Department of
Sustainability and
Environment

Ecological effects of repeated low-intensity fire on insectivorous bat populations of a mixed eucalypt foothill forest in south-eastern Australia

Research report no. 64

Victoria
The Place To Be

Effects of repeated low-intensity fire on insectivorous bat populations of a mixed eucalypt foothill forest in south-eastern Australia

Research Report No. 64

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December 2003

This report was commissioned by

Fire Management
Department of Sustainability and Environment
Victoria

For further information contact:
DSE Customer Service Centre 136 186

ISBN 1 74106 894 0

Department of Sustainability and Environment,
PO Box 500, East Melbourne, Victoria, 3002.

www.dse.vic.gov.au/fires

Cover photographs 1. Bat harp trap, DSE/K.Tolhurst 2. White-striped Freetail Bat, DSE/I.McCann

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Foreword

The vegetation, topography and climate of south-eastern Australia combine to make the region one of the most wildfire-prone areas on Earth. Over tens of thousands of years, naturally occurring fires have been highly significant in shaping the distribution and composition of much of the region's native flora and fauna. The arrival of humans here is also considered to have had a more recent influence on these evolutionary processes. Paradoxically, it has been estimated that, in the last one hundred years, two-thirds of all human deaths related to bushfires in Australia and more than half of all significant related property losses have occurred in Victoria.

The severity of a bushfire depends on topography, weather and fuel conditions. Fuel is the only factor over which a land manager can exert some control. The strategic use of prescribed fire (under specified environmental and fire behaviour prescriptions), generally in spring or autumn, is the only practical method of reducing fuels over significant areas and has been a key component of park and forest management in Victoria since the late 1950s – early 1960s.

The threat posed by fire to life and property and the relationship between fire regimes and biodiversity are arguably the key on-going issues confronting the managers of Victoria's parks and forests.

In 1984, a multidisciplinary study was established in the Wombat State Forest, 80 km north-west of Melbourne (Victoria), to investigate the effects of repeated low-intensity prescribed burning in mixed eucalypt foothill forest. The study—the Wombat Fire Effects Study—is quantitative and statistically based and includes various aspects of fauna, flora, soils, tree growth, fuel management and fire behaviour.

On the same permanent plots, various methodologies are used to investigate the ecological impacts of fire on understorey flora, invertebrates, birds, bats, reptiles, terrestrial mammals, soil chemistry and the growth, bark thickness and defect development in trees. Local climate and weather, fuel dynamics and fire behaviour are also studied, along with their interactions. Numerous published papers and reports have been produced as a result of the work. Fire Management Research Reports comprising the current (2003) series are:

No.	Title
57.	Ecological effects of repeated low-intensity fire in a mixed eucalypt foothill forest in south-eastern Australia - Summary report (1984–1999) - Department of Sustainability and Environment
58.	Effects of repeated low-intensity fire on the understorey of a mixed eucalypt foothill forest in south-eastern Australia - K.G. Tolhurst
59.	Effects of repeated low-intensity fire on fuel dynamics in a mixed eucalypt foothill forest in south-eastern Australia - K.G. Tolhurst & N. Kelly
60.	Effects of repeated low-intensity fire on carbon, nitrogen and phosphorus in the soils of a mixed eucalypt foothill forest in south-eastern Australia - P. Hopmans
61.	Effects of repeated low-intensity fire on the invertebrates of a mixed eucalypt foothill forest in south-eastern Australia - N. Collett & F. Neumann
62.	Effects of repeated low-intensity fire on bird abundance in a mixed eucalypt foothill forest in south-eastern Australia - R. Loyn, R. Cunningham & C. Donnelly
63.	Effects of repeated low-intensity fire on terrestrial mammal populations of a mixed eucalypt foothill forest in south-eastern Australia - M. Irvin, M. Westbrooke & M. Gibson
64.	Effects of repeated low-intensity fire on insectivorous bat populations of a mixed eucalypt foothill forest in south-eastern Australia - M. Irvin, P. Prevett & M. Westbrooke

65. Effects of repeated low-intensity fire on reptile populations of a mixed eucalypt foothill forest in south-eastern Australia - M. Irvin, M. Westbrooke & M. Gibson
66. Effects of repeated low-intensity fire on tree growth and bark in a mixed eucalypt foothill forest in south-eastern Australia - K. Chatto, T. Bell & J. Kellas

The foreword to the summary report (Fire Management *Research Report* No. 57) sets out more fully the background to the research, the impact it has had on fire management in the State and the future of the program.

I would like to acknowledge the very considerable efforts of the scientists and technical officers who have contributed to this specific report and more generally to this most significant project.

Gary Morgan AFSM

CHIEF FIRE OFFICER
Department of Sustainability and Environment

2003

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Summary

Seven species of bat were recorded in the Wombat Fire Effects Study Areas (FESAs). Only the three southern-most FESAs were surveyed. Bats are the most species-rich mammal group in the forest and are therefore an important fauna group. Bats feed mainly in the middle and overstorey vegetation and are therefore most likely to be affected by changes in forest structure. Bats are also one of the most difficult groups to study.

This study employed a wide range of bat survey techniques, including searches of mines, natural hollows and nest boxes, trip lines, vertical trip lines, mist nets, frame nets, harp traps, Skye ultrasonic detectors, Anabat II bat detectors and radio telemetry. This report is the summary of ten separate studies undertaken by staff and students from Ballarat University.

Five burning treatments were replicated in each FESA in this study: long-unburnt, short-rotation spring and short-rotation autumn burning, long-rotation spring and long-rotation autumn burning.

Bat activity was found to be significantly affected by air temperature and seasonal conditions. Therefore, comparison between fire treatments had to be made either by accounting for differences in the conditions at the time of surveying or by contemporaneous measurement.

Bat activity was related almost linearly with air temperature, with activity ceasing below 9 ºC. Insect activity was also correlated to air temperature; as a result it is inferred that bat activity is closely related to airborne invertebrate activity.

Tree cavities, varying from hollows to fissures, were found to be important as roost sites for bats. Different species may have different requirements for roost sites, but further research is needed to determine the range and nature of these roost sites and the effect of repeated fires on them.

No significant difference in bat activity was found in any of the fire treatments at the Blakeville and Musk Creek FESAs. This suggests that the value of habitat for bats was relatively equal for all burning treatments. This study found that bats travel at least 1–5 km, therefore the size of the treatment areas in this study is probably too small to draw firm conclusions about the impact of repeated low-intensity fire on bat populations.

Background

In 1984, a research program was initiated by the then Forest Commission in Victoria in response to growing community concerns about the ecological effects of repeated fuel reduction burning. This program looked at the effects of repeated low-intensity prescribed fire on the main elements of a foothill forest ecosystem in the Wombat State Forest in west-central Victoria.

The fire effects study comprises five replicated Fire Effects Study Areas (FESAs) located at Barkstead, Blakeville, Burnt Bridge, Kangaroo Creek and Musk Creek throughout State forest. Each FESA consisted of five Treatment Areas:

- frequent fires (approximately every three years) in spring—short-rotation spring, S3
- frequent fires (approximately every three years) in autumn—short-rotation autumn, A3
- infrequent fires (approximately every 10 years) in spring—long-rotation spring, S10
- infrequent fires (approximately every 10 years) in autumn—long-rotation autumn, A10
- fire exclusion (unburnt for more that 20 years)—long-unburnt control, C.

A full description of the program design and methodology is provided in Tolhurst (1992).

Output from this project is continually being incorporated into public land management across the State.

This report is a review of studies on bats undertaken by the University of Ballarat as part of the above research program.

Bats are the most species-rich mammal group in the forest and therefore an important fauna group. Bats feed mainly in the middle and overstorey vegetation and are therefore more likely to be affected by changes in forest structure. Bats are also one of the most difficult groups to study.

Program objectives

- To assess and describe the effects of repeated fuel reduction burning in both spring and autumn, and applied on short, medium and long rotations (five fire treatments) on bat species composition, activity and abundance.
- To study the effect of ambient air temperature on bat activity.
- To trial synchronous ultrasonic recording of activity and species composition.
- To have these findings incorporated into the Department of Sustainability and Environment’s fire protection and land management plans, policies and operations.

Introduction

In Australia, less is known about bats than any other order of mammal. They are frequently overlooked in mammal surveys, despite the fact they often occur in large numbers and may often be more diverse than other mammal groups present. The major reason for this is that bats are generally difficult to catch. Techniques for catching bats in flight have limitations, and researchers can put in much effort for few results. These limitations are due to the variety of foraging behaviour exhibited, with some species foraging above the canopy, some below and some even taking insects from the ground (McKenzie 1983). Research on Australian bats has been restricted mainly to colonial or cave-dwelling species with easily accessible roosts (Hall 1981). The study of forest-dwelling species has largely been neglected.

The primary objective of the bat research in the mixed eucalypt foothill forest of the Wombat State Forest was to compare the data from different burning treatments so that inferences can be made about the effects of fire regimes on bat species. These comparisons are difficult to make for bats as their ranges may cover several Treatment Areas.

Bat research techniques

A number of effective survey methods have been developed. Mist-netting and shooting by twilight or by floodlight (Youngson & McKenzie 1977) have been employed in the past, and various designs of the Tuttle bat trap (Tuttle 1974) have become very popular for their convenient size, portability and efficiency. Parnaby (1977) successfully caught bats by stretching fine fishing line across small dams or concrete tanks. Banding and radio-telemetry have proved useful in determining movements of bats (Stebbings 1982; Lunney et al. 1985). Analysis of echolocation calls using ultrasonic detection is becoming a useful survey method (Bell 1980; Ahlen 1981; Fenton et al. 1980; Fenton & Bell 1981; Fenton et al. 1983), often eliminating the need for capture, which is stressful to the animals and time-consuming for the surveyor.

Bat research in the Wombat State Forest 1977–2000

Bat research in the Wombat State Forest spans more than 25 years, most studies having a strong forest management focus. Several studies had objectives of trialing bat survey methods. Parnaby (1977) trialed the success of trip-lines as a capture method and compiled a species list; Kemp (1989) investigated the feasibility of using ultrasonic detectors; Pretty (1990) investigated the use of nest boxes as a survey technique and the effect of fire on nest boxes. Fowler (1988) investigated the relationship between bat species and vegetation; Irvin (1998) studied habitat requirements of bat species; and van Gaans (1987) studied the flight morphology and activity patterns of bats. Calder et al. (1979) sought to recommend forest management procedures which would provide habitat for hollow-utilising species, while several studies (Pretty 1990; Burt 1991; Preston 1992; Adler & Westbrooke 1999) tried to relate bat activity, richness and abundance to the effects of fire in the Fire Effects Study Areas (Tolhurst 1992). All studies (Table 1) have relevance to forest management.

Table 1 Bat species recorded from research in the study area

Scientific name	Parnaby (1977)	Calder et al. (1979)	van Gaans (1987)	Fowler (1988)	Kemp (1989)	Pretty (1990)	Burt (1991)	Preston (1992)	Irvin (1998)	Adler & Westbrooke (1999)	Common name
Falsistrellus tasmaniensis	*	*	*	*	*	*			*	*	Eastern False Pipistrelle
Nyctinomus australis	*		*	*					*	*	White-striped Freetail Bat
Nyctophilus geoffroyi	*	*	*	*	*	*	*	*	*	*	Lesser Long-eared Bat
Nyctophilus gouldii	*		*	*			*	*	*	*	Gould's Long-eared Bat
Chalinolobus gouldii	*	*	*	*	*	*	*	*	*	*	Gould's Wattled Bat
Chalinolobus morio	*		*	*		*	*		*	*	Chocolate Wattled Bat
Vespadelus darlingtoni	*		*	*	*	*	*		*	*	Large Forest Bat

Parnaby (1977) began bat research in the Wombat State Forest with a trial of a bat capture technique (trip-lines) infrequently used in Australia. Parnaby's results provided the basis for further development and the use of this method in preference to previously less-effective and less-ethical methods. Parnaby captured six of the seven Microchiroptera known for the area (Table 1) and lodged specimens with the Museum of Victoria. Subsequent research in the area also utilised various forms of trip-lines (van Gaans 1987; Fowler 1988; Kemp 1989; Irvin 1998; Adler & Westbrooke 1999).

In a study of the use of natural and artificial tree hollows by birds and mammals, Calder et al. (1979) found several bat species (Table 1) roosted in hollows. Some species used these hollows for maternity sites for only a few months, while other species are found in them throughout the year. Monitoring of nest boxes and natural hollows can be a useful survey method, particularly when used in combination with other methods (Pretty 1990; Burt 1991; Preston 1992).

Harp traps were used by van Gaans (1987) and later by others (Table 2). Once set, harp traps capture and retain bats without the need for the researcher to be present. The effectiveness of harp traps has resulted in them being used consistently. Irvin (1998) notes 118 harp trap captures of six species, against 47 trip-line captures of three species. Figure 1 shows the total number of captures for each bat species, combined for all researchers.

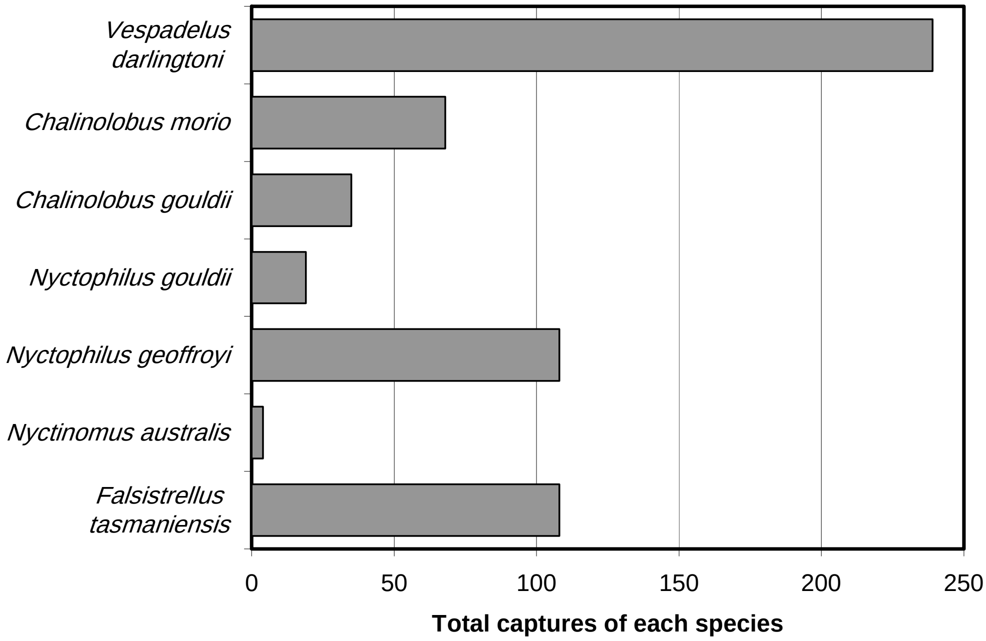

Figure 1 Combined bat captures for all researchers

Note: Data from Calder et al. (1979), Pretty (1990) and Preston (1992) do not contribute to Figure 1; nor does data from captured bats used in Adler & Westbrooke's work with Anabat detectors, which came from Irvin's work.

Most studies in the area utilised a combination of survey methods (Table 2). New techniques were enlisted as technologies developed and become more affordable. Bat activities in relation to abiotic factors, such as temperature, wind speed and lunar cycle, were first measured in the study area by van Gaans (1987), using a Skye Ultrasonic Detector. Bat activity was recorded in subsequent studies (Table 2), with recent technologies making measurement of the activity of individual species possible. Ultrasonic detectors provide a means of identifying the presence of bats without the need for capture (Fenton 1982; Fenton & Bell 1981). Kemp et al. (1992) attempted to distinguish between calls of different species. This proved unsuccessful due to the inability to differentiate between the call of a captured bat and the call of other bats in the vicinity. Adler and Westbrooke (1999) used Anabat II bat detectors (Titley Electronics ®, Ballina, NSW). This allowed measurement of activity levels of individual species.

van Gaans (1987) took wing measurements of every bat he captured and analysed these measurements to determine the flight morphology of each species. Based on the morphological data collected, van Gaans made inferences regarding the preferred forest structure of each species.

Irvin (1998) conducted research involving the use of radio telemetry to gain information on diurnal roosts of bats. Miniature radio transmitters were attached to six bat species, captured using trip-lines and harp traps, which were then tracked to their diurnal roost each day for the life of the transmitter (seven days).

Table 2 Survey techniques used by researchers in the study area

Author of research	Survey technique										
	Trip-line	Mist net	Mine searches	Frame net	Nest boxes	Natural hollows	Vertical trip-line	Skye Ultrasonic Detector	Harp trap	Anabat II Bat Detectors	Radio telemetry
Parnaby (1977)	*	*	*	*							
Calder et al. (1979)					*	*					
van Gaans (1987)	*						*	*	*		
Fowler (1988)							*				
Kemp (1989)	*						*	*	*		
Pretty (1990)					*			*	*		
Burt (1991)					*			*	*		
Preston (1992)					*			*	*		
Irvin (1998)	*								*		*
Adler & Westbrooke (1999)										*	

Methods

The following techniques were employed to capture bats in the region.

Trip-lines

Trip-lines over water bodies were first used by Parnaby (1977). Nylon fishing line was stretched over water bodies and bats would trip into the water as they attempted to drink and feed. Bats were then captured as they swam to the waters' edge. Fowler (1988) and van Gaans (1987) further developed this method, extending horizontal lines above the water (10 cm apart). This modified method proved more successful.

Harp traps

Harp traps have evolved into an efficient, portable bat survey tool. A collapsible aluminium frame with a 3 m^2 aperture and nylon lines in two banks are supported above a canvas bag. Whilst some bats avoid the harp traps, others are tripped by the lines and fall into the canvas bag.

Bats were captured in two study areas: fire dams along the Barkstead South Road, adjacent to the Barkstead FESA, and fire dams along McGees Road, adjacent to the Blakeville FESA. Captured bats were held while diagnostic features were recorded and individuals identified to species level (Reardon & Flavel 1987; Parnaby 1992), and were then released.

Recording of echolocation calls

A Skye Ultrasonic Detector connected to a tape-recorder was used to measure bat activity in five studies in the area (Table 2). Activity was measured at Blakeville, Barkstead and Musk Creek FESAs. Bat activity was related to contemporaneous air temperature in the open as recorded at weather stations located within 1.5 km of each FESA.

Adler and Westbrooke (1999) used the Anabat II bat detection system at Blakeville and Musk Creek FESAs. This system allows bat echolocation calls to be recorded simultaneously in all Treatment Areas throughout the night, reducing the effects of weather variables. The time of each call, temperature and humidity can also be recorded. Downloaded calls can be identified to species level using Anabat 5 (version 5.4) and Analook software programs written by Corben (undated) specifically for the Anabat II equipment.

Artificial hollows

Nest boxes, having 1.5-cm slit entrances and thus only accessible to bats and small arboreal mammals, such as Feathertail Gliders, were established at the Blakeville (July 1989) and Barkstead and Musk Creek (February 1990) FESAs (Kemp 1989; Kemp et al. 1992). Twenty boxes were located in each Treatment Area, spaced at 100 m along transects traversing the area. The boxes were fixed approximately 5 m above the ground.

Kemp (1989) found no evidence of usage of the nest boxes. Pretty (1990) had some success using the same nest boxes.

Results

Species recorded

Seven species of Microchiropteran bats were recorded in the study area using seven capture techniques (Table 3). There are no reliable methods of field identification for females to species level in the genus *Vespadelus* (Churchill 1998). Females in the genus *Vespadelus* were therefore classed as *Vespadelus* spp. Forearm measurements, size and fur colour of the females captured indicate that all individuals were most likely *V. darlingtoni*. All males of the genus *Vespadelus* were clearly identified as *V. darlingtoni* (Adler & Westbrooke 1999). Parnaby's (1976) recording of *Falsistrellus tasmaniensis* is one of the first in Victoria. This species has been consistently recorded in subsequent studies.

Nyctinomus australis was recorded in five studies (Table 1). It forages above the forest canopy, however, and is not readily trapped. This species has rarely been captured in the study area. Parnaby (1977), van Gaans (1987) and Fowler (1988) each captured a single individual. *Nyctinomus australis* uses echolocation calls that fall within the audible range (Churchill 1998) and was regularly heard during field surveys.

All researchers in the area detected *Nyctophilus geoffroyi* and *Chalinolobus gouldii*. This may be because they are a common species or because of their susceptibility to particular capture techniques. Preston (1992) found 19 *N. geoffroyi* in nest boxes, but provides no abundance data of other species (Table 1). However, he noted capture rates were low throughout the study.

Table 3 Bat species captured and survey technique used

Scientific name	Survey technique: Mist net	Nest boxes	Trip-line [1]	Harp trap [2]	Anabat II Detectors	Radio telemetry	Audible observation	Common name
Falsistrellus tasmaniensis	*		*	*	*			Eastern False Pipistrelle
Nyctinomus australis			*				*	White-striped Freetail Bat
Nyctophilus geoffroyi	*	*	*	*	*	*		Lesser Long-eared Bat
Nyctophilus gouldii	*		*	*	*			Gould's Long-eared Bat
Chalinolobus gouldii	*		*	*	*	*		Gould's Wattled Bat
Chalinolobus morio	*		*	*	*	*		Chocolate Wattled Bat
Vespadelus darlingtoni	*		*	*	*	*		Large Forest Bat

*Taxonomy according to Menkhorst (1996)

[1] Trip-lines and vertical trip-lines

[2] Frame nets and harp traps

Recording methods

Harp traps and trip-lines were the most successful methods employed. More recently, Adler and Westbrooke (1999) successfully applied new Anabat technology in surveys of the FESAs.

Those researchers who used Skye Ultrasonic Detectors (Table 2) had limited success. None were able to identify bats to species level but all found some relationship between bat activity and temperature.

Effects of ambient air temperature

Kemp et al. (1992) recorded bat activity from February to July of 1989 at Blakeville, Barkstead and Musk Creek FESAs. Bat activity was very low from April onwards, with little activity recorded when air temperatures were below 10 ºC (Fig. 2). Bat activity ranged between temperatures of 4º to 22 ºC throughout the study and was greatest at around 20 ºC (Fig. 2). Fowler (1988) and Burt (1991) found little or no activity below 16 ºC, while van Gaans (1987) found limited activity at 9 ºC. All researchers found that an increase in temperature increased bat activity.

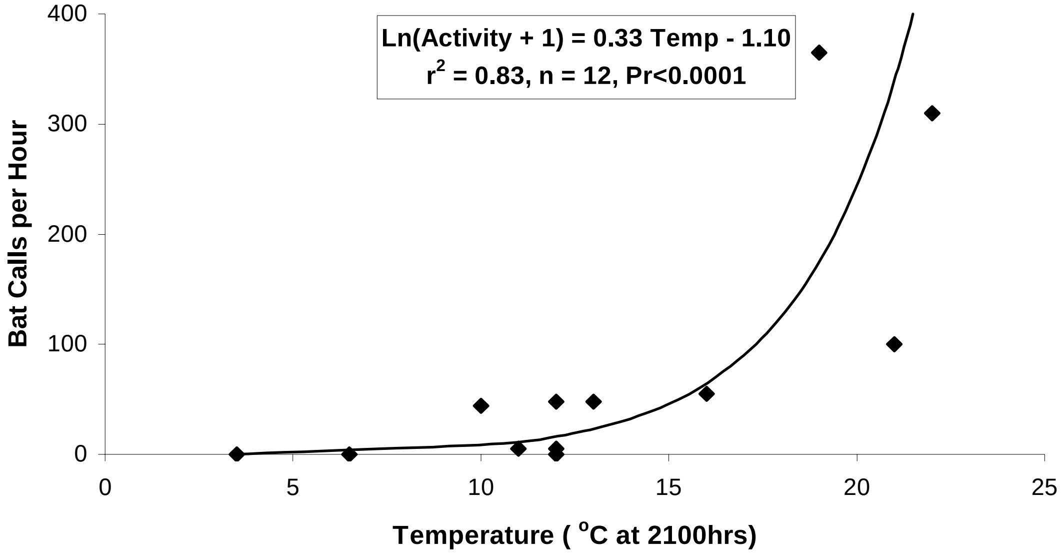

Figure 2 Bat activity based on a number of calls per hour recorded in relation to temperature (Source: Kemp et al. 1992)

Bat activity related to fire treatment

Adler and Westbrooke (1999), using the Anabat II detectors, measured bat activity concurrently in all five fire Treatment Areas at the Blakeville and Musk Creek FESAs. Despite some difficulties obtaining calls on audiotape of sufficient quality to identify bats to species level, their data provides a basis for this to be achieved. Figure 3 summarises their results.

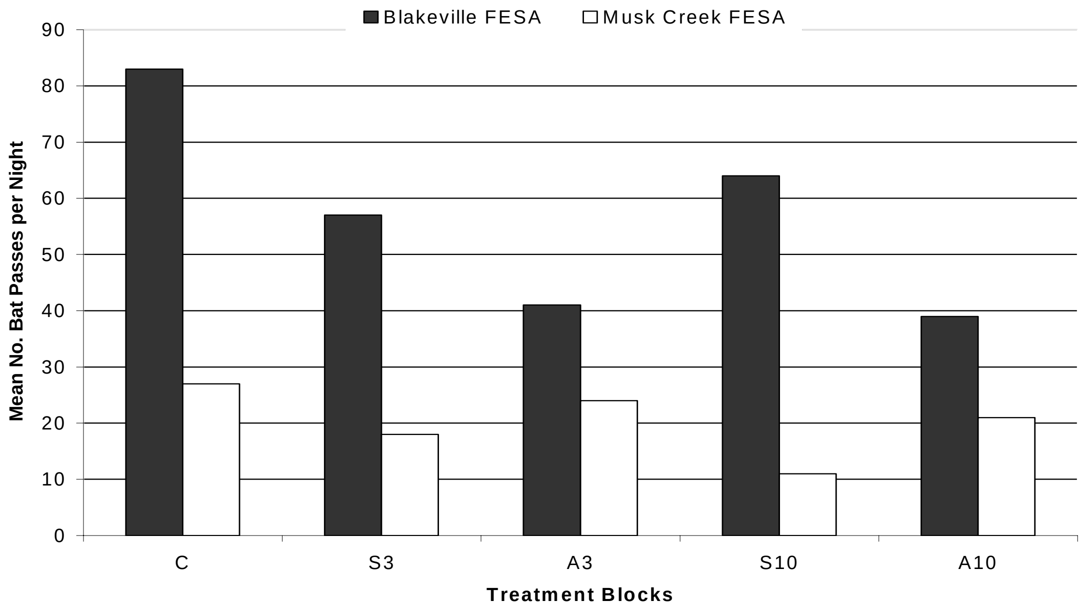

Figure 3 Bat activity at Blakeville and Musk Creek FESAs during early autumn of 1999 (Source: Adler & Westbrooke 1999).

Due to poor quality recordings of bat calls on audiotape, it was not possible to identify individual bat calls to species level. However, activity levels were established for each Treatment Area. Figure 3 displays the mean number of bat calls (bat passes) for an entire night over a three-night period and indicates the activity level of bats for each treatment. Differences in bat activity levels between Treatment Areas of the two FESAs were tested by analysis of variance (ANOVA) on the log transformed nightly activity data. This showed no significant difference in bat activity between the treatments (Adler & Westbrooke 1999), despite variations in fire history (Appendix).

Preston (1992) found that activity was greatest in the three-year treatments, followed by the control and 10-year treatments respectively. Activity levels recorded by Preston were far lower than Adler and Westbrooke (1999) in all treatments.

Diurnal roost sites

Diurnal roost site preferences were studied successfully using miniature radio transmitters. Table 4 provides basic statistics of bat captures by Irvin (1998). A total of 165 bats were captured over 32 trap nights in February and March of 1998. Irvin found 60% of captures were female and 40% male. Other studies also found a high proportion of females to males. The trip-line method caught only three bat species, whereas harp traps captured six. *Vespadelus darlingtoni* had the highest number of captures (70 bats, or 42% of all bats caught). Males and females were trapped using both methods. The species with the lowest number of captures in the Irvin (1998) study was *C. gouldii*.

Table 4 Summary of bats species captures
(Source: Irvin 1998)

Bat species	Trip-line (4 x 2.5 hrs)		Harp trap (32 trap nights)		% Harp trap captures	% Trip-line captures	% Bat captures
	Male	Female	Male	Female			
V. darlingtoni	13	21	10	26	51	49	42
F. tasmaniensis	6	4	13	6	66	34	18
N. geoffroyi			3	19	100		13
N. gouldii			5	2	100		4
C. morio			14	17	100		19
C. gouldii	3			3	50	50	4
Totals	**22**	**25**	**45**	**73**			**100**

Irvin (1998) used radio telemetry to track bats to their diurnal roosts and located 27 roosts of four bat species (Table 5). Once released, *N. gouldii* and *F. tasmaniensis* were not located again. *Vespadelus darlingtoni* and *N. geoffroyi* were the most successful radio-tracked species. Three roosts of *V. darlingtoni* were used twice and two were used three times. *Nyctophilus geoffroyi* also used the same roost on two occasions.

Table 5 Summary of transmitters fitted to bats, their success and number of roost locations recorded
(Source: Irvin 1998)

Bat species	Sex	Transmitters fitted	Times bats were located	No. roosts located	Roosts used one time	Roosts used two times	Roosts used three times
V. darlingtoni	F	5	17	10	5	3	2
N. geoffroyi	M	1	6	5	4	1	0
C. morio	M	1	2	2	2	0	0
C. gouldii	F	1	2	2	2	0	0
N. gouldii	F	1	0	0	0	0	0
F. tasmaniensis	M	1	0	0	0	0	0
Totals		**10**	**27**	**19**		**4**	**2**

The types of roost used by each bat are shown in Table 6. A Chi-square test showed a significant preference by bat species for particular roost types.

Table 6 Number of types of roosts used by each bat species
(Source: Irvin 1998)

Bat species	Roost type			
	Hollow	Bark	Fissure	Other
V. darlingtoni			14	3
N. geoffroyi		6		
C. gouldii	1			1
C. morio				2
Totals	**1**	**6**	**14**	**6**

Roost types are characterised as:

Hollow – a small opening in a tree trunk or branch occurring as a result of decay
Bark – loose ribbon bark on a tree trunk or branch (eg. as on Gum species)
Fissure – a split in dead or damaged part of a tree branch (eg. as in Gum species)
Other – roosts that could not be classified due to the difficulty of access

Using a Chi-square analysis, Irvin (1998) tested the relationship between roost type and tree species. He found a significant relationship between these two variables. Figure 4 shows that *Eucalyptus ovata* provided the most diverse roost types, with fissures being the most common.

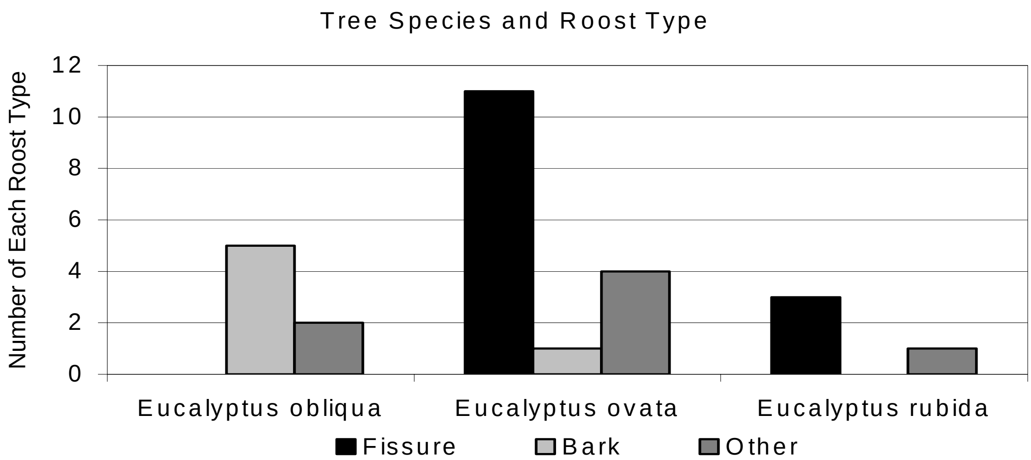

Figure 4 Interaction of tree species and roost type
(Source: Irvin 1998)

Irvin (1998) grouped diameter at breast height (DBH) data of each roost tree and found a significant relationship between these variables. Fissures used for roosting were found in trees greater than 350 mm DBH. Bats were found in bark roosts in trees with DBH less than 350 mm.

Mean straight-line distance from diurnal roosts to water (Table 7) was 545 m (Irvin 1998). The mean straight-line distances between successive roosts were 290 m for *V. darlingtoni* and 1170 m for *N. geoffroyi*. Only two roosts each were found for *C. morio* and *C. gouldii*.

Table 7 Distance to nearest water body
(Source: Irvin 1998)

Roost no.	Bat species	Distance from water (m)	Roost no.	Bat species	Distance from water (m)
1	*N. geoffroyi*	770	11	*C. morio*	660
2	*V. darlingtoni*	750	12	*C. morio*	310
3	*N. geoffroyi*	200	13	*V. darlingtoni*	980
4	*V. darlingtoni*	420	14	*V. darlingtoni*	560
5	*N. geoffroyi*	710	15	*V. darlingtoni*	560
6	*V. darlingtoni*	700	16	*V. darlingtoni*	390
7	*N. geoffroyi*	320	17	*V. darlingtoni*	270
8	*N. geoffroyi*	640	18	*C. gouldii*	780
9	*V. darlingtoni*	450	19	*C. gouldii*	290
10	*C. morio*	610			

Preston (1992) found 19 *N. geoffroyi* in a single nest box. (For reasons of survey access, all nest boxes in the FESAs were located 3–5 m above the ground.) Data obtained from the nest boxes at these sites showed that bats occupied both the three-year and ten-year fire treatments but that there were no roosting site preferences between fire treatments (Preston 1992).

Discussion

Limitations of survey techniques

The success of collecting data for bats depends on the success of the capture techniques used and the timing of the study. Early studies recorded low bat capture rates for a number of reasons, including inadequate trapping methods, timing limitations and temperature variations (Parnaby 1977; Fowler 1988; Pretty 1990).

Kemp (1989) concluded that none of the methods used on their own are suitable for an unbiased assessment of comparative abundance (Table 2). Often a range of techniques is more useful as this eliminates some of the bias where different bat species are susceptible to particular methods. For example, trapping bats using trip-lines over water is selective and an optimal height for capturing particular species exists (van Gaans 1987). Species with a low aspect-ratio are caught more readily by low-set lines while species with a high aspect-ratio are caught more readily by high-set lines due to their inability to recover flight before hitting the water (van Gaans 1987).

Most of the early studies recorded few captures and found it impossible to relate bat captures to particular Fire Effects Study Areas or treatments.

Parnaby (1977) recorded low numbers of *Nyctinomus australis* and suggests limitations such as those mentioned above might influence its capture, rather than it being extremely scarce. Despite this, it is probably present in lower numbers than other species. There have been frequent observations of this species, but the difficulties involved in its capture and its lack of detection in bat call studies has meant that little is known of its ecology in this area.

Whilst *Chalinolobus* species were captured more often at Barkstead than Blakeville FESAs, no conclusive evidence was provided to explain this apparent site preference.

Most research in the Wombat State Forest captured females in greater numbers than males (Fowler 1988; van Gaans 1987; Parnaby 1977; Irvin 1998). As most captures were at water bodies, this was possibly due to an increased water intake required for milk production (Parnaby 1977).

Ultrasonic recording

Kemp (1989), Pretty (1990) and Burt (1991) found that the greatest limitation with the ultrasonic receivers that they used is their inability to identify species. Adler and Westbrooke (1999) also had difficulties identifying calls to species level; this was due to poor quality calls recorded onto audiotapes, however. Recording calls directly onto a laptop computer should eliminate this problem in future studies.

Bat activity related to fire treatment

The limited data from Preston's autumn 1992 study of Barkstead, Blakeville and Musk Creek FESAs indicated differences in bat activity between these sites. The more comprehensive study by Adler and Westbrooke in February 1999, using multiple ultrasonic bat detectors, found no significant difference between the activity levels of bats in any of the fire effects treatments at Blakeville and Musk Creek FESAs. This was despite variations in the treatment histories of these areas (Appendix). The comparative activity levels at each Treatment Area suggests the value of habitat to bats is equal for all treatments.

Bats partition their environment into microhabitats by means of their flight morphologies and echolocation designs (Crome & Richards 1988). Data from this survey does not show the activity levels of individual species within different Treatment Areas, it may therefore be premature to suggest that prescribed burning does not have an effect on bat activity (Adler & Westbrooke 1999).

Insectivorous bats have the ability to travel large distances while foraging. *Chalinolobus gouldii* and *Nyctophilus geoffroyi* have been observed travelling 6–12 km to forage (Lumsden & Bennett 1996). The survey of the fire effects sites only sampled a proportion of the potential foraging area of bats. Results may therefore not give a true representation of foraging effort on a landscape level (Adler & Westbrooke 1999).

Temperature

Figure 3 indicates that recorded total bat activity at Musk Creek FESA is less than at Blakeville FESA. The differences in activity between sites is likely to be due to lower temperatures during the month of April compared with February; low temperatures being the most probable factor in a decline in activity by insectivorous bats (O'Neill & Taylor 1988). If comparisons of survey results are to be made between different sites, it is essential that surveys be done simultaneously or on nights of similar temperature (Kemp 1989).

An almost linear relationship was found between bat activity and air temperature (Preston 1992). The single most important factor controlling bat activity was temperature (Fowler 1988; van Gaans 1987), with activity ceasing below 9 °C. Pretty (1990) also found a correlation between temperature and bat activity. Fluctuations in temperature have been found to affect insect activity (Hill & Smith 1986). O'Neill and Taylor (1988) found insect activity and the number of bats trapped showed similar binomial distributions, suggesting that bat activity is closely related to invertebrate activity. Preston (1992) notes foraging activity of bats will increase with insect activity which, in turn, increases with temperature.

Kemp (1989) noted very high bat activity on two nights which were not at a significantly higher temperature than other survey nights. Kemp suggested that a combination of factors might contribute to activity, including factors not investigated, such as availability of insects and weather patterns over the previous few days. Fowler (1988) and van Gaans (1987) found captures were lowest on nights of a full moon.

Diurnal roosts

The tendency for Australian mixed eucalypt forests to burn with some regularity requires that forest dwelling species either be more aware of alternative roosts or less selective in the nature of the roost (Hall & Woodside 1989). These dynamic and unpredictable features of forest habitats would be reflected in the type of social organisation of the species, colony size and tendency to migrate (Hall & Woodside 1989).

Vespertilionid bats may enter periods of torpor (periods of prolonged inactivity) to overcome inclement conditions, which improves seasonal survival and longevity (Hall & Woodside 1989). The characteristics of roosts used for torpor are unknown and may be different to those used during seasons of higher activity.

Tree cavities offer protection against fluctuations in ambient temperatures and humidity (Kunz 1982). The type of roosts used by different bat species therefore reflects, to some degree, the tolerance of particular bat species to different roosting microhabitats. This is supported by the contention that the origin of a hole is of little importance to a bat, provided certain other requirements are met (Tidemann & Flavel 1987).

Tidemann and Flavel (1987) suggest that, in a regional context, one species of tree may provide more roosts than others but, overall, particular trees will be unimportant. Different roost types, which are offered by particular tree species, may be more suitable to one species than another. Whilst an individual tree may be unimportant, a natural representation of vegetation communities throughout the forest probably is (Irvin 1998).

Vespadelus darlingtoni prefer fissures in *Eucalyptus ovata* and, with 94% of *E. ovata* occurring in gullies, these gully ecosystems are important to the ecology of this bat species (Irvin 1998).

The partitioning of resources by bats to avoid niche overlap has been recognised in flight patterns and foraging behaviour (Fullard et al. 1991; Kunz 1982; McKenzie et al. 1995). The preference by bats for certain roost types is another example of a resource partitioning strategy. Although mixed species colonies are not uncommon (Kunz 1982), this strategy may be important where roosts suitable for several bat species are either unavailable or scarce.

Although many bats appear to be loyal to certain preferred roosts, there is a growing recognition that bats establish and maintain familiarity with one or more alternate roosts (Kunz 1982). Irvin (1998) found this fidelity to a general area was exhibited by *V. darlingtoni* and *N. geoffroyi*. Lunney et al. (1988), in a study on roost selection, found that *N. geoffroyi* and *N. gouldii* both roost and forage in an area of less than 1 km from their cluster of roosts. Likewise *C. morio* and *C. gouldii* confined their activity to an area within 5 km of their roosts (Lunney et al. 1985).

Roost fidelity can be affected by such factors as the relative abundance and permanency of roost sites, the proximity and stability of food resources as well as response to predator pressure and human disturbance. Roost fidelity may change seasonally and can be affected by reproductive condition, sex, age and social organisation (Kunz 1982). If ecological requirements of bats are in short supply or, conversely, are abundant in localised areas, rather than show fidelity to one roost area, it is possible that several preferred areas may be frequented.

Forest-dwelling bats experience changeable environments and are not likely to make regular long-distance forays. Rather, a high degree of home-site fidelity in the short term, with regular surveillance of nearby habitats, is to be expected (Hall & Woodside 1989; Kunz 1982; Lunney et al. 1988; Taylor & Savva 1988). Irvin (1998) found six roosts were used on multiple occasions, with the distance between day-to-day roosts in many cases being only a few hundred metres. Kunz (1982) describes the disadvantages of tree cavities in offering limited roosting space for colonial species and trees eventually rot and fall, requiring the periodic relocation of inhabitants. This suggests that forest bats are able to adapt to changes in the environment. These changes may include fuel reduction burning and silvicultural practices, though relocation to a new roost is only possible if that new roost exists. Studies on the choice of roost sites by Microchiroptera in south-eastern Australia by Tidemann and Flavel (1987) and Lunney et al. (1988) concluded that, amongst other things, it is important to retain trees that are of a size to contain bat roosts.

It is thought that fire is a factor that can contribute to the initiation of hollows. Inions et al. (1989) suggested that high-intensity fire would significantly reduce the time before hollows form. Since low-intensity burns are observed to remove most of the loose bark on the lower parts of eucalypt species, the availability of this type of roost site may be reduced (M. Westbrooke, University of Ballarat. pers. comm. 2000).

Roosts were found in a range of tree sizes, and it is significant that different roost types are provided by each tree size (Irvin 1998). Irvin observed bats using roosts in trees both larger and smaller than 350 mm diameter at breast height (DBH). Lumsden et al. (1994) found *C. gouldii* and lactating female *N. geoffroyi* were located in trees of 100–140 cm DBH, which are probably important to their roosting ecology. Small hollows and splits form as the precursors of larger ones, so bats are probably among the first mammals to recolonise regenerating stands of trees (Tideman & Flavel 1987).

In summer bats need to drink. Tideman and Flavel (1987) suggest it is probably significant that all roosts they found were within a few hundred metres of water. Irvin (1998) recorded all roosts within one kilometre of a reliable water source; however it is probable that free-standing water occurred closer in many cases. It is common also for well-watered sites to act as breeding grounds for insects (Tideman & Flavel 1987) and therefore foraging sites for bats as well. The occurrence of many bat roosts in gullies may be related to the accumulation of permanent and semi-permanent water in these areas. Given the natural availability of water in mixed eucalypt foothill forests of central Victoria, it is thought that, whilst fire dams may effect the distribution of bats, they are unlikely to have an impact on overall populations.

Gullies are protected from timber harvesting in the form of buffer strips along watercourses and drainage lines. Within the study area these buffer strips of native vegetation meander through pine plantations as well as native forest. Irvin (1998) noted that several roosts were found within these 50-m buffer strips, with bats apparently unaffected by the nature of the surrounding plantation. Whether bats use these buffer strips as a corridor to travel between forage, watering and roosting site was not determined.

Most research has focused on the numbers of bats or the amount of bat activity. While this research has provided information on species richness in the region, further research focusing on the specific requirements of each bat species will enhance future management. It should not be assumed that all seven bat species have similar requirements. Further research should focus on specific requirements of the different species.

Hollows

Calder et al. (1979) suggested that natural hollows are likely to be a fundamental habitat requirement of the mammal and bird species observed in them and that the depletion of natural tree hollows may threaten the survival or decrease the abundance and diversity of some species.

Bats may choose natural hollows in preference to otherwise suitable artificial nest boxes. Artificial nest boxes can complement existing habitat as well as provide a means for long-term monitoring. In regard to monitoring, if bats use hollows at a certain time of the year, then their presence or absence in an area could be established by inspecting hollows during that time (Calder et al. 1979). Calder et al. (1979) found Gould's Wattle Bat, two other bat species and a Feathertail Glider in the one hollow.

The significance of isolated trees close to forests needs to be investigated for bats. Recent overseas studies indicate that some species of bats avoid thicker vegetation—known as clutter (Grindal 1996). The extent to which the reduction in understorey by fire has the potential to change the species mix within bat guilds is not known in Australia.

Conclusions

Habitat protection is vital to the conservation of bats as different bat species have different requirements. The data set out here from the research so far provides a good knowledge-base from which to question current management practices where appropriate and refine questions for further study. Allocation of resources to expand our currently insufficient knowledge of bats will pave the way for current and future information to be applied to forest management.

This report has found bats to travel at least 1–5 km, therefore the study of bat ecology on a landscape scale, much larger than the FESA Treatment Areas is necessary. Since bats move widely in the landscape and are not confined to forest habitat, extending studies beyond forest boundaries to adjacent treed areas may also be required.

Very little bat activity was recorded when air temperatures were below 10 °C, with activity greatest at around 20 °C. Temperature at the time of study is critical to the level of activity observed. There is a need also to assess populations of flying nocturnal insects in each fire Treatment Area and relate these to bat activity. The effects of fire on insect populations in these areas will most probably be reflected in the observed activities of bats.

The use of Anabat to determine the distribution of bats in the forest landscape is in the early stages of development. The recent development of linking Anabat detectors directly to computers in the field will greatly facilitate an understanding of bat foraging activity. Rather than gaining activity data for insectivorous bats in general, individual bat species will be recognised and assessed via their echolocation calls.

Tree hollows do not form within the span of any currently acceptable fire rotation. All insectivorous bats of this study require some form of hollow or cavity in trees for shelter, rearing of young and protection from predators. Whilst all eucalypt species in the study area form hollows, the type of hollow produced depends partly on the tree species and partly on the stage of maturity of the tree. Surplus hollows are required for roost-switching, which, for whatever reason, occurs on a regular basis. Further characterisation of roosts to identify maternity and wintering roosts (used during periods of torpor) is required. No torpor or maternity roost trees were identified in the present study.

In this study, *Vesperdelus darlingtoni* was found to prefer roosts in *Eucalyptus ovata*, which grows primarily in wet gullies and drainage lines. Low-intensity prescribed burning strategies should be examined to determine the extent to which fire imposes change in the pattern of tree species within forest communities. The preferred habitat of various bat species will depend on this information.

Radio telemetry studies of insectivorous bats are possible within the sometimes dense and rugged terrain of foothill forests. Radio telemetry is a viable means of collecting diurnal roost information for insectivorous bats. Further telemetry studies will provide important information of the effects of fire and silvicultural management.

Recommendations for further study

The information gained from this research program is insufficient to predict the effects of repeated low-intensity burning or other management practices on bats. Ongoing research to better understand bat ecology and management effects on bat ecology should be undertaken. Attempts to answer practical research questions can provide a sound knowledge base, which can then be applied as a management tool for sustainable use of forest ecosystems. There is a perceived need to:

- obtain more detailed understanding of the use of FESA Treatment Areas by individual species of bats by using Anabat detectors linked to laptop computers for the collection of field data. Wherever possible, this research should aim to collect data prior to burning, and at a range of strategic times in the months following burning.
- conduct further assessments of roost site usage by application of radiotelemetry tracking of the full range of seven species present in the Wombat State Forest. The use of roosts by bats for different purposes throughout the night and throughout the year is not clear. Long-term monitoring of the use of roosts by bats is needed to ensure fire does not detrimentally impact on the roosts.
- initiate studies into the relationship between forage areas used by bats and aerial insect activity within study areas
- investigate the movement of bats within cluttered (dense understorey) and burnt areas, since reduction of understorey by fire may influence the bat species guilds present
- further investigate the relationships between where bats are active, why they are active and how far they will travel both in the short and long term.

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Appendix Fire treatment history of the Fire Effects Research Program, Wombat State Forest

FESA	Treatment	1985	1986	1987	1988	1989	1990	1991	1992	1993	1994	1995	1996	1997	1998
Blakeville	**S 3**	15/10			3/11			23/10			16/11				
	S 10	15/10									16/11				
	A 3			8/4					24/3					16/4	
	A 10			8/4										16/4	
Barkstead	**S 3**	13/11			28/10			15/10			18/11				
	S 10	13/11									18/11				
	A 3			27/4				11/4						17/4	
	A 10			27/4										17/4	
Burnt Bridge	**S 3**		30/9		11/11			18/11				16/11			
	S 10		30/9								23/11				
	A 3			27/3				10/4							
	A 10			27/3											
Musk Creek	**S 3**		10/11		3/11			23/10			17/11				
	S 10		10/11								17/11				
	A 3			26/3				7/5	24/3						
	A 10			26/3											
Kangaroo Creek	**S 3**	1/10			10/11			14/11			14/11				
	S 10	1/10									11/11				
	A 3			24/3					20/3					12/4	
	A 10			24/3										11/4	

(Source: K.G. Tolhurst, Forest Science Centre, pers. comm. 2000)