 26). The largest increase was measured at Castlemaine Diggings NHP, which appeared to contain a larger number of these multi-stemmed trees before thinning. This coppice growth reached around 3 m high (Plate 4), with the capacity to slow the growth of retained trees and reduce the patchiness of the tree layer.

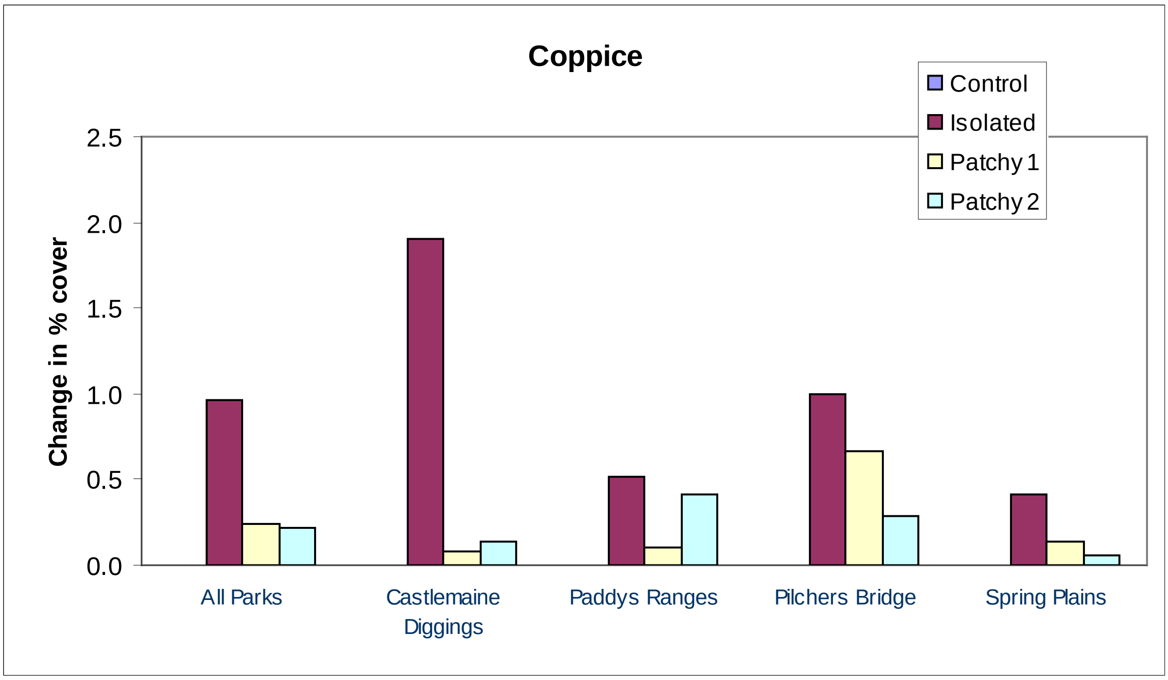

Figure 26. Changes in % cover of coppice after thinning.

Table 26. Changes in coppice cover after thinning (Two-way ANOVA).

	Time	Cont	Isol	P 1	P 2	p (time)	p (treat)	p (time*treat)
All sites	0	0.00	0.00	0.00	0.00	**<0.001**	**<0.001**	**<0.001**
	1	0.00	0.96	0.24	0.22	***	***	***
Castlemaine Diggings NHP	0	0.00	0.00	0.00	0.00	**<0.001**	**<0.001**	**<0.001**
	1	0.00	1.91	0.08	0.13	***	***	***
Paddys Ranges SP	0	0.00	0.00	0.00	0.00	**0.004**	0.124	0.124
	1	0.00	0.51	0.10	0.41	**		
Pilchers Bridge NCR	0	0.00	0.00	0.00	0.00	**<0.001**	**<0.001**	**<0.001**
	1	0.00	1.00	0.66	0.28	***	***	***
Spring Plains NCR	0	0.00	0.00	0.00	0.00	**<0.001**	**<0.001**	**<0.001**
	1	0.01	0.42	0.14	0.06	***	***	***

Plate 4. Coppice growth on Red Box stump at Castlemaine Diggings NHP, Isolated Sub-plot 7.

3.3.2.4 Perennial Grasses

The grassy layer at all Sites was dominated by perennial grasses rather than annual grasses, and comprised mostly Silvertop Wallaby-grass and, to a lesser extent, Grey Tussock-grass. A slight post-thinning increase in cover was recorded in most Plots including Control Plots, probably due to recovery from earlier drought and heavy grazing (Figure 27; Table 27). However, a reduction from 21% to 15% was measured in Patchy 2 at Spring Plains NCR. It is too early to determine if this was a genuine effect of thinning (this Site had twice the grass cover of any other Site) or a temporary effect of disturbance (thinning in Patchy 2 had been completed only 6 months earlier).

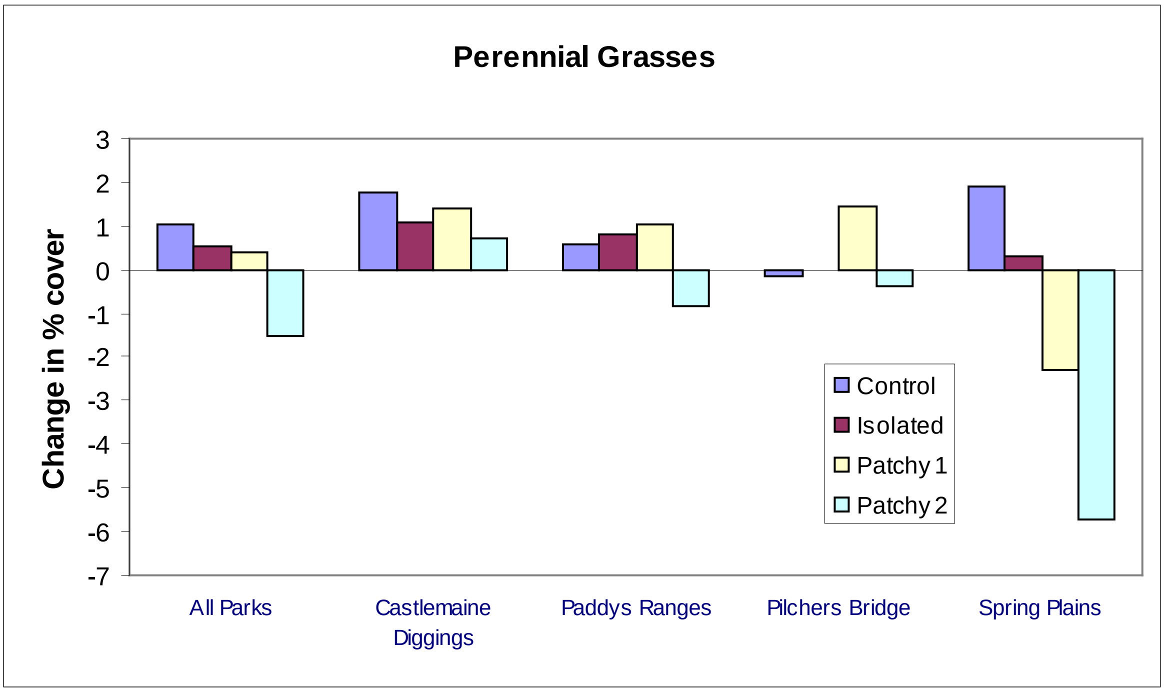

Figure 27. Changes in % cover of perennial grasses after thinning.

Table 27. Changes in perennial-grass cover after thinning (Two-way ANOVA).

	Time	Cont	Isol	P1	P2	p (time)	p (treat)	p (time*treat)
All Sites	0	8.26	9.31	9.68	7.90	0.924	0.239	0.826
	1	9.29	9.84	10.07	6.36			
Castlemaine Diggings NHP	0	7.74	6.84	10.51	7.16	0.393	0.224	0.995
	1	9.51	7.91	11.91	7.89			
Paddys Ranges SP	0	4.71	3.16	3.47	2.65	0.472	**0.007**	0.608
	1	5.27	3.98	4.51	1.80		**	
Pilchers Bridge NCR	0	2.34	8.03	2.12	1.07	0.596	**<0.001**	0.435
	1	2.19	8.02	3.57	0.69		***	
Spring Plains NCR	0	18.30	19.20	22.60	20.70	0.514	0.729	0.650
	1	20.20	19.50	20.30	15.00			

3.3.2.5 Perennial Herbs

Perennial herbs increased in all Plots after thinning at Castlemaine Diggings NHP (Figure 28; Table 28). Little change was noted at Paddys Ranges SP, and this was expected given the low initial cover of this life form and the more open pre-thinning canopy at this Site than at other Sites. Post-thinning cover reduced in Control and Isolated Plots at Pilchers Bridge NCR and Spring Plains NCR, which had been assessed in 2006, when the conditions were drier. Examples of species that decreased included sundew *Drosera*, yam-daisy *Microseris*, buttercup *Ranunculus* and various orchids. Orchids present a potential difficulty for future analyses, as the winter-flowering species detected by pre-thinning surveys are unlikely to be detected during spring surveys.

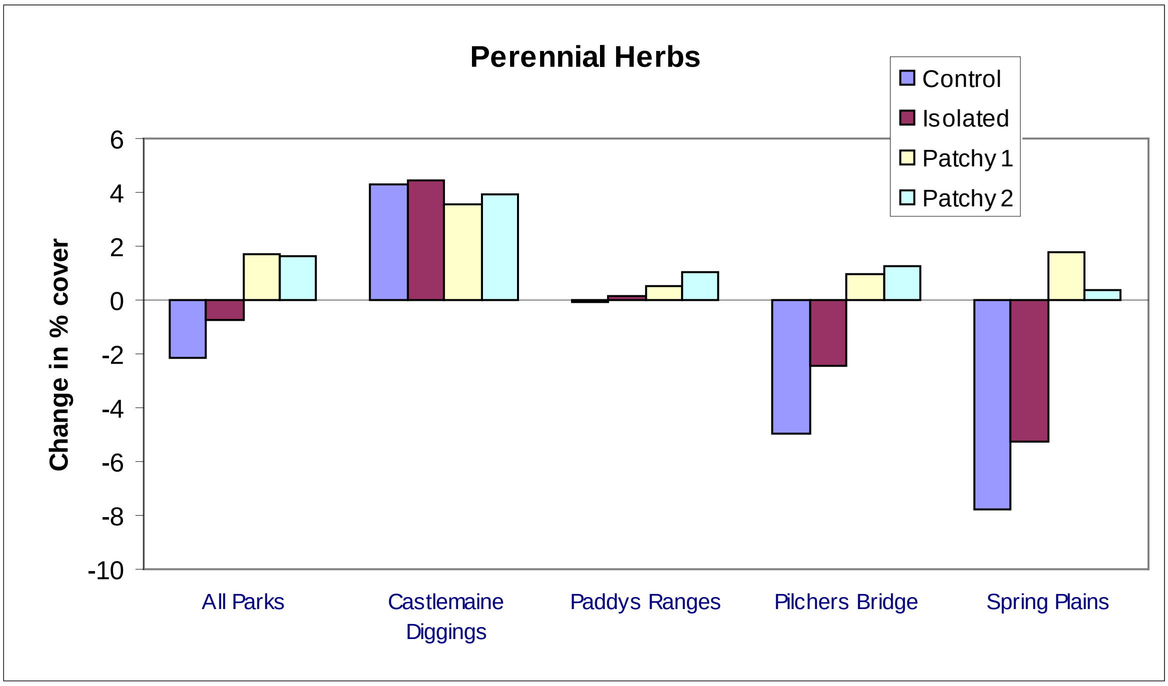

Figure 28. Changes in % cover of perennial herbs after thinning.

Table 28. Changes in perennial-herb cover after thinning (Two-way ANOVA).

	Time	Cont	Isol	P1	P2	p (time)	p (treat)	p (time*treat)
All Sites	0	5.59	5.11	5.09	4.76	0.775	**0.046**	**0.002**
	1	3.46	4.35	6.79	6.42		*	**
Castlemaine Diggings NHP	0	2.52	1.73	2.16	2.69	**<.001**	0.281	0.813
	1	6.85	6.19	5.69	6.64	***		
Paddys Ranges SP	0	1.56	1.78	0.93	0.92	**0.002**	**0.007**	**0.022**
	1	1.51	1.93	1.48	1.95	**	**	*
Pilchers Bridge NCR	0	8.74	6.54	7.33	6.73	**<.001**	**<.001**	**<.001**
	1	3.76	4.13	8.28	8.03	***	***	***
Spring Plains NCR	0	9.54	10.39	9.94	8.71	**<.001**	**<.001**	**<.001**
	1	1.73	5.16	11.71	9.06	***	***	***

3.3.2.6 Perennial Shrubs

There was a slight increase in perennial-shrub cover over time in some Control Plots (i.e. Castlemaine Diggings NHP and Spring Plains NCR) as they recovered from drought and heavy browsing (Figure 29; Table 29). However, post-thinning decreases were measured in Patchy 1 and Patchy 2 Plots, probably associated with more recent and extensive thinning disturbance. Examples of shrubs that decreased in those Plots included Golden Wattle and Daphne Heath. At Paddys Ranges SP, *Acacia* recruitment was stimulated by a fire in 1985, and some of the reduction in shrub cover at this Site may have been due to on-going senescence. Nonetheless, shrubs appear vulnerable to initial damage by the thinning activity.

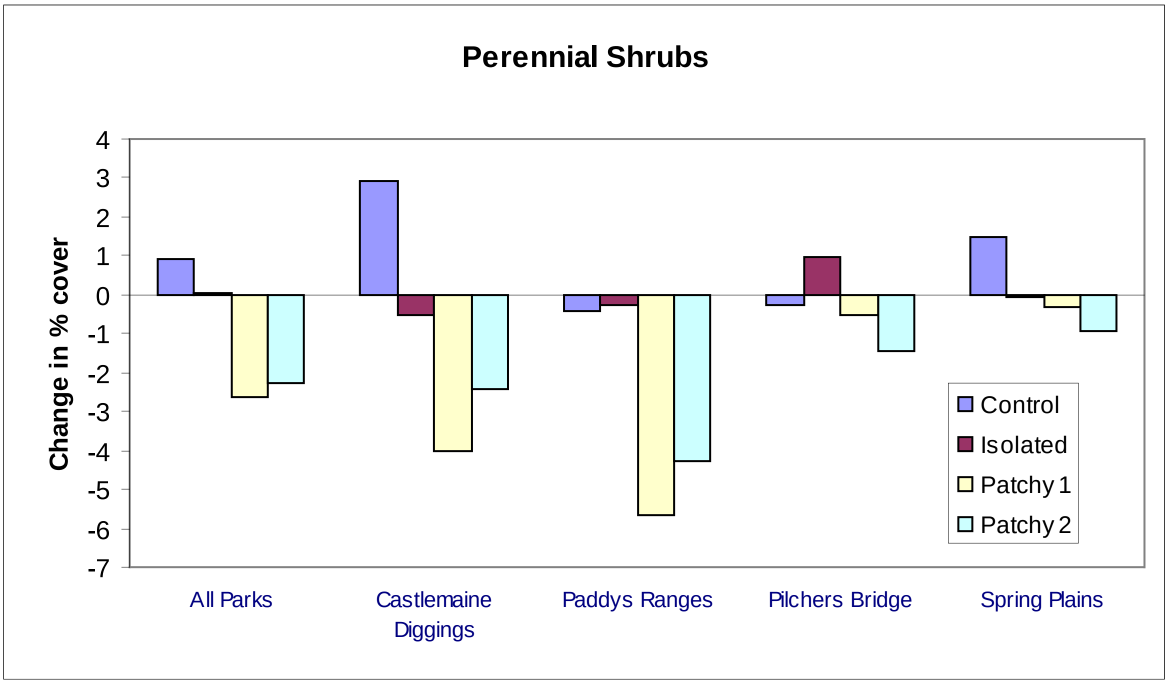

Figure 29. Changes in % cover of perennial shrubs after thinning.

Table 29. Changes in perennial-shrub cover after thinning (Two-way ANOVA).

	Time	Cont	Isol	P1	P2	p (time)	p (treat)	p (time*treat)
All Sites	0	7.27	8.22	8.60	6.96	0.082	**0.019**	0.073
	1	8.19	8.25	5.97	4.69		*	
Castlemaine Digging NHP	0	15.22	13.92	13.92	10.34	0.167	**<0.001**	**0.008**
	1	18.14	13.42	9.93	7.91		***	**
Paddys Ranges SP	0	5.69	11.09	12.26	8.62	**<0.001**	**<0.001**	**0.007**
	1	5.27	10.82	6.60	4.34	***	***	**
Pilchers Bridge NCR	0	3.65	4.77	3.66	4.74	0.545	0.061	0.458
	1	3.38	5.73	3.12	3.31			
Spring Plains NCR	0	4.51	3.12	4.55	4.13	0.946	0.059	0.512
	1	5.97	3.05	4.24	3.19			

3.3.2.7 Perennial Sub-shrubs

Post-thinning increases in perennial sub-shrub cover (e.g. rice-flower *Pimelea*) were noted in all Plots, thinned or unthinned, due to post-thinning surveys being undertaken at an optimum time of year (Figure 30; Table 30). Some increase may also have been due to recovery from heavy browsing, as surveys in the first year noted that many shrubs had been so closely browsed that they were sometimes difficult to identify. However, the extent of cover of this life form is relatively low, and more time is required before meaningful results can be gleaned from the data.

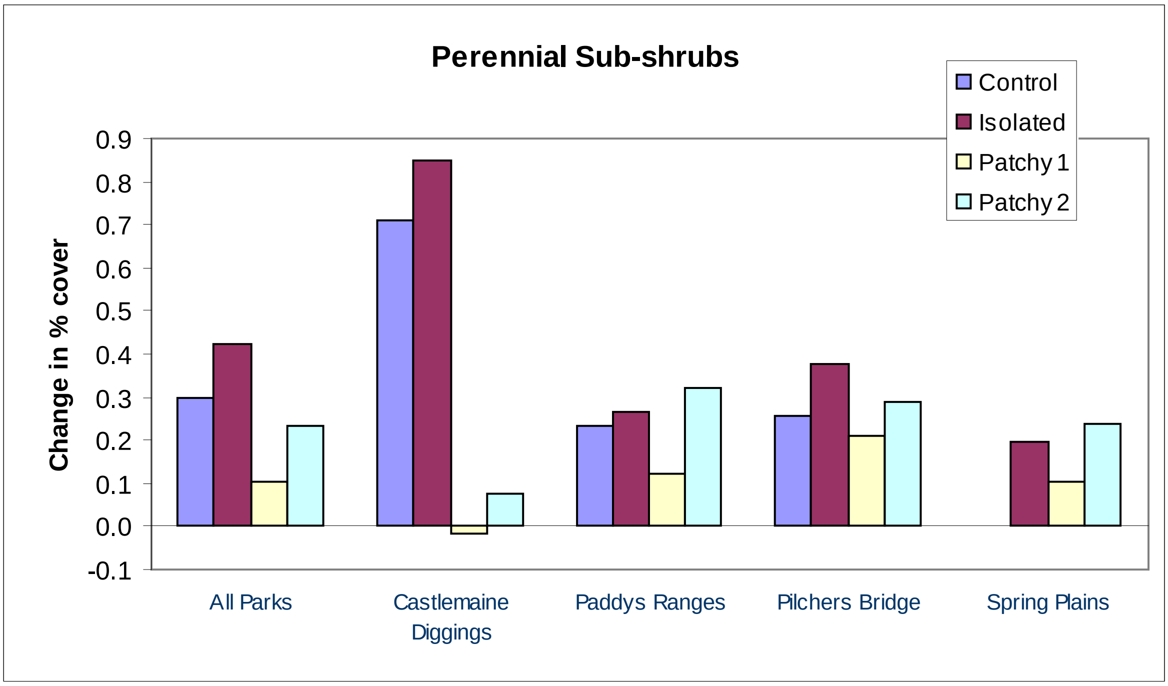

Figure 30. Changes in % cover of perennial sub-shrubs after thinning.

Table 30. Changes in perennial sub-shrub cover after thinning (Two-way ANOVA).

	Time	Cont	Isol	P1	P2	p (time)	p (treat)	p (time*treat)
All Sites	0	0.36	0.38	0.45	0.29	**<0.001**	0.200	0.297
	1	0.66	0.80	0.55	0.53	***		
Castlemaine Diggings NHP	0	0.53	0.86	0.86	0.52	**0.030**	0.056	0.241
	1	1.24	1.71	0.84	0.59	*		
Paddys Ranges SP	0	0.16	0.12	0.03	0.20	**<0.001**	**<0.001**	0.371
	1	0.39	0.39	0.15	0.52	***	***	
Pilchers Bridge NCR	0	0.23	0.18	0.27	0.18	**<0.001**	0.884	0.560
	1	0.48	0.56	0.48	0.47	***		
Spring Plains NCR	0	0.52	0.36	0.63	0.27	**0.018**	**0.003**	0.445
	1	0.52	0.56	0.74	0.51	*	**	

3.3.2.8 Perennial Tufted-herbs

There was generally little change in perennial tufted-herb cover (Figure 31; Table 31), although a post-thinning increase was measured in the Castlemaine Diggings NHP Patchy 2 Plot (from 4.6% to 8.8%). Post-thinning surveys at this Site were undertaken in 2007, when conditions were wetter, and it also had the longest time to recover of all the thinned Plots. Examples of species that increased included chocolate lily *Arthropodium*, mat-rush *Lomandra* and flax-lily *Dianella*.

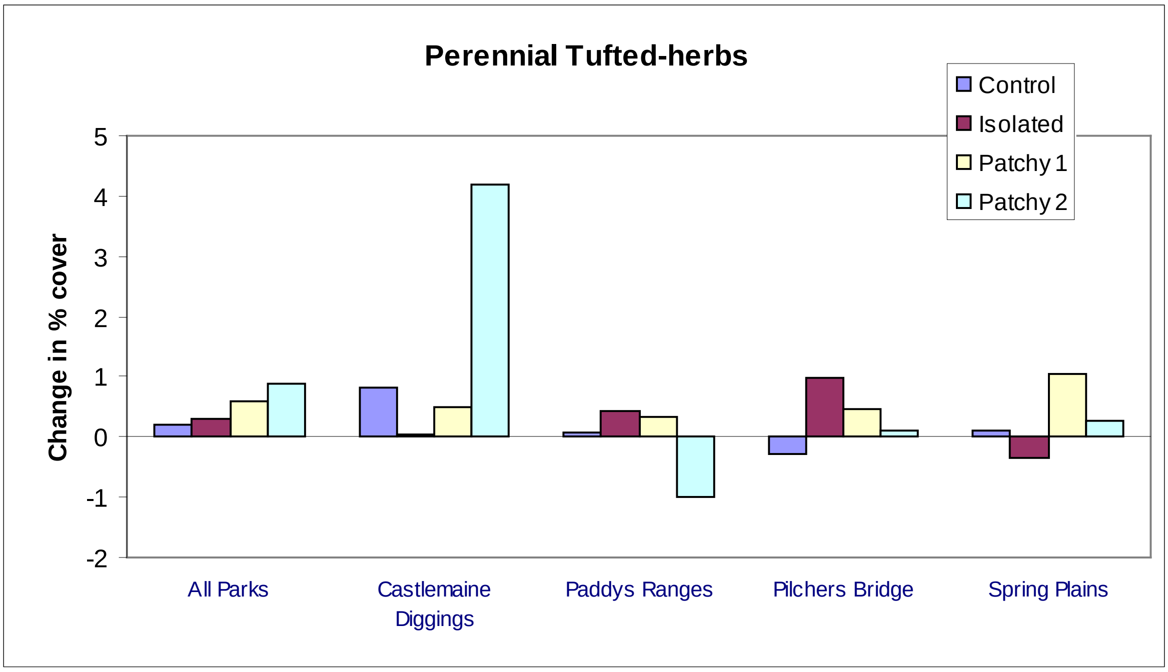

Figure 31. Changes in % cover of perennial tufted-herbs after thinning.

Table 31. Changes in perennial tufted-herb cover after thinning (Two-way ANOVA).

	Time	Cont	Isol	P 1	P 2	p (time)	p (treat)	p (time*treat)
All Sites	0	3.92	3.19	3.42	3.19	0.136	0.525	0.869
	1	4.11	3.48	4.00	4.08			
Castlemaine Diggings NHP	0	3.41	2.94	5.34	4.61	**0.036**	**<0.001**	0.104
	1	4.22	2.99	5.83	8.79	*	***	
Paddys Ranges SP	0	5.06	4.12	3.10	4.23	0.914	**0.004**	0.481
	1	5.14	4.56	3.42	3.24		**	
Pilchers Bridge NCR	0	1.84	1.89	1.63	0.96	0.235	**0.007**	0.405
	1	1.57	2.88	2.11	1.06		**	
Spring Plains NCR	0	5.39	3.82	3.59	2.94	0.731	0.181	0.938
	1	5.51	3.47	4.63	3.21			

3.3.2.9 Tree Recruits

Results for tree-recruit cover were inconsistent across Sites, with both increases and decreases in cover recorded for all treatments, including Control Plots. In any event, absolute-cover values are too small at this stage to draw any meaningful conclusions (Figure 32; Table 32).

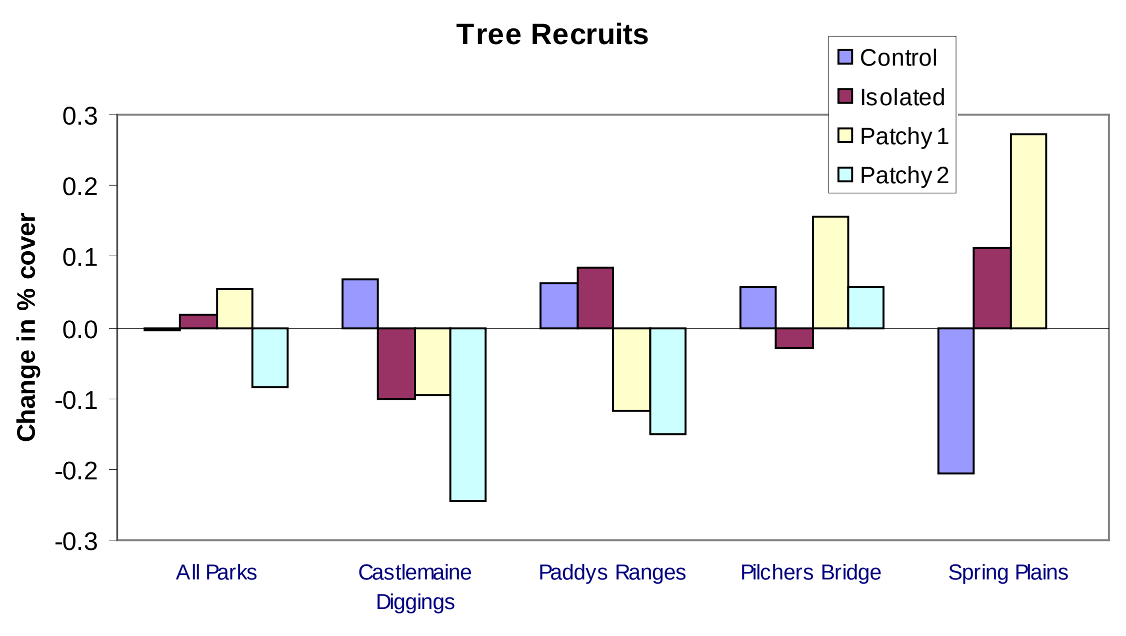

Figure 32. Changes in % cover of tree recruits after thinning.

Table 32. Changes in tree recruit cover after thinning (Two-way ANOVA).

	Time	**Cont**	**Isol**	**P1**	**P2**	**p (time)**	**p (treat)**	**p (time*treat)**
All Sites	0	0.54	0.67	0.65	0.61	0.939	0.256	0.886
	1	0.53	0.69	0.70	0.52			
Castlemaine Diggings NHP	0	0.75	0.58	0.89	1.24	0.378	**0.002**	0.777
	1	0.82	0.48	0.80	1.00		**	
Paddys Ranges SP	0	0.04	0.06	0.26	0.31	0.412	**0.007**	0.059
	1	0.10	0.14	0.14	0.16		**	
Pilchers Bridge NCR	0	0.64	0.67	0.43	0.25	0.448	**0.002**	0.875
	1	0.70	0.64	0.58	0.31		**	
Spring Plains NCR	0	0.72	1.36	1.02	0.63	0.724	**<0.001**	0.591
	1	0.51	1.47	1.29	0.63		***	

3.3.3 Effects of Thinning on Community Composition

Plant-species data from all Sites (pre- and post-thinning combined) were analysed by non-metric multi-dimensional scaling (NMDS) to derive a two-dimensional scatter plot (Figure 33). Note that pre- and post-thinning floristic data are confounded by the effects of season or year, or both, and this combined ordination has been presented as an example to demonstrate a potential statistical approach for future examination of community composition.

The relative separation of Sites confirmed that Plots at Paddys Ranges SP differed markedly from Plots at the other Sites, and that the Control Plot was different to the other three Plots at that Site (see *Understorey* for a brief summary of the major differences). The ordination also confirmed that the Isolated Plot at Pilchers Bridge NCR differed from the other three Plots, in particular, by having more perennial grasses and fewer annual grasses.

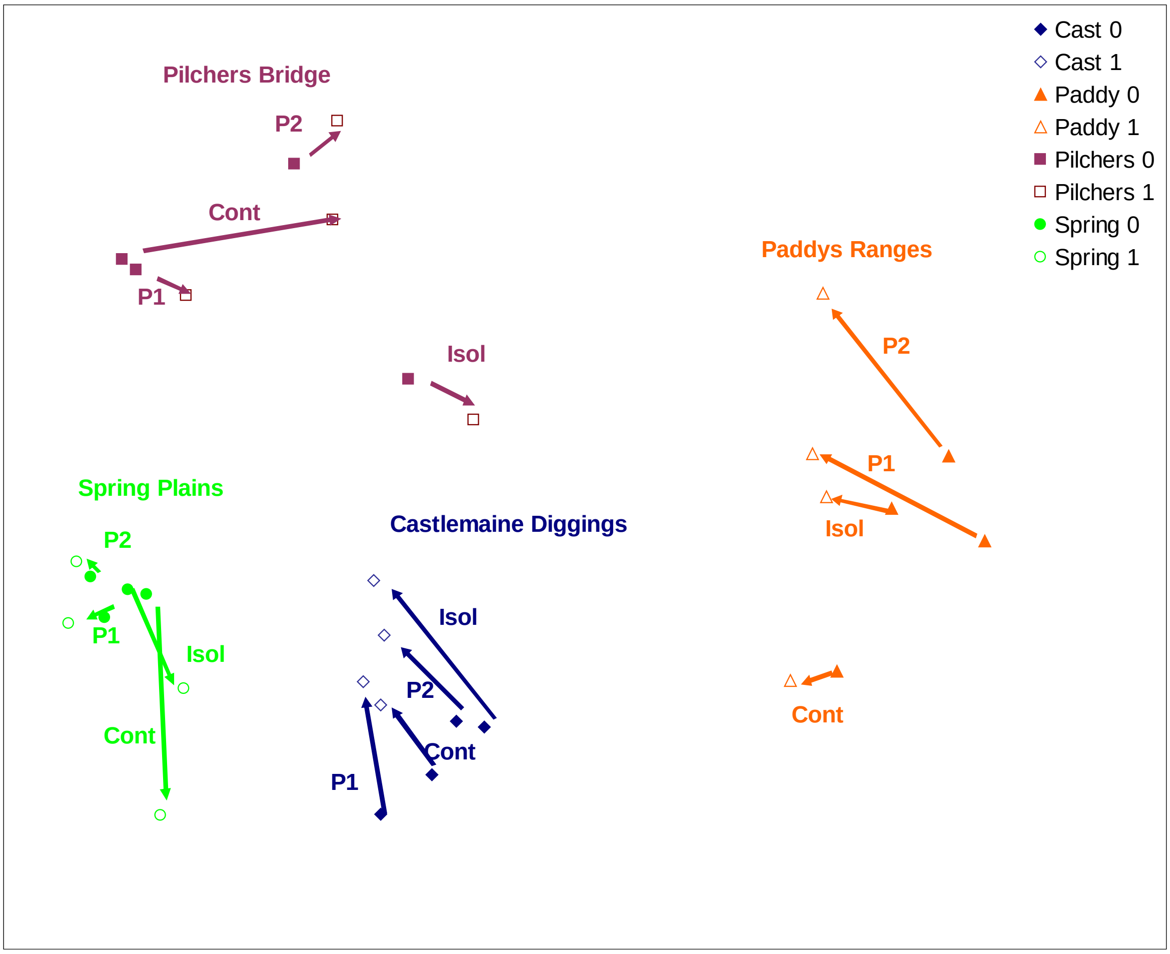

Figure 33. Two-dimensional NMDS ordination of all Sites, pre- and post-thinning.

Time 0 = pre-thinning (solid symbols); Time 1 = post-thinning (open symbols).

As expected, community changes after thinning were inconsistent. The direction of the change was relatively consistent within Sites, but substantially different between Sites, probably due to the effects of season and year. The magnitude of change also differed within and between Sites, probably for the same reasons.

3.3.4 Effects of Thinning on Flowering

Casual observations at Pilchers Bridge NCR in 2006 suggested that a larger proportion of some species was flowering in thinned Plots, and some individual plants in the open appeared to be flowering more profusely than plants under the canopy. For example, the perennial herb Black's Goodenia *Goodenia blackiana* and the shrub Grey Everlasting *Ozothamnus obcordatus* was flowering more profusely 1½ years after thinning than prior to thinning (Plate 5). This suggests that flowering intensity may be a useful additional parameter for future surveys, as it may contribute to eventual increases in the soil seed bank and understorey-plant abundance.

Plate 5. Profuse flowering of Grey Everlasting, Pilchers Bridge NCR, Isolated Plot, October 2006.

3.3.5 Data Summary

Differences between pre- and post-thinning surveys were attributed both to the effects of thinning and the more optimum season for the post-thinning surveys. While it is too early to confirm the effects of thinning on understorey species, some general trends can be estimated:

- an initial, probably temporary, increase in annual weed grasses among the thinning debris;
- an increase in annual herbs in thinned treatments;
- coppice growth on cut stumps;
- more profuse flowering of some herb and shrub species in thinned treatments; and
- some temporary decrease in perennial shrubs due to thinning damage.

More profuse flowering in the understorey is likely to lead to increases in the recruitment of herbaceous and shrubby plants. Therefore, the effects of thinning on the Box–Ironbark understorey are likely to be positive, once the short-term effects of the disturbance (e.g. increased leaf litter, physical damage to plants) settle down.

A total of 246 species was recorded across the four Sites (including 32 exotic species), with Spring Plains NCR consistently providing the greatest number (Table 33). As expected, larger numbers of species were recorded in the post-thinning surveys, particularly at Paddys Ranges SP, reflecting the more optimum time to conduct the survey: spring surveys were better able to detect small annuals such as *Crassula*, or spring-flowering orchids such as *Caladenia*, *Calochilus*, *Diuris* and *Glossodia*.

However, it is also clear that not all species were detected at any one time, as the total number of species recorded at each Site from multiple surveys always exceeded the number of species recorded in either the pre- or post-thinning surveys. This may be due to several reasons, but is mostly a consequence of differences in the timing of plant life-cycles. For example, grasses tend to flower in summer rather than spring (the defined survey season), and the inflorescences that were vital for accurate species identification were often lacking at the time of the post-thinning assessments. Thus, pre-thinning surveys were able to identify grasses such as wallaby-grass *Austrodanthonia*, spear-grass *Austrostipa* and plume-grass *Dichelachne* to species level (a total of 11 species was recorded), but post-thinning surveys were too early, and (within the constraints of time and cost) were only able to identify them to genus level. In contrast, spring post-thinning surveys were too late to detect orchids such as *Pterostylis*, *Corunastylis*, *Acianthus* and *Cyrtostylis*, which had already flowered in autumn or winter and died back. This is of concern, as many of the winter-flowering orchids that may not be adequately represented in post-thinning data prefer moist conditions, often under tree cover, and might respond negatively to thinning, while spring-flowering (hence detectable) species that often prefer drier conditions might respond positively (Mike Duncan, ARIER, pers. comm.).

In terms of broad community change, aggregated and seasonally-absent species may have little apparent impact on overall results, because relative data will be more important than absolute data in determining the long-term effects of thinning. However, it may be necessary to undertake brief additional summer and winter surveys in some years to ensure that undesirable changes in the abundance of non-tussock grasses or rare and threatened species such as orchids can be detected.

Table 33. Number of vascular plant species detected in pre- and post-thinning surveys.

Sites	Pre-thin	Post-thin	Total
Castlemaine Diggings NHP	111	116	143
Paddys Ranges SP	102	142	157
Pilchers Bridge NCR	112	136	157
Spring Plains NCR	131	144	174
Total	200	217	246

Some species will be overlooked in surveys simply because they are not abundant. For example, 117 species (nearly half the total) were detected in fewer than 1% of all measurement transects (Figure 34), and 21 of these species were detected in a single transect (of 1440 total transects). No species were ubiquitous. There is little that can be done to improve the detection of rare species without a substantial increase in survey effort, and the results of both univariate and multivariate analyses will always be driven largely by commonly occurring species. Species that are favoured by thinning will assume greater importance in future surveys.

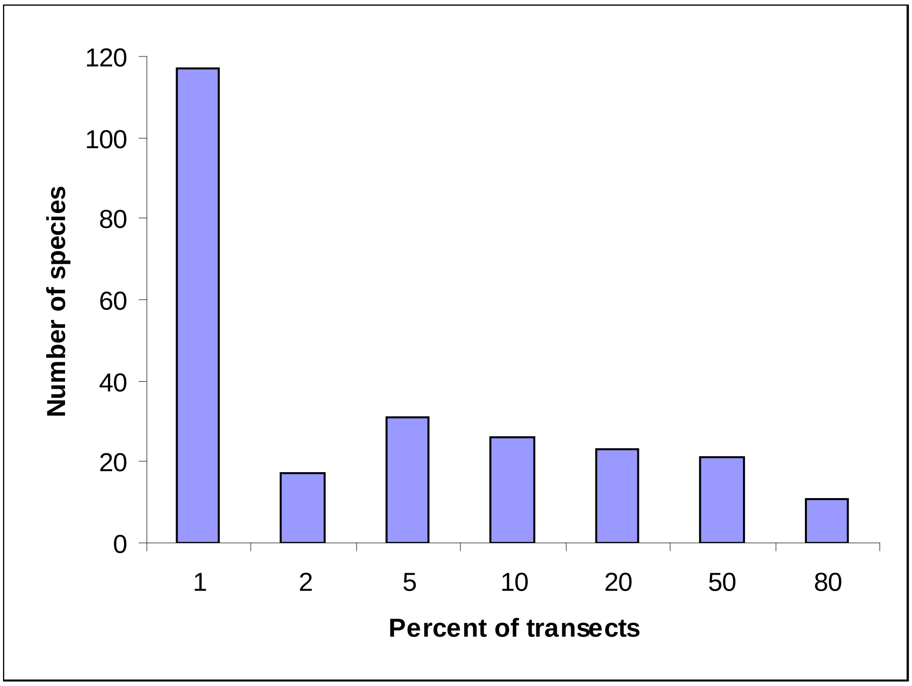

Figure 34. Histogram of plant species frequency (average of pre- and post-thinning data).

The highest number of species (84) was found in the 'perennial herb' category (Table 34), followed by 'annual herb' and 'perennial shrub' (46 species each). Thus, 72% of the species were contained in three life form categories. However, diversity does not necessarily translate to cover abundance. For example, the 46 annual herbs contributed only 0.78% of mean cover. In contrast, the 21 species of perennial grasses contributed 8.84% of cover (Table 34), with two species (Silvertop Wallaby-grass and Grey Tussock-grass) contributing 7.82%. Thus, cover and species richness should be equally important when analysing the contribution of individual species to biodiversity and structure.

The data also confirm the low overall cover of the understorey in these forests, with less than 30% mean total overlapping cover.

Table 34. Number of vascular plant species in each life form category and mean foliage cover.

Life form	No. species	% cover
Annual grass	12	2.78
Annual herb	46	0.78
Coppice regrowth (eucalypt)	1	0.18
Perennial grass	21	8.84
Perennial herb	84	5.20
Perennial shrub	46	7.27
Perennial sub-shrub	10	0.50
Perennial tufted herb	16	3.67
Tree recruit	10	0.61
Total	246	29.83

Species-area curves confirmed that 10 measurement transects per Sub-plot were adequate for detecting most of the species at a site. For example, the 27 species in Spring Plains NCR Control Sub-plot 1, were all accounted for by the seventh transect (Figure 35a), while the 36 species in Sub-plot 6 were all accounted for by the ninth transect (Figure 35b). These data suggest that an increased survey effort would be of little benefit, but a decreased survey effort (to potentially save costs) might result in missed species, reducing our ability to detect finer-scale changes. Therefore, no changes to the survey effort are recommended.

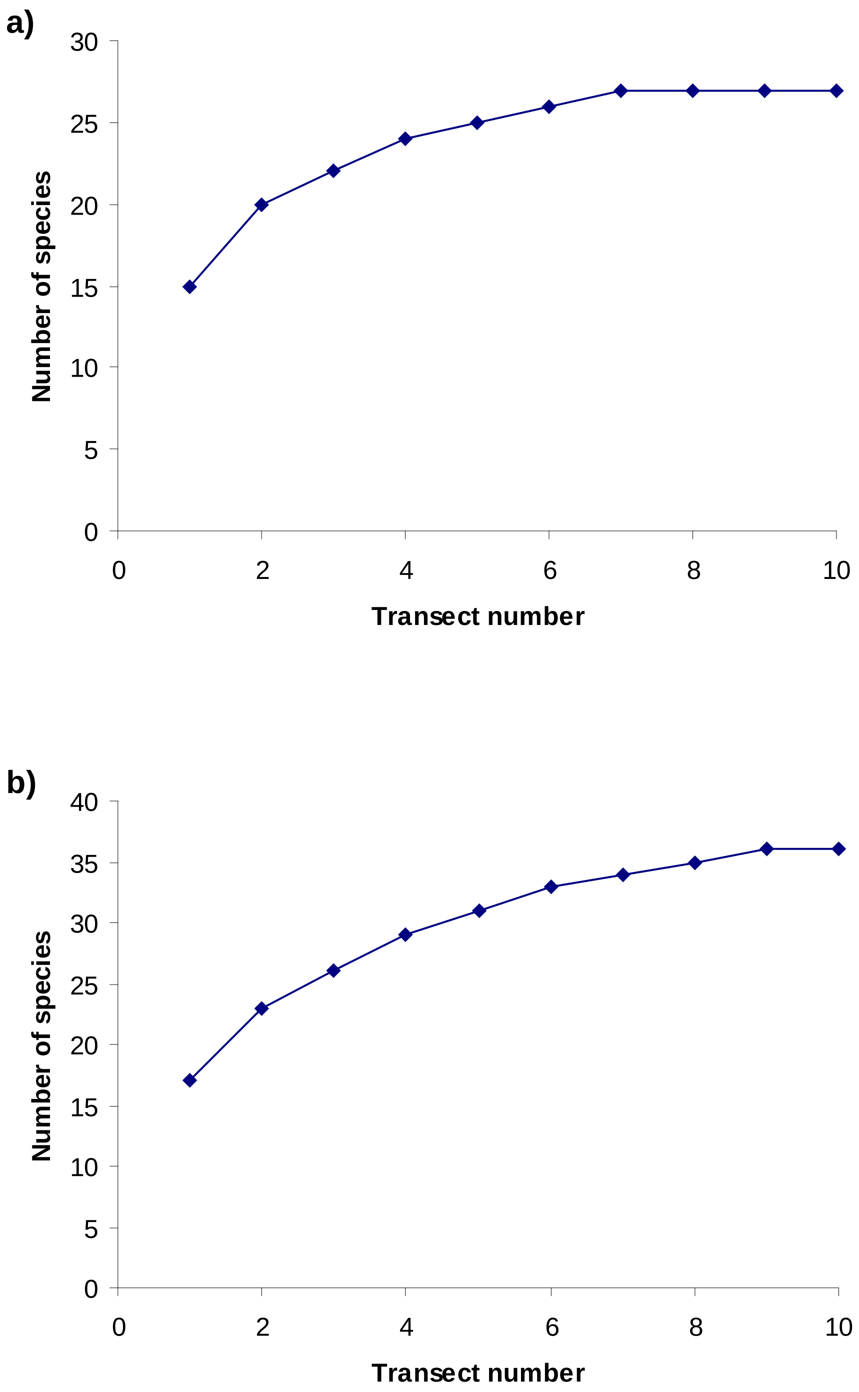

Figure 35. Species-area curve for Control Plot, Spring Plains NCR. (a) Sub-plot 1; (b) Sub-plot 6.

3.4 Ecosystem Function: Selected Vertebrates

The effect of the various thinning treatments on selected vertebrate groups (diurnal birds, nocturnal birds, ground mammals, arboreal mammals and bats) was assessed. Surveys were conducted at the Plot (nocturnal birds, ground mammals, arboreal mammals and bats) and Sub-plot level (diurnal birds) before and 12–19 months after thinning operations; post-thinning surveys were generally conducted in spring.

In this section, the results obtained for each survey technique are presented and the species composition and abundance in relation to Site, treatment and any obvious short-term impacts of thinning operations are described.

In total, 114 vertebrate species were recorded through standardised sampling, comprising 17 terrestrial mammals (including six introduced species), 12 bats and 85 birds (Appendix 1, see which for scientific names). In addition, three species of frogs were recorded during spotlight surveys, although this vertebrate group was not a target for this study. Eight reptiles were observed during an independent project conducted at some of the Sites and Plots.

Across Sites there were differences in species composition and relative abundances for most vertebrate groups (though these differences may be due, in part, to the variation in survey effort and seasonality of sampling, as well as existing structural and floristic differences). The study is notable for the numerical dominance and widespread distribution across the Sites of a minor proportion of the species, and the relative paucity and limited distribution of introduced taxa.

3.4.1 Avifauna

3.4.1.1 Diurnal Birds

A total of 70 species was recorded during bird surveys, with a total of 52 species recorded before the thinning treatments and 61 after thinning. A further eight species were only recorded off-site during surveys. The short-term nature of the surveys, coupled with the ability of many birds to move freely across forest landscapes, makes interpretation of these results difficult. For example, the combined Control Plots had similar species totals, with 35 recorded before and after thinning, yet only 25 species were common to both data-sets.

To gain an insight into the ecological construct of bird assemblages, the composition of foraging, nesting and movement guilds was examined. Ten foraging guilds were recognised: seven species of aerial-invertebrate feeders (9% of total species); one arboreal granivore (1%); six bark-invertebrate feeders (8%); eight carnivores (10%); 14 foliage-invertebrate feeders (18%); eight ground granivores (10%); 22 ground-invertebrate feeders (28%); one mistletoe feeder(1%); eight nectarivores (10%); and three shrub-invertebrate feeders (4%).

Ten nesting guilds were recognised, consisting of: one species that nests in burrows (1% of total species); 11 in foliage of canopy (14%); six on the ground (8%); two in ground vegetation (3%); 14 in hollows (18%); two non-breeding migrants (3%); three parasitic species (4%); 11 in tree boles (14%); 17 in tree branches (22%); and 11 in understorey (14%).

Species were assigned one of three movement guilds based on their known movement patterns in south-eastern Australia (Griffioen & Clarke 2002): 19 migrants (breeding and non-breeding, 24% of total species); eight partial migrants (10%); and 51 residents (65%).

Before any thinning treatment, only three bird species were common to all four Sites: Grey Fantail; Brown-headed Honeyeater; and Spotted Pardalote (Table 35). All are widespread, mobile species that would normally occur throughout Box–Ironbark forests in central Victoria (Emison *et al.* 1987; Mac Nally *et al.* 2002a; Tzaros 2005). After thinning operations, an additional seven species that are generally widespread were recorded at all sites (Table 36). Spotted Pardalote and Brown-headed Honeyeater were the only species common to all Sites both before and after thinning.

Nine species observed before thinning were not recorded after the Plots were thinned; six of these (Satin Flycatcher, Restless Flycatcher, Flame Robin, Eastern Yellow Robin, Crested Shrike-tit, White-plumed Honeyeater) were recorded in low numbers, two (Painted Button-quail, Speckled Warbler) are secretive, and the other (Swift Parrot) is a rare seasonal migrant.

Conversely, 17 species that were unrecorded in pre-thinning surveys were noted after thinning, though only eight were recorded more than once (Table 36). Most of these observations were of individual birds and, as such, the discrepancy between before and after treatment has limited significance. When all pre-treatment Plots are considered, only three species recorded in the combined Control Plots after treatment (Hooded Robin, Chestnut-rumped Thornbill, Mistletoebird) can be regarded as being independent of the treatment as they were not recorded in any thinned Plots. That is, all other new species recorded (e.g. Brown Falcon) were recorded at least once in a thinned Plot and may have been influenced by a particular treatment.

It is likely that the treatments had some effect on the diurnal-bird assemblage, either by attracting birds not usually associated with a more open forest or by enhancing suitable habitat for species already present. With the creation of a more open habitat and subsequent coppice and understorey growth, several bird species appear to have increased in number. In particular, the Superb Fairy-wren increased from five pre-thinning records to 59 post-thinning records. This increase occurred solely in treated areas, as Control Plot numbers were identical pre- and post-thinning. Other examples of population increases were shown by Brown Thornbill (16 pre-thinning, 26 post-thinning), Chestnut-rumped Heathwren (1, 7) and Grey Fantail (12, 26).

It is likely that, over time, other species with a preference for more open woodland will also increase in number. Several open-country species (e.g. Welcome Swallow, Brown Falcon, Rufous Songlark) were not recorded before thinning operations yet were recorded post-thinning, and these open-woodland birds are likely to become more abundant in the future.

Seasonal changes in the structure and composition of bird assemblages are a characteristic feature of the Box–Ironbark ecosystem (Tzaros 2005). Regular seasonal movements of migratory species occur, as well as irregular movements of species at local and landscape scales in response to variation in food availability (e.g. nectar), that contribute to the dynamism of bird assemblages. This can lead to substantial changes in the bird assemblage within and between years in Box–Ironbark ecosystems (Tzaros 2005). That diurnal bird surveys were carried out in different seasons and over several years during the Trial is likely to have captured such dynamism, introducing variation into the survey results. As a result, this data should be considered with appropriate caution. To partly address this, the bird assemblages were classified into movement guilds (breeding migrants, non-breeding migrants, partial migrants and residents) in analyses of their response to thinning (see *Relationships Among Biodiversity and Habitat Attributes*).

Table 35. Bird species detected during diurnal bird surveys conducted at each Site during pre-thinning surveys.

The total number of individuals observed for each species in each Plot is presented. Treatment: C = Control, I = Isolated, P1 = Patchy 1, P2 = Patchy 2

	Castlemaine Diggings				Paddys Ranges				Pilchers Bridge				Spring Plains				Total
Common name	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	
Common Bronzewing				2			1				1				1		5
Painted Button-quail						1	3								2		6
Galah								2		3	4						9
Sulphur-crested Cockatoo													1			1	2
Musk Lorikeet						6	2		4	3	2	5					22
Little Lorikeet					3				2								5
Crimson Rosella	1	3	3	4							2	1	8	12	4	7	45
Eastern Rosella							15	3		10							28
Swift Parrot					1	6	9										16
Laughing Kookaburra														1			1
White-throated Treecreeper	3		4	3					4	7	5	2	1	6	3	4	42
Brown Treecreeper						2	1	2	1		2						8
Superb Fairy-wren											3		2				5
Chestnut-rumped Heathwren								1									1
Speckled Warbler											5	1	1				7
Weebill					7			8	8	3	5	6				4	41
Striated Thornbill		4		7					3	1	15	7	7	2	2	4	52
Buff-rumped Thornbill	2	2	2	15					7	2	11	20	11	12	12	6	102
Brown Thornbill		1		3							3	2	3	2		2	16
Spotted Pardalote			1	6	10	10	14	10	5	2	4	5	4	11	10	6	98
Striated Pardalote					11	22	36	17	2	1	2				1		92
Yellow-faced Honeyeater		3	1	2			1	2		1							10

	Castlemaine Diggings				**Paddys Ranges**				**Pilchers Bridge**				**Spring Plains**				
Common name	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**Total**
White-eared Honeyeater			2										1	2		4	9
Yellow-tufted Honeyeater					11	34	34	7									86
Fuscous Honeyeater						1	4	8	4	18	9	5					49
White-plumed Honeyeater					3					1			1				5
Red Wattlebird					16	15	18	10	1	1			1			1	63
Black-chinned Honeyeater						8	9	2									19
Brown-headed Honeyeater		1		1		2		7	2	3	6	1		3	6		32
White-naped Honeyeater						6	5								4		15
White-browed Babbler						4											4
Spotted Quail-thrush		1	1		2						3						7
Varied Sittella	8								5				3		4		20
Black-faced Cuckoo-shrike	2																2
Crested Shrike-tit								2	1								3
Golden Whistler						2		4		2			1			1	10
Rufous Whistler	3		2	2													7
Grey Shrike-thrush					6	4	1	5	1	1	2	1	1	1	1	3	27
Crested Bellbird					1		1										2
Dusky Woodswallow						2										2	4
Australian Magpie					4		5			3							12
Grey Currawong					3	1		2								2	8
Grey Fantail		1	1	1				2	2		2		1		1	1	12
Australian Raven								1		1				1			3
Satin Flycatcher			2														2
Restless Flycatcher					1			1				1					3
White-winged Chough				6		14		13		30							63

	Castlemaine Diggings				Paddys Ranges				Pilchers Bridge				Spring Plains				
Common name	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**Total**
Jacky Winter								2									2
Scarlet Robin	1	3	2	4					3		4	2	5	5	3	5	37
Flame Robin													1				1
Eastern Yellow Robin								1									1
Silvereye		3					3										6
Total	**20**	**22**	**21**	**56**	**79**	**140**	**162**	**112**	**55**	**93**	**90**	**59**	**53**	**58**	**54**	**53**	**1127**

Table 36. Bird species detected during diurnal bird surveys conducted at each Site during post-thinning surveys.

The total number of individuals observed for each species in each Plot is presented. Treatment: C = Control, I = Isolated, P1 = Patchy 1, P2 = Patchy 2

	Castlemaine Diggings				**Paddys Ranges**				**Pilchers Bridge**				**Spring Plains**				
Common name	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**Total**
Common Bronzewing				4				5					1				10
Peaceful Dove							1	1									2
Brown Goshawk																1	1
Brown Falcon															1		1
Galah					5	3	2	7	3	8	6	2					36
Little Corella						3											3
Sulphur-crested Cockatoo									12			1	1		8	2	24
Musk Lorikeet					4	4	19	3	4	4							38
Little Lorikeet					3												3
Crimson Rosella	2		10	6			2	1				2	1	2	20	10	56
Eastern Rosella							4	6			5						15
Red-rumped Parrot							5					1					6
Shining Bronze-Cuckoo		2												1			3
Pallid Cuckoo			1			1						1					3
Laughing Kookaburra		1						2									3
Sacred Kingfisher			1														1
White-throated Treecreeper	2	1	2	7					3	1	3	3	6	4	3	3	38
Brown Treecreeper						1		10			2	2					15
Superb Fairy-wren					2			3		16	12	10		5	11		59
Chestnut-rumped Heathwren										3	2	2					7
Weebill	1	12			23			5	11	13	5	7	3	7			87

Common name	Castlemaine Diggings				Paddys Ranges				Pilchers Bridge				Spring Plains				Total
	C	I	P1	P2	C	I	P1	P2	C	I	P1	P2	C	I	P1	P2	
Striated Thornbill	31	13	11	10					15	8	4	6	15	9	4	4	130
Yellow Thornbill										2							2
Chestnut-rumped Thornbill	1																1
Buff-rumped Thornbill	15	9	11	13	2				9	9	5	11	14	5	14	9	126
Brown Thornbill	2	1	1	5					2	2	1	4		3	5		26
Spotted Pardalote	6	8	8		4	1	1	2	10	5	1	1	2	4	5		58
Striated Pardalote					1			2				1	1		1		6
Yellow-faced Honeyeater	7	7	3	2					1		1				2		23
White-eared Honeyeater			2														2
Yellow-tufted Honeyeater					8	37	25	17									87
Fuscous Honeyeater	5	10						15	5	6	13	4		2			60
Red Wattlebird	2		2		9	24	8	9		16			1				71
Black-chinned Honeyeater						9	6	5									20
Brown-headed Honeyeater	3	2			8		4		4	5			5	1	1	1	34
White-naped Honeyeater	1	9															10
White-browed Babbler						1	2	2									5
Spotted Quail-thrush	1		2														3
Varied Sittella	1	3	5						3	3		2		4	2		23
Black-faced Cuckoo-shrike						3	1				1				1		6
Golden Whistler									3	2							5
Rufous Whistler	1	2	1	1	2			1			2	2	3		3	1	19
Grey Shrike-thrush	1	1			4	9	8	5	2	2	2	2	3		2		41
Crested Bellbird						2		3									5

	Castlemaine Diggings				**Paddys Ranges**				**Pilchers Bridge**				**Spring Plains**				
Common name	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**Total**
Olive-backed Oriole						1						1					2
Masked Woodswallow							4	21									25
White-browed Woodswallow							5				31				8		44
Dusky Woodswallow						7	4	4			1	1			1		18
Australian Magpie		2			2	1	3	1							2	11	22
Grey Currawong	1		2			1									2		6
Grey Fantail	1								7	3	1		6	5	2	1	26
Willie Wagtail								2		1							3
Australian Raven				1	6		1					3					11
White-winged Chough		16	4		8	10		10								16	64
Jacky Winter					1												1
Scarlet Robin	5	2	3	2					5	3		7	9	2		2	40
Hooded Robin					3												3
Rufous Songlark											1						1
Silvereye								2									2
Welcome Swallow							2										2
Mistletoebird	1				3												4
Total	**90**	**101**	**69**	**51**	**98**	**118**	**107**	**144**	**99**	**112**	**99**	**76**	**71**	**54**	**98**	**61**	**1448**

Before treatment, Castlemaine Diggings NHP had a relatively low bird species richness that increased substantially post-treatment (19 pre-thinning, 30 post-thinning). Paddys Ranges SP revealed a similar increase (32, 41), though species richness at both Spring Plains NCR (28, 29) and Pilchers Bridge NCR (32, 35) remained reasonably constant.

During the pre-treatment surveys the total number of species in Plots was similar across all Sites: Control (35 species); Isolated (36); Patchy 1 (35); Patchy 2 (36). Following thinning, species richness was greater in all thinning treatments than pre-thinning, while species richness in the Control Plot was similar (Figure 36); however, it should be noted that post-thinning surveys were carried out at a more optimum time of year for birds (i.e. spring/summer).

During pre-thinning surveys over 1100 birds were recorded, with almost half observed at Paddys Ranges SP, where many honeyeaters were present (Table 35). Overall, the most numerous species were: Buff-rumped Thornbill (102 records); Spotted Pardalote (98); Striated Pardalote (92); Yellow-tufted Honeyeater (86); White-winged Chough (63); and Red Wattlebird (63). All are highly mobile with either expansive home ranges or large-scale seasonal movements. The Spotted Pardalote was evenly spread across the Sites, while the other species were missing from one or more Sites; the Yellow-tufted Honeyeater, for example, occurred in large numbers, but only at Paddys Ranges SP.

The total number of birds recorded after thinning increased by about 30% across the Sites (Table 36). This increase in abundance was constant across all Plots, although it was more marked at Castlemaine Diggings NHP where numbers tripled, due mainly to an influx of small insectivorous birds.

The most numerous species in post-thinning surveys were: Striated Thornbill (130 records overall); Buff-rumped Thornbill (126); Yellow-tufted Honeyeater (87); Weebill (87); and Red Wattlebird (71). The Buff-rumped Thornbill, Weebill and Red Wattlebird were recorded in all Plots across all Sites. Again, the Yellow-tufted Honeyeater was only recorded at Paddys Ranges SP; the species displays aggressive behaviour to conspecifics and other birds, and its abundance at Paddys Ranges SP may explain the absence of most thornbill species there, though they occur in large numbers elsewhere.

The composition of diurnal-bird assemblages displayed clear within-Site differences between pre- and post-thinning surveys (Figure 37). Note that the pre- and post-thinning data may be confounded by the effect of season, and this ordination has been presented as an example to demonstrate a potential statistical approach for future examination of the composition of bird assemblages.

The relative separation of Sites in the ordination (Figure 37) showed that before thinning the composition of bird assemblages was similar across all Sites, but this differed in post-thinning surveys, with the greatest contrasts being at Castlemaine Diggings NHP and Pilchers Bridge NCR. Because Control Plots moved in the same direction as treated Plots (Figure 37), it seems likely that a seasonal effect was operating (i.e. bird assemblages were different due to seasonally-driven changes in species occurrence, independent of treatments).

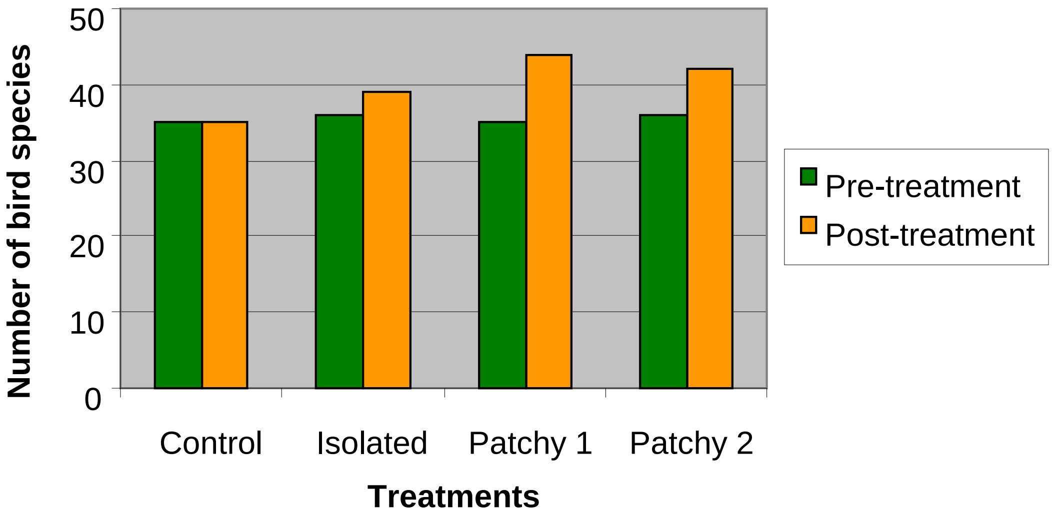

Figure 36. Number of diurnal bird species recorded in each Plot (all Sites combined), pre- and post-thinning operations.

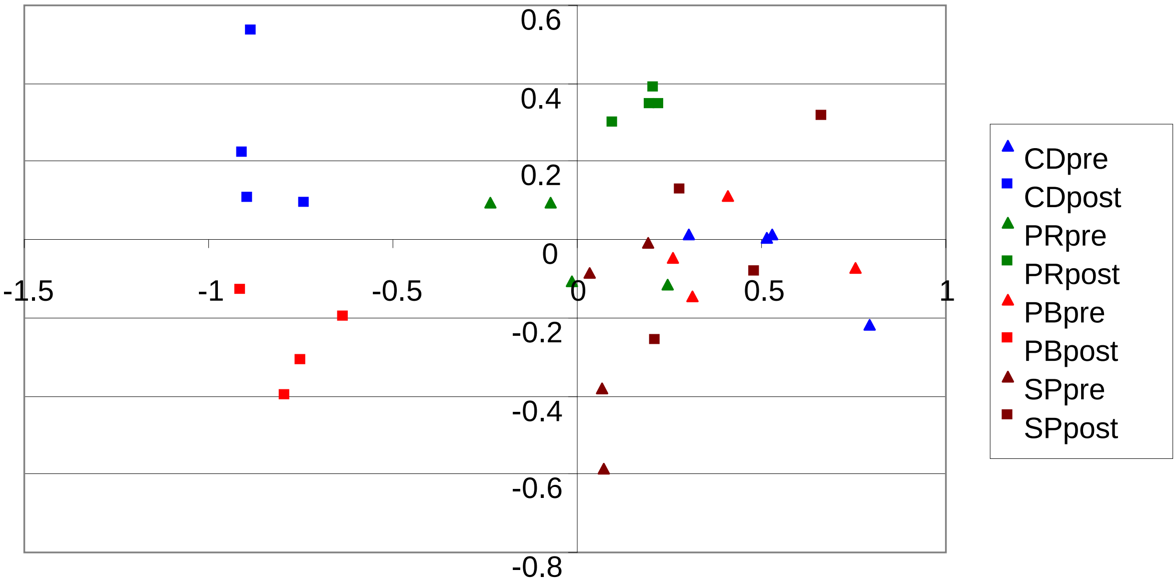

Figure 37. Two-dimensional NMDS ordination of diurnal bird data (presence-absence) for all Sites (all Plots combined), pre- and post-thinning.

Pre-thinning (triangles) and post-thinning (squares).

Site: CD = Castlemaine Diggings NHP, PR = Paddys Ranges SP, PB = Pilchers Bridge NCR, SP = Spring Plains NCR

3.4.1.2 Nocturnal Birds

Three bird species were recorded during the owl call-playback surveys, all in low numbers. Australian Owlet-nightjar (a single observation at Pilchers Bridge NCR) and Southern Boobook (single observation at Paddy Ranges SP and Spring Plains NCR) were recorded during pre-thinning surveys (Table 37). The only observations of these species after thinning were at Spring Plains NCR (Australian Owlet-nightjar, one record; Southern Boobook, three records). Another species, the Powerful Owl, was recorded at both Paddys Ranges SP and Pilchers Bridge NCR during post-thinning surveys (Table 38). There were no observations of any nocturnal birds at Castlemaine Diggings NHP during either pre- or post-thinning surveys.

Data from the owl call-playback sampling technique are limited, with few records obtained. Assigning them beyond the Site scale was difficult, as records could not be assigned to a thinning treatment with any accuracy because the home range of some species exceeds 1000 hectares (Higgins 1999; Soderquist & Gibbons 2007). The sparse results of this study are a consequence of the relative scarcity of these birds, their large home ranges, the spatial scale of the project, and the level of survey effort.

Table 37. Bird species detected during call-playback sessions conducted at each Site during pre-thinning surveys.

Site: CDNHP = Castlemaine Diggings NHP, PRSP = Paddys Ranges SP, PBNCR = Pilchers Bridge NCR, SPNCR = Spring Plains NCR
Treatment: Co = Control, Is = Isolated, P1 = Patchy 1, P2 = Patchy 2

	CDNHP				**PRSP**				**PBNCR**		**SPNCR**	
Species	**C**	**Is**	**P1**	**P2**	**C**	**Is**	**P1**	**P2**	**C**	**Is**	**Is**	**P2**
Australian Owlet-nightjar									1			
Powerful Owl												
Southern Boobook							1				1	
Total	0	0	0	0	0	0	1	0	1	0	1	0

Table 38. Bird species detected during call-playback sessions conducted at each Site during post-thinning surveys.

Abbreviations as for Table 35.

	CDNHP				**PRSP**				**PBNCR**				**SPNCR**			
Species	**C**	**Is**	**P1**	**P2**	**C**	**Is**	**P1**	**P2**	**C**	**Is**	**P1**	**P2**	**C**	**Is**	**P1**	**P2**
Australian Owlet-nightjar															1	
Powerful Owl						1				1						
Southern Boobook															3	
Total	0	0	0	0	0	1	0	0	0	1	0	0	0	0	4	0

The owls recorded during the survey, along with the Barking Owl, are resident in the Victorian Box–Ironbark region (Tzaros 2005) and depend on tree hollows for nesting. The Powerful Owl is considered vulnerable in Victoria and listed under the Victorian *Flora and Fauna Guarantee Act 1988* (DSE 2007).

3.4.2 Mammals

3.4.2.1 Terrestrial Mammals

Terrestrial mammal data (both pre- and post-thinning) from spotlight surveys and hair-tube surveys were combined for analysis by non-metric multi-dimensional scaling (NMDS) (Figure 38). This two-dimensional scatter plot confirms that each Site supported a specific complement of terrestrial mammal species, illustrated by a crude clustering on the ordination of pre- and post-thinning data, and that thinning operations appear to have had a discernible impact on this assemblage, though this is less apparent at Paddys Ranges SP.

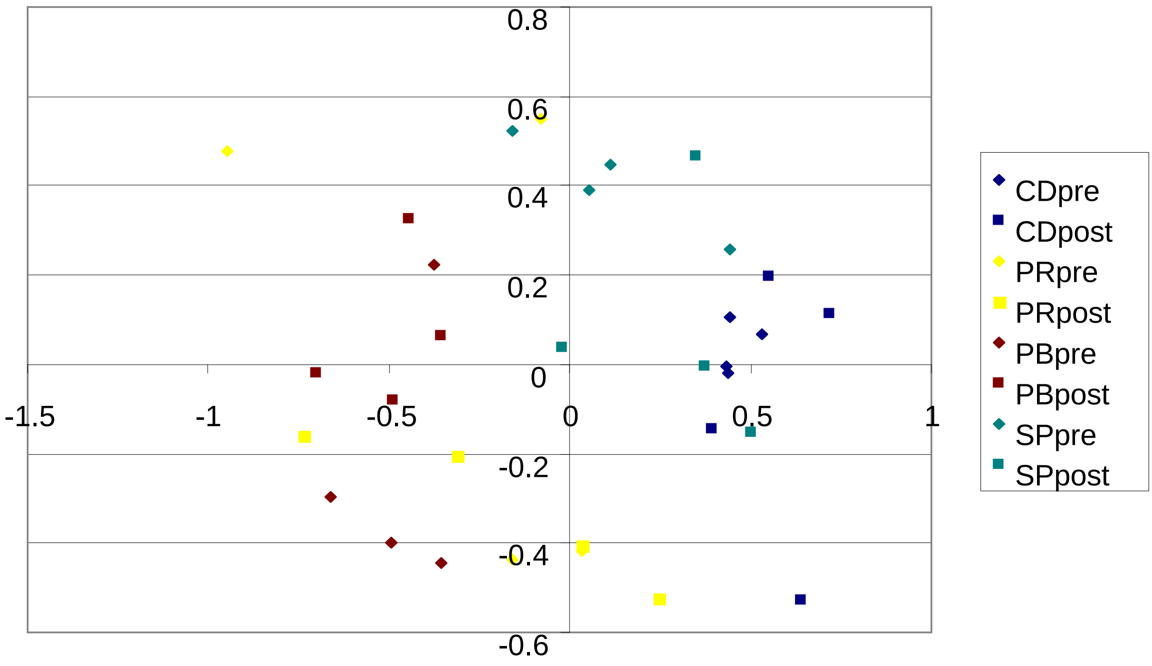

Figure 38. Two-dimensional NMDS ordination of terrestrial mammal data (presence–absence) for all Sites (all Plots and mammal-survey methods combined), pre- and post-thinning.

Pre-thinning (diamonds); post-thinning (squares).

Site: CD = Castlemaine Diggings NHP, PR = Paddys Ranges SP, PB = Pilchers Bridge NCR, SP = Spring Plains NCR

Table 39. Vertebrate taxa identified during spotlight transects at each Site and Plot during pre-thinning surveys.

Number of spotlight nights is given for each Plot.

Common Name	**Castlemaine Diggings NHP**				**Paddys Ranges SP**				**Pilchers Bridge NCR**				**Spring Plains NCR**			
	C	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**
Number of spotlight nights	5	4	5	4	5	5	6	7	12	5	9	6	3	5	3	6
Black Swan									1							
Common Bronzewing							3									
Australian Owlet-nightjar					1	1			1		2	2				
Fan-tailed Cuckoo								1								
Powerful Owl											1	2				
Southern Boobook				1					1							
Red Wattlebird							1	1								
White-winged Chough									1							
Short-beaked Echidna										1	1					
Common Brushtail Possum					1			1	6				1	2	1	2
Sugar Glider						1	1		1	1	2					
Common Ringtail Possum								2	3	8	1		3	1		2
Black Wallaby			1		2	1	1	2	2					1	1	
Unid. macropod			1													
White-striped Freetail Bat	1										1	2				
Unid. microbat									2							1
Red Fox*					1									1		
Total	**1**	**0**	**2**	**1**	**5**	**3**	**6**	**7**	**18**	**10**	**8**	**6**	**4**	**5**	**2**	**5**

* Introduced taxon

Table 40. Vertebrate taxa identified during spotlight transects at each Site and Plot during post-thinning surveys.

Number of spotlight nights is given for each Plot.

Common Name	**Castlemaine Diggings NHP**				**Paddy's Ranges SP**				**Pilchers Bridge NCR**				**Spring Plains NCR**			
	C	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**
No. of spotlight nights	4	6	6	3	6	5	5	6	11	14	8	4	8	4	5	9
Common Bronzewing					1											
Australian Owlet-nightjar								1	4	12						1
Sulphur-crested Cockatoo										4						
Powerful Owl									4	8						
Barking Owl									4							
Southern Boobook										8	4					
Red Wattlebird													1			
Spotted Quail-thrush						1										
Grey Currawong									4							
White-winged Chough			1			1		1								
Unid. bird								1								
Brush-tailed Phascogale				1												
Yellow-footed antechinus					1				4							
Unid. Antechinus										4						
Koala																1
Common Brushtail Possum				2							16					3
Sugar Glider					1											
Common Ringtail Possum									20	48	16	12				
Eastern Grey Kangaroo					1											
Black Wallaby	3		2	1	1		2	1	12	12	4	4	2	1	1	1

Common Name	**Castlemaine Diggings NHP**				**Paddy’s Ranges SP**				**Pilchers Bridge NCR**				**Spring Plains NCR**			
	C	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**
Unid. macropod						2						8	1			
White-striped Freetail Bat		2		1	2		2	4	12	8						2
Unid. microbat					1			1	4	8		4				5
Southern Bullfrog							1									
Plains Froglet									4							
Peron's Tree Frog								1	4							
Total	3	2	3	5	8	4	5	10	76	112	40	28	4	1	1	13

Table 41. Mammal taxa identified from the analysis of hair retrieved from hair-tubes (presented as number of hair-tubes) at each Site and Plot during pre-thinning surveys.

Results for both ground funnel-tubes and tree-tubes are combined; ‘probable’ records are not included.

Common name	**Castlemaine Diggings NHP**				**Paddys Ranges SP**				**Pilchers Bridge NCR**				**Spring Plains NCR**			
	C	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**
Unid. small dasyurid	2	5	4	4	3								1	2	6	1
Brush-tailed Phascogale	29	2	17	15									1		3	1
Yellow-footed Antechinus	8		1	14											3	
Unid. antechinus	2	2	8	11		5									2	
Unid. brushtail possum	1	5	4	5	2	2	5		3	2	4	1	12	7	15	15
Unid. glider			1	1											1	1
Black Wallaby	2	1	3	1	1	3	4	12	3	2	3	2	5	5	2	4
House Mouse*												1				
Black Rat*								1								
Unid. small rodent					1											
House Cat*								1		1		1				
Total	**44**	**15**	**38**	**51**	**7**	**10**	**9**	**14**	**6**	**5**	**7**	**5**	**19**	**14**	**32**	**22**

* Introduced

Table 42. Mammal taxa identified from the analysis of hair retrieved from hair-tubes (presented as number of hair-tubes) at each Site and Plot during post-thinning surveys.

Results for both ground funnel-tubes and tree-tubes are combined; ‘probable’ records are not included.

Common name	**Castlemaine Diggings NHP**				**Paddys Ranges SP**				**Pilchers Bridge NCR**				**Spring Plains NCR**			
	C	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**	**C**	**I**	**P1**	**P2**
Short-beaked Echidna													1			
Unidentified small dasyurid	3	1	5	3									4	2	3	4
Brush-tailed Phascogale	58	3	17	15									1		3	1
Yellow-footed Antechinus	4		4	7											2	
Agile Antechinus			3	5												
Unidentified antechinus	4		12	13	1	2							2		4	
Unid. brushtail possum	1		5	7	3	6	4	8	3	2	5	2	21	7	17	22
Sugar Glider	1	4		1	3	1									1	2
Squirrel Glider				1											1	1
Unidentified glider			1													
Black Wallaby	4	7	6	4	2	6	5	13	3	2	3	10	15	5	9	12
Unidentified macropod	1				1											
House Mouse*		11										1				
Black Rat*								1								
Unidentified rat*			1													
Unidentified small rodent		1			2											
House Cat*								1		1		1				
Total	**76**	**27**	**54**	**56**	**12**	**15**	**9**	**23**	**6**	**5**	**8**	**14**	**44**	**14**	**40**	**42**

* Introduced taxon

3.4.2.2 Arboreal Mammals

Arboreal mammals form a distinctive component of the Box–Ironbark mammal assemblage (ECC 1997; Tzaros 2005). Typical species include Common Brushtail Possum, Sugar Glider, Squirrel Glider and Common Ringtail Possum, as well Brush-tailed Phascogale, which forages extensively at ground level. Most of these species are hollow-dependent, and are therefore restricted to areas supporting suitable hollow-bearing trees (ECC 1997). The Box–Ironbark region is critically important for two of these species in Victoria: Brush-tailed Phascogale and Squirrel Glider (ECC 1997; Menkhorst 1995; Tzaros 2005), both of which are considered threatened in Victoria, being vulnerable and endangered, respectively, and listed under the Victorian *Flora and Fauna Guarantee Act 1988* (DSE 2007).

Five species of arboreal mammals were recorded during spotlight and hair-tube surveys: Common Brushtail Possum (all Sites); Common Ringtail Possum (Pilchers Bridge NCR, Paddys Ranges SP, Spring Plains NCR); Sugar Glider (Pilchers Bridge NCR, Paddys Ranges SP), Squirrel Glider (Castlemaine Diggings NHP, Spring Plains NCR) and Brush-tailed Phascogale (Castlemaine Diggings NHP, Spring Plains NCR).

The Common Brushtail Possum was recorded in seven Plots across three Sites in pre-thinning spotlight surveys (Table 39). Post- thinning, this species was recorded during spotlight surveys in a single Plot at each of the three Sites where it occurred pre-thinning; each of these Plots had been thinned (Table 40). The Common Brushtail Possum was the most commonly recorded species during hair-tube surveys, and was recorded across most Plots and Sites during pre- and post-thinning hair-tube surveys (Table 41, 40).

Low numbers of Common Ringtail Possum were recorded at three Sites before thinning (Pilchers Bridge NCR [3 Plots], Spring Plains NCR [3], and Paddys Ranges SP [1]). After thinning, the Common Ringtail Possum was recorded only at Pilchers Bridge NCR, but in relatively high numbers in all Plots during spotlight surveys.

The Sugar Glider was recorded at two Sites during spotlight surveys. Pre-thinning, the species was recorded in the Control, Isolated and Patchy1 Plots at Pilchers Bridge NCR, and in the Isolated and Patchy 1 Plots at Paddys Ranges SP (Table 39). After thinning, it was recorded once, during spotlight surveys in the Control Plot at Paddys Ranges SP. Sugar Gliders were recorded at three Sites during post-thinning hair-tube surveys: in three Plots at Castlemaine Diggings NHP (Control, Isolated and Patchy 2), two Plots at Paddys Ranges SP (Control and Isolated) and two Plots at Spring Plains NCR (Patchy 1 and Patchy 2). Hair from an unidentified *Petaurus* was recorded during hair-tube surveys at Castlemaine Diggings NHP (Patchy 1 and Patchy 2 Plots) and Spring Plains NCR (Patchy 1 and Patchy 2 Plots) before thinning and only in Patchy 1 Plot at Castlemaine Diggings NHP after thinning (Table 41, 40). These hair samples could not be positively identified beyond genus level and could represent either Sugar Glider or Squirrel Glider.

The Squirrel Glider was recorded in single hair samples at Castlemaine Diggings NHP (Patchy 2) and Spring Plains NCR (Patchy 1 and Patchy 2 Plots) in post-thinning hair-tube surveys (Table 42).

There were many records of Brush-tailed Phascogale in all Plots at Castlemaine Diggings NHP during pre- and post-thinning hair-tube surveys, and the number of hits was particularly high in the Control Plot (Table 41, 40). The species was also recorded at Spring Plains NCR during hair-tube surveys, with equal numbers of records from Control, Patchy 1 and Patchy 2 Plots during both pre- and post-thinning surveys. The number of hits at Spring Plains NCR was much lower than at Castlemaine Diggings NHP (Table 41, 40). The Box–Ironbark region supports a large proportion of the Victorian population of this species, with preferred habitats consisting of abundant hollow trees, stumps and fallen timber (Tzaros 2005).

The Koala was recorded once in Patchy 2 Plot at Spring Plains NCR after thinning (Table 40).

3.4.2.3 Terrestrial Mammals

The surviving ground-dwelling mammal assemblage in Box–Ironbark forest is typically sparser than assemblages in other eucalypt forests (e.g. coastal eucalypt forest) and is dominated by common and widespread species, such as Short-beaked Echidna, Black Wallaby and Eastern Grey Kangaroo. The Yellow-footed Antechinus, which forages among coarse woody debris and also over tree surfaces, is widespread but scattered in the Box–Ironbark region, the stronghold of this species in Victoria (Tzaros 2005). Other native species, including Agile Antechinus, Common Wombat *Vombatus ursinus* and Fat-tailed Dunnart *Sminthopsis crassicaudata*, have restricted distributions, mostly near the margins of the region (Menkhorst 1995; Tzaros 2005).

At least nine species of ground-dwelling mammals were recorded during hair-tube and spotlighting surveys. Native species included Black Wallaby (all Sites), Yellow-footed Antechinus (all Sites), Eastern Grey Kangaroo (Castlemaine Diggings NHP) and Short-beaked Echidna (Pilchers Bridge NCR, Spring Plains NCR). Four of the ground mammals recorded were introduced species: House Mouse (Pilchers Bridge NCR, Castlemaine Diggings NHP); Black Rat (Paddys Ranges SP); House Cat (Paddys Ranges SP, Pilchers Bridge NCR); and Red Fox (Paddys Ranges SP, Spring Plains NCR). None of the introduced species was recorded in sufficient numbers to elucidate patterns in their distribution.

The Black Wallaby is widespread and common throughout the Box–Ironbark region (Tzaros 2005), and was recorded in all Plots and at all Sites during pre- and post-thinning surveys (Table 39–40). It was the most commonly encountered ground mammal during spotlight surveys and was recorded in all Plots during pre- and post-thinning hair-tube surveys. Another macropod, the Eastern Grey Kangaroo, was recorded once during the post-thinning spotlight survey at Paddys Ranges SP Control Plot (Table 40).

Records of Yellow-footed Antechinus, a widespread species in the Box–Ironbark region (Tzaros 2005), were collected in the same Plots during pre- and post-thinning hair-tube surveys. There was also a small number of records in Control Plots at Paddys Ranges SP (one record) and Pilchers Bridge NCR (four records) during post-thinning spotlight surveys (Table 40). Another *Antechinus* species, the Agile Antechinus, was recorded only at Castlemaine Diggings NHP (Patchy 1 and Patchy 2) and only during post-thinning surveys (Table 42). This species is at the northern limit of its range in central Victoria and is not typically associated with Box–Ironbark forests (Menkhorst 1995). Samples of hair that could not be identified to species level included ‘unidentified *Antechinus*’ and ‘unidentified dasyurid’. These are likely to be either Yellow-footed Antechinus (most likely) or Agile Antechinus, although another dasyurid, the Common Dunnart *Sminthopsis murina*, possibly occurs in the region, though it is rare in Box–Ironbark forests (Tzaros 2005).

The Short-beaked Echidna was recorded on a few occasions, with a single record from Spring Plains NCR (Control) during the post-thinning hair-tube survey (Table 42), and single records from Isolated and Patchy 1 Plots at Pilchers Bridge NCR during spotlight surveys.

3.4.2.4 Bats

Bats form the largest group within the Box–Ironbark forest mammal assemblage. Thirteen species of small insectivorous bats are known to occur in the Box–Ironbark region, and most have widespread distributions (ECC 1997; Tzaros 2005). Bats are highly mobile and can use separate areas to forage and roost. They require tree hollows, crevices or decorticating bark for roost sites. Insectivorous bats (micro-bats) are likely to be medium- to long-term indicators (relative levels of activity provided by the recording-rate of calls) of thinning practice and changes to various forest-age-related characteristics (e.g. size of trees and availability of tree-hollows), though potential short-term impacts on activity, due to altered forest structure and prey availability, may also be apparent.

At least 11 taxa of bats were identified during bat echolocation surveys (Table 43, 42). At least 10 species were recorded during pre-thinning surveys, a small number of which dominated the results; the Little Forest Bat dominated (40%) overall records, mostly at Paddys Ranges SP and Spring Plains NCR (Table 43). Other common taxa during pre-thinning surveys were Southern Freetail Bat (long-penis form) and long-eared bats. In pre-thinning surveys, most call records (50%) were collected at Spring Plains NCR, though this Site was subject to greater survey effort; Paddys Ranges SP yielded 32% of overall call records despite fewer detector-nights (Table 7).

Post-thinning surveys yielded greater numbers of calls overall, although greater survey effort was dedicated to these surveys (128 post-thinning detector-nights versus 81 pre-thinning). Nevertheless, the number of identifiable calls per detector-night was substantially greater at every Site and for the study overall during post-thinning surveys than it was for pre-thinning surveys (overall: 28.9 per detector-night post-thinning versus 7.7 pre-thinning). Post-thinning surveys were dominated by several species: Little Forest Bat (48.7% of all calls); Southern Freetail Bat (long-penis form) (13.6%); and Chocolate Wattled Bat (9.7%) (Table 44).

The incidence of different bat taxa varied across Sites and Plots, with some taxa apparently quite localised. During pre-thinning surveys, the White-striped Freetail Bat was detected mainly at Paddys Ranges SP, and long-eared bats at Spring Plains NCR (Table 43). While no taxa was exclusively recorded at any Site during post-thinning surveys, some, such as Chocolate Wattled Bat, Southern Freetail Bat and White-striped Freetail Bat, were more commonly recorded at some Sites (Table 44).

All of the insectivorous bat species recorded have broad distributions, and are known residents of south-eastern Australian woodlands (Menkhorst & Knight 2004; Tzaros 2005; Churchill 2008), with some, such as Southern Forest Bat and Little Forest Bat, often occurring in large numbers. All of these species utilise tree hollows, either as diurnal roosts or for maternity colonies (Gibbons & Lindenmayer 2002; Menkhorst & Knight 2004; Tzaros 2005; Churchill 2008).

Table 43. Number of calls per bat species recorded in Plots at each Site during pre-thinning surveys.

Note that there were no effective detector-nights in Patchy 1 and Patchy 2 Plots at Paddys Ranges SP.

Species complexes exist where the calls of some species could not be differentiated. HF = high frequency, LF = low frequency

Site	**Plot**	**No. of detector-nights**	***Chalinolobus gouldii***	***Chalinolobus gouldii/Scotorepens balstoni***	***Chalinolobus gouldii/Mormopterus* sp. (lp)**	***Chalinolobus morio***	***Chalinolobus morio/Vespadelus regulus* (LF)**	***Mormopterus* sp.(lp)**	***Myotis macropus***	***Myotis macropus/Nyctophilus gouldi/Nyctophilus geoffroyi***	***Nyctophilus geoffroyi/N. gouldi***	***Nyctophilus gouldi/Vespadelus regulus* (LF)**	***Scotorepens balstoni***	***Tadarida australis***	***Vespadelus darlingtoni***	***Vespadelus regulus* (HF)**	***Vespadelus regulus* (LF)**	***Vespadelus vulturnus***	***Vespadelus darlingtoni/Vespadelus regulus* (LF)**	**Total files**	**Tot ID**	**% ID**
Castlemaine Diggings NHP	Control	4	0	0	0	0	0	0	1	0	6	0	0	1	0	0	0	4	0	149	12	8.1
	Isolated	4	0	0	0	1	0	1	0	0	3	0	0	1	0	1	0	1	0	82	7	8.5
	Patchy 1	4	1	0	0	0	0	2	0	0	4	0	0	1	0	0	0	3	0	65	11	16.9
	Patchy 2	4	0	0	0	0	0	0	1	0	9	1	0	1	0	0	0	8	0	314	20	6.4
Paddys Ranges SP	Control	6	0	0	1	5	0	13	0	4	1	0	0	17	5	0	3	29	1	583	79	13.6

Site	**Plot**	**No. of detector-nights**	***Chalinolobus gouldii***	***Chalinolobus gouldii/Scotorepens balstoni***	***Chalinolobus gouldii/Mormopterus* sp. (lp)**	***Chalinolobus morio***	***Chalinolobus morio/Vespadelus regulus* (LF)**	***Mormopterus* sp.(lp)**	***Myotis macropus***	***Myotis macropus/Nyctophilus gouldi/Nyctophilus geoffroyi***	***Nyctophilus geoffroyi/N. gouldi***	***Nyctophilus gouldi/Vespadelus regulus* (LF)**	***Scotorepens balstoni***	***Tadarida australis***	***Vespadelus darlingtoni***	***Vespadelus regulus* (HF)**	***Vespadelus regulus* (LF)**	***Vespadelus vulturnus***	***Vespadelus darlingtoni/Vespadelus regulus* (LF)**	**Total files**	**Tot ID**	**% ID**
	Isolated	6	1	0	2	12	0	6	0	0	0	0	0	13	4	2	4	32	4	511	80	15.7
	Patchy 1	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
	Patchy 2	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	-
Pilchers Bridge NCR	Control	5	0	0	0	0	0	0	0	0	0	0	0	0	0	1	0	1	0	39	2	5.1
	Isolated	4	0	0	0	0	0	0	1	0	1	2	0	0	0	8	0	3	4	193	19	9.8
	Patchy 1	5	0	0	0	0	0	0	1	1	2	0	0	0	0	0	1	10	0	247	15	6.1
	Patchy 2	5	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	0	15	0	0.0
Spring Plains NCR	Control	9	2	1	2	5	1	25	2	1	19	0	1	8	3	5	1	30	2	808	108	13.4
	Isolated	3	0	0	0	2	0	0	0	0	1	0	0	0	0	3	0	9	0	107	15	14.0
	Patchy 1	6	0	0	0	0	0	0	0	1	1	0	0	0	0	7	0	38	0	288	59	20.5

Site	**Plot**	**No. of detector-nights**	***Chalinolobus gouldii***	***Chalinolobus gouldii/Scotorepens balstoni***	***Chalinolobus gouldii/Mormopterus* sp. (lp)**	***Chalinolobus morio***	***Chalinolobus morio/Vespadelus regulus* (LF)**	***Mormopterus* sp.(lp)**	***Myotis macropus***	***Myotis macropus/Nyctophilus gouldi/Nyctophilus geoffroyi***	***Nyctophilus geoffroyi/N. gouldi***	***Nyctophilus gouldi/Vespadelus regulus* (LF)**	***Scotorepens balstoni***	***Tadarida australis***	***Vespadelus darlingtoni***	***Vespadelus regulus* (HF)**	***Vespadelus regulus* (LF)**	***Vespadelus vulturnus***	***Vespadelus darlingtoni/Vespadelus regulus* (LF)**	**Total files**	**Tot ID**	**% ID**
											3											
	Patchy 2	6	0	0	0	0	0	3	2	0	17	0	0	0	0	8	2	30	2	557	63	11.3
Total		71	4	1	5	25	1	50	8	7	76	3	1	42	12	35	11	198	13	3958	490	12.4

Table 44. Number of calls per bat species in Plots at each Site during post-thinning surveys.

Species complexes exist where the calls of some species could not be differentiated. lp= long penis, HF = high frequency, LF = low frequency

Site	**Plot**	**No. of detector-nights**	***Chalinolobus gouldii***	***Chalinolobus gouldii/Scotorepens balstoni***	***Chalinolobus gouldii/Mormopterus* (lp)**	***Chalinolobus morio***	***Mormopterus* sp.(lp)**	***Myotis macropus***	***Myotis macropus/Nyctophilus gouldi/Nyctophilus geoffroyi***	***Nyctophilus geoffroyi/N. gouldi***	***Nyctophilus gouldi/Vespadelus regulus* (LF)**	***Saccolaimus flaviventris***	***Scotorepens balstoni***	***Tadarida australis***	***Vespadelus darlingtoni***	***Vespadelus regulus* (HF)**	***Vespadelus regulus* (LF)**	***Vespadelus vulturnus***	***Vespadelus darlingtoni/Vespadelus regulus* (LF)**	**Total files**	**Tot ID**	**% ID**
Castlemaine Diggings NHP	C	7	0	0	0	6	1	0	0	12	0	0	0	0	7	15	3	55	11	570	110	19.3
	I	8	0	0	0	2	6	0	0	4	0	0	0	2	0	3	0	3	0	156	20	12.8
	P1	9	2	0	0	22	24	3	1	20	0	1	0	1	7	1	15	201	21	1720	319	18.6
	P2	9	0	0	0	8	11	2	1	32	0	0	0	3	7	2	12	108	10	1744	196	11.2
Paddys Ranges SP	C	6	2	0	0	9	23	1	0	3	1	1	0	24	1	8	4	51	6	651	102	15.7
	I	5	1	0	0	7	15	0	1	1	0	0	1	10	3	2	1	22	2	284	37	13.0
	P1	10	14	1	2	41	113	0	1	6	0	1	1	119	11	45	7	86	5	1663	453	27.2

Site	**Plot**	**No. of detector-nights**	***Chalinolobus gouldii***	***Chalinolobus gouldii/Scotorepens balstoni***	***Chalinolobus gouldii/Mormopterus* (lp)**	***Chalinolobus morio***	***Mormopterus* sp.(lp)**	***Myotis macropus***	***Myotis macropus/Nyctophilus gouldi/Nyctophilus geoffroyi***	***Nyctophilus geoffroyi/N. gouldi***	***Nyctophilus gouldi/Vespadelus regulus* (LF)**	***Saccolaimus flaviventris***	***Scotorepens balstoni***	***Tadarida australis***	***Vespadelus darlingtoni***	***Vespadelus regulus* (HF)**	***Vespadelus regulus* (LF)**	***Vespadelus vulturnus***	***Vespadelus darlingtoni/Vespadelus regulus* (LF)**	**Total files**	**Tot ID**	**% ID**
	P2	6	8	0	2	8	39	0	0	3	0	0	0	37	0	15	4	36	1	510	153	30.0
Pilchers Bridge NCR	C	9	3	0	0	46	12	1	3	33	3	0	0	8	15	73	11	125	26	2200	359	16.3
	I	10	6	1	1	28	59	4	1	21	2	2	1	30	17	52	15	167	26	2152	433	20.1
	P1	11	3	1	1	94	45	0	2	4	2	0	0	20	23	31	30	181	37	2261	474	21.1
	P2	10	1	0	1	16	53	0	1	5	0	2	1	47	0	25	5	82	2	1045	241	23.1
Spring Plains NCR	C	8	2	0	0	6	10	2	6	22	0	0	0	3	1	10	0	31	1	810	94	11.6
	I	7	0	0	0	27	10	0	2	9	1	0	0	1	3	13	9	101	18	1447	194	13.4
	P1	7	4	4	1	13	48	1	1	19	0	1	1	4	2	1	10	125	8	1055	243	23.0

Site	**Plot**	**No. of detector-nights**	***Chalinolobus gouldii***	***Chalinolobus gouldii/Scotorepens balstoni***	***Chalinolobus gouldii/Mormopterus* (lp)**	***Chalinolobus morio***	***Mormopterus* sp.(lp)**	***Myotis macropus***	***Myotis macropus/Nyctophilus gouldi/Nyctophilus geoffroyi***	***Nyctophilus geoffroyi/N. gouldi***	***Nyctophilus gouldi/Vespadelus regulus* (LF)**	***Saccolaimus flaviventris***	***Scotorepens balstoni***	***Tadarida australis***	***Vespadelus darlingtoni***	***Vespadelus regulus* (HF)**	***Vespadelus regulus* (LF)**	***Vespadelus vulturnus***	***Vespadelus darlingtoni/Vespadelus regulus* (LF)**	**Total files**	**Tot ID**	**% ID**
	P2	7	0	0	1	19	23	1	0	17	0	0	0	1	10	6	10	100	8	1647	196	11.9
Total		129	46	7	9	352	492	15	20	211	9	8	5	310	107	302	136	1474	182	19915	3624	18.2

3.4.3 Threatened Species

Predictably, most of the vertebrate species recorded during surveys are widespread and common in the Box–Ironbark forests and woodlands of Victoria (Tzaros 2005; DSE Atlas of Victorian Wildlife database). However, several are considered threatened in Victoria, and some are listed (L) under the Victorian *Flora and Fauna Guarantee Act 1988* (DSE 2007). These species include two marsupials, one bat, and nine birds:

Swift Parrot*	Endangered	L
Powerful Owl	Vulnerable	L
Barking Owl	Endangered	L
Brown Treecreeper	Near Threatened	
Chestnut-rumped Heathwren	Vulnerable	L
Black-chinned Honeyeater	Near Threatened	
Spotted Quail-thrush	Near Threatened	
Crested Bellbird	Near Threatened	L
Hooded Robin	Near Threatened	L
Brush-tailed Phascogale	Vulnerable	L
Squirrel Glider	Endangered	L
Southern Myotis	Near Threatened	

*The Swift Parrot is also listed as Endangered under the Commonwealth *Environment Protection and Biodiversity Act 1999*.

3.4.4 Herpetofauna (Reptiles and Amphibians)

The Box–Ironbark ecosystem supports a diverse herpetofauna, including 41 reptile species and 15 frogs (Tzaros 2005). Habitat loss and simplification of ground-layer are believed to have greatly reduced the suitability of Box–Ironbark forests as habitat for reptiles and amphibians in the region (Brown 2001; Tzaros 2005). Brown (2001) considered that the creation or increase of structural heterogeneity in ground-layers as important if reptile assemblages were to be conserved effectively.

Herpetofauna was not specifically targeted for monitoring during Phase 1 of the Trial. However, records of reptiles at a number of the Sites and Plots were obtained from an independent University of Ballarat BAppSc Honours project conducted at some Sites following thinning during summer 2007–08 (Olsen 2010). The Honours project was not designed to test the effects of thinning treatments on reptiles, but its use of the same Sites and Plots allows some associations to be made. There were also several incidental herpetofauna records collected during the Phase 1 field surveys.

The independent terrestrial-reptile project used pitfall trapping lines (five 20-l pits along a 20-m line) to sample the reptile assemblages occurring in the Control, Isolated and Patchy1 Plots at Castlemaine Diggings NHP, Pilchers Bridge NCR and Spring Plains NCR. It recorded seven species of reptiles: Garden Skink *Lampropholis guichenoti*; Bougainville's Skink *Lerista bougainvillii*; Large Striped Skink *Ctenotus robustus*; Eastern Three-lined Skink

Bassiana duperreyi; Tree Dragon *Amphibolurus muricatus*; Tree Goanna *Varanus varius*; and Gray's Blind Snake *Rhamphotyphlops nigrescens*. Three of these species were recorded across all Sites and in most Plots: Garden Skink; Bougainville's Skink; and Tree Dragon.

The Garden Skink was the most commonly recorded species (n = 91). This skink, recorded in all Plots except the Control Plot at Pilchers Bridge NCR, usually inhabits leaf litter and ground debris, and occurs in a wide range of habitat types, including forests, grasslands and gardens (Swan, Shea & Sadlier 2004).

Bougainville's Skink was recorded at all Sites and in most Plots, though in small numbers. The species is typically fossorial, and partially terrestrial when foraging, where it feeds among leaf litter (Tzaros 2005).

The Tree Dragon was observed at all Sites and in most Plots. It was not recorded in two of the three Control Plots (Castlemaine Diggings NHP, Pilchers Bridge NCR), despite occurring in thinned Plots at these Sites. The species is semi-arboreal and often perches on elevated substrates, such as coarse woody debris, to search for prey. It is most active during warm periods and basks extensively (Tzaros 2005).

The other four species of reptiles were recorded in low numbers, and in single Plots, during the survey. The Large Striped Skink was recorded four times in the Isolated Plot at Spring Plains NCR; the Eastern Three-lined Skink was recorded twice in the Isolated Plot at Castlemaine Diggings NHP; and the Gray's Blind Snake and Tree Goanna were each recorded once in the Isolated Plot at Pilchers Bridge NCR.

Other herpetofauna recorded incidentally during the Trial included the Red-bellied Black Snake *Pseudechis porphyriacus* (a single Snake was observed in the Patchy 2 Plot at Pilchers Bridge NCR post thinning; G. Palmer pers. obs.) and three species of frogs (Southern Bullfrog; Plains Froglet; and Peron's Tree Frog) were recorded during spotlight surveys.

3.4.5 Data Summary

Differences in the occurrence of vertebrates between pre- and post-thinning surveys were attributed to the effects of thinning or disturbance associated with thinning operations and, for diurnal birds, seasonal fluctuations. For bats, differences in survey effort and timing of surveys during pre- and post-thinning surveys probably affected the results. It is too early to confirm the effects of thinning on the vertebrate fauna, and insufficient data for most vertebrate groups means that even general trends cannot be identified yet. The speculated trajectories of vertebrates after thinning are discussed below (see *Projected Changes in Box–Ironbark Ecosystems Following Ecological Thinning*). It is expected that some vertebrates, including aerial-feeding and ground-foraging birds, terrestrial marsupials (e.g. *Antechinus*), macropods and some insectivorous bats, will respond positively at least in the short- to mid-term following thinning. This would be due to more open tree and canopy cover, increased loads of coarse woody debris, increased abundance of ground-level vegetation (especially perennial and annual grass cover) and a more open canopy structure, respectively. Other fauna, such as arboreal marsupials and most owls, will probably not respond positively for several years, until some requisite forest habitat attributes, particularly tree hollows, are more common.

It is useful to acknowledge the limitations of the existing data, so that these can be addressed in future surveys. These limitations include: timing and seasonality of surveys; variability in survey effort for some techniques; replication (especially of surveys of Sub-plots with different levels of coarse woody debris); and the collection of ‘presence’ data for some survey techniques (e.g. hair-tube surveys, bat-call detection). The considerable environmental variation between Sites, most notably in the contrast between Paddys Ranges SP and the other three Sites, also affected vertebrate occurrence.

The extent and quality of the data varied by survey technique and scale, such that some data were inadequate for analysis beyond descriptive statistics (e.g. owl-call playback) and some data had to be pooled (e.g. hair-tube data) in order to explore potential trends. The most complete fauna dataset is provided by diurnal birds — a census taken in every Sub-plot in every Plot at every Site before and after thinning operations. Data for other target vertebrate fauna were generally collected using the Plot as the sampling unit (i.e. not every Sub-plot was sampled). Even where records of some groups are lacking (and sophisticated analyses are not possible), existing records nevertheless provide a measure of ‘presence’; this data may prove useful in future analyses, especially if an ‘occupancy’ modelling approach is adopted (MacKenzie & Royle 2005).

The levels of sampling intensity for pre-thinning surveys have limitations, even when sampling at the Plot level. Much of the pre-thinning baseline data was not collected in spring–early summer, which is the optimum time to record most vertebrate taxa because of increased levels of activity due to migration, breeding or foraging. It is important to collect as much data as possible for both flora and fauna at a suitable time of year and standardise this for future surveys, despite the differences in the post-thinning interval for some Sites. The initial post-thinning data-set is arguably more important for analysis and interpretation than the pre-thinning data-set (especially since, in this Trial, the pre-thinning data were collected across several seasons). The effects of the imposed treatments on the flora and fauna are unlikely to become apparent for several years, and little will be able to be read into the immediate post-thinning data (probably not until medium- and long-term data are available).

3.5 Ecosystem Function: Invertebrate Indicators

The invertebrate indicators project investigated the effects of the different thinning treatments on the abundance and assemblage composition of invertebrates in the Box–Ironbark ecosystem. Although some invertebrates may respond rapidly to changes brought about by thinning treatments, response periods most invertebrates are likely to be 5–10 years or longer. However, there is a need to document the invertebrates present before thinning to provide benchmark data in such a way that the effects of thinning on species abundance and dynamics may be examined in the future.

The pre-thinning surveys gathered data to examine the effects that various thinning treatments have on invertebrate faunal composition and abundance over time. They also determined the methods and sampling strategy to collect pre-thinning data. Ideally, the effects of thinning would be examined using pre-and post-thinning comparisons of data collected using the same sampling regime. However, seasonal and operational constraints associated with the timing of thinning meant that the value of comparison of pre-and post-thinning data may be limited.

Data collected during this project will form the baseline data of an on-going monitoring program.

3.5.1 Ordinal Composition

A total of 26 invertebrate orders were recorded in the pitfall surveys. The number of orders recorded at each Site was similar: pre-thinning: 22 at Castlemaine Diggings NHP, Paddys Ranges SP and Spring Plains NCR Plots and 23 at Pilchers Bridge NCR; post thinning: 22 at Castlemaine Diggings NHP and Pilchers Bridge NCR, 23 at Spring Plains NCR and 24 at Paddys Ranges SP (Table 45, 44).

Six orders dominated the pitfall-trap samples: Hymenoptera (mainly ants); springtails (Collembola); mites (Acarina); spiders (Araneae); beetles (Coleoptera); and flies (Diptera). Occasionally one of the other orders dominated a particular Plot: booklice (Psocoptera); bugs (Hemiptera); wasps (non-ant Hymenoptera); silverfish (Thysanura); and millipedes (Diplopoda).

A total of 86,471 invertebrates was collected in the pitfall traps. This was divided into 35,084 in the pre-thinning samples and 51,387 post thinning. The greater number of invertebrates in the post-thinning samples could be due to undertaking the samples during warmer seasons, or increased invertebrate activity due to thinning through disruption of their microhabitats, or both.

There is considerable debate about the use of pitfall trapping as a general survey method for ground-dwelling invertebrates. Pitfall-trap catches reflect invertebrate activity on the ground (Neville & Yen 2007), but they can also collect invertebrates, such as flying insects, that are not usually active on the ground. For example, large numbers of flies (Diptera) can be attracted to pitfall traps; similarly, earthworms, usually subterranean, can also be collected in pitfall traps.

Of the 26 invertebrate orders collected, some caution is required in interpreting results involving flies (Diptera), mites (Acarina) and springtails (Collembola); Diptera, for reasons outlined, and mites because the catches probably do not realistically represent true numbers occurring in the soil and litter. Collembola (or springtails) dominated some Plots: pre-thinning: Castlemaine Diggings NHP Patchy 1, Paddys Ranges SP Control and Isolated, Pilchers Bridge NCR Patchy 1; post thinning: Paddys Ranges Patchy 1 and Patchy 2, Pilchers Bridge NCR Patchy 2 and Spring Plains NCR Patchy 1 (Table 45, 44). However, Collembola activity is influenced by weather conditions, and they dominated samples taken during cooler seasons or after rainfall. Samples taken in dry conditions have few or no Collembola, which does not provide a true reflection of the abundance of Collembolan fauna.

If Collembola are excluded, ants were the most dominant group. The relative composition of ants in the pre-thinning samples ranged from 18.27–91.23%. In pre-thinning surveys, apart from Paddys Ranges Control (30.82%), Pilchers Bridge NCR Control (18.27%) and Patchy 1 Plots (27.46%), ants comprised >59% of the invertebrate fauna in all Plots. In post-thinning samples, ants were dominant at all Sites with a range of 69.4–87.72% (Table 45 and Table 46).

It is useful to consider the invertebrates in order of ordinal dominance (pre- and post-thinning) (Table 47and Table 48). If earthworms, mites, springtails and flies (indicated in italics) are not considered in the order of dominance, then three groups dominate the pitfall traps in both pre- and post-thinning traps: ants, spiders and beetles.

Table 45. Ordinal composition of invertebrates collected in Plots pre-thinning.

Site	**Plot**	**No. orders**	**No. ind.**	**No. Collembola**	**No. ind. without Collembola**	**No. ants**	**% ants**
Castlemaine	C	19	1256	32	1224	816	66.67
Diggings	I	18	1818	24	1794	1149	64.05
NHP	P1	13	4679	3347	1332	1065	79.95
	P2	16	1916	673	1243	1011	81.34
	Total	**22**					
Paddys	C	14	4167	3411	756	233	30.82
Ranges	I	13	2262	1393	869	470	54.09
SP	P1	13	2716	36	2680	2445	91.23
	P2	18	4360	61	4299	3114	72.44
	Total	**22**					
Pilchers	C	15	608	77	531	97	18.27
Bridge	I	16	1197	51	1146	677	59.08
NCR	P1	13	1908	535	1373	377	27.46
	P2	16	1730	171	1559	1049	67.29
	Total	**23**					
Spring	C	15	1827	202	1625	1307	80.43
Plains	I	12	1486	224	1262	982	77.81
NCR	P1	19	1849	299	1550	1200	77.42
	P2	16	1305	132	1173	838	71.44
	Total	**22**					
Total pre-thinning			**35084**	**10668**	**24416**	**16830**	**68.93**

Table 46. Ordinal composition of invertebrates collected in Plots post thinning.

Site	Plot	No. orders	No. ind.	No. Collembola	No. ind. without Collembola	No. ants	% ants
Castlemaine	C	18	4631	84	4547	3666	80.15
Diggings	I	18	4334	171	4163	3402	81.72
NHP	P1	19	2672	635	2037	1516	74.42
	P2	18	2656	507	2149	1593	74.13
	Total	**22**					
Paddys	C	19	1615	212	1403	1156	82.39
Ranges	I	20	3005	269	2736	2369	86.59
SP	P1	18	4234	1849	2385	1948	81.68
	P2	21	4109	2154	1955	1660	83.21
	Total	**24**					
Pilchers	C	16	3157	237	2920	2385	81.68
Bridge	I	18	3316	99	3217	2822	87.72
NCR	P1	18	2797	111	2686	2233	83.13
	P2	16	2618	1268	1350	1043	77.26
	Total	**22**					
Spring	C	20	2825	571	2254	1842	81.72
Plains	I	22	2669	283	2386	1767	74.06
NCR	P1	16	3914	1480	2434	1874	77
	P2	17	2835	943	1892	1313	69.4
	Total	**23**					
Total			**51387**	**10873**	**40514**	**32589**	**80.39**

Table 47. The dominant orders of invertebrates collected from pre-thinning Plots at each Site in ranking of dominance.

The orders are ants (Hymenoptera excluding wasps, bees and sawflies), mites (Acarina), spiders (Araneae), flies (Diptera), beetles (Coleoptera), bugs (Hemiptera), booklice or psocids (Psocoptera), silverfish (Thysanura), earthworms (Haplotaxida), woodlice (Isopoda), termites (Isoptera), centipedes (Chilopoda) and millipedes (Diplopoda). Order names in italics indicate groups that pitfall-trap catches need some caution in interpretation of numbers collected. 0<10 indicates that no other orders had more than nine individuals in the pitfall traps at these Plots.

Pre-thinning	Treatment	1	2	3	4	5	6	7
Castlemaine Diggings NHP	C	ants	*mites*	spiders	*flies*	beetles	*springtails*	bugs
	I	ants	*mites*	spiders	beetles	*flies*	*springtails*	isopods
	P1	*springtails*	ants	*mites*	beetles	spiders	woodlice	0<10
	P2	ants	*springtails*	*mites*	psocids	spiders	beetles	woodlice
Paddys Ranges SP	C	*springtails*	*mites*	ants	beetles	*flies*	spiders	0<10
	I	*springtails*	ants	*mites*	*flies*	beetles	spiders	0<10
	P1	ants	bugs	spiders	*springtails*	hymenoptera	*mites*	beetles
	P2	ants	psocids	spiders	*mites*	*springtails*	beetles	*mites*
Pilchers Bridge NCR	C	*flies*	ants	spiders	*springtails*	beetles	*mites*	*earthworms*
	I	ants	*springtails*	*mites*	beetles	*flies*		0<10
	P1	*flies*	*springtails*	ants	silverfish	beetles	spiders	*mites*
	P2	ants	*springtails*	spiders	mites	beetles	psocids	*termites*
Spring Plains NCR	C	ants	*springtails*	*mites*	beetles	spiders	*flies*	0<10
	I	ants	*springtails*	*mites*	spiders	beetles	*flies*	centipedes
	P1	ants	*springtails*	*mites*	*flies*	spiders	beetles	centipedes & millipedes
	P2	ants	*springtails*	*mites*	*flies*	spiders	beetles	0<10

Table 48. The dominant orders of invertebrates collected from post-thinning Plots at each Site in ranking of dominance.

The orders are ants (Hymenoptera excluding wasps, bees and sawflies), mites (Acarina), spiders (Araneae), flies (Diptera), beetles (Coleoptera), bugs (Hemiptera), booklice or psocids (Psocoptera), silverfish (Thysanura), cockroaches (Blattodea), thrips (Thysanoptera), and centipedes (Chilopoda). Order names in italics indicate groups that pitfall-trap catches need some caution in interpretation of numbers collected.

Post-thinning	**Treatment**	**1**	**2**	**3**	**4**	**5**	**6**	**7**
Castlemaine Diggings NHP	C	ants	*mites*	*springtails*	spiders	beetles	cockroaches	bugs
	I	ants	*mites*	*springtails*	spiders	beetles	*flies*	bugs
	P1	ants	*springtails*	*mites*	spiders	silverfish	*flies*	beetles
	P2	ants	*springtails*	*mites*	spiders	beetles	thrips	centipedes
Paddys Ranges SP	C	ants	*springtails*	spiders	beetles	silverfish	*flies*	*mites*
	I	ants	*springtails*	spiders	*mites*	*flies*	beetles	cockroaches
	P1	ants	*springtails*	beetles	*mites*	spiders	*flies*	thrips & bugs
	P2	*springtails*	ants	spiders	*flies*	beetles	*mites*	thrips
Pilchers Bridge NCR	C	ants	*springtails*	*mites*	spiders	*flies*	beetles	cockroaches & bugs
	I	ants	*mites*	spiders	*springtails*	*flies*	cockroaches	thrips & beetles
	P1	ants	*mites*	*springtails*	spiders	*flies*	thrips	bugs
	P2	*springtails*	ants	*mites*	spiders	beetles	*flies*	bugs
Spring Plains NCR	C	ants	*springtails*	*mites*	spiders	beetles	*flies*	earwigs
	I	ants	*springtails*	millipedes	beetles	*mites*	spiders	earwigs
	P1	ants	*springtails*	*mites*	spiders	beetles	*flies*	bugs
	P2	ants	*springtails*	*mites*	spiders	*flies*	beetles	silverfish

3.5.2 Ant-Assemblage Composition

3.5.2.1 Species Richness and Abundance

Since the array of invertebrates and processes that occur in forest systems is so large, a manageable set of parameters was chosen for measurement and study. A useful and widely used invertebrate indicator group is ants. The species richness and relative abundances of ants were used to assess the effects of ecological thinning. In this study, 107 ant species were collected: 88 species were collected in pre-thinning samples; and 95 were collected in the post-thinning samples. Of these, 76 species were recorded in both pre- and post-thinning samples, while 12 species were recorded only in pre-thinning samples and 20 species only in post-thinning samples. The number of ant species recorded in each Plot varied from 17–44 (Table 49). When differences in species richness between pre- and post-thinning was analysed, there were significant differences for the Control, Patchy 1 and Patchy 2 Plots at Castlemaine Diggings NHP, Isolated and Control Plots at Paddys Ranges SP, and Control Plot at Pilchers Bridge NCR (Figure 39–42). However, it is likely that these differences are not due to the treatment but rather to the timing of the sampling. It was initially planned to undertake sampling in spring and early summer at all Sites, but some samples were collected in autumn. Despite non-uniformity in season of sampling, some of the large differences in species richness occurred when pre- and post-thinning samples were taken in the same season, and these may have been influenced by weather conditions (cool temperatures often results in low levels of ant activity). In 15 of the 16 Plots, the number of ant species collected was greater in post-thinning samples than in pre-thinning samples.

Table 49. Pre- and post-thinning ant species richness and ant abundance in relation to Plot and Site.

Site	Plot	Ant species richness	Ant species richness	Ant abundance	Ant abundance
		Pre-thin	**Post-thin**	**Pre-thin**	**Post-thin**
Castlemaine Diggings NHP	C	26	37	814	3666
	I	32	40	1190	3402
	P1	30	39	1057	1516
	P2	27	42	976	1593
Paddys Ranges SP	C	21	36	231	1156
	I	20	37	415	2369
	P1	39	43	2636	1948
	P2	41	44	2293	1660
Spring Plains NCR	C	35	41	1316	1842
	I	27	40	983	1767
	P1	33	36	1210	1874
	P2	30	38	802	1313
Pilchers Bridge NCR	C	17	44	97	2384
	I	23	35	376	2822
	P1	27	36	707	2233
	P2	35	31	1044	1043

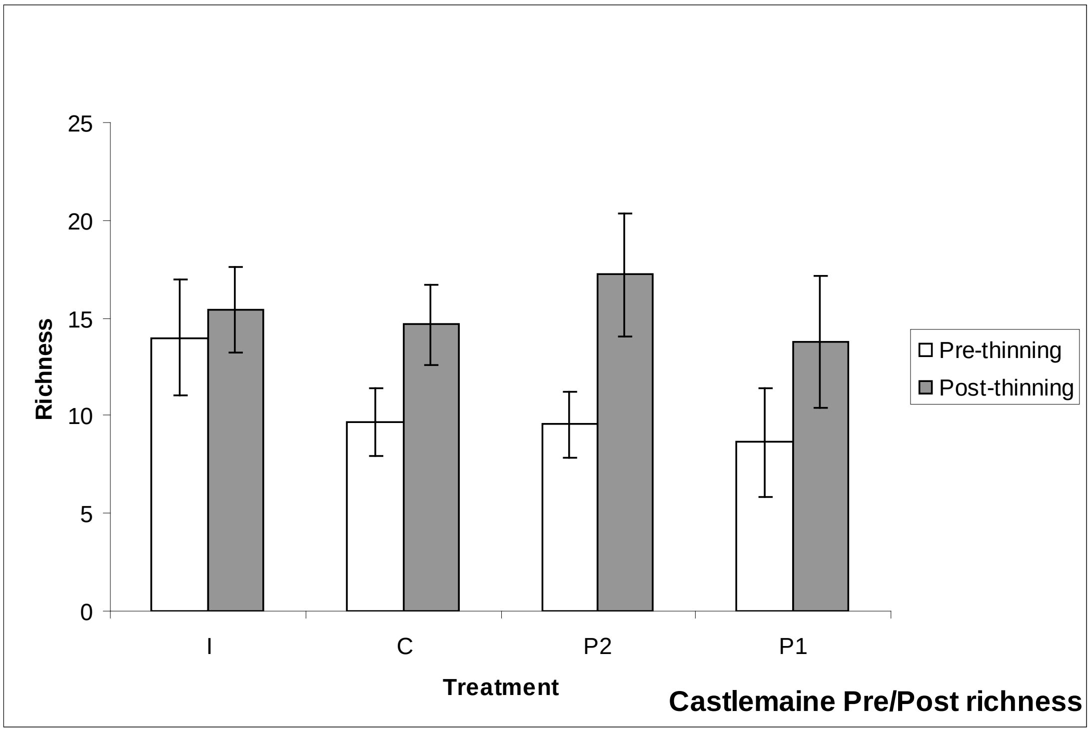

Figure 39. Pre- and post-thinning richness of the ant assemblage at Castlemaine Diggings NHP.

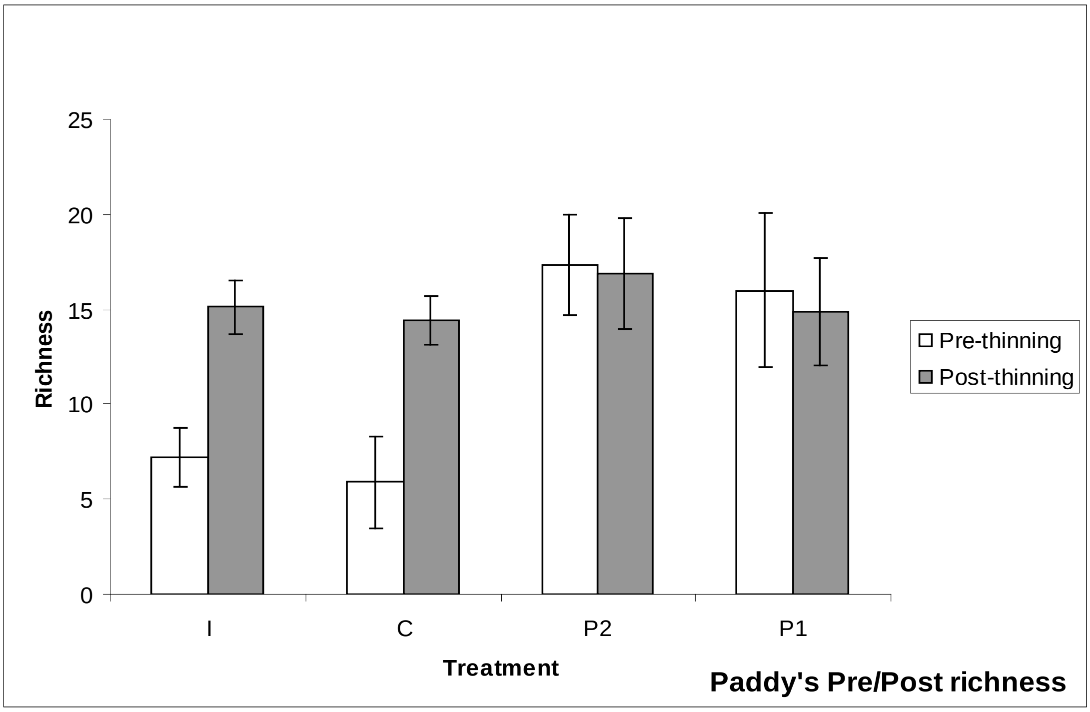

Figure 40. Pre- and post-thinning richness of the ant assemblage at Paddys Ranges SP.

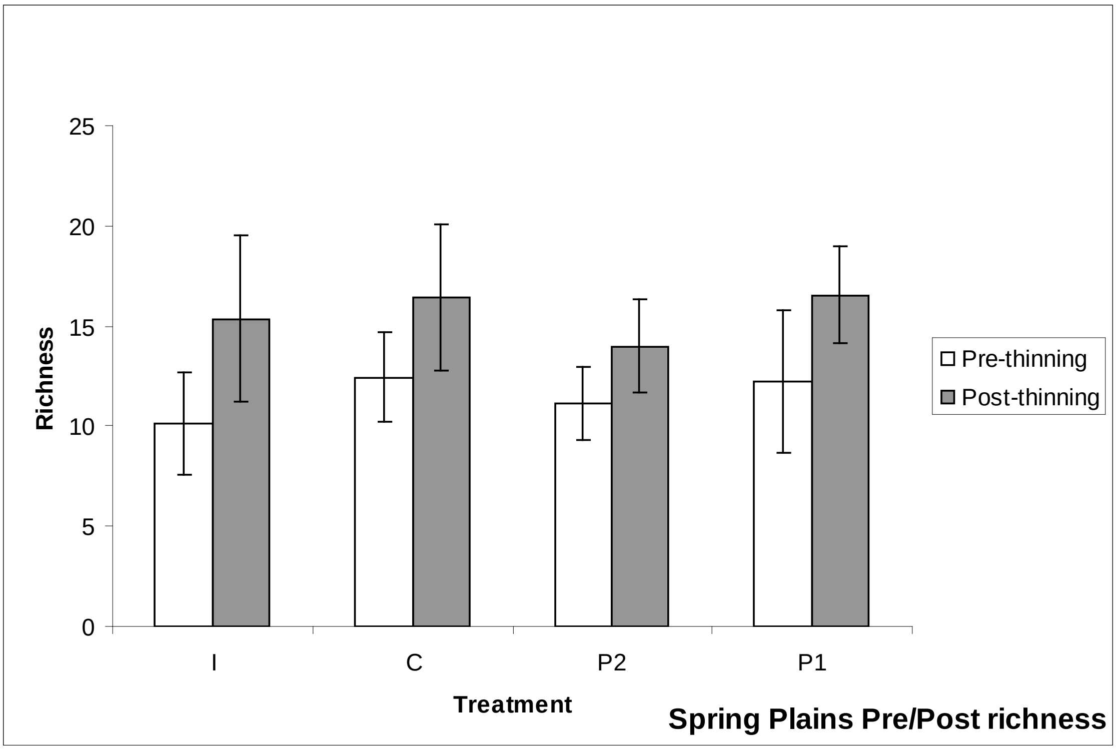

Figure 41. Pre- and post-thinning richness of the ant assemblage at Spring Plains NCR.

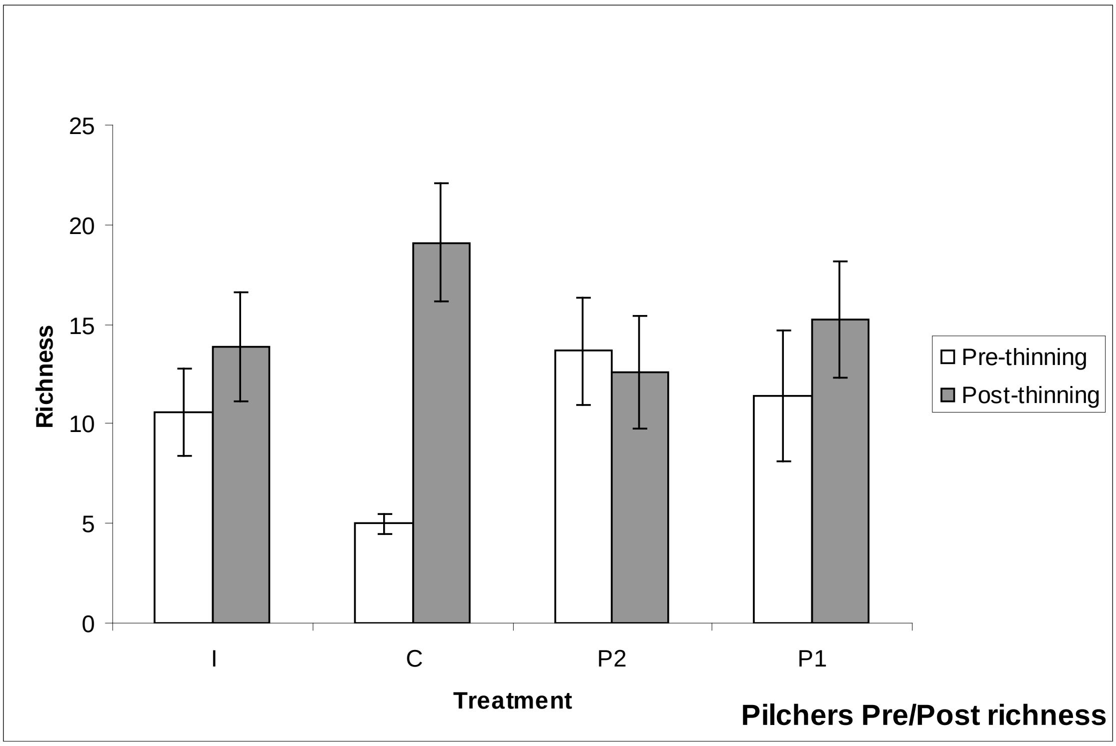

Figure 42. Pre- and post-thinning richness of the ant assemblage at Pilchers Bridge NCR.

Differences in ant abundance varied after thinning. Ant abundance was higher in post-thinning samples for 13 of the 16 treatments (Table 49), but differences between pre- and post-thinning were greater in the Isolated and Control Plots at Castlemaine Diggings NHP, Paddys Ranges SP and Pilchers Bridge NCR (Figure 43–46). The same comments regarding the timing of samples and weather conditions probably influenced ant abundance as they did for ant assemblage richness.

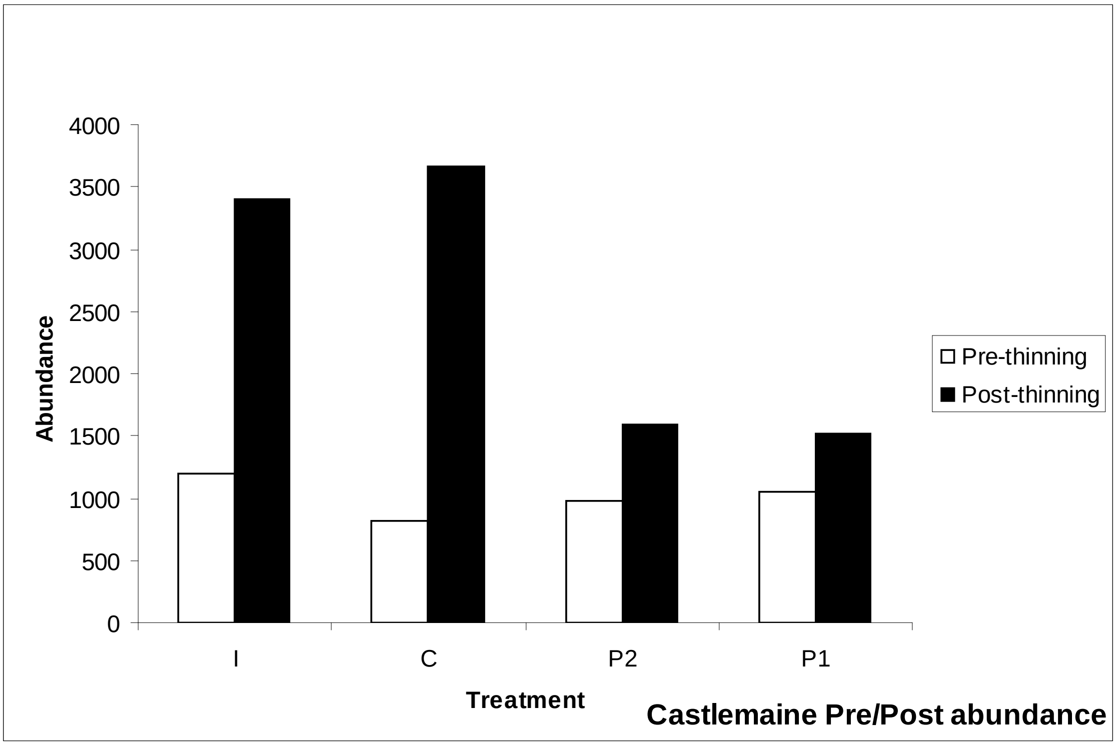

Figure 43. Pre- and post-thinning abundance of ants at Castlemaine Diggings NHP.

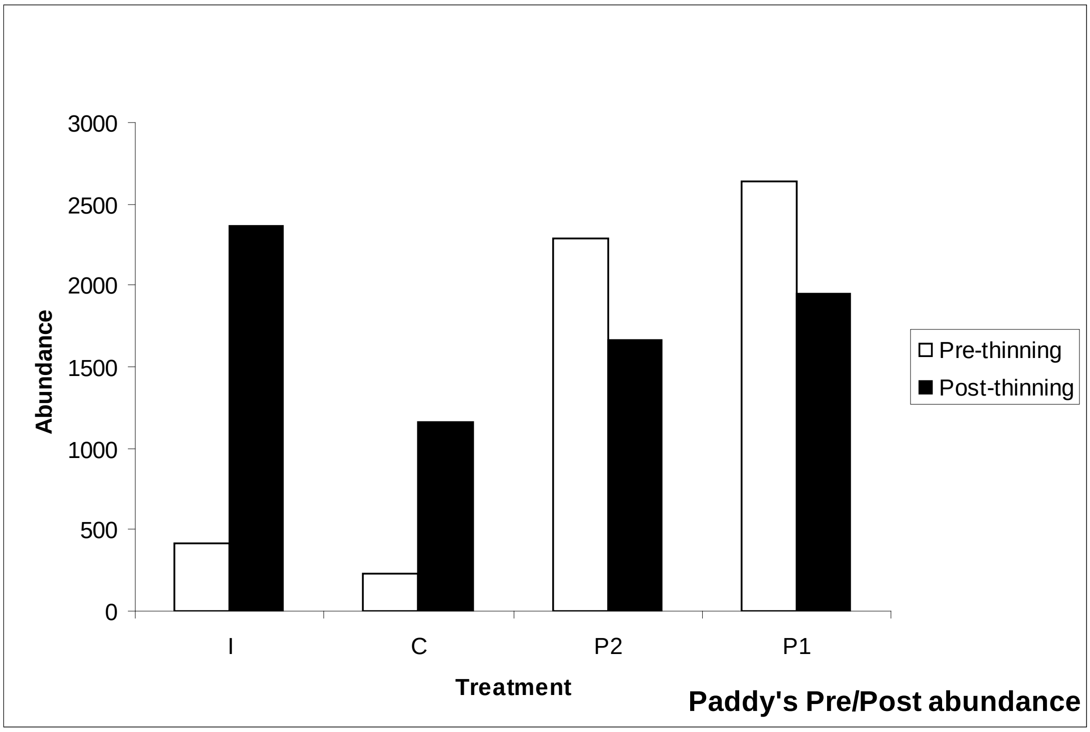

Figure 44. Pre- and post-thinning abundance of ants at Paddys Ranges SP.

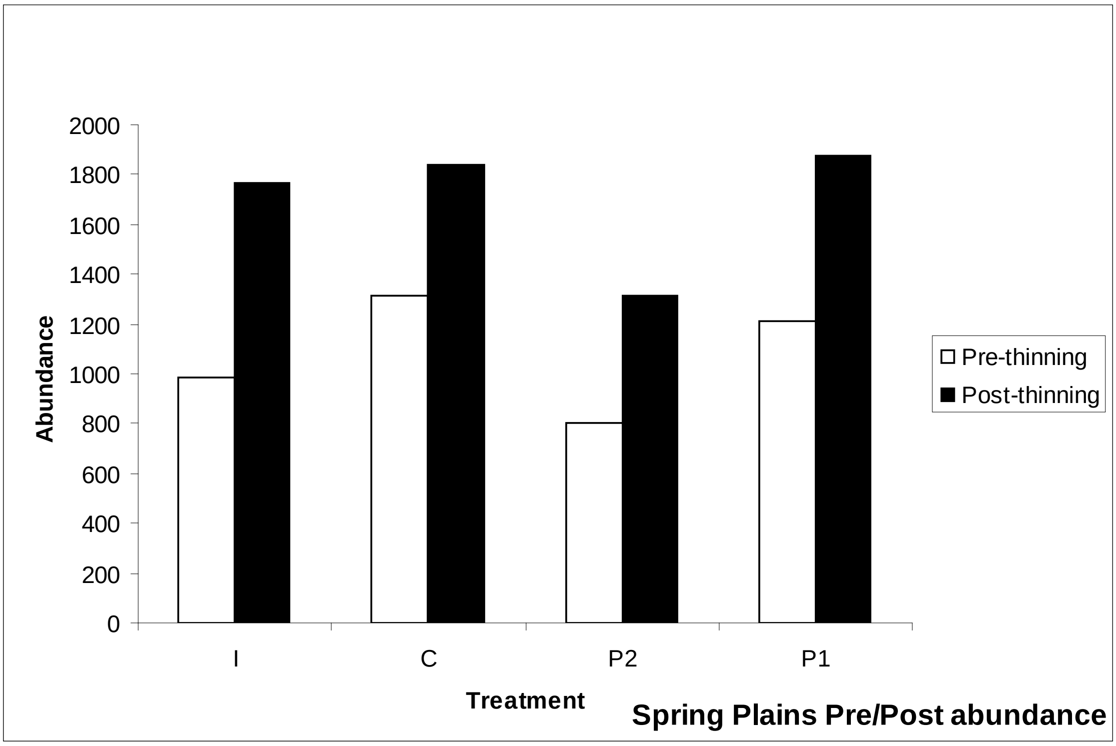

Figure 45. Pre- and post-thinning abundance of ants at Spring Plains NCR.

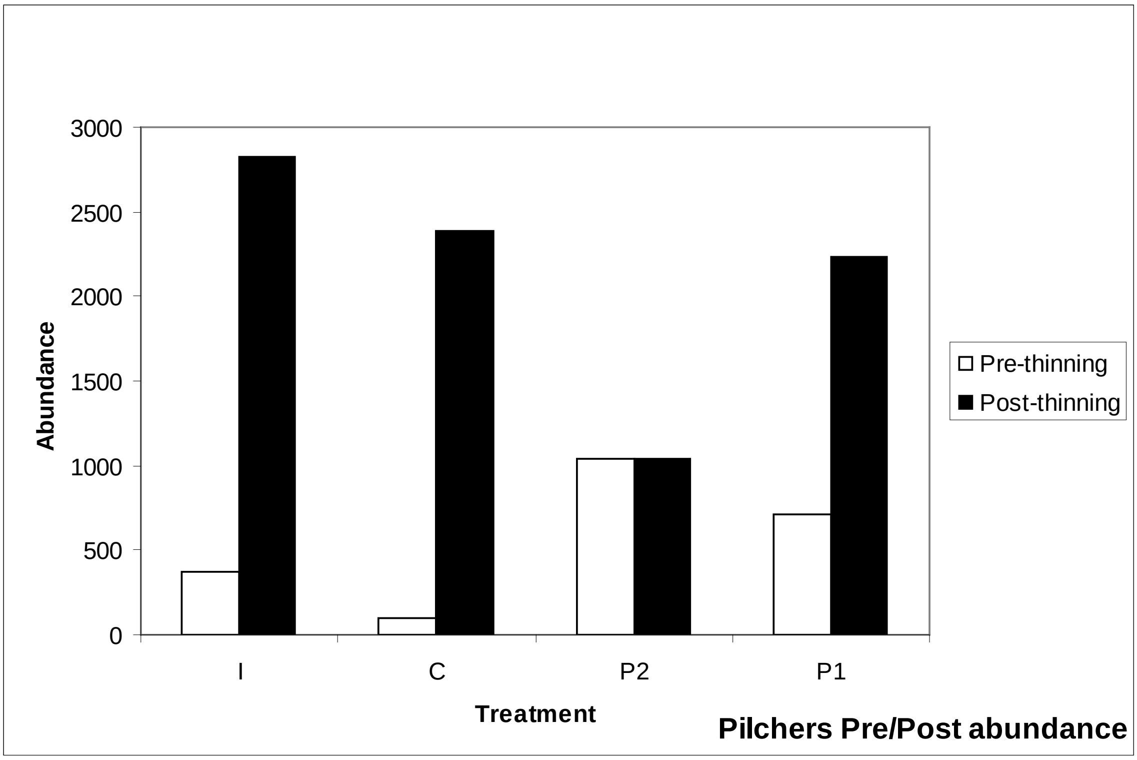

Figure 46. Pre- and post-thinning abundance of ants at Pilchers Bridge NCR.

3.5.2.2 Species Composition

The species composition of the ant samples collected in pitfall traps in pre- and post-thinning surveys is summarised in Table 50. The number of species in each genus and the total number of individuals in each genus is presented.

The dominant genera were: *Rhytidiponera* (represented by one species); *Iridomyrmex* (six species, but dominated by *Iridomyrmex* spp. 1 and 3); *Monomorium* (eight species, with *Monomorium* spp. 1, 2 and 4 dominant); *Pheidole* (three species, all in large numbers); *Melophorus* (five species, dominated by *Melophorus* spp. 1, 2 and 3); *Doleromyrma* (one species), *Crematogaster* (three species); and *Notoncus* (four species, dominated by *Notoncus* spp. 1 and 2).

Table 50. Ant genera and number of species and number of individuals in each genus collected during pre- and post-thinning surveys.

Genus	Number of species			Number of individuals		
	Pre-thin	Post-thin	Total	Pre-thin	Post-thin	Total
Amblyopone	1	1	1	12	7	19
Anonychomyrma	1	1	1	503	458	961
Camponotus	15	18	19	449	450	899
Cerapachys	3	2	4	4	12	16
Colobostruma	1	1	1	1	13	14
Crematogaster	2	3	3	854	829	1683
Doleromyrma	1	1	1	915	1608	2523
Dolichoderus	1	2	2	24	26	50
Epopostruma	1	1	2	2	6	8
Heteroponera	1	1	1	139	163	302
Hypoponera	1	1	1	7	0	7
Iridomyrmex	4	6	6	3866	8875	12741
Leptomyrmex	0	1	1	0	2	2
Mayriella	1	1	1	2	5	7
Melophorus	5	5	5	855	2409	3264
Meranoplus	1	1	1	32	48	80
Mesostruma	0	1	1	0	1	1
Monomorium	6	6	8	1503	3947	5450
Myrmecia	4	3	4	46	26	72
Myrmecorhynchus	1	1	1	1	1	2
Notoncus	4	3	4	977	510	1487
Ochetellus	1	1	1	6	5	11
Pachycondila	2	2	2	30	37	67
Papyrius	1	1	1	4	52	56
Paratrechina	1	2	2	58	140	198
Pheidole	3	3	3	1656	2747	4403
Plagiolepis	1	1	1	46	104	150
Podomyrma	3	4	4	26	41	67
Polyrhacihs	3	4	4	31	36	67
Prolasius	2	2	2	38	20	58
Rhytidoponera	1	1	1	4102	9514	13616
Solenopsis	0	1	1	0	124	124
Sphinctomyrmex	2	2	3	6	3	9
Stigmacros	9	9	10	35	115	150
Strumigenys	1	1	1	1	4	5
Tapinoma	1	1	1	112	234	346
Tetramorium	1	1	1	13	14	27

The relative abundance of the ant species was skewed in all Plots; the ants were generally dominated by either one or a small number of species, and most species only occurred in small numbers. However, some species were abundant across many Plots while others were generally recorded in low numbers but were occasionally trapped in large numbers.

Differences were found in ant species composition between Sites and Plots. Three of the four Plots were dominated by *Rhytidiponera* sp. 1. This is the most common ant across the Box–Ironbark region, and is an opportunistic species that colonises disturbed sites. It was the second most common species in the post-thinning Isolated Plot at Castlemaine Diggings NHP (*Iridomyrmex* sp. 1 was more dominant there). At Spring Plains NCR, *Iridomyrmex* sp. 1 was the most common species. The species composition of ants varied at Paddys Ranges SP and Pilchers Bridge NCR, and different species were dominant, although *Rhytidiponera* sp. 1 was common in most Plots (Table 50).

3.5.3 Ant Functional Groups

The large number of species of ants in dry Australian environments has resulted in attempts to classify ant assemblages on the basis of the ecological roles of the different species. The basis of this ant functional group classification is that a large number of ant species can co-exist because of different resource use: different foods, foraging times and habitats. Ant functional groups and their use in classifying ants from different locations are outlined in Andersen (1984, 1990).

The basis of the ant functional group concept is that the structure of ant assemblages is influenced by a group of ants known as the Dominant Dolicherinae (Functional Group 1). These are medium-sized ants, such as *Iridomyrmex*, that are abundant, highly active, aggressive, and they monopolise resources; hence, they often provide the framework around which the remaining ants work (Andersen 1984, 1990). In this Trial, these were represented mainly by *Iridomyrmex* sp. 1 and sp. 3.

Functional Group 2 comprises the Subordinate Camponotinae. These are inferior competitors to *Iridomyrmex* and can co-exist with them because they have different body sizes or foraging times (Andersen 1984, 1990). In this Trial, they were represented mainly by a large number of *Camponotus* species.

Functional Group 3 comprises climate specialists: 3a are hot-climate specialists, such as *Melophorus*, that are able to forage during extremely high temperatures (Andersen 1984, 1990). In this Trial, they are represented by *Melophorus* spp. 2 and 3. Conversely, 3b are cold-climate specialists that are active and abundant in cool environments (Andersen 1984, 1990). In the Box–Ironbark system, this is represented by *Notoncus*.

Functional Group 4 involves the Cryptic and Sub-cryptic species. Group 4a forage mostly within soil and litter, and they rely on dense litter for survival; 4b may be terrestrial or arboreal (Andersen 1984, 1990).

Functional Group 5 comprises the Opportunists. These ants have wide dietary preferences, flexible foraging times, broad physical tolerance and an ability to colonise disturbed habitats (Andersen 1984, 1990). However, they are unspecialised, poor competitors and can be excluded from diverse ant communities. In this Trial, *Rhytidponera* sp. 1 is the main Opportunist species.

Functional Group 6 are Generalist Myrmecines. They are unspecialised but may be successful opportunists, and can persist in diverse ant communities. The main genera are *Crematogaster*, *Pheidole* and *Monomorium*, and they are able to occupy gaps in the framework formed by *Iridomyrmex* (Andersen 1984, 1990).

The last group, Functional group 7, is the Large Solitary Foragers. These ants, such as *Myrmecia*, are generally large bodied and occur at low densities (Andersen 1984, 1990).

A full list of ant species, categorised into functional groups in pre- and post-thinning surveys (taxa aggregated from all Sites) is given in Appendix 3.

The relative composition of the functional groups in pre- and post-thinning treatments is similar. Numbers of Opportunists and Generalist Myrmecines increased after thinning (Table 51). This would be expected immediately after a disturbance; but, as the relative composition of all ants remained similar, the observed increase may also be due to the timing of the samples (season), as well as reduced rainfall in the post-thinning period.

Table 51. The structure of ant functional groups pre- and post-thinning at Sites.

Functional group	**Species**			**Individuals**				
	Pre-thin	**Post-thin**	**Total**	**Pre-thin**	**%**	**Post-thin**	**%**	**Total**
1 Dominant Dolicherinae	6	8	9	4373	26.72	9387	28.76	13786
2 Subordinate Camponotinae	19	23	23	480	2.93	537	1.65	1019
3a Hot-climate specialists	9	8	10	891	5.45	2469	7.56	3365
3b Cold-climate specialists	11	12	13	1066	6.51	598	1.83	1670
4a Cryptic species	5	5	7	26	0.16	138	0.42	164
4b Sub-cryptic species	13	13	14	339	2.07	616	1.89	957
5 Opportunists	6	7	7	5096	31.14	11286	34.58	16413
6 Generalist Myrmecines	11	12	14	4013	24.52	7525	23.06	11562
7 Large solitary foragers	8	8	10	79	0.48	83	0.25	162
Total	88	96	107	16363		32639		49002

It is useful to compare the functional group composition of ants in the Box–Ironbark forests with drier mallee associations in north-western Victoria; Andersen 1984) and wetter (open forest at Wilsons Promontory; Andersen 1986) environments in Victoria. Some caution is required, though, because of different pitfall-trapping methods, but the results suggest that the ant assemblage in Box–Ironbark forests is compositionally intermediate between the drier and wetter environments (Table 52).

In the Mallee, ants are strongly influenced by a high proportion of Dominant Dolicherines (Functional Group 1) while the proportion in the open forest at Wilsons Promontory is low. The proportion of Cold-climate specialists (Functional Group 3b) is high in open forests at Wilsons Promontory and low in the Mallee and Box–Ironbark forests. The high proportion of Opportunists (Functional Group 5) in the Box–Ironbark forests may be due to the long history of disturbance there (Table 52).

Andersen (1986) found greater variability in structure of ant assemblages across different vegetation types in the mesic sites at Wilsons Promontory than in the semi-arid Mallee (Table 52). The mesic open forests had lower ant species richness and abundance than in the semi-arid Mallee, and the *Iridomyrmex*, *Campontonus* and *Melophorus* taxa were less prominent in drier environments. At Wilsons Promontory, habitat has a greater influence on community organisation, and along with the prominence of *Rhytidiponera*, it is suggested that interspecific competition is less important in cool habitats than in dry ones (Andersen 1986). The results suggest that ant assemblages in the Box–Ironbark forests are structured more by interspecific competition than by habitat.

Table 52. Comparison of ant Functional Groups from Box–Ironbark sites in central Victoria (this Trial), a mallee site (Andersen 1984) and a wet open forest site (Andersen 1986).

Function Group	Mallee	Box–Ironbark	Wet open forest
1	44	28	8
2	3	2	5
3a	6	7	0
3b	1	3	58
4a	1	<1	17
4b	1	2	?
5	0	33	0
6	49	24	5
7	1	<1	1

3.5.4 Data Summary

It is valuable to compare invertebrate ordinal results obtained using pitfall trapping in this Trial with other studies in adjacent areas. Bromham *et al.* (1999) sampled woodlands and pastures around Benalla, and found that the dominant invertebrate groups were ants, beetles and spiders. Around Daylesford, Collett and Neumann (2003) had samples that were dominated by springtails, mites, spiders, beetles and ants (more beetles were collected than ants), and earwigs were abundant after prescribed fires. Both these studies were undertaken in slightly more mesic regions.

This Trial collected 26 invertebrate orders using test-tube pitfall traps. The composition of the fauna varied at the ordinal level, but this variation was probably due to differences in seasons when sampling was undertaken and also reflected environmental factors such as rainfall. If the orders that are primarily active after rainfall (springtails and earthworms) and flying insects that are attracted to the traps (flies) are excluded, then the dominant invertebrate groups, both pre- and post-thinning, were ants, spiders and beetles.

Due to the variation in sampling dates, it is impossible to determine significant pre- and post-thinning differences in ordinal composition. It is, however, possible to utilise the data obtained as a baseline for monitoring longer-term changes in the fauna as a result of the thinning treatments. At the ordinal level, there could be a change in the less-abundant orders in response to thinning. In the study of invertebrates associated with ungrazed woodlands, grazed woodlands and pastures around Benalla, while the dominant orders increased in abundance from ungrazed woodland to grazed woodland to pasture (along with increases in groups such as Orthoptera and Dermaptera, which occur mainly in pastures), the less-dominant orders showed the opposite trend (Bromham *et al.* 1999). Consequently, it would be important to assess changes in the dominances of the different invertebrate groups at the ordinal level.

A total of 107 species of ants was recorded. While differences in species composition and abundance of ants may have reflected seasonal differences, their classification into functional groups has provided a baseline indication of the ecological structure of this important group. Functional groups also provide the potential to assess the effects of thinning on forest structure in the future. The concept of functional groups could also be applied to the other two dominant groups — spiders and beetles. It is also important to remember that sampling over a short period results in underestimates of the faunal composition.

4 RELATIONSHIPS AMONG BIODIVERSITY AND HABITAT ATTRIBUTES

Using data collected during Phase 1 of the Trial, the relationships and interactions among different variables were examined to identify any effects of the experimental treatments or location. The identification and quantification of such outcomes are important as a guide to future management, as they provide a basis for predicting potential future trajectories in the response of biodiversity and key habitat variables.

The responses of four variable groups are discussed: flora; avifauna; mammals; and invertebrate functional groups. The approach taken was to use linear-regression models to explain the relationship between the response variables and a series of ecologically meaningful predictor variables (geographical, treatment, habitat). This was used to determine the relationship between ecological-thinning outcomes (e.g. increased amounts of coarse woody debris, decreased tree density) and the response of biodiversity. An advantage of linear-regression models is that they have (with appropriate recognition of limitations) the capacity to predict future trends based on changing scenarios (e.g. increased hollow abundance) using current data. This should prove useful in the ongoing monitoring and evaluation of the longer-term implications of Phase 2 of the Trial.

To assist this process, data from a range of independent research projects carried out in Box–Ironbark forests were examined. This included floristic and structural life form data (Tolsma & Newell 2003; ARIER, unpublished data), as well as data for avifauna (A.F. Bennett, unpublished data), bats and terrestrial mammals (ARIER, unpublished data). These were scrutinised to assist with the interpretation of the Trial data and further explore biodiversity and habitat associations, as well as to provide a basis for predicting potential future trajectories.

4.1 Ecological Thinning: Response of Flora

4.1.1 Thinning-Treatment Data

Relationships (from simple linear regression) between understorey variables and other site variables are presented in Table 53. Care must be taken with these data, particularly post-thinning or combined data, as many of the variables are auto-correlated. For example, thinning will have reduced tree density, and shrub cover to a lesser extent, while simultaneously increasing amounts of coarse woody debris and litter. A mathematical relationship may not reflect a direct biological relationship. Further, post-thinning data differ from pre-thinning data in terms of the season in which they were assessed, and the greater number of understorey species that were detected post-thinning may have had little to do with the effects of thinning, and may have been more influenced by the season.

Table 53. Correlations between understorey and other variables in the Trial.

Green cells = significantly positive; orange cells = significantly negative; n/a = variance too high.

	Tree density*		Understorey richness		Orchid richness		Weed cover	
Combined pre- and post-thinning data	**Variance accounted for (%)**	**F pr.**	**Variance accounted for (%)**	**F pr.**	**Variance accounted for (%)**	**F pr.**	**Variance accounted for (%)**	**F pr.**
Litter cover			5.4	**<0.001**	1.7	**0.015**	6.2	**<0.001**
Litter depth			n/a		5.7	**<0.001**	0.5	0.128
CWD <10 cm			n/a		n/a		0.5	0.131
CWD >10 cm			11.1	**<0.001**	0.8	0.067	9.4	**<0.001**
Tree density*			7.8	0.067	4.8	0.12	n/a	
Understorey cover	n/a		42.6	**<0.001**	18.6	**<0.001**		
Shrub cover	n/a		1.0	**0.048**	10.6	**<0.001**	11.2	**<0.001**
Pre-thinning								
Litter cover			1.0	0.124	5.0	**0.004**	3.5	**0.014**
Litter depth			n/a		15.1	**<0.001**	2.9	**0.024**
CWD <10 cm			3.0	**0.021**	n/a		5.0	**0.004**
CWD >10 cm			16.1	**<0.001**	14.4	**<0.001**	23.8	**<0.001**
Tree density*			3.6	0.233	1.9	0.274	1.7	0.281
Understorey cover	7.6	0.158	54.5	**<0.001**	26.3	**<0.001**		
Shrub cover	n/a		5.6	**0.002**	37.2	**<0.001**	19.7	**<0.001**
Post-thinning								
Litter cover			7.7	**<0.001**	0.3	0.232	8.2	**<0.001**
Litter depth			n/a		n/a		n/a	
CWD <10 cm			2.6	**0.03**	2.0	0.052	n/a	
CWD >10 cm			8.7	**<0.001**	2.7	**0.028**	10.0	**<0.001**
Tree density*			39	**0.006**	n/a		2.9	0.248
Understorey cover	n/a		33.7	**<0.001**	13.2	**<0.001**		
Shrub cover	3.5	0.235	n/a		n/a		4.9	**0.004**

* Tree density correlations analysed at Plot level. All other correlations based on Sub-plot data.

Understorey richness was negatively (although weakly) correlated with small coarse woody debris (Table 53), but positively associated with large coarse woody debris. The latter correlation was driven largely by differences between Sites, as evidenced by the directions of the vectors in the ordination diagram (Figure 47). In particular, Spring Plains NCR had higher species diversity and more large coarse woody debris. For similar reasons, understorey richness was also positively correlated with understorey cover, with Spring Plains NCR (high cover, high diversity) at one side of the ordination and Paddys Ranges SP (low cover, low diversity) at the opposite side. Understorey richness was negatively associated with shrub cover, and this was expected given the low amount of shrub cover at Spring Plains NCR and greater shrub cover at Castlemaine Diggings NHP. The ordination (Figure 47) also suggested that there was an association between tree density and both understorey cover and richness, but this was not supported by the regression analysis (Table 53).

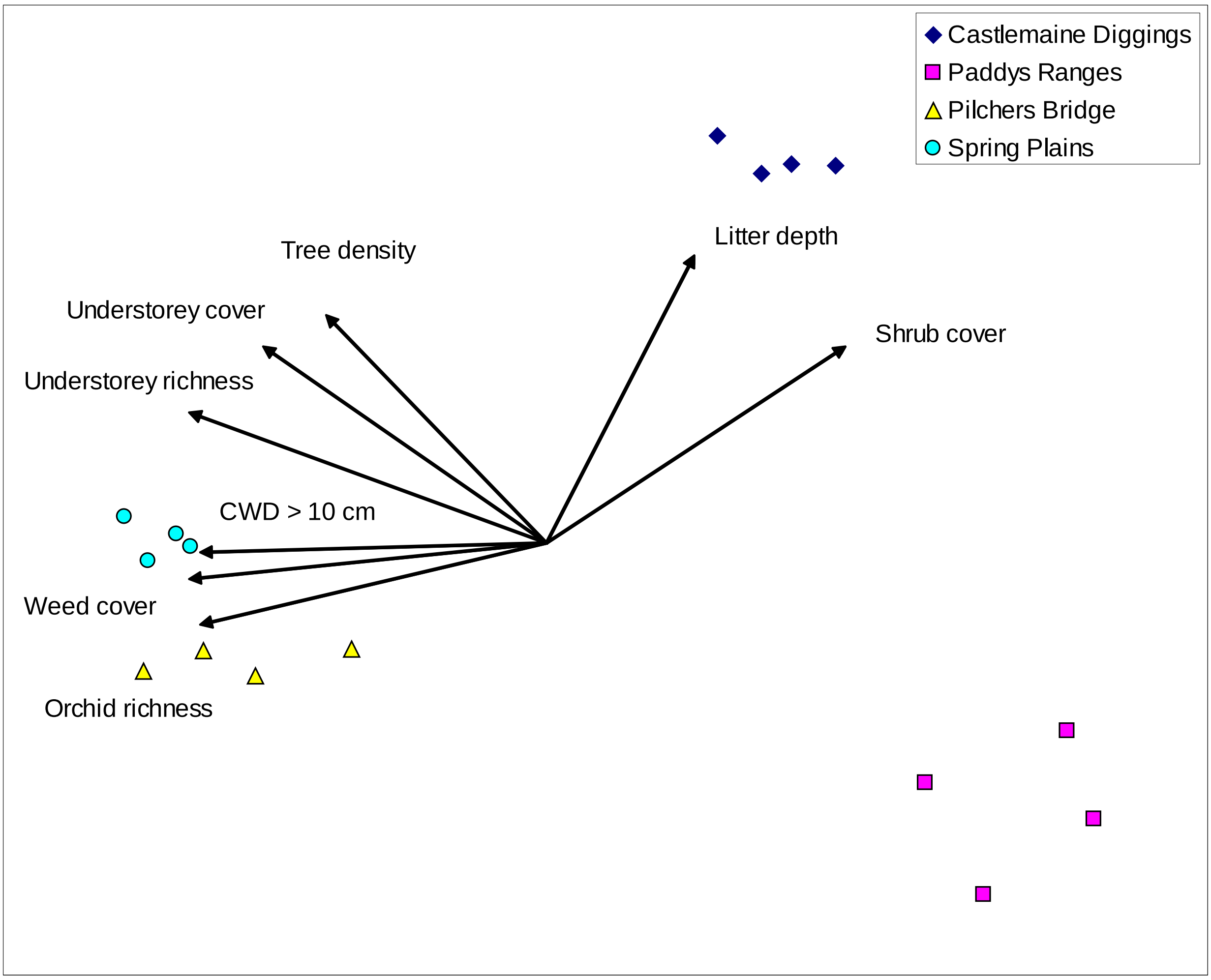

Figure 47. Two-dimensional NMDS site ordination of pre-thinning data for the Trial, with vectors for assorted Site parameters**(Stress = 0.06)**

Orchid richness was positively correlated with litter area and large coarse woody debris (Table 53), but these associations were probably driven by other (perhaps auto-correlated) factors. Orchid richness was negatively associated with litter depth, but it is unclear whether this was due to the physical effects of deeper litter, or the generally better conditions at Spring Plains NCR and Pilchers Bridge NCR (which had the highest orchid richness). Orchid richness was positively correlated with understorey cover, but negatively correlated with shrub cover (Table 53; Figure 47). This was expected, as many moisture-loving, winter-flowering orchids (such as *Pterostylis* detected in the pre-thinning surveys) prefer a herby/grassy environment (Mike Duncan, ARIER, pers. comm.), and would be favoured by the conditions provided by environments similar to Spring Plains NCR.

The cover of weeds was strongly positively correlated with large coarse woody debris, supporting the observations made previously that piles of debris favoured annual weed grasses (e.g. at Pilchers Bridge NCR). There was a strong negative correlation between weed cover and shrub cover (Table 53; Figure 47). This was driven substantially by differences between Sites, with Castlemaine Diggings NHP having high shrub cover and low weed cover, but Spring Plains NCR had low shrub cover and high weed cover (mostly the annual Large Quaking-grass). Drier, rockier microsites, such as those at Castlemaine Diggings NHP, appear to provide an environment that is suited to shrubs but not weeds.

4.1.2 Data from Independent Projects

Limited understorey and structural data were available from 85 independent sites in Box–Ironbark Forest (from Rushworth to St Arnaud) and from 41 sites in Grassy Dry Forest (north-east of the Melbourne metropolitan area) that were surveyed for vegetation condition (Tolsma & Newell 2003). Understorey and structural data that were comparable to the current thinning data were subjected to regression analysis as before.

Although no correlations were found to be significant at the p<0.05 level, there may be a weak association between tree cover and understorey cover and between tree cover and shrub cover (Table 54). Additional sampling is required to investigate these relationships further. Should these relationships be real, for these Sites at least, actions leading to reduced tree cover might increase understorey and shrub cover.

Table 54. Correlations between understorey and structural variables for 85 sites in Box–Ironbark Forest.

n/a = variance too high; % = variance accounted for; — = negative association.

	Understorey cover	Understorey richness	Shrub cover
Tree cover	p=0.054, 3.3% (—)	n/a	p=0.065, 2.9% (—)
Tree density	n/a	n/a	n/a
Log length	n/a	n/a	p=0.242, 0.5%
Litter cover	n/a	p=0.221, 0.6%	n/a

The ordination diagram for the 85 independent Box–Ironbark Forest sites (Figure 48) suggested that associations between some parameters were different to those determined in this Trial. For example, shrub cover in the Trial was negatively associated with understorey richness (Table 53), but shrub cover in the 85 independent sites was positively associated with understorey richness, as well as understorey cover. However, the independent sites tended to have a more homogenous, shrub-dominated understorey, and did not cluster as discretely on the ordination as the thinned Plots at the four Sites, with their mix of shrubby and grassy understoreys. Further, care needs to be taken in the interpretation of Figure 48, as the stress level of 0.2 is the upper limit of what is considered reasonable (Clarke 1993).

Future analyses will therefore benefit from stand-alone ordinations with lower stress values which are not confounded by substantial Site-to-Site variation.

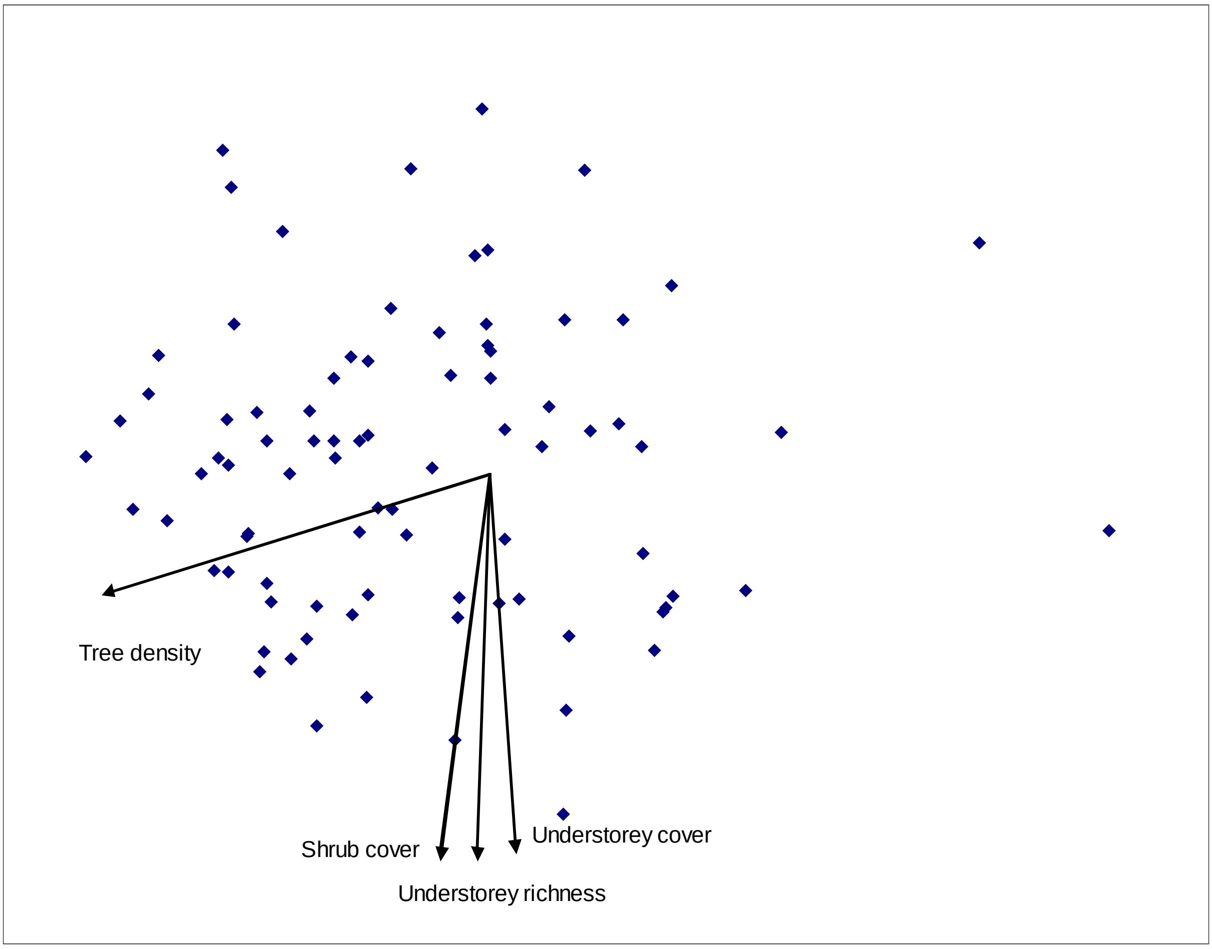

Figure 48. Three-dimensional NMDS ordination (Axes 1 and 3 only) of 85 independent sites in Box–Ironbark Forest, with vectors for assorted site parameters.

(Stress = 0.20)

In Grassy Dry Forest, there were significant positive correlations between the canopy cover of trees and the cover of understorey (p = 0.011) and shrubs (p = 0.049) (Table 55), contrasting with the results from the 85 independent Box–Ironbark Forest sites. Thus, forests with a well-defined perennial tussock-grass layer (e.g. Spring Plains NCR) and different soil and environmental factors might respond to thinning differently to forests with a shrubby understorey. Interestingly, there was no clear relationship between canopy cover and the cover of perennial tussock grasses (data not shown). This suggests that the cover of perennial grass tussocks in Grassy Dry Forest might be driven to a large extent by factors other than tree cover, possibly soil depth and moisture.

There were significant positive correlations in Grassy Dry Forest between the canopy cover of trees and the cover of weeds, and between canopy cover and understorey richness; these variables appear to be auto-correlated with understorey cover in this forest type (Figure 49). These relationships might reflect the naturally moister conditions in this forest type. Orchid richness in Grassy Dry Forest was significantly positively correlated with litter cover, supporting the results from this Trial, although the biological relationship remains unclear. The surveys may simply have been conducted at the right time to detect orchid species that prefer a more open habitat.

Table 55. Correlations between understorey and structural variables for 41 sites in Grassy Dry Forest.

Green cells = significantly positive; n/a = variance too high; % = variance accounted for.

	Understorey cover	Understorey richness	Shrub cover	Weed cover	Orchid richness
Tree cover	**p=0.011, 13.2%**	**p=0.003, 17.9%**	**p=0.049, 7.2%**	**p=0.003, 18.5%**	p=0.105, 4.2%
Tree density	p=0.311, 0.1%	n/a	n/a	n/a	n/a
Log length	n/a	n/a	p=0.23, 1.2%	n/a	p=0.274, 0.6%
Litter cover	n/a	n/a	n/a	n/a	**p=0.016, 11.9%**
Shrub cover				p=0.24, 1.1%	n/a
Understorey cover					p=0.301, 0.2%

The ordination (Figure 49) largely reflects the relationships established in Table 55. However, the precautionary notes that applied to Figure 48 also apply here, with the stress level of 0.19 at the upper limit of the range that is considered acceptable for meaningful interpretation.

In general, understorey cover and richness are associated with factors that are expected to have a direct impact on them. This includes canopy cover and tree density.

Gaps in the canopy are likely to be a major driver of understorey change. Accordingly, canopy cover, which was not yet available for the Trial, is likely to be an important variable in future surveys, and should be included in those surveys as a matter of course. Measurements should ideally be made at each of the 10 measurement transects, which are common to the understorey, habitat and invertebrate components of the Trial.

Litter cover, litter depth and large and small coarse woody debris may be important variables for various fauna groups, but relationships with understorey variables (with the possible exception of weed cover) appear to be indirect, auto-correlated or confounded by inter-Site variation. These habitat variables should continue to be measured, although conditions at a Site may need to change substantially through future ecological processes before relationships can be detected.

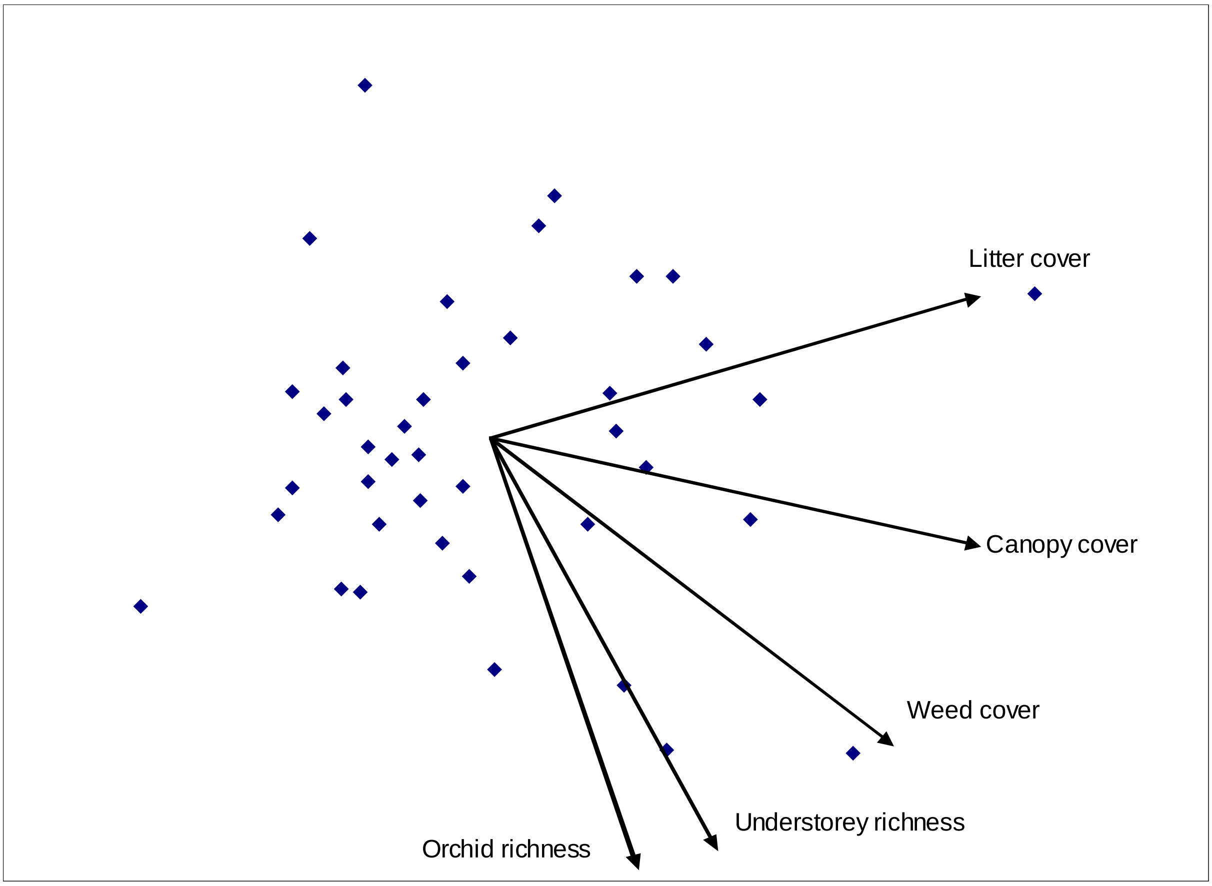

Figure 49. Two-dimensional NMDS ordination of 41 independent sites in Grassy Dry Forest, with vectors for assorted site parameters.

(Stress = 0.19)

4.2 Ecological Thinning: Response of Avifauna

4.2.1 Avifauna of the Box–Ironbark Region

The Box–Ironbark forests of Victoria provide habitats for a distinct and species-rich bird community (ECC 1997; Bennett 1999; Tzaros 2005). Around 186 species of native birds (excluding waterbirds) have been recorded in the Box–Ironbark ecosystem and over 85% of these have bred in the region (Tzaros 2005). The Box–Ironbark avifauna is particularly rich in nectarivorous species (honeyeaters, lorikeets, Swift Parrot), ground foragers (e.g. Speckled Warbler, Spotted Quail-thrush), hollow-dependent species (e.g. Brown Treecreeper, Turquoise Parrot) and arboreal insectivores (e.g. Weebill, Yellow Thornbill, Varied Sittella).

The decline of bird species associated with widespread clearing and modification of Box–Ironbark forests and woodlands has been well documented (Bennett 1993; Robinson & Traill 1996; Pigott *et al.* In Press). The Victorian temperate woodland bird community, which is strongly dependent on Box–Ironbark forests and woodlands (SAC 2000), is listed as a threatened community under the Victorian *Flora and Fauna Guarantee Act 1998*.

Many species associated with Box–Ironbark forest are threatened, either nationally or at a state level. Nationally threatened species include the Critically Endangered Regent Honeyeater *Anthochaera phrygia* and Endangered Swift Parrot. At a State level, species considered to be threatened include Barking Owl (Endangered), Bush Stone-curlew *Burhinus grallarius* (Endangered), Painted Honeyeater *Grantiella picta* (Vulnerable), Speckled Warbler (Vulnerable) and Brown Treecreeper (Near Threatened).

Processes that have been implicated in the decline of Box–Ironbark avifauna include habitat loss and degradation (Antos & Bennett 2005), fragmentation (Mac Nally & Horrocks 2002a; Mac Nally *et al.* 2002a), loss of hollow-bearing trees (Traill 1991) and the degradation of the understorey (Palmer 1998). Groups that have been particularly affected are species that depend on tree hollows for shelter and breeding (Traill 1991; DNRE 1997), ground-dwelling species (Palmer 1998; Antos & Bennett 2005) and mobile species that depend on resources that vary in space and time (e.g. nectar) (Traill 1993; McGoldrick & Mac Nally 1998).

Coarse woody debris is an important microhabitat feature for many birds in Box–Ironbark forests (Laven & Mac Nally 1998; Tzaros 2005). Several species are reliant on a well-developed layer of coarse woody debris, and a number of these species are threatened in Victoria (e.g. Bush Stone-curlew and Brown Treecreeper). In Box–Ironbark forests around Dunolly, in central Victoria, ground-foraging birds occurred more frequently and in greater diversity in areas where there was fallen timber, irrespective of the amount of fallen timber in the surrounding area (Laven & Mac Nally 1998).

Ground habitats that have a complex structure of fallen branches and logs, leaf and bark litter, ground vegetation (e.g. grasses, herbs and low shrubs) and open areas are important for many bird species (Palmer 1998; Antos & Bennett 2005). Birds that forage or nest on or among ground layer habitats are highly susceptible to changes in this habitat zone, and many species have suffered major declines (e.g. Hooded Robin, Bush Stone-curlew and Speckled Warbler) (Robinson 1991; Bennett 1993; Robinson & Traill 1996). Prolonged, sustained grazing in Box–Ironbark communities has contributed to a substantially modified understorey, including reduced shrub-species richness and less low-shrub and grass cover. The simplified structure of disturbed sites leads to reduced diversity and changes in the composition of bird assemblages (Palmer 1998). Cover-dependent ground-foraging birds are particularly affected, and several species (e.g. Spotted Quail-thrush, Painted Button-quail, Buff-rumped Thornbill, Superb Fairy-wren and Chestnut-rumped Heathwren) are generally absent from disturbed sites.

The loss of hollow-bearing trees from native forests in Victoria is listed as a potentially threatening process under the *Flora and Fauna Guarantee Act 1988.* Tree hollows provide a vital habitat resource for many birds associated with Box–Ironbark forest (Soderquist *et al.* 1994), and are largely associated with mature vegetation. As a tree ages, its physiology becomes weaker and its large branches die and are shed, allowing hollows to form. Eucalypts, including those characteristic of Box–Ironbark forests and woodlands, develop hollows at all ages, but hollows suitable for vertebrate fauna typically do not appear until trees are at least 120 years old, and hollows for larger species may not appear until trees are at least 220 years old (Gibbons & Lindenmayer 2002). As a result of past land-use practices there are no consolidated areas of mature Box–Ironbark forest left in Victoria (Traill 1991). Tree hollows have been recognised as a limited resource within the Box–Ironbark region (DNRE 1997; Adkins *et al*. 2005). The loss of tree hollows has been implicated in the decline of several Box–Ironbark fauna species, including Powerful Owl and Barking Owl (DNRE 1997).

4.2.2 Data from Independent Projects

Over the past decade or so, the avifauna of Box–Ironbark forest has been the focus of major research effort. As a result there are data on avifauna that may be useful in interpreting the results and projected outcomes of the Trial.

The composition and structure of bird assemblages in Box–Ironbark forests varies at a number of scales. Firstly, the composition of bird assemblages changes along a gradient from east to west (e.g. from Chiltern to St Arnaud). Several characteristic species occur mainly in the north-east, in the Chiltern region, including Turquoise Parrot *Neophema pulchella* and Leaden Flycatcher *Myiagra rubecula* (Tzaros 2005). Others once occurred more widely but have undergone significant declines, including local extinctions, in the western part of their distribution, such as Regent Honeyeater and Painted Honeyeater (ECC 1997; Tzaros 2005). Secondly, the structure and composition of Box–Ironbark forest bird assemblages change between different floristic communities. For example, across the Box–Ironbark region, bird assemblages surveyed at 80 sites distributed across 14 EVCs showed strong associations between sites of same EVC (A.F. Bennett, unpublished data) (Figure 50).

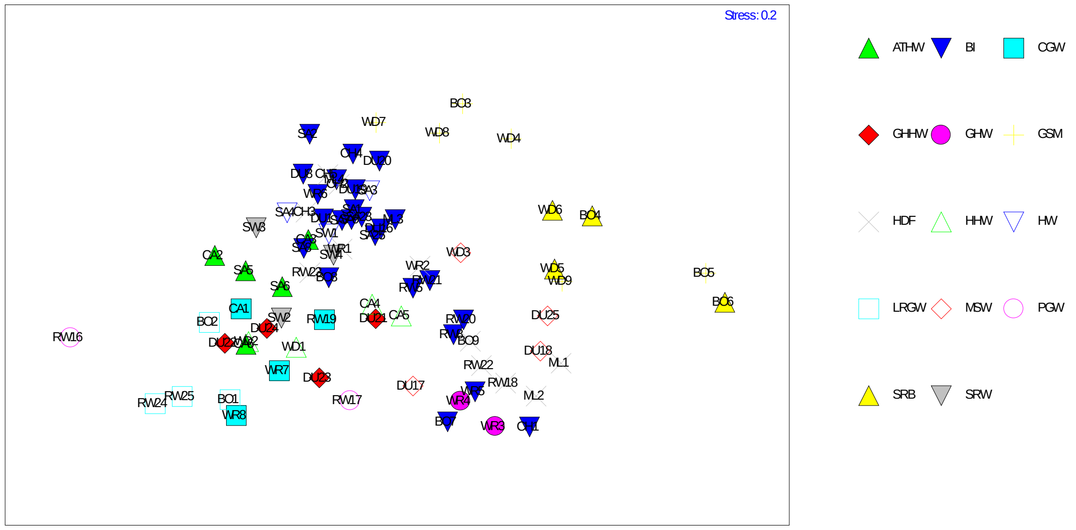

Figure 50. MDS ordination of bird assemblages occurring at 85 sites in Box–Ironbark forest in Victoria (from A.F. Bennett, unpublished data).

The bird assemblages were sampled across a range of EVCs including: Alluvial Terraces Herb-rich Woodland (ATHW); Box–Ironbark Forest (BI); Creekline Grassy Woodland (CGW); Granitic Hills Herb-rich Woodland (GHHW); Granitic Hills Woodland (GHW); Gravelly Sediment Mallee (GSM); Heathy Dry Forest (HDF); Hilltop Herb-rich Woodland (HHW); Heathy Woodland (HW); Low-rises Grassy Woodland (LRGW); Metamorphic Slopes Woodland (MSW); Plains Grassy Woodland (PGW); Sandstone-rise Broombush (SRB); and Sandstone-rise Woodland (SRW). (Stress = 0.2)

The Box–Ironbark Forest EVC is characterised by an abundant and species-rich nectarivore assemblage, including honeyeaters, lorikeets and the Swift Parrot, which is attracted to profusely flowering eucalypts such as Red Ironbark, Mugga Ironbark, Yellow Gum and Grey Box. Many individuals and species move into this EVC during autumn and winter when these key eucalypts are flowering (Bennett 1993; McGoldrick & Mac Nally 1998). Many of the species that form the recognised temperate-woodland bird community are also strongly associated with this EVC, including Yellow-tufted Honeyeater, Fuscous Honeyeater, Speckled Warbler and Brown Treecreeper.

Heathy Dry Forest EVC bird assemblages are typically rich in insectivorous species such as Buff-rumped Thornbill, Brown-headed Honeyeater, Rufous Whistler, Leaden Flycatcher and Dusky Woodswallow. A diverse range of honeyeaters occurs, but not the abundance or richness of species that occur in Box–Ironbark Forest EVC, due to less profuse flowering of Heathy Dry Forest eucalypts (e.g. Red Stringybark, Red Box and Long-leaf Box). Ground-foraging species form a prominent component of the Heathy Dry Forest assemblage, and these include Spotted Quail-thrush, Painted Button-quail and White-winged Chough.

The richness and composition of Box–Ironbark bird assemblages is strongly linked to landscape characteristics including patch size, degree of fragmentation, isolation and interior-to-edge ratio (Mac Nally & Horrocks 2002a; Mac Nally, Horrocks & Bennett 2002a; Taylor *et al.* 2008). Mac Nally & Horrocks (2002a) attributed a lower-than-expected species richness of bird assemblages in small fragments (<10 ha) in Box–Ironbark forests to current area of remnants, density of Noisy Miners *Manorina melanocephala*, and habitat quality. The Noisy Miner presents an interesting case in fragmentation processes, as it has the ability to aggressively exclude other small birds from its territories. This species benefits from fragmentation and the creation of edge habitats (Taylor *et al*. 2008), and its increasing abundance is considered one of the most important threats to woodland bird communities in south-eastern Australia (Mac Nally 1999).

Habitat quality has a strong influence on the structure and composition of bird assemblages in Box–Ironbark forest (Palmer 1998; Mac Nally *et al*. 2000). In the Box–Ironbark forest landscape, gullies support more diverse bird assemblages with higher total densities than ridges (Mac Nally *et al.* 2000). Gullies are characterised by having more large trees and a more open vegetation structure, while ridges typically have smaller trees and a denser structure (Mac Nally *et al.* 2000; Soderquist & Mac Nally 2000). The more open vegetation structure and larger tree size occurring in gullies is more likely to reflect the pre-European state of these forests (see Newman 1961), but, historically, the landscape was believed to be heterogeneous and ridges and gullies would still have differed from each other in terms of their structure.

Disturbance processes are also important influences on bird assemblages in the Box–Ironbark region. Palmer (1998) found disturbance associated with grazing in Box–Ironbark forest around Rushworth had a significant impact on the structure of vegetation communities, which led to substantial changes in bird assemblage composition. Disturbed sites supported a number of species typical of open country habitats, such as Australian Magpie, Australian Raven and Noisy Miner; conversely, several species showed strong association with undisturbed sites. For example, cover-dependent ground-foraging species, such as White-browed Babbler, Brown Thornbill and Superb Fairy-wren, showed a strong association with complex ground habitats, and were particularly vulnerable to changes in understorey habitat structure, including decreased shrub richness and cover, and decreased grass cover.

The bird assemblages occurring at ‘young’ sites (which were recently subjected to timber removal) and ‘old’ sites (no recent timber removal) in the same EVCs in Box–Ironbark forests maintained a high degree of similarity: across the 31 sites there were clear distinctions for bird assemblages based on location (St Arnaud versus Rushworth), but the distinction between ‘young’ sites and ‘old’ sites in a given forest area was unclear (A.F. Bennett, unpublished data; see Figure 51).

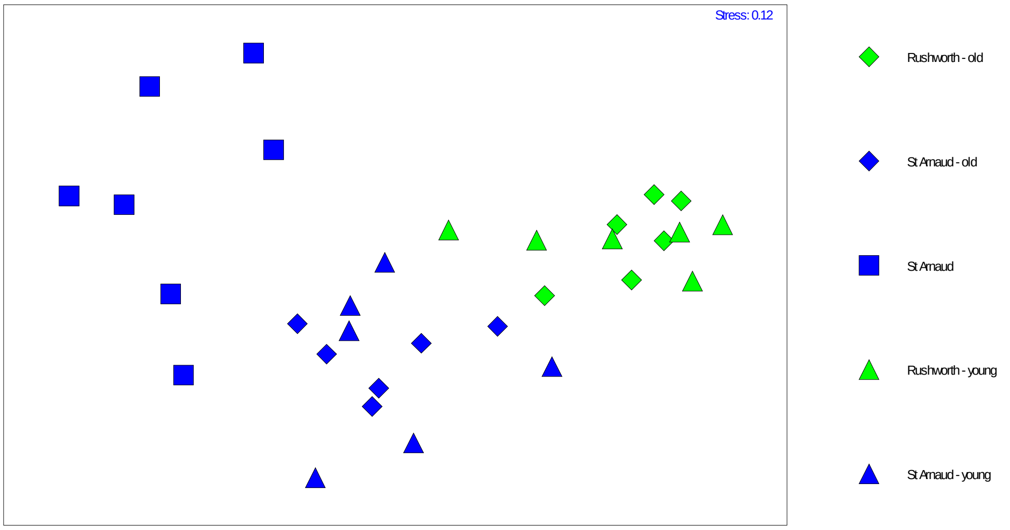

Figure 51. MDS ordination of bird assemblages occurring at 31 sites in Box–Ironbark forest in Victoria (from ARIER, unpublished data).

Table 56. Differences in the scores (based on Habitat Hectare method) for habitat components measured at 12 'old' and 12 'young' sites in Box–Ironbark forest in central Victoria (paired t-tests) (ARIER, unpublished data).

Habitat component	**'Old' sites (mean score)**	**'Young' sites (mean score)**	**t**	**p**
Large trees	9.25	1.42	15.516	**<0.001**
Litter	4.5	4.67	-0.432	0.674
Logs	3.67	4.67	-2.872	**0.015**
Canopy	3.17	4.25	-2.493	**0.015**
Understorey	6.67	7.5	-0.804	0.438

The habitat structure of 'young' and 'old' sites was clearly different (Table 56). 'Old' sites typically supported at least 15 large trees (>70 cm DBH) per hectare, compared with fewer than three large trees per hectare at 'young' sites (numbers derived from EVC 61 Box–Ironbark Forest benchmark; DSE 2009). 'Young' sites generally had greater log cover (10–20 linear m/0.1 ha) than 'old' sites, including some large logs (>35 cm diameter). Canopy cover was greater at 'young' sites (Figure 51). Litter cover and understorey cover and diversity were relatively similar between 'young' and 'old' sites (Table 56). While changes in habitat structure occurred between 'young' and 'old' sites, they did not support distinctly different bird assemblages. The geographic location of the sites appeared to be a stronger driver of the differences in bird assemblages (Table 56).

In the Trial, the influence of geographic location on differences in bird-assemblage composition between Sites could not be distinguished. Assemblages at Paddys Ranges SP differed from those Sites further east (Figure 37) (because Paddys Ranges SP supported Box–Ironbark Forest rather than the Heathy Dry Forest at the other Sites), and it is expected that differences in vegetation community strongly influenced the differences in the bird assemblages.

4.2.3 Response of Box–Ironbark Bird Assemblages to Ecological Thinning

Relationships between bird assemblages and a range of variables, such as floristic (e.g. understorey richness) and structural components (e.g. coarse-woody-debris volume, tree density, shrub cover) of habitats, as well as ant richness, are presented in Table 57. Only significant relationships are presented in these tables. The significance level of $p<0.05$ is used to indicate a significant result, but significance values of $p<0.01$ and $p<0.001$ are highlighted and represent a more stringent level of significance to account for the large number of correlations undertaken (this reduces the risk of spurious results resulting from chance alone). These analyses have been applied to all data (pooled pre- and post-thinning data), as well as separately for both pre- and post-thinning data. These relationships are based on simple linear regression and their interpretation should be treated with caution given the expected autocorrelation between a number of variables in the Trial (see *Floristics* for further explanation).

Many avifauna variables exhibited significant relationships with many habitat variables (Table 57–57). All avifauna variables (assemblage, foraging groups, nesting groups and migrants) were tested against all habitat variables. Only significant positive or negative relationships are presented in Table 57–57; those relationships that have a logical ecological basis are discussed further.

Table 57. Significant correlations between bird variables and habitat variables using all data from the Trial.

Correlations were calculated using the whole dataset (pre- and post-thinning). 'Type' indicates whether the relationship was positive (+) or negative (–). All correlations where calculated at the Plot level (16 Plots × 2 periods).

* = <0.05, ** = <0.01, *** = <0.001.

Bird variable	Habitat variable	Var. (%)	Type	p-value	sig
All species					
Bird species richness	Litter depth	15.0	–	0.028	*
Bird total abundance	Understorey cover	16.4	–	0.022	*
Foraging groups					
Aerial invertebrates (no. of species)	Coarse woody debris (1–10 cm diam.) volume	13.7	+	0.037	*
	Log (>10 cm diam.) volume	18.4	+	0.014	*
	Number of trees with hollows	17.5	+	0.017	*
Aerial invertebrates (abundance)	Coarse woody debris (1–10 cm diam.) volume	14.8	+	0.029	*
	Log (>10 cm diam.) volume	15.8	+	0.024	*
	Tree density	14.1	–	0.034	*
Arboreal granivores (no. of species)	Number of trees with hollows	12.5	+	0.047	*
	Understorey cover	30.3	+	0.001	**
Arboreal granivores (abundance)	Coarse woody debris (1–10 cm diam.) volume	14.9	+	0.029	*
	Log (>10 cm diam.) volume	23.8	+	0.005	**
	Number of trees with hollows	28.2	+	0.002	**
	Understorey cover	56.7	+	0.000	***
	Understorey richness	41.7	+	0.000	***
	Weed cover	43.6	+	0.000	***
Bark invertebrates (no. of species)	Litter cover	14.1	+	0.034	*
	Litter depth	20.5	–	0.009	**
Carnivores (no. of species)	Orchid richness	17.2	+	0.018	*
Carnivores (abundance)	Litter cover	29.1	-	0.001	**
Foliage invertebrates (no. of species)	Litter depth	21.5	-	0.008	**
Foliage invertebrates (abundance)	Litter depth	19.8	-	0.011	*
Ground granivores (no. of species)	Shrub cover	15.5	-	0.026	*
	Understorey cover	13.7	-	0.037	*
Ground granivores (abundance)	Understorey cover	17.4	-	0.017	*
Ground invertebrates (no. of species)	Understorey cover	12.2	-	0.050	*

Bird variable	Habitat variable	Var. (%)	Type	p-value	sig
Ground invertebrates (abundance)	Tree density	19.1	-	0.012	*
Mistletoe (no. of species)	Litter cover	23.5	-	0.005	**
Mistletoe (abundance)	Litter cover	35.0	-	0.000	***
Nectarivores (no. of species)	Litter cover	13.9	-	0.035	*
	Understorey cover	43.2	-	0.000	***
	Understorey richness	18.5	-	0.014	*
	Weed cover	12.7	-	0.045	*
Nectarivores (abundance)	Understorey cover	24.8	-	0.004	**
Number of foraging groups	Ant richness	23.8	+	0.005	**
	Understorey richness	14.3	+	0.033	*
Shrub invertebrates (no. of species)	Shrub cover	12.3	+	0.049	*
Shrub invertebrates (abundance)	Litter cover	13.5	+	0.039	*
Migratory groups					
Migrants (no. of species)	Coarse woody debris (1–10 cm diam.) volume	14.9	+	0.029	*
	Log (>10 cm diam.) volume	14.6	+	0.031	*
	Tree density	19.1	-	0.012	*
Non-breeding migrants (no. of species)	Ant richness	19.2	-	0.012	*
Partial migrants (no. of species)	Litter depth	20.6	-	0.009	**
	Tree density	15.0	+	0.028	*
Partial migrants (abundance)	Understorey cover	15.9	-	0.024	*
Residents (no. of species)	Litter depth	21.4	-	0.008	**
Residents (abundance)	Litter depth	13.5	-	0.038	*
	Tree density	16.0	-	0.023	*
Nesting groups					
Burrow (no. of species)	Litter depth	26.2	-	0.003	**
Burrow (abundance)	Litter depth	23.4	-	0.005	**
	Orchid richness	18.3	+	0.015	*
Canopy foliage (no. of species)	Litter depth	20.1	-	0.010	*
Canopy foliage (abundance)	Understorey cover	13.5	-	0.038	*
	Weed cover	13.6	-	0.037	*
Ground (no. of species)	Litter cover	15.5	+	0.026	*
	Shrub cover	16.6	+	0.021	*
Ground (abundance)	Ant richness	18.7	+	0.014	*
	Litter cover	20.9	+	0.008	**

Bird variable	Habitat variable	Var. (%)	Type	p-value	sig
Ground vegetation (no. of species)	Ant richness	29.0	+	0.001	**
	Coarse woody debris (1–10 cm diam.) volume	33.2	+	0.001	***
	Fallen log (>10 cm diam.) volume	27.8	+	0.002	**
	Tree density	12.9	-	0.043	*
	Understorey richness	13.4	+	0.039	*
Ground vegetation (abundance)	Ant richness	18.3	+	0.015	*
	Coarse woody debris (1–10 cm diam.) volume	44.5	+	0.000	***
	Log (>10 cm diam.) volume	36.9	+	0.000	***
	Litter cover	14.4	+	0.032	*
	Tree density	24.5	-	0.004	**
	Understorey richness	23.6	+	0.005	**
Number of nesting groups	Coarse woody debris (1–10 cm diam.) volume	13.9	+	0.036	*
	Litter depth	25.7	-	0.003	**
Parasitic (no. of species)	Tree density	13.7	-	0.037	*
Parasitic (abundance)	Coarse woody debris (1–10 cm diam.) volume	12.3	+	0.049	*
Tree branch (no. of species)	Litter cover	17.4	-	0.018	*
Tree branch (abundance)	Litter cover	13.8	-	0.036	*
Tree hollow (no. of species)	Shrub cover	16.7	-	0.020	*
	Tree density	13.8	-	0.036	*
	Understorey cover	20.8	-	0.009	**
Tree hollow (abundance)	Shrub cover	25.7	-	0.003	**
Understorey (abundance)	Understorey cover	15.0	-	0.028	*

Table 58. Significant correlations between bird variables and habitat variables using pre-thinning data only.

Correlations were calculated using the pre-thinning data. 'Type' indicates whether the relationship was positive (+) or negative (–). All correlations where calculated at the Plot level (16 Plots × 2 periods).

* = < 0.05, ** = < 0.01, *** = < 0.001.

Bird variable	Habitat variable	Var. (%)	Type	p-value	sig
All species					
Bird species richness	Litter depth	34.5	–	0.017	*
	Shrub cover	25.9	–	0.044	*
Bird total abundance	Litter depth	24.8	–	0.049	*
	Shrub cover	28.4	–	0.034	*
Foraging groups					
Aerial invertebrates (number of species)	Number of trees with hollows	28.8	+	0.032	*
Arboreal granivores (number of species)	Ant richness	36.3	+	0.014	*
	Understorey cover	39.6	+	0.009	**
Arboreal granivores (abundance)	Orchid richness	35.0	+	0.016	*
	Understorey cover	67.4	+	0.000	***
	Understorey richness	62.1	+	0.000	***
	Weed cover	39.6	+	0.009	**
Bark invertebrates (number of species)	Coarse woody debris (1–10 cm diam.) volume	44.3	+	0.005	**
	Log (>10 cm diam.) volume	40.8	+	0.008	**
	Litter depth	34.5	–	0.017	*
Carnivores (number of species)	Litter cover	37.2	–	0.012	*
	Orchid richness	36.1	+	0.014	*
Carnivores (abundance)	Litter cover	36.2	–	0.014	*
	Orchid richness	34.2	+	0.017	*
	Shrub cover	27.4	–	0.038	*
Foliage invertebrates (number of species)	Litter depth	25.7	–	0.045	*
Foliage invertebrates (abundance)	Litter depth	33.5	–	0.019	*
	Shrub cover	34.1	–	0.017	*
Ground invertebrates (number of species)	Ant richness	27.0	+	0.039	*
Ground invertebrates (abundance)	Tree density	40.2	–	0.008	**
Nectarivores (number of species)	Understorey cover	50.6	–	0.002	**
Nectarivores (abundance)	Understorey cover	27.6	–	0.037	*
Migratory groups					

Bird variable	Habitat variable	Var. (%)	Type	p-value	sig
Migrants (number of species)	Coarse woody debris (1–10 cm diam.) volume	36.9	–	0.013	*
	Log (>10 cm diam.) volume	32.7	–	0.021	*
Residents (number of species)	Litter depth	39.2	–	0.009	**
Residents (abundance)	Litter depth	31.4	–	0.024	*
	Tree density	24.9	–	0.049	*
Nesting groups					
Burrow (number of species)	Litter depth	46.8	–	0.003	**
	Shrub cover	39.2	–	0.009	**
	Tree density	25.8	–	0.044	*
Burrow (abundance)	Litter depth	47.0	–	0.003	**
	Orchid richness	31.7	+	0.023	*
	Shrub cover	72.2	–	0.000	***
Canopy foliage (number of species)	Litter depth	29.1	–	0.031	*
	Understorey cover	25.7	–	0.045	*
Canopy foliage (abundance)	Tree density	27.4	–	0.037	*
	Understorey cover	35.8	–	0.014	*
	Understorey richness	35.6	–	0.015	*
Ground (number of species)	Ant richness	52.7	+	0.001	**
Ground (abundance)	Ant richness	39.1	+	0.010	**
	Coarse woody debris (1–10 cm diam.) volume	50.6	+	0.002	**
	Log (>10 cm diam.) volume	48.8	+	0.003	**
	Tree density	31.1	–	0.025	*
Ground vegetation (number of species)	Ant richness	36.3	+	0.013	*
	Coarse woody debris (1–10 cm diam.) volume	32.6	+	0.021	*
Ground vegetation (abundance)	Ant richness	31.9	+	0.023	*
	Coarse woody debris (1–10 cm diam.) volume	39.2	+	0.010	**
	Log (>10 cm diam.) volume	30.4	+	0.027	*
Number of nesting groups	Coarse woody debris (1–10 cm diam.) volume	26.9	+	0.040	*
	Log (>10 cm diam.) volume	27.6	+	0.037	*
	Litter depth	40.2	–	0.008	**
	Orchid richness	31.0	+	0.025	*
	Shrub cover	49.5	–	0.002	**
Tree bole (number of species)	Number of trees with hollows	32.7	+	0.021	*

Bird variable	Habitat variable	Var. (%)	Type	p-value	sig
	Orchid richness	39.8	+	0.009	**
Tree bole (abundance)	Orchid richness	45.5	+	0.004	**
Tree hollow (number of species)	Litter depth	28.6	–	0.033	*

Table 59. Significant correlations between bird variables and habitat variables using post-thinning data only.

Correlations were calculated using the post-thinning data. 'Type' indicates whether the relationship was positive (+) or negative (–). All correlations where calculated at the Plot level (16 Plots × 2 periods).

* = < 0.05, ** = < 0.01, *** = < 0.001.

Bird variable	Habitat variable	Var. (%)	Type	p-value	sig
All species					
Bird total abundance	Ant richness	37.7	-	0.011	*
Foraging groups					
Arboreal granivores (abundance)	Log (>10 cm diam.) volume	36.4	+	0.013	*
	Number of trees with hollows	59.9	+	0.000	***
	Understorey cover	53.7	+	0.001	**
	Understorey richness	37.3	+	0.012	*
	Weed cover	45.8	+	0.004	**
Carnivores (abundance)	Litter cover	35.0	-	0.016	*
Foliage invertebrates (abundance)	Shrub cover	34.0	+	0.018	*
	Tree density	36.4	+	0.013	*
Ground granivores (no. of species)	Shrub cover	31.8	-	0.023	*
	Understorey cover	32.0	-	0.022	*
Ground granivores (abundance)	Ant richness	27.3	-	0.038	*
	Understorey cover	28.8	-	0.032	*
Mistletoe (no. of species)	Coarse woody debris (1–10 cm diam.) volume	28.8	-	0.032	*
	Litter cover	45.3	-	0.004	**
	Tree density	34.8	+	0.016	*
Mistletoe (abundance)	Litter cover	64.2	-	0.000	***
Nectarivores (no. of species)	Litter cover	42.0	-	0.007	**
	Understorey cover	40.2	-	0.008	**
	Weed cover	27.7	-	0.036	*
Nectarivores (abundance)	Ant richness	28.1	-	0.035	*
Shrub invertebrates (no. of species)	Shrub cover	39.8	+	0.009	**
Migratory groups					
Migrants (no. of species)	Canopy openness	33.6	+	0.019	*
	Tree density	34.0	-	0.018	*
Migrants (abundance)	Canopy openness	26.4	+	0.042	*
Partial migrants (no. of species)	Litter depth	35.5	-	0.015	*
	Tree density	28.6	+	0.033	*

Bird variable	Habitat variable	Var. (%)	Type	p-value	sig
Residents (abundance)	Ant richness	31.0	-	0.025	*
Nesting groups					
Canopy foliage (no. of species)	Shrub cover	26.5	+	0.042	*
Canopy foliage (abundance)	Shrub cover	33.1	+	0.020	*
	Tree density	29.1	+	0.031	*
Ground (no. of species)	Ant richness	30.5	+	0.027	*
	Orchid richness	36.4	-	0.013	*
Ground (abundance)	Canopy openness	36.3	-	0.013	*
	Shrub cover	28.5	+	0.033	*
	Understorey cover	26.9	+	0.040	*
Ground vegetation (# spp.)	Coarse woody debris (1–10 cm diam.) volume	26.8	+	0.040	*
Ground vegetation (abundance)	Coarse woody debris (1–10 cm diam.) volume	33.7	+	0.018	*
	Log (>10 cm diam.) volume	26.1	+	0.043	*
	Understorey richness	33.0	+	0.020	*
Tree bole (abundance)	Coarse woody debris (1–10 cm diam.) volume	35.8	-	0.014	*
	Log (>10 cm diam.) volume	35.8	-	0.014	*
Tree branch (no. of species)	Canopy openness	33.5	+	0.019	*
	Litter cover	26.2	-	0.043	*
	Number of trees with hollows	27.5	+	0.037	*
	Orchid richness	25.5	+	0.046	*
Tree branch (abundance)	Orchid richness	35.7	+	0.015	*
Tree hollow (no. of species)	Shrub cover	30.5	-	0.026	*
	Understorey cover	31.5	-	0.024	*
Tree hollow (abundance)	Ant richness	27.8	-	0.036	*
	Number of trees with hollows	33.8	+	0.018	*
	Shrub cover	32.0	-	0.022	*
Understorey (no. of species)	Ant richness	50.9	-	0.002	**
Understorey (abundance)	Ant richness	31.3	-	0.024	*
	Canopy openness	26.2	+	0.043	*

The abundance of aerial invertebrate feeders was negatively correlated with tree density. All aerial invertebrate feeders observed forage in midstorey spaces between trees, mainly below canopy level. It would be expected that forests with gaps and a patchy tree layer would benefit these species. Many of these species, such as White-browed Woodswallow, Grey Fantail and Welcome Swallow, were observed more often after thinning; however, a number of these species are migratory (e.g. woodswallows, flycatchers) and a seasonal effect may have contributed to the higher numbers of individuals and species recorded during post-thinning surveys.

Changes to the ground layer corresponded with changes in birds that utilise ground habitats, including ground-invertebrate feeders, ground granivores, bark-invertebrate feeders, ground nesters and species that nest in ground vegetation (Table 59). The richness and abundance of ground-invertebrate feeders (e.g. Buff-rumped Thornbill, Scarlet Robin and Superb Fairy-wren) showed a strong positive relationship with coarse woody debris (both <10 cm and >10 cm) and understorey richness. This group had a negative relationship with tree density (Table 57). Before thinning, ground-invertebrate feeders showed a strong positive association with ant richness. Ant richness may act as a surrogate for general invertebrate availability, as ants form a component of the diet of some ground-invertebrate foraging species, such as White-winged Chough (Barker & Vestjens 1990).

At a species level, ground-invertebrate foragers showed mixed responses to thinning. Four species recorded in low numbers before thinning (Flame Robin, Eastern Yellow Robin, Speckled Warbler and Painted Button-quail) were not recorded post thinning. Some open-country species (e.g. Rufous Songlark) were recorded only after thinning. Several common species maintained stable numbers (e.g. Buff-rumped Thornbill) or were recorded more often after thinning (e.g. Superb Fairy-wren). Diverse, complex ground layers characterised by patchy, open litter areas and much coarse woody debris are preferred by ground-invertebrate foragers, and their availability is crucial for the ongoing conservation of these species (Palmer 1998; Tzaros 2005; Antos & Bennett 2008).

The richness and abundance of ground-nesting birds (e.g. Chestnut-rumped Heathwren, Speckled Warbler and Spotted Quail-thrush) showed a strong positive relationship with litter cover, particularly in the pre-thinning environment (Table 58). The abundance of this group was positively related to post-thinning shrub and understorey cover (Table 57). Ground-vegetation nesters (e.g. Superb Fairy-wren and Brown Thornbill) displayed a strong positive association with coarse woody debris (both <10 cm and >10 cm) and understorey richness, and a strong negative association with tree density in both pre- and post-thinning environments (Table 58, 57). These guilds of species form part of a suite of birds which is of serious conservation concern in south-eastern Australia (Robinson 1991). Apart from the Buff-rumped Thornbill, Brown Thornbill and Superb Fairy-wren, these species occurred at low abundances throughout the Trial. In light of the habitat changes brought about by thinning (including decreased tree density, and increased litter cover and coarse woody debris), it is probable that habitat suitability should increase for these ground-foraging and ground-nesting birds.

Bark-invertebrate feeders formed a common and widespread component of the Box–Ironbark bird community. The richness of this guild displayed a strong positive relationship with the amount of coarse woody debris (both <10 cm and >10 cm). This relationship was strongest in pre-thinning data (Table 58). The Brown Treecreeper and Grey Shrike-thrush forage extensively among coarse woody debris (Laven & Mac Nally 1998).

The richness of the shrub-invertebrate feeding group was positively related to shrub cover after thinning and when pre- and post-thinning environments were combined. This relationship was driven by the Brown Thornbill, which occurred in greater abundance and at more Sites after thinning. This species mainly forages among shrubs, but also forages widely, and may have benefited from the increased complexity in understorey habitat provided by the retained felled tree crowns and stems. In the early stages of post-thinning recovery, this material provided suitable habitat for species which move through the shrub layer, such as Brown Thornbill and Superb Fairy-wren.

One guild of species of note is the foliage-invertebrate feeders. In post-thinning environments, this guild was negatively associated with tree density (Table 59). Several species that were commonly recorded in pre-thinning surveys at treated Sites (e.g. Spotted and Striated Pardalotes) were recorded at lower abundances after thinning, although they were still relatively widespread; other foliage-invertebrate feeders (e.g. Brown-headed Honeyeater) occurred in similar numbers during both pre- and post-thinning surveys. The removal of substantial canopy volume and reduction in availability of potential foraging substrate is expected have had a negative effect on some of these species.

Ongoing monitoring is required to fully decipher the changes in bird assemblages brought about by ecological thinning, and to determine which habitat features birds are responding to. The massive changes to many components of habitat structure that were brought about by thinning (including changed vertical and horizontal profiles, ground layers and understorey) make deciphering specific relationships difficult at this early stage.

4.3 Ecological Thinning: Response of Mammal Groups

4.3.1 Response of Box–Ironbark Mammals to Ecological Thinning

Thinning operations, among other things, reduced tree density as well as understorey and shrub cover, and increased loads of coarse woody debris and litter. Each of these changes was likely to have an impact on at least some resident mammalian taxa. This is illustrated by the significant correlations between the mammal data (such as overall mammal activity, native mammal activity and *Antechinus* activity) and the environmental parameters of tree density and litter depth before thinning and the lack of such significant associations after thinning. The relationships (linear regressions) between various mammal groups and habitat variables are presented in Table 60; further correlations between mammal and invertebrate parameters are presented in Table 61. For the calculation of correlations, effort was standardised for those survey techniques where there was unequal effort across Sites or Plots, or between pre- and post-thinning survey periods (i.e. spotlight transects and bat detector-nights). These results should be treated with caution given the limitations of the data (see *Future Challenges*).

Overall bat activity (as measured by the mean number of bat passes detected per detector-night, all data) was positively correlated with large coarse woody debris and ant species richness. The activity levels of the bat genera *Vespadelus* and *Chalinolobus* were also significantly positively correlated with large coarse woody debris. The activity of *Vespadelus* and *Chalinolobus*, and that of the White-striped Freetail Bat, were negatively correlated with tree density and, in the case of the White-striped Freetail Bat, understorey cover. Greater activity levels in these bat taxa may point to issues of detectability (thinning may increase the chances of recording bats) or increased levels of foraging, potentially in response to greater numbers of invertebrate prey or a different suite of invertebrates brought on by thinning.

The White-striped Freetail Bat is a large, fast-flying insectivore that typically forages above the forest canopy or in open cleared areas (Churchill 2008). This accounts for its greater activity in study areas with reduced tree density and understorey cover. Although it has been reported that ants form a large component of its diet (Churchill2008), no significant correlation was found in the Trial between the bat's activity and ant species richness.

The activity levels of terrestrial mammals, especially *Antechinus*, and native mammal richness revealed a significant positive correlation with various structural characteristics of the ground strata (litter depth, litter area, shrub cover, understorey cover). *Antechinus* activity, along with total native mammal species richness (from all hair-tubes), also yielded a significant negative relationship with fine litter (coarse woody debris <10 cm), which points to greater dependence on larger components of the litter layer (e.g. pieces >10 cm) by small terrestrial mammals at the Sites.

The number of arboreal mammals recorded during spotlight transects revealed a significant negative relationship with shrub cover (all data and pre-thinning data). This may appear to be an odd result, but the Common Brushtail Possum and the Common Ringtail Possum, the two arboreal mammals that dominated the results in this study, have idiosyncratic diets: the Common Brushtail Possum eats mostly *Eucalyptus* foliage and herbaceous ground species — shrubs are not generally consumed — and the Common Ringtail Possum, while known to consume shrubs, typically restricts its intake to a couple of plant species at any particular locality (Menkhorst 1995).

Regressions were also performed on the activity of insectivorous mammals (all bats, all *Vespadelus* bats, all *Antechinus*, and Brush-tailed Phascogale) and the occurrence of the dominant invertebrate taxa collected during the study (Table 61). While the results are unlikely to truly reflect these associations, because only ground-active invertebrate taxa were targeted, some significant relationships emerged. Overall, bats were positively associated with several invertebrate taxa, namely Hemiptera, ants and arboreal/aerial invertebrates, as well overall invertebrate abundance and the number of invertebrate orders; bats of the genus *Vespadelus* virtually mirrored this pattern. These associations were not surprising, as microchiropteran bats of the Box–Ironbark woodlands in Victoria are all known to feed on various flying and terrestrial invertebrates (Menkhorst 1995; Churchill 2008). However, another take on this association is that both bats and invertebrates generally respond to the environment in much the same way, and there may not be a direct association between these two animal groups.

The Brush-tailed Phascogale was positively associated with abundance of isopods, and overall *Antechinus* activity was negatively associated with ant abundance. *Antechinus* usually take large, soft-bodied prey, yet ants sometimes also feature in their diets; the Agile Antechinus and Dusky Antechinus *A. swainsonii* are closely related to the Yellow-footed Antechinus, and have been reported to eat ants (Statham 1982; Lunney *et al.* 2001). The negative relationship in the Trial may point to different responses to the prevailing environment. Several of the correlations that emerged during this Trial, while mathematically significant, are probably not biologically meaningful. A case in point is the relationship between bats, coarse woody debris and ant species richness: these relationships may either reflect the detectability of bats (coarse woody debris loads are greater in thinned stands) or a surrogate relationship for another habitat parameter (ants are barometers of structural disturbance). Thus, care should be taken in interpreting these results.

Table 60. Correlations between Site habitat parameters and mammal groups, at Plot level.

Where there was unequal survey effort between Plots (*), effort was standardised to recording-rate. Level of significance ($p<0.05$) and % variance accounted for are presented where relevant. Green = positive correlation; orange = negative correlation; significant correlations in bold; white = n/a (i.e. residual variance exceeds variance of response variable).

	Total bat activity *		*Vespadelus* activity *		*Chalinolobus* activity *		White-striped freetail bat activity *		Mammal activity — tree-tubes		Mammal activity — ground-tubes		*Antechinus* activity		Brush-tailed Phascogale activity		Native mammal activity — all hair-tubes		Native mammal richness — all hair-tubes		Total arboreal mammals — spotlight transect *	
All data	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	
Litter area			1.6	0.234			2.7	0.188			10.1	0.052					4.8	0.131				
Litter depth	0.1	0.318											31.5	**<0.001**					4.2	0.148		
CWD <10 cm	1.4	**0.244**			3.7	0.157															16.8	**0.011**
CWD >10 cm	28.7	**0.001**	25.4	**0.003**	24.8	**0.003**															10.2	**0.042**
Tree density	28.4	**0.001**	14.1	**0.023**	35.5	**<0.001**	18.5	**0.01**					1.3	0.254	7.3	0.085			4.2	0.146	1.3	0.247
No. trees with hollows							5.9	0.105														

	Total bat activity *		*Vespadelus* activity *		*Chalinolobus* activity *		White-striped freetail bat activity *		Mammal activity — tree-tubes		Mammal activity — ground-tubes		*Antechinus* activity		Brush-tailed Phascogale activity		Native mammal activity — all hair-tubes		Native mammal richness — all hair-tubes		Total arboreal mammals — spotlight transect *	
All data	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	
Understorey cover					4.6	0.133	22.4	**0.005**			7.5	0.082	2.8	0.189			9.6	0.056	32.4	**<0.001**	1.9	0.216
Shrub cover	0.2	0.311			2.1	0.212							10.8	**0.045**					6.2	0.103	13.9	**0.02**
Understorey richness											0.3	0.309							5.4	0.118		
Ant species richness	24.3	**0.003**	17.6	**0.012**	18.5	**0.01**	0.5	0.296			1.6	0.24	7	0.089								
Pre-thinning																						
Litter area											12.1	0.132	20.5	0.068			17.1	0.089	12.2	0.13		
Litter depth	8.7	0.16	9.8	0.146							31.5	**0.027**	77.2	**<0.001**			36.6	**0.017**	17.4	0.087	14.4	0.081
CWD <10 cm	1.5	0.296	4.8	0.222	6.3	0.197					22.3	0.059	40.9	**0.011**			33.4	**0.023**	33.9	**0.022**		
CWD >10 cm	0.2	0.332	1.9	0.284																		
Tree density					30.9	**0.023**	4.5	0.228			32.9	**0.024**	1.4	0.303	8.8	0.17	17.8	0.084	39.7	**0.012**		

	Total bat activity *		*Vespadelus* activity *		*Chalinolobus* activity *		White-striped freetail bat activity *		Mammal activity — tree-tubes		Mammal activity — ground-tubes		*Antechinus* activity		Brush-tailed Phascogale activity		Native mammal activity — all hair-tubes		Native mammal richness — all hair-tubes		Total arboreal mammals — spotlight transect *	
All data	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	
No. trees with hollows	21.8	0.053	25.3	0.038					0.4	0.329											0.9	0.303
Understorey cover	4.9	0.22	10.3	0.14			2.0	0.282			13.5	0.118					5.2	0.225	16.8	0.092		
Shrub cover	0.8	0.314	5.4	0.211							24.5	**0.049**	30.2	**0.03**			31.7	**0.026**			28.2	**0.02**
Understorey richness					2.6	0.27	19.5	0.064													9.1	0.136
Ant species richness					7.9	0.172	5.2	0.214														
Post-thinning																						
Litter area							15.1	0.076			30.1	**0.016**	40.5	**0.005**			32.2	**0.013**	16.4	0.067		
Litter depth											12.8	0.095					3	0.247			0.1	0.331
CWD <10 cm	13.3	0.091	3.9	0.224	11.2	**0.111**															23.3	**0.033**
CWD >10 cm	0.8	0.308			2.1	0.268							3.7	0.23							2.3	0.265
Tree density					6.3	0.178	8.5	0.144														
No. trees with hollows							9.6	0.13									22.1	**0.038**	10.7	0.117		

	Total bat activity *		*Vespadelus* activity *		*Chalinolobus* activity *		White-striped freetail bat activity *		Mammal activity — tree-tubes		Mammal activity — ground-tubes		*Antechinus* activity		Brush-tailed Phascogale activity		Native mammal activity — all hair-tubes		Native mammal richness — all hair-tubes		Total arboreal mammals — spotlight transect *	
All data	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	F pr.	Variance accounted for (%)	
Understorey cover	5.3	0.197			12.4	0.099	36.4	**0.008**			4.1	0.222	12.8	0.095			8	0.151	38.8	**0.006**	12.2	0.101
Shrub cover					11.4	0.109													4.9	0.204	9.4	0.132
Understorey richness																			13.5	0.089		
Ant species richness																					12.8	0.095

Table 61. Correlations between mammal and invertebrate groups, at the Plot level (all data).

Where there was unequal survey effort between Plots (*), effort was standardised to recording-rate. Level of significance and % variance accounted for are presented where relevant. Green = positive correlation; orange = negative correlation; significant correlations in **bold**.

Invertebrate taxa	**Total bat activity***	***Vespadelus* activity***	***Antechinus* activity**	**Brush-tailed Phascogale activity**
Araneae	n/a	n/a	p=0.244, 1.5%	n/a
Acarina	n/a	n/a	n/a	n/a
Isopoda	n/a	p=0.171, 3.2%	p=0.296, 0.5%	**p=0.003, 26.5%**
Collembola	n/a	n/a	n/a	n/a
Coleoptera	n/a	p=0.316, 0.1%	n/a	n/a
Orthoptera	p=0.28, 0.7%	p=0.216, 2.0%	p=0.083, 7.4%	n/a
Hemiptera	**P=0.002, 27.8%**	**p=0.005, 22.5%**	p=0.183, 3%	n/a
Hymenoptera	p=0.165, 3.4%	p=0.055, 9.4%	p=0.055, 9.8%	n/a
Hymenoptera (ant)	**p=0.002, 26.2%**	**p=0.002, 28.1%**	**p=0.026, 13.9%**	n/a
Ordinal richness	**p=0.012, 17.6%**	**p=0.004, 23.4%**	p=0.265, 1%	p=0.287, 0.6%
Total number of invertebrates	**p=0.006, 21.3%**	**p=0.039, 11.2%**	p=0.293, 0.5%	n/a
Total arboreal/aerial invertebrates	**p=0.023, 14.2%**	**p=0.01, 18.7%**	p=0.042, 11.3%	n/a

4.3.2 Data from Independent Projects

Vertebrate and habitat data were collected in the 1990s using comparable survey methods to the Trial from 35 sites in two EVCs (Box–Ironbark Forest, Heathy Dry Forest) across the Box–Ironbark region of central Victoria (ARIER, unpublished data). Correlations (simple linear regression) between these vertebrate groups (bats, terrestrial mammals) and select habitat variables are presented in Table 62.

The importance of tree hollows for a large proportion of south-eastern Australia's bat assemblage is well-established (Gibbons & Lindenmayer 2002; Gibbons *et al.* 2002; Churchill 2008). Bats (abundance, species richness) showed a significant positive relationship with the number of tree hollows or number of shrub species; neither of these relationships was found to be significant in the Trial, suggesting between-site variability in these habitat features. The frequency of occurrence of tree hollows at the Sites may be of limited importance if the Sites are used by bats simply for foraging; the landscape context of the Sites as well as the proportion of trees with hollows at each Site will clarify the value of the Sites for bats.

Limited information was obtained from the analysis of the hair-tube data: the number of individual mammals was positively correlated with canopy cover. This may reflect the density or age of the overstorey trees, both of which influence the occurrence of terrestrial mammals (Lindenmayer *et al.* 1990; Scotts 1991; Alexander *et al.* 2002).

Analysis of the spotlighting data in Table 62 (which includes all diurnal and nocturnal vertebrate species recorded during the transect surveys) reveals a significant positive correlation between total number of individuals and both grass cover and number of tree hollows; superficially, this suggests the importance for vertebrates of within-site structural variability and advanced succession characteristics (e.g. tree hollows).

Other data-sets provide information on the relationships between vertebrate fauna and habitat characteristics of the Box–Ironbark ecosystem, and these could potentially inform the Trial. These data-sets include:

- Box–Ironbark habitat fragmentation study (Monash University) (Mac Nally & Bennett 1997; Deacon & Mac Nally 1998; Mac Nally 1999; Mac Nally & Brown 2001; Mac Nally & Horrocks 2002a; Mac Nally *et al.* 2002a)
- Box–Ironbark ground-layer disturbance study (ARIER) (Brown 2001)
- Box–Ironbark Ecological Vegetation Class survey (ARIER) (unpublished data)
- Tree hollows of Box–Ironbark forests (DSE) (Alexander 1997; Soderquist 1999)
- Mesic gullies and arboreal mammals in Box–Ironbark forests (DSE; Monash University) (Mac Nally *et al.* 2000; Soderquist & Mac Nally 2000)
- Monitoring vertebrate diversity and abundance in ‘advanced’ Box–Ironbark woodland (ARIER) (Brown *et al.* 2003)
- Mammals, coarse woody debris and large old trees in Box–Ironbark woodlands and River Red Gum floodplain communities (Monash University) (Lada *et al.* 2008)
- Reptile occurrence in relation to environmental/habitat characteristics (ARIER) (Brown *et al.* 2008)

Table 62. Correlations between habitat variables and select vertebrate groups for Box–Ironbark Forest (24 sites) and Heathy Dry Forest (11 sites) in central Victoria (ARIER, unpublished data).

Level of significance ($p<0.05$) and % variance accounted for are presented where relevant. Green = positive correlation; orange = negative correlation, blank = n/a; significant correlations in **bold**.

	Total reptiles	No. of reptile species	Bat individuals (bat-trap)	No. of bat species (bat-trap)	Mammal activity (hair-tubes)	No. of mammal species (hair-tubes)	Spotlight individuals	Spotlight species
Litter depth								
Log volume					p=0.131, 0.1%			
Mean tree height			p=0.208, 1.9%				p=0.276, 0.7%	**p=0.037, 9.9%**
No. shrub species			**p=0.016, 13.9%**					
Bare ground % cover		p=0.195, 2.2%						
Coarse litter % cover								
Fine litter % cover	p=0.079, 6.3%	p=0.213, 1.8%						
Grass % cover	p=0.16, 3%	p=0.103, 5.1%					**p=0.031, 10.7%**	
Low shrub % cover	**p=0.03, 10.9%**	**p=0.007, 17.7%**						
High shrub % cover	p=0.124, 4.2%	p=0.139, 3.7%		p=0.173, 2.7%		p=0.267, 0.8%		
Canopy cover				p=0.141, 3.6%	**p=0.015, 14%**		p=0.237, 1.3%	p=0.115, 4.5%
No. large trees			p=0.299, 0.3%	p=0.208, 1.9%	p=0.148, 3.4%			
Total no. trees			p=0.253, 1%	p=0.109, 4.8%				
Total no. hollows			**P=0.001, 24.6%**	**p=0.011, 15.4%**			**p=0.015, 14.1%**	p=0.129, 4%

4.4 Ecological Thinning: Response of Key Invertebrate Functional Groups

4.4.1 Ordinal Response to Thinning

Significant correlations were found between various habitat features and invertebrates (at the order level: number of orders, total abundance, and abundance of individual orders) and ants (ant species richness and ant total abundance) (Table 63): litter depth was significantly correlated with seven invertebrate groups; coarse woody debris <10 cm with three invertebrate groups; coarse woody debris >10 cm with six invertebrate parameters; understorey cover with five invertebrate groups; and understorey richness with four invertebrate parameters. Surprisingly, for ants (despite the large number of species), there were no significant correlations except ant abundance and coarse woody debris >10 cm.

The results indicate that for some invertebrate orders, the structure of the ground layer (litter area, litter depth and coarse woody debris) provided suitable habitat. Understorey cover and richness may influence ground-layer invertebrates through provision of shade and shelter, but it can also be an important source of leaf litter and coarse woody debris.

Table 63. Significant correlations of invertebrate and environmental data from the Trial.

	Litter area	Litter depth	CWD < 10 cm	CWD > 10 cm	Understorey cover	Understorey richness
Order richness				p<0.001		p=0.027
Scorpions		p<0.001		p=0.024		
Araneae		p=0.006	p=0.03		p=0.001	
Pseudoscorpions		p=0.012				
Acarina		p=0.002		p=0.043	p<0.001	p=0.005
Isopoda		p=0.034			p=0.004	
Chilopoda	p=0.004			p=0.002	p<0.001	p<0.001
Dermaptera				p=0.036	p<0.001	p=0.041
Coleoptera		p=0.028				
Diptera			p<0.001			
Ant richness						
Ant abundance				p=0.035		
Hymenoptera (not ants)			p=0.05			
Larvae		p=0.027				

There were significant correlations between some invertebrate data and some bird data. Significant correlations included: total number of individual invertebrates with total bird species (p = 0.016); total number of ants with total individual birds (p = 0.002), total bird species (p = 0.003), and abundance of insectivorous birds (p = 0.033); numbers of cockroaches (Blattodea) with total individual birds (p = 0.018); numbers of bugs (Hemiptera) with total individual birds (p = 0.01) and total bird species (p = 0.014); numbers of ants with total individual birds (p = 0.002), total bird species (p = 0.002) and abundance of insectivorous birds (p = 0.046); and number of non-ant Hymenoptera with total individual birds (p=0.034) and abundance of insectivorous birds (p = 0.0017).

It is not feasible to consider correlations of invertebrates with bird factors as cause and effect. Pitfall trapping concentrated on ground-dwelling invertebrates, and a large proportion of the birds either feed on foliage/bark-dwelling invertebrates or resources other than invertebrates. Invertebrate numbers and bird data may have been responding to other environmental factors.

This study was limited to assessing possible pre- and post-thinning treatment effects on ground-dwelling invertebrates of Box–Ironbark forests in central Victoria. Representatives of 26 invertebrate orders were collected by pitfall trapping, but the samples were dominated by six orders: ants (Hymenoptera); springtails (Collembola); mites (Acarina); beetles (Coleoptera); spiders (Araneae); and flies (Diptera). However, for reasons already outlined, neither springtails nor flies are suitable as indicators for this project, and mite identification is difficult. Hence, the emphasis here is on ants, spiders and beetles. As ants dominated the fauna (around 70–80% of total individuals at most sites, if springtails are excluded), they are the most obvious group to identify to species (morphospecies). Over 100 species of ants were collected.

4.4.1 Response of Ants to Thinning

With regard to ants, there are a few conclusions that can be drawn from the Trial:

Ground-active fauna sampled by pitfall trapping was dominated by ants, spiders and beetles. While other orders, such as springtails and flies, occurred in large numbers, analysis of the catches in pitfall traps should be interpreted carefully .

- Ants dominate the ground-active invertebrate fauna of the Box–Ironbark forests in terms of both species richness and relative abundance.
- Ant species richness is not a good indicator for the thinning treatment, even though >100 species were collected: it is probably too dependent upon the season of sampling and the weather conditions at the time of sampling. This could be overcome if there were more frequent periods of sampling each year, but it is unlikely that ant species richness would increase dramatically with further sampling.
- Ant relative abundances are affected by the same factors that influence ant species richness.
- Ant species composition could be an indicator of treatment. Ants are diverse, but their relative abundances were generally highly skewed in the samples taken between 2004 and 2007. Differences in composition were found across Sites and Plots, and these may reflect changes in the longer term. When ants are considered as a functional group, there is little difference between pre- and post-thinning samples. This may be due to the long history of disturbance in these forests, as the samples had a high proportion of Opportunist and Generalist Myrmecine species that flourish in disturbed environments. As the forests mature and the effects of disturbance diminish, a reduction in the dominance by Opportunist species such as *Rhytidiponera* sp. 1 as well as a less-skewed relative abundance in the ant fauna would be expected. Likewise, as the treated Plots age, a greater proportion of Cryptic and Climate specialist species would be expected.
- Based on ant functional groups, the fauna of Box–Ironbark forests is intermediate between the dry Mallee fauna and the fauna of wet open forests. However, the ants of the Box–Ironbark forests seem to be more structured by competition from the Dominant Dolicherine ants (*Iridomyrmex*). Hence, the effect of habitat structure on these Dominant Dolicherine ants will probably determine the future composition of the ant fauna as the forests become older and more structurally complex.
- While spiders and beetles occurred in lower numbers than ants, it is important that they be retained for future comparisons. There is potential to classify spiders and beetles into functional groups, as was undertaken with the ants.

There were several significant correlations between ordinal and ant data and environmental factors. These included significant correlations with litter area, litter depth, coarse woody debris (both <10 and >10 cm), understorey cover and richness. The number of invertebrate orders whose abundance was correlated with litter or coarse-woody-debris factors indicates the importance of these ground elements for invertebrates. Management of these factors, either through harvesting or fire, could have a significant effect on the development of the ground-dwelling invertebrate fauna, and this requires careful management.

There appears to be no data on the nature of invertebrates associated with large coarse woody debris in Victorian Box–Ironbark forests, though the importance of coarse woody debris as habitat for invertebrates and its influence on their diversity and abundance is well documented (Grove 2002; Hanula *et al*. 2006). However, information on coarse woody debris as habitat for invertebrates in Australia is primarily based on subtropical rainforests in Queensland or wet eucalypt forests in Tasmania.

Coarse woody debris represents an important food source and habitat in itself, but it has the potential to influence the immediate surrounding environment both as a physical entity on its own (as a barrier to organic matter and water movement, providing shelter inside, beneath or nearby), and as a source of soil nutrients during decomposition. Some soil-dwelling invertebrates, such as the Tasmanian Stag Beetle *Lissotes latidens*, rely on the area between large coarse woody debris and the soil for their survival (Meggs & Munks 2003).

The amount and nature of coarse woody debris is important. Yee *et al.* (2006) reported that the composition of saproxylic beetle assemblages in large-diameter logs differed from those inhabiting smaller-diameter logs. This was attributed to the presence of brown rotted heartwood in large-diameter logs that provided a stable microclimate. The presence of coarse woody debris maintains invertebrates involved in ecosystem functions, such as decomposition of organic matter, and these invertebrates are an important food source for other invertebrates and for vertebrates. Larger coarse woody debris would be expected to maintain larger-bodied invertebrates (especially the immature stages of saproxylic beetles), and these are likely to form an important food item for insectivorous mammals.

Coarse woody debris cannot be considered outside the landscape context. Firstly, the moist gullies are more important to mammals than drier ridges in Box–Ironbark forests because their accumulated runoff encourages the presence of more large trees (Soderquist & Mac Nally 2000). It is important to determine whether the gully and ridge environments support different invertebrate faunas. Secondly, fragmentation of forests can affect the composition of the invertebrate fauna; the distance between remnants of forests are important in determining the ability of log-dependent invertebrates to disperse successfully (Schmuki *et al*. 2006).

This project was based solely on ground-dwelling invertebrates, and if a holistic approach is required, then canopy-dwelling species and decomposers (mainly termites and oecophrid moths) should be considered. Oecophorid moths are the main decomposers of dead eucalypt leaves, and as the litter layer develops, the relationships between leaf decomposers, other ground-dwelling invertebrates and fire will become more important.

5 PROJECTED CHANGES IN BOX–IRONBARK ECOSYSTEMS FOLLOWING ECOLOGICAL THINNING

The preceding sections of this report have described the changes that have occurred for a range of biodiversity and habitat variables soon after thinning. This section of the report discusses the changes that are predicted to occur as time increases since the thinning operations. To provide a context for the predictions, an extensive literature search was undertaken.

5.1 Forest Structure

The impact of thinning on overall potential growth at a forest scale has been well documented for a range of forest types throughout the world (e.g. Australia [Connell *et al.* 2004]; Europe [Canellas *et al.* 2004]; and USA [Latham & Tappeiner 2002]). At the tree level, thinning will probably lead to an increase in the canopy size of individual trees (see also *Floristics*, below). This could be influenced by the size and proximity of other retained trees; in the Trial, the proximity of retained trees was different in the three treatment types. The growth rates of eucalypts differ between species, and therefore the level of change in the size of tree may be an interaction between thinning and species composition at the Plot scale.

Numbers of trees (i.e. stems) may increase due to recruitment and surviving coppicing (post-coppice management), but this effect will be reduced if the coppice regrowth resulting from the thinning operation is removed. Patchy 2 Plots are most likely to show the least growth because they exhibit the highest level of patchiness, lowest stem/basal area reduction and, therefore, the lowest level of canopy openness.

Prediction: Thinning will lead to an immediate decrease in canopy cover (which slowly increases over time) but has little impact in the short- to medium-term (post thinning) on stem density or distribution of overstorey trees. This will depend on the management of coppice regrowth as, if allowed to continue to grow, it would be expected to suppress growth and lead to increased stem density.

Although it is too soon to provide empirical evidence, it is likely that thinning will stimulate slow growth, depending on the treatment and, to a lesser extent, Site. Position in the landscape may also be important for increased levels of growth at an individual tree level, where access to resources such as moisture can be a limiting factor. This is evident in the field, where large trees occur along ephemeral drainage lines (e.g. Isolated Plot at Spring Plains NCR). Plot size may be large enough to account for the impact of this factor. As previously stated, the localised impact of thinning at species level is unknown but it could be a factor in the long-term.

Prediction: Thinning will lead to a slow increase in the stem diameter (and basal area) of overstorey trees in the short- to medium-term. Increases in stem diameter are expected to be influenced by the level of retention of surrounding stems and therefore should differ between the Isolated Plots and those remaining as part of a clump (i.e. Patchy 1 and Patchy 2 Plots).

The availability of hollow-bearing trees in the Box–Ironbark forests of Victoria is considered to be significantly lower than it was before European settlement and is likely to be a significant limiting factor for species that require hollows for breeding (Traill 1991, 1993; Soderquist 1999). A low proportion of trees with hollows recorded during the Trial, probably because most trees were <40 cm DBHOB (Soderquist 1999). This finding accords with other assessments on the availability of hollows suitable for fauna in Box–Ironbark forests (Bennett 1993; Traill 1993; Soderquist 1999; Adkins *et al.* 2005). Hollow development in eucalypts is associated with tree age, with older trees supporting more and larger hollows (Gibbons & Lindenmayer 2002). Large hollows, which are important for Box–Ironbark fauna, including Powerful Owl, Barking Owl and arboreal mammals, are associated with large trees (Gibbons & Lindenmayer 2002). In Box–Ironbark forest in the Warby Ranges SP, the formation of hollows in forest subject to fire was investigated: tree size rather than fire was found to be the major determinant of the occurrence of hollows, although this may be influenced by time since the forest was burnt or the intensity of the fire (Adkins *et al.* 2005). The potential development of large trees in Box–Ironbark forests as a result of ecological thinning will be important for these species, and it is expected that such development should be associated with increasing availability of large hollows at thinned sites over many decades.

Differences between species in the formation and development of hollows could lead to future differences in the availability of hollows , potentially overriding any influence of thinning treatment. However, the impact of thinning on species distribution and species level autecology was not the primary focus of the Trial.

Unknown: The effect of ecological thinning on the development of tree hollows in Box–Ironbark forest is largely unknown. The potential development of larger tree sizes as time progresses after thinning would be expected to be associated with an increase in the availability of hollows, including large hollows.

5.2 Floristics

The degree to which thinning affects the understorey environment (and hence drives species change) differs substantially depending on forest type. In forests dominated by conifers in the Northern Hemisphere, thinning leads to a large increase in the amount of light reaching the light-limited understorey, causing pronounced (although variable) increases in the cover of herbaceous species, particularly grasses (McConnell & Smith 1970; Alaback & Herman 1988; Thomas *et al.* 1999; Dodson *et al*. 2007), and promoting flowering in the understorey (Lindh 2008). The differences in the understorey between thinned and unthinned treatments then disappear over time as the canopy density increases (He & Barclay 2000). In temperate deciduous forests, seasonal change in canopy is a confounding influence that is superimposed over the longer-term changes in canopy structure. In those ecosystems, forest herbs that sprout and mature before the cover of the canopy increases may show little response to gaps in the canopy because the ambient conditions during their lifecycle may not be substantially altered (Collins *et al.* 1985). Changes may be complex and unpredictable in these broadleaved forests, with the same species showing both increases and decreases in response to thinning at different sites (Götmark *et al.* 2005).

In Australia, however, the canopies in eucalypt forests are persistent but often open, with more light reaching the understorey, reducing the need for understorey species to be particularly shade-tolerant (Kirkpatrick 1997). The nature of the canopy is associated with increasing water stress, as foliage projective cover of the overstorey tends to decline from humid to arid zones (Specht 1972; Specht & Morgan 1981). Box–Ironbark and Heathy Dry forest canopies are relatively open, so that understorey species may not be light-limited, and changes to the understorey following increased light penetration might be substantially less than that noted in denser or drier forest types. However, little is known about the effects that ecological thinning might have in these forests.

In herb-rich communities, competition between plants in the understorey can be a major factor driving species diversity (Grime 1973), although small-scale facilitating interactions between trees and herbaceous species may also be important (Vetaas 1992). ‘Competitive’ species, which often possess rapid growth rates, a tall stature and a rhizomatous or tussock structure, can dominate in low-stress environments, leading to reductions in species diversity

(Grime 1973). However, in higher-stress environments, the competitive ability of dominant species might decline, allowing species of lower competitive ability to survive. The soils underlying many Box–Ironbark forests are shallow and stony, with low water-holding capacity (Muir *et al.* 1995), and could be considered to represent a higher-stress environment, leading to an open, sparse ground layer. However, at Spring Plains NCR, the high cover of tussock grasses and high numbers of perennial herbs suggest that this Site might be a lower-stress environment than the other Sites. If different conditions have contributed to different pre-thinning floristic composition between Sites, then changes in the competitive or facilitative interactions between both understorey and overstorey plants as a result of thinning may also differ. Fortunately, the methods chosen for understorey assessments are sufficiently robust to ensure that most changes will be able to be detected at a useful scale, whether that is at a community, life form or species level.

Prediction: changes in floristic composition and cover are likely to differ across the four Sites, and future analyses should carefully examine changes at the species scale as well as the community scale.

At a broad community level (depending on site conditions), a reduction in the foliage projective cover of the overstorey may be compensated by an increase in the cover of the understorey, as the cover of the two strata in many forest types tend to be inversely related (Specht & Morgan 1981). Previous research suggests that the grassy layer is particularly responsive to change. For example, tree thinning in Narrow-leafed Ironbark *Eucalyptus crebra* woodland in Queensland resulted in a significant increase in herbage biomass (Walker *et al.* 1986). Similarly, thinning in Bimble Box *E. populnea* shrub woodlands led to increasing yields of herbage biomass (Walker *et al.* 1972), as it did in Mulga *Acacia aneura* scrub (Beale 1973), while eucalypt sites in central Queensland produced higher pasture yields when tree basal area was lower (Scanlan & Burrows 1990). The difference between high- and low-basal area sites was more pronounced at sites of lower productivity. In mixed *Eucalyptus* communities in central Queensland, sites with lower tree-basal area had increased amounts of grasses such as Black Spear-Grass *Heteropogon contortus* and Kangaroo Grass *Themeda triandra* than sites with higher tree-basal area (Scanlan & Burrows 1990), while sites in plantations of Flooded Gum *Eucalyptus grandis* had higher cover of grass under a more severe thinning treatment (Cummings *et al*. 2007).

A thinner canopy cover may, however, not always lead to greater grass cover. For example, grass-dominated herbaceous layer productivity in a semi-arid savanna in Kenya was greater under tree canopies (Belsky *et al.* 1989). Similarly, in a Flooded Gum plantation in Queensland, the yield of Paspalum *Paspalum notatum* was higher from the sward under the trees than in the open (Wilson *et al.* 1990). These conflicting examples suggest that changes are species specific, and that thinning might lead to changes in the species composition of grasses, depending on individual habitat preferences. In open Silvertop Stringybark *Eucalyptus laevopinea* forest in northern New South Wales, Weeping Grass *Microlaena stipoides* was dominant beneath mature forest canopy, while Purple Wiregrass *Aristida ramosa* (and to a lesser degree Grey Tussock-grass) was dominant in large open spaces (Gibbs *et al.* 1999). Similarly, the abundance of Weeping Grass was significantly correlated with higher tree density in paddocks (Magcale-Macandog & Whalley 1994). Local frequency and site occurrence of Wallaby Grass *Austrodanthonia racemosa* were both positively correlated with increasing tree cover, as was site occurrence of Smooth-flower Wallaby Grass A*ustrodanthonia pilosa* (Scott & Whalley 1982). Given that grasses tend to flower in summer, making identification difficult in spring, occasional summer surveys may need to be undertaken to determine if thinning leads to changes in the composition of non-tussock grasses.

Data from Grassy Dry Forest (with a grassy layer most similar to Spring Plains NCR) suggest that the cover of *Joycea*-dominated perennial tussock grasses is independent of canopy cover when within the 'normal' range encountered (ARIER, unpublished data), but this does not preclude changes under thinning. For example, *Poa*, which is highly successful in grasslands, might increase at the expense of *Joycea* after the canopy cover has been thinned. Further, observations by early explorers suggested that Box–Ironbark forests were originally open, with a highly diverse grassy or shrubby understorey (Calder *et al*. 1994). This suggests that the thinning treatment may have a positive effect on overall grass cover.

Prediction: Total cover of perennial tussock grasses may increase slightly in Isolated Plots. Poa and overall grass cover is likely to increase in Patchy Plots, at the expense of Joycea, especially at Spring Plains NCR. Composition of currently minor, non-tussock-forming grasses may change with thinning, with, for example, a reduction in Microlaena.

Factors that drive the abundance and richness of grasses will also combine to drive the abundance and richness of other herbaceous species. In a semi-arid savanna in Kenya, increased species diversity was found away from the shelter of the canopies of trees (Belsky *et al.* 1989). In Silvertop Ash forest in Victoria, thinning promoted the abundance of herbaceous species, particularly Raspwort *Gonocarpus teucrioides*, although there were no significant changes in total understorey cover, species richness, species diversity or guild diversity (Bauhus *et al.* 2001). Tree thinning in Narrow-leafed Ironbark woodland in Queensland resulted in a significant increase in the biomass of herbage and density of forbs (Walker *et al.* 1986). In contrast, maximum forb richness in a Flooded Gum plantation was associated with greater canopy cover (Cummings *et al*. 2007).

Kirkpatrick (1997) commented on the strong differentiation in floristic composition in eucalypt forests depending on the distance from trees. This distance might vary depending on forest type, as the extent of the root zone (hence, the suppression zone) in relation to the canopy is often greater in dry areas than in wet areas. However, herbaceous species in the suppression zone seem to be less affected than shrubs, suggesting rooting depth is a major factor.

Microsite conditions are also important. Many of the winter-flowering orchids prefer moister conditions, often under tree cover, and might respond negatively to thinning, while spring-flowering species that often prefer drier conditions might respond positively (M. Duncan, ARIER, pers. comm.). A thinning treatment that leads to a patchy mosaic is likely to be preferable to one that uniformly reduces the canopy and thereby consistently favours one suite of species over another. It may be necessary to conduct occasional, systematic winter surveys to detect potential changes in winter-flowering species.

Limited observations from the Trial suggest that the cover-abundance of annual herbs increased more in thinned Plots than in control Plots. Flowering of some perennial forbs was also greater in thinned Plots, and this may contribute to future increases in abundance.

Prediction: Thinning will increase the abundance of perennial and annual herbs within the thinned Plots, e.g. Black’s Goodenia and spring-flowering orchids such as Caladenia, Calochilus, Diuris and Glossodia. Winter flowering orchids such as Pterostylis, Corunastylis, Acianthus and Cyrtostylis may be disadvantaged within thinned Plots.

Opportunistic species such as weeds are likely to be favoured at some Sites, at least in the early years of the Trial. For example, clearfelling in wet and dry forests in Tasmania (in the absence of slash-burning) led to substantial invasion by introduced herbs (Dickinson & Kirkpatrick 1987), while soil disturbance associated with the thinning of Mountain Ash forest led to an initial, abrupt increase in ruderal and weed species (Peacock 2008). In the Trial, increases in weeds were noted at Spring Plains NCR, where moister conditions appear to have led to a higher cover of weeds than at other Sites, and at Pilchers Bridge NCR, where high cover of Large Quaking-grass and hair-grass were observed under the protective cover of dense thinning debris. This protective effect should diminish over time as the foliage and small branches on the felled crowns rot away. Weeds are not usually a major feature of dry Box–Ironbark forests, but should, nonetheless, be carefully evaluated in future analyses, particularly at Spring Plains NCR.

Prediction: Short-term increases in annual weed grasses such as quaking-grass, silver-grass Vulpia and hair-grass may occur, especially in Plots where debris is retained after thinning. Herbaceous weeds such as chickweed Cerastium may also increase in 'run-on' zones.

The suppression zone resulting from tree roots may extend well beyond the canopy (Incoll 1979; Rotheram 1983; Lamont 1985), and shrubs and overstorey regrowth appear to be suppressed mostly by root competition for water in this zone rather than by other factors. However, responses may also be species-specific, making it difficult to predict structural or floristic changes. For example, in semi-arid Bimble Box woodland in New South Wales, shrubs such as Wilga *Geijera parviflora* and Turkey Bush *Myoporum deserti* grew beneath the canopy, while Mulga and Desert Cassia *Cassia nemophila* grew away from the canopy (Harrington *et al.* 1981). In mixed *Eucalyptus* communities in central Queensland, sites with lower tree basal area had fewer native legumes or broad-leaved plants than sites with higher tree basal area (Scanlan & Burrows 1990). In a plantation of Flooded Gum, the cover, density and richness of shrubs and woody climbers were lowest in plots with the least canopy cover (Cummings *et al*. 2007), suggesting regeneration in these species was more vigorous under a closed canopy.

Anecdotal evidence from early explorers suggested that the shrub layer in the original Box–Ironbark forest was well developed, under widely spaced trees (Calder *et al*. 1994). Given this implied negative association between tree and shrub density, extant shrubs are likely to respond positively to thinning in these forests, particularly at Sites with rocky areas and less grass cover. Casual observation during the Trial has suggested that shrubs such as Grey Everlasting flowered more profusely in some thinned Plots, which is likely to increase the number of seeds in the soil seed bank. However, germination cues are important, making it difficult to predict the rate at which changes may occur. For example, Spreading Wattle *Acacia genistifolia*, Golden Wattle and Kangaroo Thorn *A. paradoxa* all germinate in response to heating (Brown, Enright & Miller 2003), yet persist at low levels (with occasional recruitment) in long-unburnt forest (ARIER, unpublished data). The soil disturbance associated with thinning is likely to encourage some germination, but will affect different species in different ways. As with herbaceous species, shrub diversity is likely to be enhanced by a treatment that results in a mosaic of habitats.

Finally, the physical disturbance associated with the thinning activities in the Trial appears to have had an impact on shrub cover, at least initially. Post-thinning decreases in the cover of shrubs such as Golden Wattle and Daphne Heath were observed in Patchy 1 and Patchy 2 Plots. At Paddys Ranges SP, some of the reduction in Golden Wattle may have been due to natural, on-going senescence after fire-stimulated regeneration in 1985. However, the reduction in cover of other species is probably associated with more recent and extensive thinning disturbance, with shrub branches being broken off as trees were felled or debris was removed. For example, felling disturbance in Mountain Ash forest led to significant decreases in tall shrubs and small trees (Peacock 2008).

Prediction: Shrub cover will increase in thinned Plots, especially at rocky Sites such as Castlemaine Diggings NHP. This will be assisted by more profuse flowering by some species. The response may be greater among species for which germination is less strongly associated with fire cues.

Previous research has suggested that tree-species recruitment may be affected by an intact canopy, although forest type is a major determinant. For example, mature Alpine Ash *Eucalyptus delegatensis* trees, due to their impact on soil moisture, suppress seedlings under their canopies (Bowman & Kirkpatrick 1986a,b); a similar situation also occurs in Silvertop Ash forests (Incoll 1979), and Jarrah *E. marginata* seedlings growing at sites which lack an overstorey experience smaller soil- and leaf-water deficits and higher rates of survival than seedlings where the overstorey is retained (Stoneman *et al.* 1994). In temperate stringybark open forest, few eucalypt seedlings were noted in areas where large, mature trees formed a closed canopy, but small seedlings were common in open areas (Gibbs *et al.*

1999). In contrast, regeneration of canopy species in a Flooded Gum plantation was higher in areas with greater canopy retention (Cummings *et al*. 2007), suggesting that response is species-specific.

Overstorey recruitment in Box–Ironbark forest, as in Grassy Dry and Heathy Dry Forests, is a continual process, and does not appear to be inhibited by the relatively low level of shade or the presence of mature trees. Seedlings of Long-leaf Box, Red Stringybark and Red Box are common, regardless of canopy density (ARIER, unpublished data). It is possible that thinning disturbance might create small microsites that further encourage seedling germination, but short-term effects are not yet evident, making the long-term effects of the Trial difficult to predict.

In Wandoo *Eucalyptus wandoo* woodland in Western Australia, shrub seedlings were able to become established in the suppression zone around the overstorey trees, but the premature death of mature shrubs appeared to occur when shrub roots met the large lateral root system of the trees (Lamont 1985). Thus, initial establishment by tree recruits (or shrubs) may not translate to longer-term increases in cover. Nonetheless, recruitment needs to be carefully monitored as a major increase in unchecked recruitment might act to counter the effects of thinning.

Recruits of Red Ironbark are often sparsely scattered, as this species flowers and produces seeds sporadically (Kellas 1991). The germination requirements of this species are poorly understood; seeds appear short-lived and lack dormancy, and while they germinate readily under laboratory conditions, they do not germinate readily in the field (Orscheg 2006). The response of Red Ironbark to thinning will be of particular interest.

Where recruitment of canopy eucalypts occurs, its success might be affected by the coarse-woody-debris retention treatment. In grazed eucalypt woodlands, the mass of small branches and foliage from a fallen branch or tree might act as protection against grazing (Kirkpatrick 1997). However, increased amounts of leaf litter (as may be expected immediately after thinning) may adversely affect seedling survival, at least initially, which has been noted in Jarrah forests (Stoneman *et al.* 1994).

Prediction: Recruitment of canopy eucalypts is likely to be stimulated by the thinning activities, although the presence of more mature trees may then suppress their growth. The possible effects on Red Ironbark are unknown.

One of the implicit aims of ecological management is to preserve or promote biological diversity, under the assumption that management activities (e.g. thinning or burning) can promote species or guilds whose numbers have declined, or threatened species that have a limited distribution. However, floristic response is dictated to a large extent by the composition of extant vegetation in conjunction with the availability of propagules, such as in the soil seed bank. In dry sclerophyll forest in Victoria, plant species that returned to logged plots were generally the same as those that were originally present (Loyn *et al.* 1983), while no species were gained as a result of applied fire in the Wombat State Forest (Tolhurst 1996, 2003). Similarly, clear-felling in wet and dry forests in Tasmania (in the absence of slash-burning) resulted in few changes to the relative or absolute abundances of understorey species (Dickinson & Kirkpatrick 1987).

Floristic composition and ecological processes in Box–Ironbark forest are likely to have been substantially changed as a result of post-European land-use, and soil seed banks are small, often with low viability (Stoner 2001; Meers 2002). Ecological thinning may therefore not result in non-eucalypt components of the vegetation reverting towards a pre-European composition, or even a more diverse condition, because local propagules of previously extant species may no longer exist. 'Lost' species are unlikely to be restored to the system unless they can be recruited from off-site propagules.

Prediction: Thinning will increase the cover and abundance of understorey plants, but is unlikely to lead to increases in species richness.

This review has determined that thinning of Box–Ironbark and Heathy Dry forests may affect the recruitment, growth and survival of both understorey and overstorey species, both in the short- and long-term, with implications for future floristic composition and structure. In general, we predict that the understorey will benefit from thinning, with an increase in the cover and abundance of extant species, but there may be little change in overall species richness. However, uniform thinning may disadvantage some species that require the protection of canopy cover, and maximum diversity will be attained through a thinning treatment that provides a mosaic of conditions. Analysing the changes in the Isolated and Patchy Plots will therefore be a critical part of future analyses.

5.3 Avifauna

Birds are typically the most abundant and diverse group of vertebrates in forest ecosystems, and thus they have been widely used as indicators of biodiversity change under forest management. Ecological thinning is expected to affect bird assemblages through its influence on forest structure and associated changes to the spatial distribution and availability of foraging, nesting and general habitat features.

There has been limited research into the effects of thinning on bird assemblages in temperate eucalypt forest communities in Australia (*q.v.* Brown *et al.* 1991; Kutt 1996; Williams *et al.* 2002), but the effect of timber harvesting on birds has been well studied (e.g. Loyn *et al.* 1980; Kutt 1996). Based on the similarities between logging studies and this Trial (the scale of operation and the ‘opening’ up of forests), studies into the effects of logging eucalypt forests provide some guidance for the expected outcomes of ecological thinning in Box–Ironbark forests, particularly long-term outcomes.

Previous studies have found that silviculturally thinned forests support lower densities and lower species richness of birds due to of simplification of the habitat through the loss of floristic and structural complexity (Brown *et al.* 1991; Kutt 1996). When silvicultural thinning is undertaken, felled merchantable logslogs as well firewood quality timber areare usually removed, contrasting with the ecological-thinning practices applied in this Trial (Fagg & Bates 2009). The retention of this material and its subsequent contribution to loads of coarse woody debris and ground-habitat complexity is expected to positively influence bird assemblages (e.g. bark-invertebrate feeders, ground-nesting birds). While there was evidence in the Trial that species richness generally increased at Sites after thinning, this outcome was confounded by the timing of post-thinning surveys which were conducted during more favourable conditions in spring (as opposed to winter when pre-thinning surveys were conducted).

Greater structural complexity affords greater resources and opportunities for microhabitat segregation by fauna, and therefore they support more species and more individuals (MacArthur *et al.* 1966). Considerations of habitat structure may include a number of floristic components, vertical and horizontal zonation of vegetation (e.g. intact shrub layer), resource availability (e.g. tree hollows) and amounts of cover (e.g. coarse woody debris, rocks and litter). The simplification of habitats (a reduction in any of these habitat components) generally leads to reduced species richness and abundance (Traill 1991, 1993; Laven & Mac Nally 1998; Palmer 1998). Ecological thinning has effectively increased some components that contribute to the structural complexity of the Box–Ironbark forests, particularly in the understorey and ground layers. Increased amounts of coarse woody debris, litter cover and various floristic components (including perennial tufted-herbs and perennial sub-shrubs) all added complexity to the treated Plots. Assessment of canopy openness indicates that the homogeneity of the canopy layer has been reduced in treated Plots; this patchiness should benefit some fauna. The changes in avian assemblages after silvicultural activities varied, and was proportional to the magnitude of the alteration to forest structure; as more of the original environmental conditions are safe-guarded the effect is likely to be reduced (Lencinas *et al.* 2009). The Trial incorporated the retention of key resources, including large trees and hollow-bearing trees, as well as higher stem density than other timber harvesting operations, and this is expected to have ameliorated some potential impacts, such as the retention of breeding sites.

Early evidence suggests that the abrupt changes in habitat structure which resulted from ecological thinning have led to changes in some components of the avifauna which are comparable with changes that are brought about by timber harvesting. For example, open-country species, such as Brown Falcon and Rufous Songlark, were first recorded at Sites after they had been thinned. Reduction in the stem density of canopy trees and associated increases in canopy openness in thinned Plots effectively decreased the overall area of canopy available for canopy-foraging insectivores (Franzreb & Ohmart 1978). Some of these species, including Spotted and Striated Pardalotes and Brown-headed Honeyeater, were recorded in lower numbers in the Plots after thinning.

Prediction: The effects of ecological thinning on bird assemblages are unlikely to result in the same short- to mid-term effects in Box–Ironbark forest as those caused by traditional silvicultural practices. The structural complexity of sites after ecological thinning is likely to be greater due to the retained patchiness in thinned Plots and the retention of debris. This is expected to provide more diverse opportunities for birds and cater for a greater range of species.

Change in forest structure, specifically by removal of all or many stems, causes significant changes in the composition of bird assemblages (Williams *et al.* 2002). Following stem removal, bird assemblages change in a ‘succession-like’ pattern as the floristics and vegetation structure gradually change, making different habitats become available; such responses have been described in various studies in eucalypt forests (Loyn 1985; Williams *et al.* 2002). Bird assemblages should show similar successional responses as thinned Sites in Box–Ironbark forest mature.

Prediction: There are likely to be successional changes in bird assemblages as treated Plots mature after thinning treatments. The successional changes will occur as vegetation composition and structure and the availability of habitat features, such as the shrub layer and tree hollows, change through time.

In dry eucalypt forests and woodlands that form part of the Box–Ironbark vegetation in Victoria, ground-foraging birds form a prominent component of the assemblage. Studies of the foraging ecology of these species (e.g. Red-capped and Hooded Robins, Brown Treecreeper and Diamond Firetail *Stagonopleura guttata*) have shown open habitats with a low density of trees and shrubs, high herb cover and much coarse woody debris to be particularly important for this suite of birds (Antos & Bennett 2008). Many ground-foraging birds are threatened and declining throughout their range in Victoria and their dependence on heterogeneous ground-layer habitats is a contributing factor (Robinson & Traill 1996). A complex ground layer is needed to provide potential habitat for such species, and achieving suitable heterogeneity in Box–Ironbark forests and woodlands requires active management; ecological thinning may enhance foraging sites for many ground-foraging birds (Antos & Bennett 2008), as it provides a substantial increase in the amount of coarse woody debris, coupled with an observable change in its vertical and horizontal arrangement, resulting in a greater complexity in the structure of coarse woody debris. It is expected that this would contribute to enhanced shelter and foraging opportunities for associated fauna. The positive response of ground-foraging species that require ready access to cover, such as Superb Fairy-wren, provides evidence of the habitat value of this resource.

Prediction: Enhancement of volume and structure of coarse woody debris resulting from thinning will increase the amount of suitable habitat for ground-foraging and ground-nesting birds in Box–Ironbark forests.

Increased shrub cover (see *Floristics*) is expected to lead to an associated increase in the number and diversity of shrub foragers and species that nest in the understorey. A well-developed but low-density shrub layer is an important component of foraging microhabitats for ground-foraging birds such as Brown Treecreeper, Jacky Winter, Red-capped Robin and White-winged Chough, but high densities of shrubs may adversely impact on many of these species (Antos & Bennett 2008) as patches of dense regrowth make the habitat unsuitable for them.

The thinning operation appears to have affected shrub cover, although this may be a short-term impact. Several species of tall shrubs (e.g. Golden Wattle and Daphne Heath) declined after thinning, probably due to damage caused during tree felling, which has been recorded in other tree-removal studies (Peacock 2008). The recovery of this layer in the short-term will provide habitat for birds such as Brown Thornbill and Superb Fairy-wren.

Prediction: As shrub cover increases and matures in thinned Plots, the suitability of the habitat will increase for birds that forage or nest in shrubs. The density of the shrub layer that becomes established in the years after thinning will partly determine the suitability of habitat for ground foraging birds.

The retention of large amounts of coarse woody debris during the Trial is considered to have imparted numerous benefits on the avifauna by providing potential foraging habitat and nest sites, as well as potential shelter sites. The volume of coarse woody debris increased significantly as a result of ecological thinning and the retention of felled material. There was a significant difference in volumes of coarse woody debris between Plots and across all Sites after thinning. The post-thinning data on bird assemblages is inconclusive (due largely to limited survey effort), but based on observations of loads of coarse woody debris and its distribution across Sites, it is unlikely that there were strong differences in bird responses to loads of coarse woody debris between the different treatments.

The rates of decomposition of coarse woody debris in these forests are expected to be slow (and there were no significant differences in loads of coarse woody debris at control Plots over the two monitoring periods).

Prediction: Although birds are likely to respond to the change in forest structure and coarse-woody-debris load after ecological thinning, responses to variation in litter loads as part of the Trial will be too subtle to detect.

At a landscape scale, heterogeneity of patches is important in promoting biodiversity (Forman 1995). By providing a diversity of patches in the forest landscape (thinned and unthinned patches), more opportunities are provided for different birds, including forest-interior species (e.g. Powerful Owl), generalists (e.g. Grey Shrike-thrush and Rufous Whistler) and species that prefer open habitats (e.g. Rufous Songlark and Australian Magpie).

Prediction: The creation of a patchy mosaic at the landscape scale as a result of thinning is likely to benefit the avifauna by providing a greater variety of habitats.

The Noisy Miner occurs throughout the Box–Ironbark region, but is uncommon in large, intact and relatively undisturbed forests (Emison *et al.* 1987; Palmer 1998; Taylor *et al.* 2008). The species was not recorded at Sites during bird surveys in the Trial, but is likely to occur in landscapes surrounding the Sites and along their edges. Miners have benefited from land clearance in south-eastern Australia as they successfully exploit disturbed and fragmented landscapes (Mac Nally & Horrocks 2002a; Taylor *et al.* 2008), and thus the disturbance and ‘opening-up’ of forest areas following ecological thinning could potentially provide suitable habitat for this species. Miners actively exclude small birds from their territories and are considered a significant threat to woodland bird communities in the Box–Ironbark region (Mac Nally & Horrocks 2002a; Taylor *et al.* 2008).

Prediction: The dynamics of Noisy Miner populations in Box–Ironbark forests after ecological thinning are difficult to predict. The potential future establishment of populations of Noisy Miners at treated Sites due to a more open tree structure could have major implications for bird assemblages, particularly honeyeaters and small arboreal-invertebrate feeders.

5.4 Selected Mammals and Reptiles

The predictions of future trajectories for most of the mammals considered during the Trial should be considered with respect to the data limitations already outlined. Despite this, it is likely that vertebrate abundance and composition will change in response to the changes in structure that brought about by ecological thinning. It is too early to identify the ecological impacts of thinning on vertebrate fauna, but the relationships between some fauna and habitat/Site variables were explored early in the post-thinning period to provide reference points for future studies. These relationships are expected to occur across various scales used in the Trial. Over time, as the immediate effects of disturbance and thinning operations abate, the effects of each thinning treatment should emerge from the ‘background noise'.

Arboreal mammals are generally considered to be disadvantaged by the removal of trees from forests (Smith & Lindenmayer 1988; Milledge *et al.* 1991), including during forest thinning practices (Kutt 1994). After trees have been removed from a forest, it is generally considered to provide lower quality habitat as a result of the loss of tree hollows and a simplification in forest structure. In a comparison of old-growth, unthinned-regrowth and thinned-regrowth areas in lowland eucalypt forest in East Gippsland, thinned-regrowth areas supported the lowest densities of arboreal mammals and old-growth areas supported the highest. Higher densities of arboreal mammals were recorded in unthinned regrowth than in thinned areas of the same age, and this was attributed to the more complex understorey vegetation in unthinned areas (Kutt 1994). The ecological thinning that formed the basis of the Trial was undertaken to reduce the density of existing trees to accelerate growth of retained habitat trees and allow development of older-growth characteristics, such as tree hollows, which benefit fauna. The thinning resulted in a simplification of ‘arboreal’ habitat structure through reduced stem density and shrub cover. Observations of arboreal mammals were too few to analyse quantitatively, but a general post-thinning decrease in the number of Sites and Plots occupied by most arboreal mammals was apparent.

The Common Ringtail Possum was recorded only at Pilchers Bridge NCR after thinning; it occurred in higher numbers in all Plots. This species forages among the foliage of both eucalypt and acacia shrub (Tzaros 2005). The reduction in shrub cover at thinned Plots is likely to have negatively impacted on this species across Sites, but an anomaly was detected at Pilchers Bridge NCR, where reductions in shrub cover were among the lowest of all treated Plots, and actually increased in the Isolated Plot, where the highest numbers of Common Ringtail Possums were recorded after thinning.

Prediction: The loss of shrub cover (particularly Golden Wattle) following ecological thinning may have a negative impact on some arboreal mammals (e.g. Sugar Glider and Common Ringtail Possum). This impact is expected to be short-term as this habitat is expected to recover within 5 years.

Prediction: The reduction in stem density associated with ecological thinning will continue to provide suitable habitat resources and benefit arboreal mammals in the mid- to long- term.

Potential short-term impacts on activity of small insectivorous bats are likely, due to altered forest structure and availability of prey (Kutt 1995). The bat genera *Vespadelus* and *Chalinobolus*, as well as the White-striped Freetail Bat, displayed a significant negative correlation with increasing tree density. After standardising results for different sampling effort between pre- and post-thinning surveys, bat activity across Sites appeared to be substantially greater in the post-thinning environment. The patchiness created by ecological thinning may influence the habitats used by bats by altering the spatial arrangement of the canopy and sub-canopy, and by effects on prey availability. In forests, higher density of vegetation results in greater acoustic clutter, leading to possible reductions in foraging efficiency, particularly for larger bat species (Fenton 1990; Patriquin & Barclay 2003). A study in boreal forest in North America found that small forest bats generally exploit more types of forest environments (e.g. intact forest, thinned forest and clear-cuts) than larger bats, and forest thinning provided minimal immediate benefit to foraging bats, but, over time, thinning may prove beneficial as thinned patches develop older-growth characteristics, such as hollows for roosting (Patriquin & Barclay 2003).

In thinned, unthinned and old-regrowth lowland eucalypt forest in East Gippsland, there were no significant differences in either individual species or total relative bat activity across the three treatments, but species which foraged above the canopy at high speed with low manoeuvrability (e.g. White-striped Freetail Bat and *Mormopterus*) tended to be associated with recently thinned sites (Kutt 1995). In the ecological thinning trial, White-striped Freetail Bat and *Mormopterus* appeared to be associated with thinned Plots across all Sites. It is likely that the reduction in stem density and increase in canopy openness provided a more open, accessible structure, contributing to increased suitability as foraging habitat for these two species.

Prediction: The reduction in stem density and increase in canopy openness associated with ecological thinning will benefit some bat species by providing a more open and accessible foraging habitat.

It is possible that not all species of bats will benefit from ecological thinning in the short-term as typical forest-bat assemblages comprise species with a range of habitat preferences, including complex vegetation structure (Kutt 1995). However, thinning is unlikely to have a significant negative impact, beyond the effects of short-term disturbance, given the protection afforded to key resources such as hollows during the thinning operation. For example, two of the most common species in pre- and post-thinning surveys were Little Forest Bat and Chocolate Wattled Bat. Both forage below the canopy at medium-to-high speeds with medium-to-high manoeuvrability (Kutt 1995). In East Gippsland, these species were associated with older regrowth forest, reflecting an ability to forage in more structurally complex vegetation (Kutt 1995). At Box–Ironbark sites, both species occurred widely (although Chocolate Wattled Bat was recorded in much lower numbers during pre-thinning surveys) and neither showed a strong preference for either thinned or unthinned Plots during post-thinning surveys. For bats recorded in sufficient numbers, none was recorded exclusively at any Site or within either thinned or unthinned Plots, indicating that these species utilised thinned and unthinned Plots at some stage. This is a similar finding to that for the bat assemblage in East Gippsland (Kutt 1995).

In general, bats may be expected to be more active in the thinned Plots, or to colonise them more rapidly, than other hollow-using arboreal mammals, as they are able to roost in small hollows, crevices, tree fissures and decorticating bark. Due to their mobility, their roosting and foraging habitats are not necessarily the same, as they are capable of covering large distances to meet their daily requirements (Lunney *et al.* 1985). Consequently, the roosting habitat of bats and their foraging habitat can be widely separated (Lunney *et al.* 1985; Lumsden & Bennett 2005).

Through the creation of a mosaic of patches of different tree densities, ecological thinning is likely to influence the habitat use by foraging bats. At the landscape scale, the creation of a patchy mosaic of thinned and unthinned patches is expected to provide resources for a diverse range of bat species and thus accommodate their different needs.

Prediction: The creation of a patchy mosaic at the landscape scale as a result of thinning treatments is likely to generally benefit the bat assemblage by providing a greater variety of habitats.

The Yellow-footed Antechinus (and to a lesser extent the Brush-tailed Phascogale) forages extensively in coarse woody debris (Tzaros 2005). Neither the Yellow-footed Antechinus nor the Brush-tailed Phascogale were recorded in sufficient numbers to analyse their responses to thinning at Sites or Plots, but based on their known habitat requirements, the increase in the volume of coarse woody debris as a result of thinning should provide suitable foraging habitat (Mac Nally & Horrocks 2002b; Lada *et al.* 2008). In River Red Gum floodplain forests in northern Victoria, both the density and activity of the Yellow-footed Antechinus increased at sites experimentally manipulated to carry high loads of coarse woody debris. Large logs and branches were particularly important to the species, but plots with increased loads of coarse woody debris comprising only 'crown' material were avoided by them (Mac Nally & Horrocks 2002b). The lack of coarse woody debris (and low potential for its natural accumulation) at Sites before thinning may have restricted their suitability for both species. Coarse woody debris as a habitat component of Box–Ironbark forests may be particularly important for ground-foraging insectivorous species, as invertebrate abundance among fine litter is lower than in other forest types (e.g. wet eucalypt forest) (Taylor 2008). '*Loss of coarse woody debris from Victorian native forests and woodlands*' is listed as a threatening process under the *Flora and Fauna Guarantee Act 1988*. Native ground-foraging mammals recorded in the Trial (Yellow-footed Antechinus, Agile Antechinus, Brush-tailed Phascogale) and most of the bat species are listed as being affected by this process. The increase in the volume of coarse woody debris, particularly significant increases in larger debris (>10 cm diameter) after ecological thinning, should increase suitability of habitat for the mammal assemblage of the forest floor.

The Brush-tailed Phascogale was recorded in both pre- and post-thinning surveys. It is semi-arboreal, being less-dependent on trees, and it forages extensively among coarse woody debris (Menkhorst 1995; Tzaros 2005); the substantial increase in coarse woody debris across treated Plots is likely to have increased foraging opportunities for the species.

Several species of reptiles, particularly some lizards, forage over or around coarse woody debris or bask on it. Ecological thinning is likely to affect the suitability of the habitat for such reptiles by changing the availability and structure of coarse woody debris, at least in the short-to-mid term. After logging in montane eucalypt forests in New South Wales, several common species of lizards including Southern Water Skink *Eulamprus tympanum*, Yellow-bellied Water Skink *E. heatwolei* and Spencer's Skink *Pseudemia spenceri* were significantly more abundant in logged plots than unlogged plots, while the abundance of McCoy's Skink *Nannoscincus maccoyi* and Coventry's Skink *Niveoscincus conventryi* did not differ between the two treatments. Those reptiles whose numbers increased after logging probably responded to the greater abundance of logs, their most favoured microhabitat (Goldingay *et al.* 1996). A study of reptile assemblages at some of the Sites in Box–Ironbark forests found one species, the Tree Dragon, was closely associated with thinned Plots (Olsen2010). This species is semi-arboreal and often perches on elevated substrates, including coarse woody debris, to search for prey or to bask (Tzaros 2005). It is likely that the changes brought about by thinning including increased levels of coarse woody debris and increased canopy openness, which are likely to benefit some reptiles by providing increased foraging and basking sites, though other thigmothermic species may be adversely affected.

Prediction: The significant increase in coarse woody debris is likely to increase habitat suitability for small ground-foraging mammals such as Yellow-footed Antechinus, Agile Antechinus and Brush-tailed Phascogale, as well as some reptiles.

The early response by large macropods (e.g. Black Wallaby and Eastern Grey Kangaroo) to ecological thinning in Box–Ironbark forest is unclear. Black Wallaby was recorded in all Plots, both pre- and post-thinning; the species is unperturbed by harvesting in eucalypt forests (Di Stefano *et al.* 2007). In open, dry sclerophyll forest in the foothills of the Great Dividing Range, sites became favourable for wallabies approximately 8–10 months after harvesting as coppice and shrub cover increased (Di Stefano *et al.* 2007). At the Box–Ironbark Sites, after thinning, similar conditions were observed, with an increase in the cover of eucalypt coppice regrowth across all treated Plots, with greater increases in Isolated Plots. An increase in the cover of perennial and annual grasses after thinning should also benefit large macropods. In the longer term, the more-open forest structure that is predicted to result from ecological thinning is likely to provide ongoing suitable habitat for the Black Wallaby and Eastern Grey Kangaroo.

Prediction: Ecologically thinned Plots will continue to provide suitable habitat for large macropods in Box–Ironbark forests.

High densities of mammalian herbivores can have an adverse impact on plant-community composition (Shepherd *et al.* 1997; Horsley *et al.* 2003). Observations of browsing by Black Wallabies in recently harvested eucalypt forest in central Victoria showed that browsing damage caused seedling mortality, particularly in the first 6 months (Di Stefano 2005), but the level of this damage was considered unlikely to have a significant impact on the success of regeneration (Di Stefano *et al.* 2007). However, normal behavioural patterns in large, free-ranging herbivores may promote a diverse resource base, reducing the probability of excessive pressure on any particular plant species (Shepherd *et al.* 1997).

The impacts of herbivory may vary temporally and are likely to be influenced by environmental conditions. For example, the impacts of herbivores are expected to be more severe during periods of environmental stress, such as droughts. It is possible that the post-thinning monitoring environment may have experienced high levels of herbivory due to the extended period of below average rainfall recorded before and during the Trial. Pressure from browsing macropods can be high in forests regenerating after timber harvesting (Di Stefano 2005) (and likewise ecological thinning), and this may impact on the re-establishment of vegetation and floristic composition. Thus, the monitoring of macropods and the impacts of herbivory should be given a high priority.

Unknown: Although the response by macropods to ecological thinning is unknown; potentially high numbers of macropods in ecologically thinned areas of Box–Ironbark forests could have a negative impact on the re-establishment of vegetation, including life form cover and floristic composition.

5.5 Invertebrates

The diversity and abundance of invertebrates encountered during pre- and post-thinning surveys make predictions at the species level difficult. This was further compounded by insufficient information on arboreal invertebrates and termites at the Sites.

The composition of the invertebrate fauna will change as a result of successional development of the Plots, but the nature of this change may not be apparent for several years until the understorey and ground layers have time to develop greater structural complexity. Before the commencement of the Trial, all Plots were heavily disturbed in terms of ground-layer composition and structure. It is likely to be 40–50 years before changes in habitat structure brought about by ecological thinning will have a clear effect on invertebrates, although some trends may be apparent in 5 years.

Thinned Plots will have a higher level of nutrient input than unthinned Plots due to the decomposition of the plant material resulting from the thinning. The woody debris left on the ground should provide food and habitat for ground-active invertebrates, and it is likely that thinned Plots with large amount of debris will develop a more complex and diverse fauna than Control Plots within 5 years.

Prediction: In the early years after thinning, the invertebrate assemblage will comprise a high proportion of early-successional and disturbance-adapted species responding to the sudden changes in habitat structure brought about by thinning. This is likely to lead to a more diverse invertebrate assemblage occurring in treated Plots than in Control Plots.

As the mean tree size increases, it should coincide with a lower density of trees (and thus greater spacing between them), leading to a more diverse and richer understorey and ground layer. Larger trees will generate more large coarse woody debris, an important habitat for larger insects that is also utilised by some mammalian insectivores. In addition, the activity of termites in establishing tree cavities will increase, and there should also be an increase in the strength of the relationship between ground-active invertebrates and the arboreal invertebrates as interactions increase between species for space and resources. For example, some species will use both overstorey and understorey plants as habitat or food, such as parasitoids and predatory insects using nectar resources of different plants as a food. Although most ants inhabit the soil or coarse woody debris, many species actively forage in the trees where they tend herbivorous insects for honeydew. Larger trees could induce an increase in the diversity of herbivorous insects and this could influence the ant fauna.

Although ants should remain the most dominant group of ground invertebrates, there will be a reduced dominance by opportunist species and more specialist species, and the role of seed-harvesting ants will become more important. An increase in other invertebrate orders in response to greater diversity of microhabitats and a reduced dominance by ants would be expected: the soil-litter fauna should become richer in abundance and diversity with the decomposition of increased levels of litter and coarse woody debris, and there would also be more available habitat for predators such as web-building spiders.

Prediction: In the long term, as treated Plots mature, invertebrate assemblages will increase in diversity in response to a greater diversity of microhabitats. Greater opportunities will be available for invertebrates, including cryptic and specialist species.

Larger trees will ultimately result in the deposition of more large coarse woody debris, changing the nature of the microhabitats and providing an important habitat and food source for many invertebrates. The size and age of coarse woody debris influences the structure, abundance and composition invertebrate assemblages. For example, mature logs yielded 26% more individual invertebrates and 30% more species than smaller logs from regrowth in temperate eucalypt forests in Tasmania that were subjected to harvesting (Bashford *et al.* 2001). There were consistent differences between mature and regrowth logs, with some species (e.g. saproxylic beetles) showing distinct preferences for either mature or regrowth logs. This suggests that forests lacking mature logs are unlikely to support some invertebrates, such as some saproxylic beetle species. Litter-dwelling invertebrates respond to factors such as vegetation, microclimatic conditions and conditions in the soil and litter layer, which in turn are likely to vary between mature forest and young forest regrowth (Greenslade 1968). For example, litter beetle (Coleoptera) assemblages in young, recently clear-felled eucalypt forests in Tasmania were distinct from those in mature forests (Baker 2006).

Prediction: In the long term, as treated Plots mature, invertebrate assemblages will increase in diversity in response to a greater amount of older and larger coarse woody debris.

6 FUTURE CHALLENGES

This section provides a constructive guide to the limitations of the Phase 1 monitoring component of the Trial. Due to the long-term nature of the Trial and the associated ongoing monitoring, the focus of this section is to identify the key components of the monitoring in Phase 1 that should be continued, as well as potential changes or additions to the design that would provide a useful insight into ecological thinning as a management technique for Box–Ironbark forests and woodlands.

6.1 Research Limitations and Considerations

Through Phase 1 of the Trial, several limitations were encountered, and they should be recognised when considering the Trial's outcomes.

The three thinning treatments (Isolated, Patchy 1, Patchy 2) applied during the Trial resulted in tree densities which directly reflected the density at the start of the Trial, and these varied considerably between Sites and Plots (Table 3). As a result, any detection of differences between Plots could easily be affected by high intra-treatment variation. To adjust for this, a regression-based approach was used to analyse the relationships between biodiversity and habitat-response variables. Therefore, in place of rigid inter-treatment comparisons, the analysis focused on the response of biodiversity and habitat variables to changes brought about by thinning, largely independent of Site and treatment (instead using thinned versus unthinned), although consistent trends across Sites for particular treatments have been described. By using this approach, the ability to recommend a particular treatment over another is lost, but it is still possible to provide guidelines for large-scale ecological-thinning operations, including retention of habitat trees and coarse woody debris that achieve ecological outcomes based on responses measured during the Trial (Pigott *et al*. 2009).

The manipulation of loads of coarse woody debris in Sub-plots was difficult and was inconsistently applied across Plots (Pigott *et al.* 2010), and biodiversity and habitat variables measured at the Sub-plot level (e.g. ground cover, coarse woody debris, floristics and birds) were subsequently not analysed at that level. Therefore there was no differentiation of the effects of the different treatments of coarse-woody-debris removal.

Field surveys of the floristic component of the Trial were conducted at different times in the annual cycle for the pre- and post-thinning surveys. Pre-thinning surveys were mostly conducted in autumn or winter, while post-thinning surveys were conducted in spring. Spring is the optimum time to conduct flora surveys in Box–Ironbark forest as it coincides with the non-dormant period for various annuals (e.g. *Crassula*) and spring-flowering orchids (e.g. *Caladenia*, *Calochilus*, *Diuris* and *Glossodia*). However, autumn–winter surveys were more suited to identifying grasses beyond genus level (assisted by species-defining inflorescences) and winter-flowering orchids (e.g. *Pterostylis*, *Corunastylis*, *Acianthus* and *Cryostylis*). While these scenarios have obvious impacts on assessments of species composition, in terms of the broad community change between the pre- and post-thinning monitoring, seasonally-absent species may have little apparent impact on overall results, because relative data are more important than absolute data in determining the long-term effects of ecological thinning.

It is useful to acknowledge the limitations of the existing fauna data, so that these can be addressed in future surveys. These limitations include: timing and seasonality of surveys; variability in survey effort for some techniques; replication (especially for surveys of Sub-plots with different levels of coarse woody debris); and the collection of 'presence' data for some survey techniques (e.g. hair-tube surveys, bat-call detection). The considerable environmental variation between Sites, most notably between Paddys Ranges SP and the other three Sites, will also affect vertebrate occurrence.

The select vertebrate-fauna monitoring involved a number of different survey techniques designed to cover a diverse range of fauna. While the experimental design and the vertebrate-survey techniques are sound, the level of sampling effort and the amount of data collected for most vertebrate groups was insufficient to enable quantitative analysis between Plots and Sites. In particular, data for nocturnal birds and, to a lesser extent, arboreal and ground mammals were limited. This was a function of both survey effort (a lack of repeated surveys) and the density and distribution of target fauna in the forests. For example, owls have species with large home ranges, and they occur at low abundance within forests, and thus their detectability at the Plot level is low. The timing and duration of thinning operations contributed to limitations within the data, and the Trial was conducted during a protracted drought, so the vertebrate data may not have reflected 'normal' levels of abundance and species composition. This meant that the analysis of data for some groups (e.g. owls) was limited to descriptive statistics, and some data (e.g. total bat activity) had to be pooled to explore potential patterns. The most complete fauna dataset was provided by diurnal birds — every Sub-plot in every Plot at every Site was surveyed before and after thinning operations. Data for other target vertebrate fauna were generally collected using the Plot as the sampling unit (not every Sub-plot was sampled). Even where records for some groups are lacking (and sophisticated analyses were not possible), existing records provide a measure of 'presence'; this data may prove useful in future analyses, especially if an 'occupancy' modelling approach is adopted (MacKenzie & Royle 2005).

Other factors may have influenced the described outcomes. Much of the pre-thinning baseline data for vertebrates was not collected during spring–early summer, which is the optimum time to record most vertebrate taxa because of increased levels of activity due to migration, breeding or foraging. Also, there was considerable environmental variation between Sites, most notably in the contrast between Paddys Ranges SP and the other Sites, which is also likely to affect vertebrate occurrence and limited the capability to compare results across Sites. For selected vertebrate monitoring, the Phase 1 post-thinning data-set is arguably more important for analysis and interpretation than the pre-thinning data-set (especially since, in the Trial, the pre-thinning data were collected across several seasons). The effects of the treatments on the flora and vertebrate fauna are unlikely to become apparent for several years; at this early stage, few clear, direct responses to thinning can be drawn from the immediate post-thinning data, at least not until medium- and long-term data from the Trial become available.

A number of limitations and constraints were identified in invertebrate monitoring during Phase 1. Firstly, the huge numbers of invertebrates (86,471 individuals) collected meant that it was necessary to focus on a particular group due to resource constraints; ants were selected because they are the dominant group within the ground-surface-active invertebrates in Box–Ironbark forests. They are also well studied and include a range of functional groups with different ecological requirements. The other invertebrates collected were sorted and identified to order. Secondly, some pre-thinning samples were collected during autumn in conjunction with the implementation of the thinning operations; the optimum time for surveying ground-invertebrate groups is summer (or other warm periods).

There is a need to consider the implications of coppice regrowth in thinned Plots across the Sites. Its continued growth is likely to be a major impediment to the long-term ecological outcomes intended by the Trial. The level of coppice regrowth after thinning varied between Plots and Sites, with Plots at Castlemaine Diggings NHP considered most affected (based on visual assessment). Active management of coppice regrowth will be required if it is deemed to adversely affect outcomes for the Trial.

It is important to collect as much data as possible for both flora and fauna at a suitable time of year and standardise this for future surveys, despite the differences in post-thinning interval at some Sites. The initial post-thinning data-set is arguably more important for analysis and interpretation than the pre-thinning data-set, especially since the pre-thinning data were collected across several seasons.

6.2 Ongoing Monitoring

Phase 2 of the Trial will involve ongoing monitoring, evaluation and reporting of the examination of the long-term implications of ecological thinning. The information collected during Phase 1 will be used to assist the development of Phase 2, and should provide Parks Victoria some guidance in developing a strategy for the application of ecological thinning at other sites across the Box–Ironbark region in Victoria. The wide range of biodiversity (floristics, select vertebrates and invertebrates) and habitat components (e.g. tree density, tree hollows, ground cover, coarse woody debris, canopy openness) examined in Phase 1 was considered a strength of the Trial.

Ongoing monitoring of the variables assessed in the key fauna habitat project will be paramount in the success of the Trial. The methods used in Phase 1 provided important baseline information on the pre- and post-thinning conditions, and they are repeatable. This information was sufficient to enable statistical comparisons between the two monitoring periods and detected some changes at the Plot level (using Sub-plots as a replicate) and the Site level. The variables measured in the Trial, including volume of coarse woody debris, litter cover and depth, bare-ground cover and bryophyte cover, are expected to change. Several of these variables were significantly related to the presence of vertebrate fauna and their abundance or activity, and their response through time must be recorded to measure the ongoing success of the Trial. The quantitative assessment of tree-canopy cover in the post-thinning environment was considered a practical and accurate technique that provided an important baseline reference that will be crucial to monitoring changes in canopy cover. The method is repeatable and a high level of confidence is held that real changes in canopy cover will be detectable.

The potential for change identified in this report suggests that the ongoing monitoring of understorey vegetation is a vital component of the Trial. The methods currently employed are robust and appropriate, and should detect notable changes at both species and community level. No changes to the understorey survey protocols are needed or recommended, although it will be important to standardise the timing of future surveys (i.e. spring flora surveys), and it will be necessary to undertake additional surveys in winter and summer in some years to determine whether any changes have occurred in the abundance of non-tussock grasses or rare and threatened species such as orchids. Future data collected during more benign climatic conditions may help gauge the relative effect of climate.

The ongoing monitoring of the vertebrate and invertebrate fauna will continue to play an important role in the Trial and will serve two specific functions. Not only will it provide a constant process of identifying and documenting the outcomes of the Trial, essential for determining the appropriateness of ecological thinning as a management technique, but it will also be important in the adaptive management framework of the Trial.

Most of the methods used to monitor the vertebrate fauna are practical and appropriate. The importance of standardised methods and survey effort across monitoring periods was realised, and it is important that future monitoring is standardised to facilitate robust comparisons through time. Low detection rates for some groups (e.g. cryptic bird species such as Painted Button-quail) would benefit from increased survey effort using the same techniques. Increasing survey effort is also warranted for other vertebrate fauna groups, including arboreal mammals and bats. The use of both spotlighting surveys and hair-tubes to sample mammals should continue, since results reveal the techniques to be complementary; for example, Yellow-footed Antechinus was recorded mostly in hair-sample surveys. The experimental design and methods used are considered sound, but standardised surveys in spring and a greater survey effort should overcome several of the issues confronted in Phase 1 relating to inadequate data, such as meeting the assumptions of statistical tests.

Continued surveys targeting some nocturnal birds, specifically large owls, are unlikely to contribute meaningful information on the effects of ecological thinning at the scale applied in the Trial. These birds occupy large territories in Box–Ironbark forests (Higgins 1999; Soderquist & Gibbons 2007), and although they prefer high-quality habitats (patches of older growth forest), other areas are regularly incorporated into their foraging territories (Milledge *et al.* 1991; Lumsden & Bennett 2005). Thus, impacts of ecological thinning are unlikely to be detectable at the Plot scale applied in the Trial. Nevertheless, it is recognised that, in the long-term, ecological thinning is likely to contribute to increased habitat suitability for such species through greater abundance of hollows and increased abundance of prey. Other nocturnal birds, including Tawny Frogmouth *Podargus strigoides*, White-throated Nightjar *Eurostopodus mystacalis*, Australian Owlet-nightjar and Southern Boobook, may also respond to the habitat changes brought about by thinning (see Kutt 1994), and ongoing monitoring should provide meaningful ecological information about thinning outcomes.

The dynamics of Noisy Miner populations should be carefully monitored. The potential exists for ecologically thinned Plots to provide suitable habitat for Miners, at least in the short-term (Hastings & Beattie 2006; Taylor *et al.* 2008), which could create negative consequences for the resident bird assemblage. Information on Noisy Miner occurrence and associated impacts on bird assemblages will be detectable using ongoing bird surveys.

Invertebrates are often overlooked in habitat manipulation and restoration programs, particularly in landscape-scale studies. The large amount of data generated and their strong associations with habitat variables shaped by ecological thinning makes ants, and ground invertebrates in general, ideal candidates for ongoing monitoring. Ants are the most dominant group of ground invertebrates in Box–Ironbark forest but there is limited knowledge on how they contribute to the ecology of these forests, so there is a need to understand the roles that some key groups play. The technique used to sample ground invertebrates was suitable, but future invertebrate sampling should be limited to spring and early summer when the ground invertebrate assemblage is most active.

An important aspect of ongoing monitoring will be the timing of surveys to assess changes in biodiversity and habitat features. While documenting initial post-thinning changes forms the backbone of this report, one of the strengths of Phase 1 was the collection, collation and documentation of baseline data which describes the pre-thinning and initial post-thinning conditions of the range of biodiversity and habitat features assessed. While this should provide the basis of future comparisons, some of the datasets were confounded by differences in the timing of the surveys between pre- and post-thinning monitoring periods, and this must be considered.

Changes in some habitat features were considered to be a direct result of thinning (e.g. increase in coarse woody debris), as opposed to a response to thinning, and as discussed previously, the responses of most fauna were difficult to determine soon after thinning, with potential for a time-lag effect. There is limited information on the longer-term, sequential re-establishment of fauna after thinning or timber removal, though Williams *et al.* (2002) recorded changes to bird assemblages for many decades after timber harvesting. There are, however, many examples of faunal re-establishment following fire which illustrate similar processes: after fires, fauna assemblages change rapidly from year to year, and over longer time-frames (e.g. Reilly 1991, 2000; Recher *et al.* 2009). Similar responses are also evident as vegetation matures in studies of revegetated areas (Vesk & Mac Nally 2006; Munro *et al* 2007).

Based on this information, it is recommended that subsequent monitoring should be carried out at least every 2–3 years, particularly in the first 10 years after thinning. This frequency is necessitated by the rapid changes to a number of floristic life forms already observed. It is also important to synchronise the field surveys of all biodiversity and habitat features so that any ecological relationships can be identified.

6.3 Suggested Improvements to Monitoring Design

Parks Victoria has strongly promoted the Trial as adopting an adaptive experimental approach to investigating how ecological thinning may be used to restore a greater diversity of habitat types to the landscape and therefore allow improved functioning and persistence of key communities and species populations. In accordance with this approach, this section of the report describes the changes or additions to the monitoring design that should be addressed to enhance the outcomes of ongoing monitoring. The changes suggested below do not involve changes to the underlying experimental design, but focus more on potential sources of additional information to improve monitoring outcomes.

Establishment of a set of advanced sites to benchmark biodiversity and habitat outcomes of the Trial was planned as part of Phase I monitoring. It is accepted that almost no areas of Box–Ironbark forest remain that satisfy the formal definition of ‘old growth’. However, as part of the ECC investigation, areas supporting higher numbers of large old trees were mapped across public land in the Box–Ironbark region in Victoria (ECC 2001). Such areas could be used to provide a contemporary benchmark of biodiversity and habitat parameters against which to compare current and ongoing outcomes (Phase 2) of the Trial, and to assist in the prediction of trajectories of response variables (i.e. biodiversity and habitat variables) through time. When this issue was investigated in 2005, no suitable sites were found in near the current Control Plots. In consultation with the Scientific Reference Group, the continuation of this work was postponed to focus on implementation of the treatments (Parks Victoria, unpublished data). The feasibility of establishing advanced sites should be re-investigated in conjunction with potential monitoring of previously thinned Box–Ironbark sites.

In the long term, assessment of the outcomes of the Trial would benefit from a more holistic assessment of the invertebrate fauna. To date, only the invertebrates active at the ground surface have been considered, but other groups may provide further important insights into other aspects of the Trial: groups such as canopy-dwelling invertebrates and litter invertebrates should also be considered. For example, termites and oecophorid moths are the main decomposers of dead eucalypt leaves, and as the litter layer develops, the relationships between leaf decomposers, other ground-dwelling invertebrates and habitat features such as coarse woody debris will be important for nutrient-cycling and other ecological processes . There are well-established and practical methods suitable for sampling both canopy (Tassone & Majer 1997) and litter invertebrates (York 1999) that should be considered.

Options to incorporate reptiles and frogs into the vertebrate-monitoring program should be explored, although it is considered that the fauna groups monitored in Phase 1 are the most practical to survey and provide a comprehensive coverage of fauna responses to ecological thinning. While the reptile assemblage inhabiting Box–Ironbark forest is characterised by low species richness and density (Brown 2001), the number of captures obtained during independent research at a number of the Plots was encouraging. These results indicated a trend towards some species being associated with recently thinned Plots, although this has not yet been analysed. Ecological characteristics considered important for Box–Ironbark reptiles include the load and structure of coarse woody debris (important for the Tree Dragon) and litter layer (important for Bougainville’s Skink and Gray’s Blind Snake), and these are habitat characteristics that were changed by ecological thinning. Reptiles and frogs would be best sampled using pitfall traps (this technique was used in the independent research). Another appropriate technique to sample frogs would be acoustic surveys (see below).

Future monitoring may yield an opportunity to establish the effectiveness of additional vertebrate-survey techniques, such as automatic cameras or recording stations (e.g. for recording the calls of birds and frogs). Such techniques can be used to collect targeted information, including species-specific information, observations of cryptic species and measures of pest activity (e.g. House Cat and Red Fox activity). Such automated techniques can be cost-effective and the information gathered would supplement that collected by more traditional field-based methods.

The Trial provides a suitable template for ongoing research which could provide valuable information on temporal changes and species relationships. It is imperative that Parks Victoria actively promotes the Trial to research institutions such as universities, as well as to independent researchers and community groups to encourage research under the established framework. The outcomes of such research will be crucial to supplementing the information collected during the ongoing monitoring program, and will benefit the adaptive experimental approach that forms the basis of the Trial.

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APPENDIX 1

Vertebrate Species Recorded During the Trial

List of vertebrate species recorded during the Trial, February 2004–March 2008, with Atlas of Victorian Wildlife species code. Bird species include off-Plot (though within reserve) records.

Common Name	Species	Species Code
Birds		
Black Swan	*Cygnus atratus*	203
Common Bronzewing	*Phaps chalcoptera*	34
Peaceful Dove	*Geopelia striata*	30
Australian Owlet-nightjar	*Aegotheles cristatus*	317
Brown Goshawk	*Accipiter fasciatus*	221
Wedge-tailed Eagle	*Aquila audax*	224
Brown Falcon	*Falco berigora*	239
Masked Lapwing	*Vanellus miles*	133
Painted Button-quail	*Turnix varius*	14
Galah	*Eolophus roseicapillus*	273
Long-billed Corella	*Cacatua tenuirostris*	272
Little Corella	*Cacatua sanguinea*	271
Sulphur-crested Cockatoo	*Cacatua galerita*	269
Musk Lorikeet	*Glossopsitta concinna*	258
Little Lorikeet	*Glossopsitta pusilla*	260
Crimson Rosella	*Platycercus elegans*	282
Eastern Rosella	*Platycercus eximius*	288
Swift Parrot	*Lathamus discolor*	309
Red-rumped Parrot	*Psephotus haematonotus*	295
Shining Bronze-Cuckoo	*Chalcites lucidus*	344
Pallid Cuckoo	*Cacomantis pallidus*	337
Fan-tailed Cuckoo	*Cacomantis flabelliformis*	338
Powerful Owl	*Ninox strenua*	248
Barking Owl	*Ninox connivens*	246
Southern Boobook	*Ninox novaeseelandiae*	242
Laughing Kookaburra	*Dacelo novaeguineae*	322
Sacred Kingfisher	*Todiramphus sanctus*	326
White-throated Treecreeper	*Cormobates leucophaeus*	558
Brown Treecreeper	*Climacteris picumnus*	555
Superb Fairy-wren	*Malurus cyaneus*	529
Chestnut-rumped Heathwren	*Hylacola pyrrhopygia*	498
Speckled Warbler	*Chthonicola sagittata*	504
Weebill	*Smicrornis brevirostris*	465
Striated Thornbill	*Acanthiza lineata*	470
Yellow Thornbill	*Acanthiza nana*	471

Common Name	Species	Species Code
Chestnut-rumped Thornbill	*Acanthiza uropygialis*	481
Buff-rumped Thornbill	*Acanthiza reguloides*	484
Brown Thornbill	*Acanthiza pusilla*	475
Spotted Pardalote	*Pardalotus punctatus*	565
Striated Pardalote	*Pardalotus striatus*	976
Yellow-faced Honeyeater	*Lichenostomus chrysops*	614
White-eared Honeyeater	*Lichenostomus leucotis*	617
Yellow-tufted Honeyeater	*Lichenostomus melanops*	619
Fuscous Honeyeater	*Lichenostomus fuscus*	613
White-plumed Honeyeater	*Lichenostomus penicillatus*	625
Red Wattlebird	*Anthochaera carunculata*	638
Black-chinned Honeyeater	*Melithreptus gularis*	580
Brown-headed Honeyeater	*Melithreptus brevirostris*	583
White-naped Honeyeater	*Melithreptus lunatus*	578
Noisy Friarbird	*Philemon corniculatus*	645
White-browed Babbler	*Pomatostomus superciliosus*	445
Spotted Quail-thrush	*Cinclosoma punctatum*	436
Varied Sittella	*Daphoenositta chrysoptera*	549
Black-faced Cuckoo-shrike	*Coracina novaehollandiae*	424
White-bellied Cuckoo-shrike	*Coracina papuensis*	425
Crested Shrike-tit	*Falcunculus frontatus*	416
Golden Whistler	*Pachycephala pectoralis*	398
Rufous Whistler	*Pachycephala rufiventris*	401
Grey Shrike-thrush	*Colluricincla harmonica*	408
Crested Bellbird	*Oreoica gutturalis*	419
Olive-backed Oriole	*Oriolus sagittatus*	671
Masked Woodswallow	*Artamus personatus*	544
White-browed Woodswallow	*Artamus superciliosus*	545
Dusky Woodswallow	*Artamus cyanopterus*	547
Grey Butcherbird	*Cracticus torquatus*	702
Australian Magpie	*Cracticus tibicen*	705
Grey Currawong	*Strepera versicolor*	697
Grey Fantail	*Rhipidura albiscapa*	361
Willie Wagtail	*Rhipidura leucophrys*	364
Australian Raven	*Corvus coronoides*	930
Little Raven	*Corvus mellori*	954
Satin Flycatcher	*Myiagra cyanoleuca*	366
Restless Flycatcher	*Myiagra inquieta*	369
Magpie-lark	*Grallina cyanoleuca*	415
White-winged Chough	*Corcorax melanorhamphos*	693
Jacky Winter	*Microeca fascinans*	377
Scarlet Robin	*Petroica boodang*	380
Red-capped Robin	*Petroica goodenovii*	381

Common Name	Species	Species Code
Flame Robin	*Petroica phoenicea*	382
Hooded Robin	*Melanodryas cucullata*	385
Eastern Yellow Robin	*Eopsaltria australis*	392
Rufous Songlark	*Cincloramphus mathewsi*	509
Silvereye	*Zosterops lateralis*	574
Welcome Swallow	*Hirundo neoxena*	357
Mistletoebird	*Dicaeum hirundinaceum*	564
Mammals		
Short-beaked Echidna	*Tachyglossus aculeatus*	1003
Brush-tailed Phascogale	*Phascogale tapoatafa*	1017
Yellow-footed Antechinus	*Antechinus flavipes*	1027
Agile Antechinus	*Antechinus agilis*	1028
Koala	*Phascolarctos cinereus*	1162
Common Brushtail Possum	*Trichosurus vulpecula*	1113
Sugar Glider	*Petaurus breviceps*	1138
Squirrel Glider	*Petaurus norfolcensis*	1137
Common Ringtail Possum	*Pseudocheirus peregrinus*	1129
Eastern Grey Kangaroo	*Macropus giganteus*	1265
Black Wallaby	*Wallabia bicolor*	1242
House Mouse*	*Mus musculus*	1412
Black Rat*	*Rattus rattus*	1408
Red Fox*	*Vulpes vulpes*	1532
Dog*	*Canis familiaris*	1836
House Cat*	*Felis catus*	1536
Cattle*	*Bos taurus*	1518
Bats		
Yellow-bellied Sheathtail Bat	*Saccolaimus flaviventris*	1321
White-striped Freetail Bat	*Tadarida australis*	1324
Southern Freetail Bat (long penis)	*Mormopterus sp.*(lp)	1808
Gould's Wattled Bat	*Chalinolobus gouldii*	1349
Chocolate Wattled Bat	*Chalinolobus morio*	1351
Large Forest Bat	*Vespadelus darlingtoni*	1381
Southern Forest Bat (high frequency)	*Vespadelus regulus* (HF)	1378
Southern Forest Bat (low frequency)	*Vespadelus regulus* (LF)	1378
Little Forest Bat	*Vespadelus vulturnus*	1379
Large-footed Myotis	*Myotis adversus*	1357
Inland Broad-nosed Bat	*Scotorepens balstoni*	1364
Long-eared Bats (Lesser/Gould's)	*Nyctophilus geoffroyi/N. gouldi*	1335/1334
Frogs		
Southern Bullfrog	*Limnodynastes dumerilii*	3058

Common Name	Species	Species Code
Plains Froglet	*Crinia parinsignifera*	3131
Peron's Tree Frog	*Litoria peronii*	3204

* Introduced species

APPENDIX 2

Bird Species and their Ecological Groupings in Trial Assemblages

Migratory status: R = resident; M = Migrant; PG = Partial migrant; BS = Bass Strait migrant

Migrant group: S = sedentary; I = Inland route; C = Coastal route; L = Local movement; A = Altitudinal migrant

Bird	Foraging group	Nest group	Migratory status	Migrant group
Common Bronzewing	ground granivore	tree branch	R	S
Peaceful Dove	ground granivore	tree branch	R	S
Brown Goshawk	carnivore	tree branch	R	S
Wedge-tailed Eagle	carnivore	tree branch	R	S
Brown Falcon	carnivore	tree branch	R	S
Painted Button-quail	ground invertebrates	ground	R	S
Galah	ground granivore	hollow	R	S
Long-billed Corella	ground granivore	hollow	R	S
Little Corella	ground granivore	hollow	R	S
Sulphur-crested Cockatoo	ground granivore	hollow	R	S
Musk Lorikeet	nectar	hollow	R	S
Little Lorikeet	nectar	hollow	PG	L
Crimson Rosella	arboreal granivore	hollow	R	S
Eastern Rosella	ground granivore	hollow	R	S
Swift Parrot	nectar	non-breeding migrant	M	B
Red-rumped Parrot	ground granivore	hollow	R	S
Shining Bronze-Cuckoo	foliage invertebrates	parasitic	M	C
Pallid Cuckoo	ground invertebrates	parasitic	M	I
Fan-tailed Cuckoo	ground invertebrates	parasitic	M	C
Laughing Kookaburra	carnivore	hollow	R	S
Sacred Kingfisher	carnivore	hollow	M	I

Bird	**Foraging group**	**Nest group**	**Migratory status**	**Migrant group**
White-throated Treecreeper	bark invertebrates	hollow	R	S
Brown Treecreeper	bark invertebrates	hollow	R	S
Superb Fairy-wren	ground invertebrates	ground vegetation	R	S
Chestnut-rumped Heathwren	ground invertebrates	ground	R	S
Speckled Warbler	ground invertebrates	ground	R	S
Weebill	foliage invertebrates	canopy foliage	R	S
Striated Thornbill	foliage invertebrates	canopy foliage	R	S
Yellow Thornbill	foliage invertebrates	understorey	R	S
Chestnut-rumped Thornbill	shrub invertebrates	tree bole	R	S
Buff-rumped Thornbill	ground invertebrates	ground	R	S
Brown Thornbill	shrub invertebrates	ground vegetation	R	S
Spotted Pardalote	foliage invertebrates	burrow	R	S
Striated Pardalote	foliage invertebrates	hollow	PG	I
Yellow-faced Honeyeater	nectar	understorey	M	C
White-eared Honeyeater	bark invertebrates	understorey	R	S
Yellow-tufted Honeyeater	nectar	understorey	R	S
Fuscous Honeyeater	nectar	canopy foliage	R	S
White-plumed Honeyeater	foliage invertebrates	canopy foliage	R	S
Red Wattlebird	nectar	understorey	PG	L
Black-chinned Honeyeater	foliage invertebrates	canopy foliage	M	I
Brown-headed Honeyeater	foliage invertebrates	canopy foliage	R	S
White-naped Honeyeater	foliage invertebrates	canopy foliage	R	S
Noisy Friarbird	nectar	canopy foliage	M	C
White-browed Babbler	ground invertebrates	understorey	R	S
Spotted Quail-thrush	ground invertebrates	ground	R	S

Bird	**Foraging group**	**Nest group**	**Migratory status**	**Migrant group**
Varied Sittella	bark invertebrates	tree branch	PG	L
Black-faced Cuckoo-shrike	foliage invertebrates	tree branch	M	I
Crested Shrike-tit	bark invertebrates	canopy foliage	R	S
Golden Whistler	foliage invertebrates	tree bole	PG	C
Rufous Whistler	foliage invertebrates	tree bole	M	I
Grey Shrike-thrush	bark invertebrates	tree bole	R	S
Crested Bellbird	ground invertebrates	tree bole	R	S
Olive-backed Oriole	foliage invertebrates	canopy foliage	M	I
Masked Woodswallow	aerial invertebrates	understorey	M	I
White-browed Woodswallow	aerial invertebrates	understorey	M	I
Dusky Woodswallow	aerial invertebrates	tree bole	M	C
Australian Magpie	ground invertebrates	tree branch	R	S
Grey Currawong	carnivore	tree branch	R	S
Grey Fantail	aerial invertebrates	understorey	PG	C
Willie Wagtail	ground invertebrates	understorey	R	S
Australian Raven	carnivore	tree branch	R	S
Little Raven	carnivore	tree branch	R	S
Leaden Flycatcher	aerial invertebrates	tree branch	M	I
Satin Flycatcher	aerial invertebrates	tree branch	M	C
Restless Flycatcher	ground invertebrates	tree branch	R	L
Magpie-lark	ground invertebrates	tree branch	R	S
White-winged Chough	ground invertebrates	tree branch	R	S
Jacky Winter	ground invertebrates	tree branch	R	S
Scarlet Robin	ground invertebrates	tree bole	R	S
Red-capped Robin	ground invertebrates	tree bole	R	S
Flame Robin	ground invertebrates	non-breeding migrant	M	A

Bird	**Foraging group**	**Nest group**	**Migratory status**	**Migrant group**
Hooded Robin	ground invertebrates	tree bole	R	S
Eastern Yellow Robin	ground invertebrates	tree bole	R	S
Rufous Songlark	ground invertebrates	ground	M	I
Silvereye	shrub invertebrates	understorey	PG	C
Welcome Swallow	aerial invertebrates	tree bole	M	I
Mistletoebird	mistletoe	canopy foliage	PG	L

APPENDIX 3

Ant Species and their Functional Groups Collected During the Trial

Ant functional group	No. ind. pre-thin	No. ind. Post-thin
1 Dominant Dolicherinae		
Anonychomyrma sp.1	503	458
Iridomyrmex sp.1	1717	6338
Iridomyrmex sp.2	48	64
Iridomyrmex sp.3	2050	2258
Iridomyrmex sp.4	51	212
Iridomyrmex sp.5	0	2
Iridomyrmex sp.6	0	1
Leptomyrmex sp.1	0	2
Papyrius sp.1	4	52
2 Subordinate Campontoninae		
Camponotus sp.1	126	141
Camponotus sp.10	13	3
Camponotus sp.11	18	16
Camponotus sp.12	1	3
Camponotus sp.13	4	0
Camponotus sp.14	4	2
Camponotus sp.15	4	7
Camponotus sp.16	2	1
Camponotus sp.17	0	7
Camponotus sp.18	0	1
Camponotus sp.19	0	1
Camponotus sp.20	0	1
Camponotus sp.3	70	72
Camponotus sp.4	67	28
Camponotus sp.5	1	9
Camponotus sp.6	2	1
Camponotus sp.7	30	6
Camponotus sp.8	54	20
Camponotus sp.9	53	131
Polyrhachis sp.1	13	11
Polyrhachis sp.2	17	23
Polyrhachis sp.3	1	1
Polyrhachis sp.4	0	1
3a Hot-climate specialists		
Cerapachys sp.1	1	0
Cerapachys sp.2	2	9

Ant functional group	No. ind. pre-thin	No. ind. Post-thin
Cerapachys sp.3	1	0
Cerapachys sp.4	0	3
Melophorus sp.1	119	303
Melophorus sp.2	31	903
Melophorus sp.3	696	1192
Melophorus sp.4	8	6
Melophorus sp.5	1	5
Meranoplus sp.1	32	48
3b Cold-climate specialists		
Dolichoderus sp.1	24	20
Dolichoderus sp.2	0	6
Myrmecorhynchus sp.1	1	1
Notoncus sp.1	559	439
Notoncus sp.2	380	70
Notoncus sp.3	37	1
Notoncus sp.4	1	0
Podomyrma sp.1	4	1
Podomyrma sp.2	12	4
Podomyrma sp.3	10	34
Podomyrma sp.4	0	2
Prolasius sp.1	14	17
Prolasius sp.2 (not Paratrechina)	24	3
4a Cryptic species		
Amblyopone sp.1	12	7
Hypoponera sp.1	7	0
Solenopsis sp.1	0	124
Sphinctomyrmex sp.1	1	2
Sphinctomyrmex sp.2	5	0
Sphinctomyrmex sp.3	0	1
Strumigenys sp.1	1	4
4b Subcryptic species		
Heteroponera sp.1	139	163
Hypoponera sp.1	7	0
Plagiolepis sp.1	46	104
Stigmacros sp.1	4	19
Stigmacros sp.10	1	24
Stigmacros sp.11	0	7
Stigmacros sp.2	10	10
Stigmacros sp.3	5	10
Stigmacros sp.4	6	29
Stigmacros sp.5	2	0
Stigmacros sp.6	2	6
Stigmacros sp.7	4	6

Ant functional group	No. ind. pre-thin	No. ind. Post-thin
Stigmacros sp.8	1	4
Tapinoma sp.1	112	234
5 Opportunists		
Doleromyrma sp.1	915	1608
Mayriella sp.1	2	5
Ochetellus sp.1	6	5
Paratrechina sp.1	58	137
Paratrechina sp.2	0	3
Rhytidoponera sp.1	4102	9514
Tetramorium sp.1	13	14
6 Generalist Myrmecines		
Crematogaster sp.1	757	331
Crematogaster sp.2	97	287
Crematogaster sp.3	0	211
Monomorium sp.1	978	3123
Monomorium sp.10	0	18
Monomorium sp.2	297	789
Monomorium sp.3	2	6
Monomorium sp.4	217	0
Monomorium sp.5	1	0
Monomorium sp.8	8	10
Monomorium sp.9	0	1
Pheidole sp.1	677	1859
Pheidole sp.2	790	634
Pheidole sp.3	189	254
7 Large solitary foragers		
Colobostruma sp.1	1	13
Epopostruma sp.1	0	6
Epopostruma sp.2	2	0
Mesostruma sp.1	0	1
Myrmecia sp.1	39	13
Myrmecia sp.2	1	0
Myrmecia sp.3	3	11
Myrmecia sp.4	3	2
Pachycondyla sp.1	11	16
Pachycondyla sp.2	19	21

Parks Victoria is responsible for managing the Victorian protected area network, which ranges from wilderness areas to metropolitan parks and includes both marine and terrestrial components. Our role is to protect the natural and cultural values of the parks and other assets we manage, while providing a great range of outdoor opportunities for all Victorians and visitors.

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