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Powerline easements: ecological impacts  
and effects on small mammal movement

Tanya C. Strevens  
University of Wollongong

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**Powerline easements: ecological impacts and effects on small  
mammal movement.**

**A thesis submitted in fulfillment of the requirements for  
the award of the degree**

**DOCTOR OF PHILOSOPHY**

**from the**

**UNIVERSITY OF WOLLONGONG**

**by**

**Tanya C. Strevens BA Mod. (Hons)**

**SCHOOL OF BIOLOGICAL SCIENCES**

**2007**

## **Certification**

I, Tanya Strevens, declare that this thesis, submitted in fulfilment of the requirements for the award of Doctor of Philosophy, in the School of Biological Sciences, at The University of Wollongong is wholly my own work. It does not include any material published by another person without due reference within the text. The fieldwork presented in this thesis was performed by the author, except where acknowledged. Similarly, all photographs were taken by the author, except where acknowledged. The document has not been submitted for qualifications at any other academic institution.

Tanya Strevens

25<sup>th</sup> January 2007

*“It seems to me that the natural world is the greatest source of excitement; the greatest source of visual beauty; the greatest source of intellectual interest. It is the greatest source of so much in life that makes life worth living.”*

~ Sir David Attenborough

*Antechinus stuartii*

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## Abstract

Habitat loss and fragmentation are recognised as the two primary threats to biological diversity worldwide. Powerline easements are linear habitat features that occur in all land tenures, including national parks. Where they occur in areas of natural vegetation, the vegetation is periodically mowed to maintain short grassy conditions. This creates a stark discontinuity with the natural vegetation in the area.

With the creation of powerline easements comes the simultaneous generation of large tracts of ‘edge habitat’ at the boundary between the easement and natural vegetation. In these regions, ecological processes and abiotic conditions can vary considerably from those in the bushland interior, with potentially negative effects on biodiversity. It is important, therefore, to understand the magnitude of the effects of powerline easements. By generating a series of scenarios using GIS, I explored this in a 5,735km<sup>2</sup> region of New South Wales that is rich in conservation reserves but highly fragmented by linear anthropogenic features. While the area of habitat replaced by powerline easements was not great (0.57% of all habitat in the study area), the total area of habitat likely to be ecologically affected by these features is very extensive, up to 14,070ha. Powerlines make a substantial contribution to the subdivision of native bushland in this study area.

Linear features, such as powerline easements, can inhibit the movement of small mammals. Isolated populations are more vulnerable to extinction as a result of environmental stochasticity (e.g. bushfire, disease), and are also liable to loss of genetic diversity. To quantify the barrier effect posed to small mammals by powerline easements, I conducted a mark-recapture study at four sites over a 2-year period. This revealed an extremely low rate of easement crossing by the two common small mammal species, *Rattus fuscipes* and *Antechinus stuartii*, even where vegetation in the linear opening had grown tall and dense. There was some evidence to suggest that when animals did cross from one side of the easement to the other, it tended to be when vegetation was denser. There were generally very few captures of animals in the easements themselves, even where numbers were substantial in the adjacent forest. This suggested that competitive exclusion did not explain the infrequent easement crossings.

However, one site in which easement vegetation was well-established, individuals were captured relatively regularly in the easement.

As a first step in developing a strategy to mitigate the barrier effect observed, I sought a better understanding of the habitat preferences and movement behaviour of my study species. Using the spool-and-line technique, I followed the paths of spooled animals through the habitat and, at intervals, scored the vegetation in the immediate vicinity of the spool trail. I compared these results to availability of these habitat features in the habitat in order to quantify preferences of the two species for particular microhabitats. *Rattus fuscipes* responded positively to logs and to higher densities of shrub cover. A preference for areas with higher densities of shrub cover was also identified. *Antechinus stuartii* exhibited a significant association with leaf litter, and preferential use of larger logs and trunks.

Based on the knowledge of these habitat preferences, I constructed two habitat corridors in the easement at each of the four study sites. These ‘linkages’ were composed of rows of logs and branches that linked the natural vegetation on the two sides of the easement. After initial experimentation with straight linkages, I incorporated kinks to test more effectively whether spooled animals would follow the course of these structures to the shelter of the adjacent habitat or would ignore the favoured habitat characteristics provided in the linkages.

*Antechinus stuartii* used the linkages more than *R. fuscipes*; they were less inclined to move away from it and into the easement. While some *R. fuscipes* individuals did use the linkages either partially or entirely, others strayed from them into the open easement. They strayed significantly further when shrub vegetation in the linkage was dense. *Rattus fuscipes* was less likely to leave the linkages when they were straight than when there were kinks incorporated into them. The level of ground vegetation had little effect on the distance that *R. fuscipes* moved away from the linkages following release.

The path taken by animals released on linkages, as well as in the open easement was described using a measure of ‘tortuosity’; the numbers of angles in each of four size classes per unit distance. It was then possible to compare the nature of the movement

paths of animals in the open easement, on the habitat linkages, and in the adjacent habitat. Overall, the greatest number of turns per metre was made in the open easement, with fewest in the forest habitat. For both *R. fuscipes* and *A. stuartii*, the trend was for more of the smallest angles in the open than the habitat, and more large angles in the habitat. I found no significant difference between the open easement and the linkage in terms of the proportions of turns in each angle category for either species.

Finally, I carried out a series of translocations of *R. fuscipes* and *A. stuartii* to test whether easement crossing could be induced in individuals that usually showed no evidence of inclination to travel into the easement. Selection of habitat characteristics and the tortuosity of the movement path were recorded. More than half of the individuals translocated to the opposite side of the easement returned to their side of origin in 1-5 days. Others may have returned after trapping was concluded or were simply not recaptured during the trapping session. Thus, animals can and will cross the powerline easements. Translocated animals exhibited a more tortuous movement path than animals in familiar habitat, which may be related to searching behaviour as the animal investigates its new environment, perhaps selecting a travel path for the return journey to its home range.

Powerlines are a little-studied source of habitat fragmentation, despite the widespread nature of their distribution. Given the barrier effect that has been demonstrated in this study and the potential ecological consequences of this and also of edge effects, these habitat features deserve greater attention. While corridors may in some situations mitigate the barrier effect for native animal species, linkages across powerline easements constructed in this study had little impact on the number of easement crossing events. This suggests that our understanding of what characteristics of natural habitats need to be incorporated into corridors to make them more suitable is insufficient. Closer examination of the factors that influence the movement behaviour of small mammals in a variety of habitat situations will provide useful insights into how management actions could be improved.

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## Chapter 1 – General Introduction

### 1.1 Habitat Fragmentation

Natural landscapes are usually fragmented from the perspective of a species because resources tend to be unevenly distributed throughout the landscape (Tischendorf & Wissel, 1997). Most wild species are adapted to this natural phenomenon. By contrast, habitat fragmentation arising from human activities presents a great threat to native species due to reduction of the overall habitat available to flora and fauna, as well as reduced patch size, increased isolation of habitat patches and generation of large proportions of edge habitat (Rosenblatt *et al.*, 1999). Also associated with habitat fragmentation is increased vulnerability of native populations to invasion of species from nearby anthropogenic landscapes (Janzen, 1983). The impacts of these phenomena are central to the field of conservation biology (Harrison & Bruna, 1999). However, despite the general appreciation of the significance of these issues, more detailed studies of the response of biota to habitat fragmentation, across a range of biogeographical contexts are required (Lindenmayer *et al.*, 1999).

#### 1.1.1 Ecological Impacts

The result of habitat fragmentation at the landscape level is the loss of continuous habitat, producing a mosaic of habitat patches of remnant forest that are reduced in size and surrounded by structurally and functionally dissimilar, usually inhospitable, altered land (Cox *et al.*, 2004). Fragmentation has been associated with changes in biotic and abiotic components of landscapes (Reed *et al.*, 1996). These changes and their ecological implications can be subdivided into three main components: habitat reduction, the barrier effect and edge effects. These will be discussed in the following sections.

##### 1.1.1.1 Habitat Reduction

Reduction of total habitat area is just one impact of fragmentation that could lead to local extinction (Rosenblatt *et al.*, 1999). Dunstan & Fox (1996) demonstrated the negative relationship between small mammal abundance and habitat patch size in a

fragmented landscape in Australia. Similarly, smaller fragments have been shown to support only ‘subsets’ of mammal fauna present in larger intact fragments in Australian systems (Deacon & Mac Nally, 1998). Although not all species appear to be equally sensitive to fragmentation (Crooks, 2002), these findings raise concerns for the status of populations in fragmented landscapes, particularly in the light of the conclusion of Reed *et al.* (2003), that population size is a major determinant of extinction risk. Implicit in reduction of total area of habitat is increased distance between remaining fragments, which leads to isolation of populations in smaller islands or patches. The effects of habitat loss are not discrete, but rather, are intricately related to patch size and isolation, such that the loss of species will be greater than expected from habitat loss alone (Andr  n, 1994).

With the reduction of the area of pristine habitat comes an increased risk of immigration of exotic plants and animals from nearby anthropogenic habitats (Janzen, 1983). In the case of predator invasions, this in turn may lead to further reduction of critical patch size for a prey metapopulation by altering spatial distribution of habitat patches (Cantrell *et al.*, 2001).

#### 1.1.1.2 Barrier Effect

As landscape becomes fragmented, the mobility of organisms becomes more restricted (Fahrig & Merriam, 1985; Stamps *et al.*, 1987). Dispersal is a fundamental process in ecology, affecting the associated issues of population regulation, stability, extinction and recolonisation (Peakall *et al.*, 2003). An abrupt contrast in vegetation composition and structure between two contiguous landscape elements can also act as a barrier to the dispersal of small mammals (Swihart & Slade, 1984; Burnett, 1992), insects (Bhattacharya *et al.*, 2003; Keller *et al.*, 2004), amphibians (Chan-McLeod, 2003; Marsh *et al.*, 2005), birds (van der Zande *et al.*, 1980), as well as mammals such as hedgehogs and wolves (Rondini & Doncaster, 2002; Whittington *et al.*, 2004). Compared to populations in a continuous landscape, isolated small mammal populations can suffer reduced genetic variation (Gaines *et al.*, 1997; Peakall *et al.*, 2003) as a result of limited gene flow (Mader, 1984), and are more susceptible to extinction (Fahrig &

Merriam, 1985) resulting from environmental stochasticity, demographic fluctuations or genetic deterioration (Bennett, 1990a).

#### 1.1.1.3 Edge Effects

Included in the potential effects of habitat fragmentation caused by a range of landscape barriers is a wide array of physical and biological impacts that are collectively known as 'edge effects' (Murcia, 1995). The physical and biological changes in regions adjacent to disturbance, such as forest clearance, are collectively known as edge effects (Murcia, 1995). This term generally refers to disruptions to ecological processes such as predation (Paton, 1994), seed dispersal (Landenberger & McGraw, 2004), animal movements (Oxley, 1974; Goosem, 2001) and seedling recruitment (Curran *et al.*, 1999). Altered patterns of species abundance (Luck *et al.*, 1999), and species composition (Laurance, 1991b; Matlack, 1994; Temple, 1998) have been reported at the edges of habitat fragments. In general, changes in biotic and abiotic parameters at edges make ecological processes more variable than in habitat interiors (Ewers & Didham, 2006).

The magnitude and distance of the edge effect are related to the contrast in structure between adjacent communities on either side of the edge (Harper *et al.*, 2005b). In forest, edge structure and sharpness determine the magnitude of changes in microclimate and vegetation structure (Didham & Lawton, 1999). Removal of vegetation results in diverse changes in microclimatic conditions which include, for example, alteration to temperature and vapour pressure deficit (Pohlman *et al.*, 2007), wind (Zheng & Chen, 2000; Burton, 2002) and incident light (Chen *et al.*, 1992). All of these factors will have associated impacts on local flora and fauna. Table 1.1 summarises some edge effects that have been reported to date.

Edge effects do not always have a negative impact on wildlife (Harris, 1988; Boulton & Clarke, 2004). The ability to exploit edge habitats may allow some species to increase in number as a result of fragmentation (Bright, 1993). For example, Menzel (1999) found that habitat generalists responded favourably to edge microhabitat. The same applied to species that are adapted to the matrix between fragmented habitat remnants (Harrington,

2001). Greater wildlife abundance at edges can occur, for example, because of higher foliage density at edges (Harding & Gomez, 2006) or because of greater vegetative complexity allowing access to two different habitat types (Janzen, 1983).

Edge effects are discussed further in Chapter 2, where an estimate of the magnitude of the impacts of powerline easements in respect of flora and fauna is presented.

**Table 1.1 Summary of potential ecological edge effects reported for plants and animals**

Process/phenomenon	Effect at edge	Reference
<i>Responses of animals</i>		
Small mammal diversity	Increased	(Johnson <i>et al.</i> , 1979)
Small mammal species composition	Increase in grassland species	(Adams & Geis, 1983)
Mammal habitat preference	Preference for edge	(Laurance, 1990)
Predation	Elevated	(Andrén & Angelstam, 1988) (May & Norton, 1996)
Competitive interactions	Elevated	(Laurance, 1994)
Mammal activity	Avoidance of edge	
Brood parasitism	Elevated	(Paton, 1994)
Reproduction (birds)	Lowered	(Robinson <i>et al.</i> , 1995)
Invasion of exotic species	Elevated	(May & Norton, 1996)
Genetic variation (small mammals)	Decreased	(Gaines <i>et al.</i> , 1997)
Small mammal community composition	More generalists	(Goosem & Marsh, 1997)
Macroinvertebrate soil fauna	Decreased	(Haskell, 2000)
<i>Edge characteristics</i>		
Tree fall	Increased	(Levenson, 1981)
Leaf litter	Increased rate of leaf drop	(Lovejoy <i>et al.</i> , 1986)
Humidity	Reduced	(Kapos, 1989)
Photosynthetically active radiation	Increased	
Tree mortality	Increased	(Chen <i>et al.</i> , 1992)
Plant stem density	Increased	(Matlack, 1993)
Wind turbulence	Increased	(Laurance, 1997)
Plant species composition	Loss of rare and shade tolerating plants	(Hill & Curran, 2001)
Vegetation composition	Reduced vegetation cover, increased exotic species prevalence	(Watkins <i>et al.</i> , 2003)
Seed dispersal	Decreased	(Khan <i>et al.</i> , 2005)

### 1.1.2 Powerline Easement Ecology

Powerlines are one example of man-made linear structures that contribute to landscape fragmentation. In Australia, vegetation growing in powerline easements is regularly mowed or otherwise treated (e.g. by herbicide) in order to control the regrowth which would otherwise interfere with power supply and also increase the potential for ignition of bushfires (Brown, 1995; Clarke *et al.*, 2006). Furthermore, in fire-prone regions of Australia, the mowed easements, with their scant vegetation cover are thought to act as a firebreak (Steve Douglas, Integral Energy pers. comm.). Creation and maintenance of a powerline easement by cutting through a forested region has two main effects. First, a new, structurally different plant community is created and, second, an area of edge habitat is created at the boundary between the new community and the original habitat (Anderson *et al.*, 1977). Complex, human-dominated landscapes provide unique challenges for animals (Russell *et al.*, 2005) which include phenomena such as altered microclimates, reduced habitat area, invasion of exotic species and inhospitable terrain to negotiate.

Roads, the most common and obvious form of linear fragmentation, are well-recognised as a cause of habitat loss and direct mortality of animals (Trombulak & Frissell, 2000). However, powerline easements are sufficiently different from roads to suggest that their ecological impacts may also be different. Despite their prevalence in our landscape, the ecological effects of these linear features may be great in magnitude but have attracted little research attention to date.

Replacement of habitat by powerline easements affects different vertebrate groups in different ways. Foliage height diversity has been correlated with bird species richness (MacArthur & MacArthur, 1961). However, the loss of this structural feature can offer more nesting sites and protective runways for small mammals (Johnson *et al.*, 1979). Several studies have shown that powerline easements facilitate the movement of non-forest species (Anderson *et al.*, 1977; Schreiber & Graves, 1977; Johnson *et al.*, 1979; Kroodsmma, 1982; Goosem & Marsh, 1997). Other research has confirmed that powerline easements can inhibit the movement of forest-dwelling small mammals (Goosem & Marsh, 1997). The same has been found for mowed grassland strips (Cole, 1978), forest roads (Bakowski & Kozakiewicz, 1988; Burnett, 1992; Goosem, 2001)

and other roads (Swihart & Slade, 1984). The potential ecological impacts of this barrier effect are discussed in Section 1.1.1.2, and Chapters 2 and 3.

The general consensus is that forms of linear habitat fragmentation have a negative effect on biodiversity (Andrews, 1990; Forman & Alexander, 1998), however, some studies report the opposite. In certain landscape contexts, powerline easements can offer ecological benefits for some taxa. For example, in landscapes that lack sufficient early successional native habitat, powerline easements have been found to provide a valuable habitat resource for native bees (Russell *et al.*, 2005). Additionally, five native, non-grassland species of small mammal were detected in a powerline easement in Victoria, Australia (Macreadie *et al.*, 1998). This was unusual given the grassy conditions in the easement, and the typical habitat preferences of the species captured. Clarke *et al.* (2006) reported that mid-seral vegetation in powerline easements provided habitat for native small mammals that were rare in adjacent forest habitats. Similarly, Johnson *et al.* (1979) found greater small mammal diversity in a right-of-way containing a powerline than in adjacent habitat. In summary, it is evident that the ecological impacts of powerline easements can vary greatly depending on factors such as the landscape context, easement physical characteristics and vegetation cover, and also the biology of the local fauna.

## 1.2 Habitat Corridors

Habitat loss and fragmentation rank among the most pervasive threats to the conservation of biological diversity (Wilcox & Murphy, 1985). Wilson & Willis (1975) originally promoted the inclusion of corridors of intact habitat into the landscape as a mechanism to mitigate some of the negative effects of habitat fragmentation by enhancing dispersal and recolonisation. Today, the inclusion of corridors in reserve design remains a common tactic in biological conservation (Rosenberg, 1997). However, corridors have been a highly debated topic in conservation biology, to the extent of provoking correspondence between the supporters and opponents of corridors in conservation biology literature e.g. Beier & Noss (1998) and Haddad *et al.* (2000).

Some of the benefits for wildlife associated with corridors include movement facilitation (Machtans *et al.*, 1996; Laurance & Laurance, 1999), gene flow (Bennett, 1990a) and increased survival (Mansergh & Scotts, 1989) and dispersal (La Polla & Barrett, 1993). Corridors have been shown to increase movement between habitat patches, not just for small mammals, but also for a variety of species (Haddad *et al.*, 2003), and might provide routes and habitat for animals moving in response to climate change (Channell & Lomolino, 2000). On the other hand, however, evidence from Bowne *et al.* (1999) shows that corridors have little benefit for native species in fragmented landscapes. Other researchers, also working on small mammals, have reported functional connectivity between patches even without corridors (Bowman & Fahrig, 2002). Indeed, some researchers have described negative effects of corridors for native species (Downes *et al.*, 1997b). Additionally, other authors describe how corridors may be beneficial for some members of a community, but only under certain conditions (Hannon & Schmieglow, 2002). For example, associations between corridor width and degree of usage by wildlife have been drawn (Andreassen *et al.*, 1996; Tischendorf & Wissel, 1997; Haddad, 1999). Similarly, corridors can be beneficial in some respects (e.g. channelling dispersal) but have no impact on other aspects of movement (e.g. enhancing population level shifts between patches) (Andreassen & Ims, 2001). Elsewhere the efficacy of corridors has depended on the presence of forest in the surrounding matrix (Perault & Lomolino, 2000). In order to clearly present the reason for the lack of a general consensus on the question of corridor efficacy, I now describe a range of reported positive and negative ecological effects reported for corridors.

Research has shown that for some small mammals, foraging and movement behaviour are dependent on habitat connectivity, amongst other factors (Brinkerhoff *et al.*, 2005). Accordingly, for ecosystems in which small mammals may play a role in pollination, herbivory, seed dispersal or predation, for example, connectivity provided by habitat corridors may be essential. Bennett (1990a) explored the role of corridors in the conservation of small mammals in fragmented forests, stressing that corridors offer dispersal continuity between otherwise isolated populations. This is achieved in two ways: by providing a pathway along which individuals may disperse, and by enabling gene flow through resident members of the corridor. Meffe & Carroll (1997) supported this view, describing how landscape connectivity can enhance population viability. The

examples of corridor use cited here refer mainly to mammals, though there are also many studies that report positive effects of corridors for other animals (Haas, 1995; Machtans *et al.*, 1996; Collinge, 1998) and also for plants (Tewksbury *et al.*, 2002). Such benefits include lower rates of species loss and also enhanced recolonisation. Corridors are reported to benefit different species at different stages in time. In the short term, for example very soon after disturbance, corridors best serve species with fast-growing populations but low survival in the matrix. In the longer term, corridors are more likely to benefit species with slow-growing populations with low survival when dispersing through the matrix (Hudgens & Haddad, 2003).

It must be stressed that, in spite of these potential benefits, corridors may, in certain circumstances, be entirely ineffective at ameliorating effects of habitat isolation such as in very small fragments (Collinge, 1998; Hannon & Schmieglow, 2002). Instead, corridors must be considered as just one of several options available to land managers. The importance of this is stressed by the results of a study by Laurance (1991b) in northeast Queensland which showed that, although some species used corridors, the most vulnerable mammals rarely used them, if ever. Harrison and Bruna (1999) adopted a cautious tone in relation to the role of corridors in fragmentation. They conceded that corridors may indeed prevent loss of some species from fragmented landscapes but noted that evidence is limited and, furthermore, that corridors cannot remedy edge effects in the fragments. Moreover, movement through corridors is necessary, but not sufficient, for corridors to be able to enhance gene flow and reduce the probability of extinction from otherwise isolated patches (Haddad *et al.*, 2003). Similarly, Fahrig & Merriam (1998) stressed that it remains to be shown that corridors can mitigate the overall loss of habitat that is a feature of landscape fragmentation.

Corridors can also have negative effects, for example, the facilitation of the movement of pathogens, fire and predators (Simberloff & Cox, 1987; Simberloff *et al.*, 1992). Simberloff is a notable corridor-sceptic and has stated that corridors are “as likely [to] not do good as to do good” (cited in Kaiser (2001)). Additionally, corridors can be utilised by exotic species for movement and as habitat (Downes *et al.*, 1997b; Parendes & Jones, 2000; Proches, 2005), which may threaten native species through interference competition.

Levey *et al.* (2005) stressed that the issue is more about the net benefit corridors offer than whether they involve some environmental costs. It is important to note here that while there are conclusive studies that demonstrate the success of different forms of corridor (e.g. Mansergh & Scotts, 1989; Bennett, 1990a; Machtans *et al.*, 1996; Collinge, 1998), those that describe the spread of exotic species via corridors are more conjectural (Levey *et al.*, 2005).

### 1.2.1 Corridor Research

Typical of the corridor debate, the literature relating to small mammal use of corridors is extensive, though varied in its approach and conclusions (Table 1.2). Research to date has been mainly directed at the function of habitat strips or remnants as corridors (e.g. Bennett, 1990a; Downes *et al.*, 1997b; Laurance & Laurance, 1999), and the degree of isolation caused by the absence of corridors (e.g. Bowne *et al.*, 1999; Bowman & Fahrig, 2002). Other studies have examined the effects of corridors on small mammal population dynamics (La Polla & Barrett, 1993) and home range sizes (Mabry & Barrett, 2002). In addition, there is an increasing trend of linking corridor use to the local landscape ecology (Lindenmayer *et al.*, 1994), and landscape configuration (Andreassen & Ims, 2001). Replicated studies that quantify corridor use where mitigative measures have been implemented (e.g. Mansergh & Scotts, 1989) are rare.

### 1.2.2 Corridors in Powerline Easements

Though a range of studies report a barrier effect on small mammals caused by roads (e.g. Bakowski & Kozakiewicz, 1988; Goosem, 2001), and also by powerlines (e.g. Goosem & Marsh, 1997; 2000), studies which demonstrate mitigation of the reported movement inhibition are rare (but see Goosem & Marsh, 1997). The potential ecological effects of habitat fragmentation and edge effects, both phenomena that are associated with linear features such as powerline easements, are discussed in Section 1.1.1. These factors combined provided the impetus for my research, in an environment where extensive anthropogenic disturbance occurs in an ecologically rich landscape.

**Table 1.2 Summary of studies that report the impact of corridors on movement patterns of small and medium-sized animals**

#	Species	Corridor description	Impact	Location	Reference
1	<i>Burramys parvus</i> , the mountain pygmy possum	2 tunnels under a road, filled with rocks, 60m long	Population structure and survival rates in the disturbed areas, which had been elevated before tunnel construction returned to the rates observed in the undisturbed area	Victoria, southeastern Australia	(Mansergh & Scotts, 1989)
2	<i>Peromyscus leucopus</i> , white-footed mouse.	Fencerows present in farmland were grouped into three structural classes based on complexity.	Fencerows were used by resident and translocated mice, with the latter showing a strong preference for more structurally complex fencerows	5km south of Ottawa, Canada	(Merriam & Lanoue, 1990)
3	<i>Antechinus stuartii</i> , the brown antechinus, <i>Isoodon obesulus</i> , southern brown bandicoot, <i>Perameles nasuta</i> , long-nosed bandicoot, <i>Potorus tridactylus</i> , long-nosed potoroo, <i>Rattus fuscipes</i> , the bush rat and <i>Rattus lutreolus</i> , the swamp rat	Forest strips on road reserves formed corridors. They varied in width from 10m to 40m. Corridors occurred in landscape of forest patches, subject to grazing by domestic stock	Corridors facilitated continuity between otherwise isolated populations of small mammals. This was done by providing a dispersal pathway between patches, and by enabling gene flow through resident populations in the corridor.	Narringal, south-western Victoria, Australia	(Bennett, 1990a)
4	Arboreal possums including <i>T. vulpecula</i> , <i>Dendrolagus lumholtzii</i> , Lumholtz tree kangaroo, <i>Antechinus flavipes</i> , the agile antechinus and several rodents	Narrow strips of secondary vegetation along streams, <50m wide	Corridors were used by several species, supporting the notion that the strips supported mammalian diversity, which is apparently achieved through facilitation of immigration from larger forest patches	Southern Atherton Tableland, NE Queensland, Australia	(Laurance, 1991a)
5	<i>Microtus pennsylvanicus</i> , the meadow vole, a dense grassland species	Patches of old-field community, measuring 20m <sup>2</sup> either connected or unconnected by a 10m corridor	Significantly more dispersal of male voles between patches with corridors than between patches without corridors	Southwest Ohio, North America	(La Polla & Barrett, 1993)

**Table 1.2 (ctd.) Summary of studies that report the impact of corridors on movement patterns of small and medium-sized animals**

#	Species	Corridor description	Impact	Location	Reference
6	<i>Tamias striatus</i> , the eastern chipmunk	Fencerows of varying width	Resident individuals lived in fencerows. Transient individuals used fencerow network as a pathway through farmland	Near Ottawa, Canada	(Bennett <i>et al.</i> , 1994)
7	13 species in total but mainly <i>A. stuartii</i> , <i>R. fuscipes</i> and <i>Wallabia bicolor</i>	Retained linear strips of forest	Different factors influenced the occurrence of mammals in the corridors. These included variation in topography, the number of roads and tracks, and the dominant tree types	Central Highlands of Victoria, southeastern Australia	(Lindenmayer <i>et al.</i> , 1994)
8	<i>Microtus oeconomus</i> , root voles	Three widths were tested, 3m, 1m and 0.4m. Corridor was 310m in length, connecting two patches	The corridor of intermediate (1m) width provided the greatest connectivity, in terms of transference of individuals	Southeast Norway	(Andreassen <i>et al.</i> , 1996)
9	<i>Trichosurus vulpecula</i> , the common brushtail possum, <i>Petauroides volans</i> , the greater glider, <i>Pseudochirus peregrinus</i> , the common ringtail possum, <i>Trichosurus caninus</i> , the mountain brushtail possum	Corridors attached to forest patches 20-80ha in area. Corridors were continuous linear strips of remnant vegetation either near to or far from the forest	Differences can occur in the composition of mammal assemblages that use corridors. Corridor use can differ within species. Higher total density of animals in corridors than in forests. Fewer species using corridors distant from forest than close to forest	Strathbogie Ranges of northeastern Victoria, Australia	(Downes <i>et al.</i> , 1997a)
10	<i>Sigmodon hispidus</i> hispid cotton rat	32m wide corridor connecting patches of <i>Pinus teada</i> forest	No significant effect on the number of rats leaving connected patches. Corridors were the preferred route to leave connected patches. Colonisation success for animals leaving connected/isolated patches not significantly different	Aiken County, South Carolina, USA	(Bowne <i>et al.</i> , 1999)

**Table 1.2 (ctd.) Summary of studies that report the impact of corridors on movement patterns of small and medium-sized animals**

#	Species	Corridor description	Impact	Location	Reference
11	Six species in total, including <i>Hemibelideus lemuroides</i> , the lemuroid ringtail possum, <i>Pseudochirulus herbertensis</i> , the Herbert River Possum and <i>Dactylopsila trivirgata</i> , the striped possum	Linear forest remnants, some as narrow as 30-40m, others >200m	Floristically diverse linear forest remnants that are at least 30-40m in width can function as habitat corridors for arboreal mammals in the region. The most vulnerable species <i>H. lemuroides</i> requires corridors of primary rainforest at least 200m wide	Tropical North Queensland, Australia	(Laurance & Laurance, 1999)
12	<i>Microtus oeconomus</i> , root voles	1.5m wide corridor with 15m between small patches	Corridors channelled dispersal between the patches connected by corridors, but did not enhance the frequency of population-level shifts between patches	Hedmark County, southeast Norway	(Andreassen & Ims, 2001)
13	<i>Tamias striatus</i> , the eastern chipmunk	Forest woodlots separated by gaps of varying size. No fencerow corridors	Forest woodlots may be functionally connected for chipmunks even without fencerow corridors	Near Ottawa, Canada	(Bowman & Fahrig, 2002)
14	<i>Peromyscus gossypinus</i> , the cotton mouse, <i>P. polionotus</i> , the old field mouse and <i>Sigmodon hispidus</i> , the cotton rat	Corridors between patches were 32m wide and ranged in length from 128 to 384m	Corridor home range did not have a significant effect on average home range size. Results suggest that small mammals may be more capable of interpatch movement in the absence of corridors than is currently assumed	South Carolina, USA	(Mabry & Barrett, 2002)
15	<i>S. hispidus</i> and <i>P. polionotus</i>	Early successional vegetation, 32m in width	No preferential movement between connected patches for <i>S. hispidus</i> , though <i>P. polionotus</i> moved more frequently between connected patches	Near Aiken, South Carolina, USA	(Haddad <i>et al.</i> , 2003)
16	<i>Peromyscus polionotus</i> , old-field mice (inhabits open, grassy habits)	One central patch surrounded by 4 peripheral patches 150m away. Central patch by a 25m-wide clearcut corridor	No evidence of corridors to alter dispersal of small mammals, but corridors do influence behaviour in other ways, for example in combination with predation	Savannah River National Environmental Research Park, South Carolina	(Brinkerhoff <i>et al.</i> , 2005)

### 1.3 Small Mammals

There are several ecological and practical reasons that make small mammals particularly suitable for the study of movement behaviour, habitat use and response to habitat fragmentation. In my study area they are abundant, they can be easily captured, are small and manageable, tend to have high fecundity and are highly vagile. Additionally small mammals are of particular ecological interest in Australia, for reasons explained in the following section.

#### 1.3.1 Mammal Decline in Australia

Australia has a unique and diverse mammal fauna. Since the arrival of Europeans on the continent 200 years ago, this has declined as a result of habitat clearance (Lunney & Leary, 1988), intensified agricultural practices (Burbidge & McKenzie, 1989) and predation by exotic predators such as *Felis catus*, the domestic cat and *Vulpes vulpes*, the red fox (Christensen, 1980; Catling, 1988; Sinclair *et al.*, 1998; Risbey, 2000; Burbidge & Manly, 2002). During this time, Australia has experienced a higher rate of mammal extinctions than any other continent (Cardillo & Bromham, 2001) with the level of decline greatest among marsupials and native rodents (Short, 2004). At a national level, the changes in land use and vegetation cover have led to the presumed extinction of 27 species of terrestrial Australian mammals alone with 13 more regarded as threatened and 55 classed as vulnerable (DEH, 2001). In the state of New South Wales alone, 59% of the 130 mammal species to be found have been described as endangered (Lunney, 1996).

An understanding of movement behaviour can contribute to the resolution of many ecological questions (Swingland & Greenwood, 1983). This is of particular relevance in the context of disturbance and reduced habitat availability. Furthermore, as Gillis and Nams (1998) explain, understanding habitat selection mechanisms may be useful in explaining how animals respond to habitat fragmentation. Recording and describing patterns of movement behaviour and habitat use in response to anthropogenic modification of the environment is a first step in the evaluation of these mechanisms and ultimately in formulating biodiversity conservation strategies.

### 1.3.2 Habitat Use

A foraging animal is presented with a range of costs and benefits likely to influence its fitness and behaviour. Basic ecological theory holds that the costs of foragings such as predation risk and competition must be outweighed by nutrient and energy gain (MacArthur & Pianka, 1966). Below I outline the dominant factors that influence habitat use patterns of small mammals.

#### 1.3.2.1 Habitat Characteristics

Habitat structure is a complex issue, incorporating habitat density, complexity, floristic composition and heterogeneity. The importance of habitat structure for small mammals has been widely discussed in the ecological literature (Barnett *et al.*, 1978; Fox, 1979; Fox & Fox, 1981; Hockings, 1981; Coops & Catling, 1997; Gentile & Fernandez, 1999; Knight & Fox, 2000; McCay, 2000; Vásquez *et al.*, 2002; Williams, 2002; Anderson *et al.*, 2003; Arthur, 2003; Fox *et al.*, 2003; Spencer & Baxter, 2006). Habitat is a dynamic concept by virtue of the fact that its composition is subject to change arising from stochastic events (e.g. bushfire) as well as more gradual changes over time. Coops & Catling (2000) used measures of habitat complexity to represent habitat structure in a way that illustrates the close relationship between these two issues.

Specific habitat features elicit a positive response in some species. For example, several species of small mammal have been found to be positively associated with logs and woody debris (Barnett *et al.*, 1978; Barry & Francq, 1980; Hayes & Cross, 1987; Tallmon & Scott Mills, 1994; McCay, 2000; Dickman & Steeves, 2004). There is a number of possible explanations as to why logs may be a favoured movement medium for small mammals. For example, Barry & Francq (1980) suggested that logs may provide small mammals with escape routes and may also be important for navigating. Additionally, logs may provide shelter and a source of food (see Chapter 4).

Another way of interpreting habitat use is through the identification of microhabitats – that is, fine-scale habitat characteristics or groupings of characteristics. This approach is particularly popular for small mammals (e.g. Bennett, 1993; Sutherland & Predavec, 1999; Maitz & Dickman, 2000; Cunningham *et al.*, 2005; Haythornthwaite, 2005; Vieira *et al.*, 2005; Bakker, 2006) because a combination of small body size and

complex habitat structure can mean that a wide range of possible variables and combinations of variables are used by the animals.

Research has shown that floristic classifications have been very useful as indicators of preferred habitats of small mammals (Braithwaite & Gullan, 1978; Newsome & Catling, 1979). For example, Bennett (1993) found significant variations in the capture rate of *A. stuartii* between floristic groups, reporting that wetter forest vegetation was favoured. By contrast, Wilson *et al.* (1986) did not find any overall preference for a particular floristic type for *A. stuartii*. On a local scale, where the floristic composition is relatively homogenous, structural features are important (Catling, 1991). On a broader scale, differences in floristic composition, caused by landscape level variation in soil fertility, for example, can mask the importance of structural features at the local scale (Catling & Burt, 1994).

While environmental variables determine the type of habitat at a site (Catling *et al.*, 2002), it is the local habitat, and especially the understorey that often determines the presence and abundance of small mammals (Catling & Burt, 1994). Furthermore, with regard to small mammals, it is widely reported that loss of forest complexity results in a corresponding reduction in diversity and/or abundance of small mammals (Bennett, 1990b; Laurance, 1994; Dunstan & Fox, 1996; Tasker *et al.*, 1999; Cox *et al.*, 2004) in the remaining regions of altered habitat.

#### 1.3.2.2 Predation Risk

The general consensus in studies of small mammal ecology is that vegetation cover is favoured because of the protection from predators it affords (Barnum *et al.*, 1992; Bos & Carthew, 2003). Perceived predation risk is greater in open areas (Vásquez *et al.*, 2002). Manipulation of habitat to test this has shown that small mammals may seek out regions with more complex habitat structure to reduce the risk of predation (Stokes *et al.*, 2004; Spencer *et al.*, 2005). Dense vegetation may simultaneously offer other benefits to a foraging small mammal such as nesting sites, shelter from adverse weather conditions and protection from competitors (Braithwaite, 1979; Knight & Fox, 2000; Monamy & Fox, 2000). For these reasons, small mammals may be expected to avoid the barren, exposed conditions that are a feature of powerline easements.

For some species, the links between habitat structural complexity and risk-sensitive behaviour indicate that management of habitat may be useful in conservation programs, especially when coupled with direct control of exotic predators (Stokes *et al.*, 2004). Observations such as these strengthen the case for the establishment of powerline easement conditions that are more favourable for small mammals.

#### 1.3.2.3 Food Availability

The movement path of a foraging animal may be a reflection of the larger or more abundant food sources available in the habitat (Haythornthwaite, 2005). Episodes of arboreality (tree-climbing) (e.g. Dickman, 1982) and log use (e.g. Stewart, 1979) can also be indicative of foraging by small mammals. *Antechinus stuartii*, though primarily an insectivore, is attracted by the nectar-rich inflorescences of *Banksia* species (Carthew, 1994). Movement paths of this species will feature regular visitations of these plants, where they occur in the habitat (Carthew, 1994).

#### 1.3.2.4 Competition

It is typical to encounter several species of small mammal while conducting trapping studies in south-eastern Australia (e.g. Barnett *et al.*, 1978; Friend, 1979; Stewart, 1979; Read *et al.*, 1988; Bennett, 1993; Dunstan & Fox, 1996; Goldingay & Whelan, 1997; Lindenmayer *et al.*, 1999; Penn *et al.*, 2003; Cox *et al.*, 2004). As Barnett *et al.* (1978) explained, habitat components such as structure may be more useful than floristics in explaining habitat preferences of some co-existing species. Research has repeatedly shown that at the fine scale, microhabitat segregation exists between species whose ranges overlap (e.g. Dueser & Shugart Jr., 1978). Highly complex habitats offer more potential niches than habitats with lower structural complexity (Downes *et al.*, 2000). Similarly, complex habitats have many distinct vertical strata (August, 1983). In eastern Australia, potentially competing species show different habitat use patterns which may be driven by competition. For instance, stronger arboreal tendencies are recognised in *Uromys caudimaculatus* and *Melomys cervinipes* than in *Rattus fuscipes* (Redhead, 1995). This may explain the apparent sharing of habitats by ecologically similar species, and may also mediate the intensity of competition between them.

### 1.3.2.5 Disturbance

There are many forms of disturbance which impact upon native fauna, including deforestation, traffic and intensive agriculture. One form of natural disturbance that is a feature of Australian landscapes in particular is bushfire. Aside from anecdotal reports, there are few quantitative records of the instantaneous impacts of bushfire on animal populations (Whelan, 1995). What is known is that mortality is surprisingly low, as studies have reported captures and other records of animals soon after bushfires (see Catling & Newsome, 1981). Evidence of species recolonisation times following bushfire varies greatly. For example, Fox (1983) found that after 5-6 years *R. lutreolus* and *R. fuscipes* had returned to pre-fire habitats, though Catling (1986) found *R. lutreolus* returned to favoured habitats within 2 years after fire. Other studies describe how populations are sustained in sites that have burned and furthermore record successful reproduction just 9 months after the event (Whelan *et al.*, 1996). In cases of wildfire, vegetation secondary succession, rather than time *per se*, may be more an indicator of how small mammal species respond to bushfire (Monamy & Fox, 2005).

Changes in abundance and species diversity are typically used as indications of anthropogenic disturbance (e.g. Martell & Radvanyi, 1977; Yahner, 1988; Dunstan & Fox, 1996; Bayne & Hobson, 1998; Bentley *et al.*, 2000; Harrington, 2001; Silva, 2001; Cox *et al.*, 2004). Studies conducted in fragmented landscapes use inter-patch movement inhibition and resultant population isolation to describe the effects of anthropogenic disturbance (e.g. Mader, 1984; 1995; Vos & Chardon, 1998). However, despite the breath of literature on these aspects of anthropogenic disturbance, the effects on habitat use or foraging patterns are less clear. Rather than discuss specific habitat features, some authors describe the effects of processes such as grazing (Tasker *et al.*, 1999), logging (Lunney & Ashby, 1987), fire (Penn *et al.*, 2003) and habitat fragmentation (Knight & Fox, 2000; Cox *et al.*, 2004) on patterns of habitat use. These authors describe the negative effects of such disturbances on habitat use by small mammals. However, the impacts of habitat fragmentation (e.g. Knight & Fox, 2000; Cox *et al.*, 2004) dominate the small mammal literature.

### 1.3.3 Habitat Description

Descriptions of habitat are important when assessing possible changes due to habitat fragmentation. Studies of small mammals vary greatly in the way in which habitat is quantified, the number of habitat features that are recorded, and the number of measures for each feature. Investigations that analyse the use of specific habitat features such as logs usually include more descriptive detail of the feature under investigation (e.g. Hayes & Cross, 1987; Tallmon & Scott Mills, 1994; McCay, 2000). For more general investigations of habitat use by small mammals, typical features recorded include logs, leaf litter, canopy cover, shrub cover and vegetation density. Many of these feature in small mammal studies both in Australia and elsewhere (e.g. Dueser & Shugart Jr., 1978; Dunstan & Fox, 1996; Gentile & Fernandez, 1999; Knight & Fox, 2000; Maitz & Dickman, 2000; Cox *et al.*, 2004). Some studies include other variables such as soil moisture (e.g. Catling & Burt, 1994; Maitz & Dickman, 2000), measures of bare ground (Knight & Fox, 2000; Bos *et al.*, 2002) or numbers of trees of varying sizes (Laurance, 1997). A 'habitat complexity score' is occasionally used which provides an index of ground-dwelling mammal habitats related to changes in structure and biomass of vegetation, regardless of plant species (Coops & Catling, 2000). For example, Newsome and Catling (1979) incorporated measures of tree and shrub canopy, cover of rocks, litter and logs as well as soil moisture, to generate their habitat score.

In a comparative study of several vegetation classification systems, Fox and Fox (1981) found that, while the results based on floristic and structural classifications were highly correlated with the mammal classification under investigation, there were substantial differences. They concluded that while classifications based on either floristic or structural variables were successful at the coarse scale in their study, both floristic and structural variables may be necessary for finer-scale studies.

Just as the habitat characteristics that are recorded vary in small mammal studies, there is no standard method for recording each of these characteristics in the field. For example Statham & Harden (1982) measured a number of variables at fixed circular plots. They argued that the use of these circular plots, in which randomly allocated quadrat sites were scored, was more accurate than plotless data. Maitz and Dickman

(2000) also scored microhabitat within a 1m radius of selected points, though other studies scored the vegetation within a certain radius of a point e.g. Sutherland and Predavic (1999) (10m radius); Williams *et al.* (2002) (5m radius). Other researchers used quadrats to define the area in which they assessed the structural composition of a habitat (e.g. Laurance, 1994; Bakker, 2006).

The use of a board has been described in studies that measure habitat complexity. In this method, estimates of vegetation density are made based on the amount of the board that is obscured (Knight & Fox, 2000; Monamy & Fox, 2000). Hockings (1981) recorded the number of plants of each structural type within 5cm of the board. A variation on this involves the use of a pole with coloured segments (Wells *et al.*, 2004). Visibility of the segments is scored from a number of directions and distances. In other cases, a vertical pole placed in the habitat served as a marker and the number of contacts with the pole made by adjacent vegetation was counted (Bos *et al.*, 2002; Bos & Carthew, 2003), sometimes on the basis of height category (Ford *et al.*, 2003). Some studies have used several of these techniques in combination (Dueser & Shugart Jr., 1978; Gentile & Fernandez, 1999). Finally, in recent times airborne videography has been used as a method for describing habitat complexity, and thus for predicting the presence of small mammals for which the relationships between forest structure and distribution and abundance are known (Coops & Catling, 1997; Catling & Coops, 1999).

The use of subjective scoring methods is not uncommon in ecological studies (e.g. Barnett *et al.*, 1978; Catling & Burt, 1994; Wells *et al.*, 2004). Based on the wide variety of techniques described above, it is apparent that there is no standard set of habitat scoring measures. Instead, the evidence illustrates that the approach will vary depending on the research question and the ecological system under investigation

#### **1.3.4 Measuring Movement Paths of Small Mammals**

Animal movement patterns are closely associated with habitat selection as well as social interactions and foraging behaviour (Bascompte & Vilà, 1997). More specifically, how individuals move influences the probability of their encountering favourable habitat, food and predators (Wiens *et al.*, 1995). Furthermore, better understanding of fine-scale

interactions between species and their environment at one scale facilitates extrapolation to other interactions within the domain of that scale (Wiens & Milne, 1989). Tortuosity (or turning frequency) of an animal's movement path is a measure that can be related to a range of habitat variables. Tortuosity can be a reflection of habitat quality (Stapp & Van Horne, 1997; Etzenhouser *et al.*, 1998; Schultz & Crone, 2001) and the ability of habitat to provide cover (Nams & Bourgeois, 2004). Path tortuosity a complex issue, however, because there is a range of other factors such as life cycle and habitat complexity that can also affect this measure (Whittington *et al.*, 2004).

Detecting the spatial scale at which animals perceive their habitat is confounded by the fact that an animal's environment is both hierarchical and patchy. The first factor causes the movement path to vary with spatial scale and the second factor causes variation in the movement path through space (Nams, 2005). Some studies have used a combination of measurements of path tortuosity (using fractal dimension) and spatial scale to measure how animals respond to various structural elements in their environment e.g. (Wiens *et al.*, 1995). The efficacy of the straightness index, another measure of path tortuosity (Batschelet, 1981), can be reduced due to the physical structure of the environment (Benhamou, 2004). Such a measure may not be appropriate in an environment with great structural complexity, as was the case at all of the sites in my study, where an animal must travel around objects such as rocks, logs and tree stumps in order to progress through the habitat.

In summary, it appears that the theory and techniques required to measure and describe the movement behaviour of animals, and to infer their ecological significance, are very complex yet critical in understanding proximate responses of animals to habitat. Key criteria of a suitable technique would include the following; efficiency in terms of time and materials, simplicity of application and replication and the return of an accurate record of movement path. This led me to consider the spool-and-line technique, which meets the above criteria and has been used previously in small mammal studies (Table 1.3).

### 1.3.5 The Spool-and-line Technique

There is a growing awareness of the importance of understanding individual movements and the role of these movements in the spatial dynamics of populations (Turchin, 1991; Stapp & Van Horne, 1997). Understanding how animals use their habitat is paramount when populations are the focus of management and conservation efforts (Bos & Carthew, 2003). This is of particular relevance for species threatened by habitat fragmentation. The spool-and-line tracking technique is one means of gathering accurate data on the habitat components selected by animals as well as their direction of travel as they move through an area.

The spool-and-line technique was used by Breder (1927), and later by Stickel (1950) in tracking movement patterns of turtles (*Terrapene c. carolina*). Greigor (1980) used a similar procedure in studies of the home range of the armadillo *Chaetophractus vellerosus*, in which rolls of polyester thread were attached to individuals. Miles *et al.* (1981) was the first to apply the spool-and-line technique to small mammals in Amazonia, as part of a study of parasites. Boonstra and Craine (1985) improved on this technique by excluding the plastic casing previously used, thereby reducing both the weight and the cost of the device. Instead of using adhesive tape in the harness, they used surgical tape, making the package less restrictive. A further advantage of this design was that the animal could remove the package itself, eliminating the need to recapture the animal to remove the device.

More recently, Loretto and Vieira (2005) have used the spool-and-line technique to measure the intensity of habitat use and the daily movement areas of *Didelphis aurita*, the black-eared opossum. The technique provided an efficient method to reveal the effect of reproductive and climatic seasons on movement distances of male and female opossums.

There are two other common methods of tracking small mammals short distances through habitat; radio-tracking and fluorescent-powder tracking. Radio-tracking is a popular alternative to the spool-and-line technique because of the temporal component to the information it provides, and has been used widely in small mammal studies e.g. (Price *et al.*, 1994; Leung, 1999; McCay, 2000). However, it is also more expensive to

use (Anderson *et al.*, 1988). Delicate radio-tracking equipment requires careful handling (Sargeant, 1980) and, therefore, may be difficult to use in dense forest. Additionally, powerlines can interfere with radio signals, thereby reducing their range (Sargeant, 1980). This is particular relevance to this study. Fluorescent pigment or powder has also been used in small mammal research (e.g. Goodyear, 1989; 1992; McMillan & Kaufman, 1995; Haythornthwaite, 2005). However, this technique can be ineffective in wet or windy conditions (Haythornthwaite, 2005). It also involves the use of ultra violet lamps and requires that paths are traced in darkness which risks disturbing fauna in the area. The spool-and-line technique offers advantages over both of these methods and has been greatly refined and widely applied since its original application in 1927 (Breder).

The primary disadvantage of spool-and-line tracking is that it is limited by the amount of thread that the animal can carry. For animals as small as *Antechinus stuartii*, for example, even a spool weighing 3g can represent 10% of its bodyweight. Also, the thread may be snagged, thereby preventing further tracing of the animal's path. Another disadvantage of this technique is that it is unlikely to be useful in studies of species that nest primarily underground (Boonstra & Craine, 1985). These authors also point out that when parting the vegetation to reveal the presence of the thread, some disturbance of that vegetation does occur. Finally, the behaviour of the spooled animal may be affected by the trapping and handling process, although investigations into the impacts of the spooling process on *Dipodomys spectabilis*, the banner-tailed kangaroo rat, failed to find any significant negative effect on recapture probability, survival or body mass (Steinwald *et al.*, 2006). Key & Woods (1996) also report that the method of handling and occasion of capture (first/second etc.) had no significant effect on the total length of the spool recorded or the proportion of time spent on the ground.

**Table 1.3 Summary of studies that have employed the spool-and-line technique**

#	Experimental focus/objective	Species	No. animals spooled and/or spool distance	Location	Reference
1	Populations and home range	<i>Terepene c. carolina</i>	Four animals spooled. Two spooled for three runs, the two others made eight trails	Near Haskell, New Jersey, USA	(Breder, 1927)
2	Home range and distances moved by box turtles	<i>Terepene c. carolina</i>	11 turtles, over extended time period (Max = 161days)	Laurel, Maryland, USA	(Stickel, 1950)
3	Examining of technique merits and weaknesses. Nesting sites and inter-species comparison of behaviour.	Various, 16 sp. including 9 <i>Dasypus novemcinctus</i> (banded armadillo), <i>Didelphis marsupialis</i> (common opossum), <i>Tamandua tetradactyla</i> (Anteater), <i>Coendou prehensilis</i> (porcupine), <i>Myoprocta acouchi</i> (cutia), <i>Nasua nasua</i> (coati), <i>Philander opossum</i> (4-eyed opossum), <i>Caluromys philander</i> (woolly opossum), <i>Marmosa cinerea</i> (murine opossum)	170 of 263 spooled animals retrieved.	Brazilian rainforest	(Miles <i>et al.</i> , 1981)
4	Tracking small mammals and locating natal nest	<i>Microtus pennsylvanicus</i> (Meadow voles)	157 attempts at spooling. 138 traceable paths. 62 nests with young located	Toronto, Ontario, Canada	(Boonstra & Craine, 1985)
5	Efficacy of the technique. Evaluation as an alternative to radio-tracking	<i>Echymipera kalubu</i> (New Guinea spiny bandicoot)	18 tracks from 12 individuals	Western Highlands, Papua New Guinea	(Anderson <i>et al.</i> , 1988)

Table 1.3 (ctd) Summary of studies that have employed the spool-and-line technique

#	Experimental focus/objective	Species	No. animals spooled and/or spool distance	Location	Reference
6	The relationship between bandicoot home range and invertebrate food abundance	<i>Isoodon obesulus</i> (southern brown bandicoot)	28 animals spooled, 14 each of male/female	Western Australia	(Broughton & Dickman, 1991)
7	Pollinating behaviour of small mammals.	<i>Petaurus breviceps</i> (sugar glider), <i>Antechinus stuartii</i> (brown antechinus), <i>Cercartetus nanus</i> (Eastern pygmy possum)	66 <i>P. breviceps</i> 64 <i>D. aurita</i> , 26 <i>M. nudicaudatus</i>	Southeastern New South Wales, Australia	(Carthew, 1994)
8	Response of <i>Antechinus stuartii</i> to bushfire. Trap success and habitat use	<i>A. stuartii</i>	7 (5 successful)	Royal National Park, New South Wales, Australia	(Whelan <i>et al.</i> , 1996)
9	Arboreal tendencies and nature of movement path	<i>Rattus rattus</i> and <i>Rattus norvegicus</i>	110 spooled, 25 lost them almost immediately after release. Mean length for <i>R. rattus</i> = $74 \pm 8.5$ , for <i>R. norvegicus</i> = $49 \pm 5.8$	Santa Cruz Island, Galapagos	(Key & Woods, 1996)
10	Ecology of Australian tropical rainforest mammals	<i>Antechinus leo</i> (the Cape York antechinus)	16 individuals	Cape York Peninsula, North Queensland	(Leung, 1999)
11	Habitat use relative to availability	<i>R. rattus</i>	6 individuals spooled, 10 data points used from each line	North Head, New South Wales	(Cox <i>et al.</i> , 2000)

**Table 1.3 (ctd.) Summary of studies that have employed the spool-and-line technique**

#	Experimental focus/objective	Species	No. animals spooled and/or spool distance	Location	Reference
12	Construction and site selection of nests of two murid rodents	<i>Oryzomys intermedius</i> (Rice rat) and <i>Nectomys squamipes</i> (Neopical water rat)	9 <i>N. squamipes</i> and 15 <i>O. intermedius</i>	Brazilian Atlantic Rainforest	(Briani <i>et al.</i> , 2001)
13	Movement paths, foraging patterns and habitat use of an endangered marsupial	<i>Bettongia tropica</i> (Northern bettong)	41 separate movement paths obtained from 11 individuals. Path length = 89m-778m, Mean = 426m	Northeastern Australia	(Vernes & Haydon, 2001)
14	Use of vertical strata in forest: support diameter, incline, distance and height above ground	<i>Didelphis aurita</i> , <i>Philander frenatus</i> , <i>Metachirus nudicaudatus</i> . Didelphid marsupials	72 (19 males and 16 females) Animals were respooled	Coastal Atlantic forest in Brazil	(Cunha & Vieira, 2002)
15	Movement distances and estimates of density using the spool-and-line technique	Three species of didelphid marsupial. <i>D. aurita</i> , <i>P. frenata</i> and <i>Metachirus nudicaudatus</i>	64 <i>D. aurita</i> , 26 <i>M. nudicaudatus</i> , 30 <i>P. frenata</i> . 'MaxDspool' (linear distance) ranged from 20m to 50m	Coastal forest, near Rio de Janeiro, Brazil	(Mendel & Vieira, 2003)
16	Travel along coarse woody debris, influence of canopy closure and shrub coverage	<i>Tamias striatus</i> (Eastern chipmunks)	52 chipmunks tracked. Average distance to burrow was $71.8 \pm 7.8$ m	Oneida County, Wisconsin	(Zollner & Crane, 2003)
17	Effects of reproductive and climatic seasons on movements	<i>Didelphis aurita</i> (black eared opossum)	80 tracks (44males and 36 females). Mostly 100-200m thread recovered	Atlantic Rainforest of Brazil. 90km from Rio de Janeiro	(Loretto & Vieira, 2005)

Table 1.3 (ctd.) Summary of studies that have employed the spool-and-line technique

#	Experimental focus/objective	Species	No. animals spooled and/or spool distance	Location	Reference
18	Habitat utilisation, microhabitat selection and daily movement patterns	<i>Necomys lasiurus</i> and <i>Oryzomys scotti</i> . Sigmodontine rodents	13 <i>O. scotti</i> , mean spool length $28.7\text{m} \pm 14.2\text{m}$ 9 <i>N. lasiurus</i> , mean length $41.9\text{m} \pm 42.2\text{m}$ .	35km south of Brasília, Federal District of Brazil	(Vieira <i>et al.</i> , 2005)
19	Habitat selection by three didelphid marsupials, an alternative method of evaluation	<i>D. aurita</i> , <i>M. nudicaudatus</i> , <i>P. frenatus</i>	17 <i>D. aurita</i> , 12 <i>P. frenatus</i> , 10 <i>M. nudicaudatus</i>	Atlantic Rainforest of Brazil. 90km from Rio de Janeiro	(Moura <i>et al.</i> , 2005)
20	The effects of the spool-and-line process on small desert mammals	<i>Dipodomys spectabilis</i> , (The banner-tailed kangaroo rat)	90 experimental animals, 81 control animals	Southeastern Arizona	(Steinwald <i>et al.</i> , 2006)
21	Movement trajectories and habitat segregation of eight different species of mammal in logged and unlogged forest	<i>Leopoldamys sabanus</i> (long-tailed giant rat), <i>Maxomys rajah</i> (rajah spiny rat), <i>Maxomys surifer</i> (red spiny rat), <i>Niviventer cremoriventer</i> (dark-tailed tree rat), <i>Sundasciurus lowii</i> (Low's squirrel), <i>Tupaia longipes</i> (long-footed tree shrew), <i>Tupaia tana</i> (large tree shrew), <i>Tupaia gracilis</i> (slender tree shrew)	212 movement tracks comprising 13, 525m from at least 188 different individuals. Mean length was $63.8\text{m} \pm 26.7\text{m}$	Lowland rainforest in Sabah (Malaysia, northern Borneo)	(Wells <i>et al.</i> , 2006)

### 1.3.6 Powerline Easements – Unique Ecological Questions

Unnatural landscape features such as powerline easements provide native fauna with unique challenges. In addition to disrupting ecological processes by increasing the area of the edge effect zone, cleared regions within otherwise intact habitat can inhibit movement and dispersal. Negative ecological impacts of other forms of linear habitat fragmentation, such as roads, have been widely reported but this not the case for powerline easements. Little is known about the nature or the magnitude of their impacts. There is a close relationship between small mammal movement behaviour and habitat structure (see Chapter 4). Therefore, the abrupt contrasts in vegetation characteristics between mowed powerline easements and adjacent habitat are likely to result in movement behaviour with potentially broad-ranging consequences, given the important ecological role of many small mammal species (Section 3.1).

The efficacy of corridors as a means of mitigating the impacts of habitat fragmentation has been much debated, as described in Section 1.2. Despite the controversy, there remains much evidence that suggests they can facilitate the movement of animals between habitat patches in a fragmented landscape. This is important for the maintenance of healthy populations, particularly in a landscape subject to disturbance, both anthropogenic (e.g. habitat removal) and natural (e.g. bushfire). In order to better understand the responses of small mammals to impact mitigation strategies such as corridors, to varying levels of easement vegetation and to the presence of abrupt habitat boundaries created by powerline easements, a fine scale study of movement patterns and habitat use is required.

### 1.4 Study Aims and Thesis Structure

Conservation biology is a field that aims, among other things, to provide guiding principles for the preservation of biodiversity (Soulé, 1985). As human populations and infrastructure expand into natural areas, the barrier effects and edge effects that are a feature of habitat fragmentation threaten an increasing number of ecosystems. In order to formulate effective conservation strategies, the effects of fragmentation on the biota remaining in remnant patches of natural habitat need to be determined (Rosenblatt *et al.*, 1999).

### 1.4.1 Specific Thesis Aims and Questions

The research described in this thesis had three broad aims, which were as follows: 1. To estimate the potential magnitude of the ecological impacts of powerline easements. 2. To understand how powerline easements affect the movement patterns of small mammals 3. Based on manipulative experimentation, to explore how two species of small mammal respond to artificial habitat corridors.

More specifically, I sought to answer the following questions relating to small mammals and habitat fragmentation:

#### A. The Magnitude of the Ecological Effects of Powerline Easements

- (i) What is the length of powerline easements in the reserve tenures in my study area?
- (ii) How much land in the study area is occupied by powerline easements?
- (iii) How much habitat is replaced by powerline easements in each of the tenures and in total?
- (iv) To what extent do powerline easements contribute to existing habitat fragmentation in the study area?

#### B. The Barrier Effect Caused by Powerline Easements

- (i) What small mammals are found in the vicinity of powerline easements?
- (ii) What are the typical directions and distances of travel by small mammals in the vicinity of powerline easements?
- (iii) Do small animals move across powerline easements?
- (iv) Does the vegetation present affect the rate of crossing?
- (v) Is competition exclusion a possible explanation for the observed frequency of easement crossing frequency small mammals?

#### C. Habitat Use by *Rattus fuscipes* and *Antechinus stuartii*

- (i) What habitat features are most commonly associated with the two species?
- (ii) How do the species differ in their use of their habitat?

**D. Small Mammal Response to Release in Powerline Easements**

- (i) Is there any difference in the movement behaviour of small mammals in a powerline easement compared in familiar habitat?
- (ii) Is the movement behaviour in a manmade habitat linkage between two areas of natural habitat similar to that in the familiar habitat or the open easement?
- (iii) How do *R. fuscipes* and *A. stuartii* differ in their response to habitat linkages in terms of movement behaviour?
- (iv) Is the use of habitat linkages associated with conditions in the powerline easement?

**E. The Effect of Translocation of Small Mammals Across Powerline Easements**

- (i) Do translocated animals return to the side of the easement where captured?
- (ii) What path do translocated animals follow if returning to the side of capture?
- (iii) What are the characteristics of the movement path of translocated animals?
- (iv) Do translocated animals use habitat differently when compared to habitat use of animals in familiar habitat?

Before embarking on the full account of my estimates of powerline impact magnitude, studies of habitat utilisation and research into effects of habitat corridors, I first describe my study species and sites in greater detail.

**1.5 Descriptions of Study Species**

The animals targeted for my study of the responses of small mammals to powerline easements were *Rattus fuscipes*, the bush rat and *Antechinus stuartii*, the brown antechinus. Despite the fact that these are two of the most studied mammals in Australia, there are aspects to their ecology that remain poorly understood (Lindenmayer & Lacy, 2002). Furthermore, it is easier to identify resource and habitat requirements of abundant species, and to construct predictive models of factors

affecting their abundance. (e.g. Dickman & Steeves, 2004). Evidence suggests that although *R. fuscipes* and *A. stuartii* have a widespread distribution, and are not regarded as threatened, they are nonetheless susceptible to the effects of habitat fragmentation and disturbance (Dunstan & Fox, 1996; Lindenmayer *et al.*, 1999). For example, Laurance (1997) listed *A. stuartii* as a forest specialist that may be prone to extinction at a local scale. For much of their range, the fire-prone landscape inhabited by both *R. fuscipes* and *A. stuartii* is intersected by barriers to movement (including powerline easements) and is occupied by introduced predators (foxes; feral cats). This suggests their status may also be less secure than it appears. There is recurring evidence of negative impacts of disturbances such as logging (Lunney & Ashby, 1987) and habitat fragmentation (e.g. Bennett, 1990b; Laurance, 1997; Cox *et al.*, 2004) on *A. stuartii*. Moreover, it has been reported that the relative immobility of small mammals, and potentially small population densities makes them more likely to be affected by habitat fragmentation than other taxa (Bright, 1993).

### 1.5.1 *Rattus fuscipes*, The Bush Rat

*Rattus fuscipes*, the bush rat (Fig. 1.1(a) & (b)) a terrestrial native murid rodent, is thought to be the most common small mammal of the closed, tall and open forests of Australia (Robinson, 1987), occurring throughout many parts of south-eastern Australia (Watts & Aslin, 1981). For this reason it is considered an ideal target species for ecological studies. *Rattus fuscipes* is grouped with the ‘new’ endemic species of Australian rodents which arrived in Australia during the last one million years (Heinsohn & Heinsohn, 1999). This group is characterised by small litters, shorter gestation rates and weaning periods, and early maturity (Yom-Tov, 1985). The ‘old’ endemics, include *Melomys cervinipes*, for example, which invaded Australia from the North as much as 15 million years ago (Heinsohn & Heinsohn, 1999). Compared to *M. cervinipes*, *R. fuscipes* is larger, weighing between 66-225g (Lunney, 1995).

**Figure 1.1 Pictures of *Rattus fuscipes*, the bush rat, one of the target species in this study.**

Photo credits (a) <http://www.communitywebs.org/> (b) [http://www.amonline.net.au/factsheets/bush\\_rat.htm](http://www.amonline.net.au/factsheets/bush_rat.htm)

Also, it can breed all year, up to five times, producing about five young per litter. Generally most individuals die after one reproductive year. *Rattus fuscipes* has a broad diet that includes plant tissue, fungi, seeds, fruit and arthropods. It is a shy, nocturnal species typically occupying regions with dense, moist vegetation, from sea level to sub-alpine areas (Menkhorst & Knight, 2004).

**1.5.2 *Antechinus stuartii*, The Brown Antechinus**

*Antechinus stuartii* (Macleay), the brown antechinus (Fig. 1.2(a) & (b)), is a widespread, small (17-36g), native Australian marsupial (Strahan, 1983), which feeds predominantly on arthropods, but also occasionally on vertebrates (Goldingay *et al.*, 1991) and on nectar when available. It is a common and widespread species, occurring in many habitats throughout East, and Southeast Australia (Menkhorst & Knight, 2004). For this reason, and also because it is easily trapped, it is a highly suitable study species.

Like *R. fuscipes*, *A. stuartii* is also found from sea level to sub-alps and in a range of habitats that include rainforest, sclerophyll forest, woodland and heath. *Antechinus* spp. are members of the dasyurid family, which are a very successful group and today may be found in the entire range of terrestrial habitats of Australasia (Fox, 1982b).

**Figure 1.2 (a) and (b) Pictures of dasyurid marsupial, *Antechinus stuartii*, the brown antechinus.**

Picture (b) <http://www.abc.net.au/news/newsitems/200611/s1779428.htm>

Feeding on invertebrates from leaf litter and tree hollows, *A. stuartii* is strongly arboreal and moves in short staccato bursts (Menkhorst & Knight, 2004). *Antechinus* spp. are known for their simple life cycles, in which all males in the population die after a highly synchronised 2-week mating period in early spring. Males at this time show symptoms

of stress-related illnesses, such as resultant parasite loads and internal bleeding (Lazenby-Cohen & Cockburn, 1991). Occasionally, this species is called ‘brown marsupial mouse’ though, in fact, it is far more agile than a mouse, displaying both terrestrial and pronounced scansorial (capable or adapted for climbing) habits (King, 1978). Owing to the strength to body ratio of the antechinus (Marlow, 1961), this species is particularly well-adapted for climbing. Anatomical features which may contribute to this are hind feet that have a wide range of rotation, and granulated soles on hind feet pads (Menkhorst & Knight, 2004).

### 1.5.3 Other Species

Several other species of small mammal may be found in bushland in coastal New South Wales. *Sminthopsis murina*, the common dunnart, is also a nocturnal, insectivorous dasyurid, with a widespread distribution including the region of New South Wales in which I conducted my study. This species is typically found in a range of habitats, including heathy dry sclerophyll forest and mallee heath and particularly favours open

habitats (Menkhorst & Knight, 2004). Despite its broad habitat use, and contrary to its name, this species is not commonly trapped (Fox, 1995). The nomadic movements of this species, thought to be a reflection of its narrow range of habitat requirements, may translate into low capture rates or low site fidelity (Monamy & Fox, 2005). *Sminthopsis murina* is easily distinguishable from *A. stuartii* by its large rounded ears, pale underside and aggressive nature (pers. obs.) Almost indistinguishable from this species, aside from the striations present on its feet, is *Sminthopsis leucopus*, the white-footed dunnart. The northernmost record of *S. leucopus* was at Booderee National Park, in the Jervis Bay Region of the South Coast of New South Wales.

*Cercartetus nanus*, in the Family Burramyidae, is listed as a vulnerable species (NSWSC, 2001) several records of this species exist for my study region. This small (15-38g), nocturnal, arboreal marsupial eats mainly nectar and pollen (Menkhorst & Knight, 2004). *Cercartetus nanus* may be found in a range of habitats including woodland, heathland, sclerophyll forest and rainforest (Harris, 2006), typically nesting in tree hollows and other recesses. It is readily distinguishable by its prehensile tail.

The final species of small mammal present in coastal New South Wales and which features regularly in Elliott trapping programs is *Rattus lutreolus*, the swamp rat. This species favours wet habitat with dense vegetation (Monamy & Fox, 1999) and is distinctly different from *R. fuscipes* with much darker feet and tail (Menkhorst & Knight, 2004).

## 1.6 Study Area

### 1.6.1 Location

The 5,735km<sup>2</sup> study area is located on the south coast of the state of New South Wales (NSW) (Fig 1.3), and is made up of four local government areas: Wollongong, Kiama, The Shoalhaven and Shellharbour.

**Figure 1.3 Study area on the South Coast of New South Wales, Australia.**

Inside the study area boundary (represented by a thick dark line), ■ = natural habitat, ■ = other land. □ = ocean. The powerline easement network is represented by thin black lines. Inset shows location of the study area on the South Coast of the state of New South Wales, Australia.

Map (Marji Puotinen)

While much of this region is within commuting distance to Sydney, and therefore becoming extensively developed for housing, it is also rich in biological diversity and

features a high proportion of National Parks (41% of the total area), with a further 11% of land contained within State Forest and Crown Land reserves. Stretching for more than 170km along the coast, the area includes several urban centres such as Wollongong, Kiama and Shellharbour. The coastal portion of the study area experiences a mild climate while the plateau, at 550m above sea level, experiences cooler temperatures. Summer and autumn are characterised by moderate to high temperatures, high humidity and on-shore winds. The rainfall also reaches its peak at this time of year. Westerly airflows dominate in winter and spring giving cooler, dryer conditions with occasionally blustery winds. Frost is rare on the coastal plain but winters on the plateau can be cold. Overall the climate is mild and this is reflected in the vegetation (Fuller & Mills, 1985). Exposure to wind on the coast, along with exposure to high fire frequency, limits the distribution of rainforest.

Beginning in the 1880's, the foothills and valleys of the escarpment in the Shoalhaven and Kangaroo Valley, as well as the flatter more fertile parts of the upper Shoalhaven valley, were subject to clearing for agricultural development (Thomas *et al.*, 2000a). During the 1960s and 1970s, much of the Crown Land along the south coast escarpment was declared National Park. During the 1980s and 1990s coastal National Parks were established to protect the coastline. However, many of these reserves are on infertile, steep or dissected terrain, and, therefore, offered a biased representation of the vegetation types in the region. While wetlands, grassy woodlands and certain types of forest present on more valuable agricultural land in the region have been extensively cleared or ecologically degraded (Tindall *et al.*, 2004), the National Parks and other reserves such as State Forests have become extremely important from a biodiversity conservation perspective.

The area is very fire-prone, as is much of coastal southeastern New South Wales. Some regions are subject to regular prescribed burns (Catling, 1991). Much of the ecological literature originating from this region of Australia describes the responses of flora and fauna to wildfire (e.g. Newsome & Catling, 1979; Lunney & Leary, 1989; Whelan *et al.*, 1996; Monamy & Fox, 2000; Penn *et al.*, 2003; Monamy & Fox, 2005).

### 1.6.2 Individual Site Description

Four study sites were selected, all of which were situated on the South Coast of the state of New South Wales (Fig. 1.4). All of the sites were located in the Shoalhaven Local Government Area, in the vicinity of Jervis Bay. Three of these were located within National Parks, with a fourth contained within land controlled by State Forests of New South Wales. The sites were a minimum of 9km from each other to ensure that animals captured at each location originated from discrete populations.



**Figure 1.4 Location of four main trapping sites (bold text) on the South Coast of New South Wales, Australia.**

A fifth trapping site, at Sussex Easement is also shown in regular text. ■ = National Park, ■ = State Forest, ■ = 'Other Land'. □ = ocean. Powerline network is shown in black.

The sites were selected because they met the following criteria;

- Powerline easement present in otherwise intact native bushland.
- Accessible by 4-wheel drive vehicle.
- At a distance from disturbance e.g. regions with road noise, proximity to buildings and farm land were avoided.
- Habitat on opposing sides of the powerline easement as similar as possible.

- Habitat on the same side of the powerline easement as constant as possible, with few/no open patches.
- Habitat accessible on foot for trap laying and small mammal handling.
- Minimal disturbance from recreational pursuits (dirtbike riding, horse-riding etc.).
- Similar easement width at each site.

#### *1.6.2.1 Currambene State Forest*

This site, located in Currambene State Forest, is on land managed by State Forests of New South Wales (Fig. 1.5), though the powerline easement itself is maintained by Integral Energy, as are those at the other trapping sites. Since there are fewer restrictions on the recreational activities in State Forests, this trapping site was more affected by disturbance from activities such as horse-riding and dirt-bike riding (pers. obs.) Furthermore, it is closer to a road than the other sites. The road in question is an unsealed, little used road, (status as of May 2006), but is sometimes used by some heavy vehicles drawing material from the nearby quarry.

**Figure 1.5 Trapping site at Currumbene State Forest ('Currumbene'), featuring a 33kV powerline easement.**

The site at Currumbene was more 'heathy' than the other three trapping sites in this study (Fig. 1.5). Vegetation communities described for this location are (1) Currumbene Lowlands Forest, (2) Jervis Bay Lowlands Shrub/Grass Dry Forest, and also small pockets of (3) Northern Coastal Sands Shrub/Fern Forest. Currumbene Lowlands Forest is recognised by its eucalypt forest, which has an open shrub layer and a dense grassy groundcover (Tindall *et al.*, 2004). Tree species present in the canopy include *Allocasuarina littoralis*, *Corymbia gummifera*, *C. maculata* and *Eucalyptus pilularis*. The shrub layer includes *Pimelea linifolia*, *Lomatia ilicifolia*, *Banksia spinulosa* and *Persoonia linearis*. At ground level *Entolasia stricta*, *Lomandra longifolia*, *Dianella caerulea* and *Lepidosperma laterale* are typical species present.

Jervis Bay Lowlands Shrub/Grass Dry Forest is a medium forest, dominated by *Eucalyptus punctata*. Other tree species, such as *C. gummifera* and *Eucalyptus eugenioides* are also present. This ecosystem has co-dominant shrub and grass layers. The shrub layer comprises patches of *Allocasuarina littoralis*, along with *Daviesia ulicifolia*, *Melaleuca decora*, *Persoonia sp.*, and *Pimelea linifolia ssp linifolia*. Grasses

common at ground level are *Entolasia stricta* and *Themeda australis*, small sedges *Lomandra multiflora* ssp. *multiflora*, *Dianella caerulea* var *caerulea*, and *Lepidosperma laterale*, with herbs *Opercularia diphylla* and *Brunionella pumila*. Currumbene State Forest is henceforth referred to as 'Currumbene'.

#### 1.6.2.2 Conjola National Park

Conjola National Park is the southernmost of the study sites (Fig. 1.6). It is located in a dry, rocky, undulating region, which is typified by three ecosystems: (1) Lowland Dry Shrub Forest, (2) Northern Coastal Hinterland Heath Shrub Dry Forest and (3) Northern Foothills Moist Shrub Forest (Thomas *et al.*, 2000a). The first of these, Lowland Dry Shrub forest is typically 20m in height and is dominated by *Corymbia gummifera*, with *Eucalyptus globoidea*, *Eucalyptus consideniana*, *Eucalyptus piperita* and *Syncarpia glomulifera* also present.

**Figure 1.6 Trapping site located within Conjola National Park 'Conjola'), on the South Coast of New South Wales, Australia.**

Species present in the dry shrub understorey include *Persoonia linearis*, *Banksia spinulosa*, *Acacia obtusifolia*, *Tetratheca thymifolia*, *Leucopogon lanceolatus*, *Lomatia ilicifolia*, *Acacia terminalis*, *Platysace lanceolata*, *Bossaia obcordata*, and

*Gompholobium latifolium*. The ground cover contains grasses *Entolasia stricta*, and herbs *Patersonia glabrata*, *Dianella caerulea* var *caerulea*, and *Gonocarpus teucriodes*. The second community described in this trapping site, Northern Coastal Hinterland Heath Shrub Dry Forest, is moderately dense, with a shrub layer dominated by the sandstone broadleaved hakea *Hakea dactyloides*, the banksias (*Banksia paludosa* and *B. spinulosa*), *Lambertia formosa*, and rough-barked tea-tree (*Leptospermum trinervium*). Dominant species in the forest, which is low to medium in height, are scribbly gum (*Eucalyptus sclerophylla*) with red bloodwood (*Corymbia gummifera*) usually present as a subdominant. As with Lowland Dry Shrub Forest, the groundcover features the grass *Entolasia stricta*, but *Lepyrodia scarisosa* is also present. In damper regions, where Northern Foothills Moist Shrub Forest occurs, tall species, over 30m in height such as *Corymbia maculata* and *Eucalyptus pilularis* occur in a more varied canopy. The immediate vicinity of the trapping site was particularly sparse in terms of ground vegetation, frequently with just bare earth or sandstone rock exposed. However, leaf litter cover was denser here than at any other site, owing to the well-established eucalypt canopy. Conjola National Park is henceforth referred to as ‘Conjola’.

#### 1.6.2.3 Jervis Bay National Park (‘Parnell’)

The narrowest of the powerline easements in this study, measuring 23m wide, ‘Parnell’ is located in a region of Jervis Bay National Park that was severely burned in the 2000-2001 bushfires (Fig. 1.7)

**Figure 1.7 Parnell Road trapping site ('Parnell'), located within Jervis Bay National Park, on the South Coast of New South Wales.**

Owing to vigorous resultant regrowth following bushfire, as well as accumulation of burnt logs and branches at ground level, this was also the densest site in terms of vegetation and structural complexity (Fig. 1.8). Three recognised vegetation communities may be found in the vicinity of the Parnell site: (1) Northern Coastal Hinterland Heath Shrub Dry Forest (NCHHSDF), (2) Northern Coastal Tall Wet Heath (NCTWH) and (3) Northern Coastal Sands Shrub/Fern Forest (NCSS/F). The first of these communities (NCHHSDF), which is mainly medium to low forest, is dominated by scribbly gum (*Eucalyptus sclerophylla*) with red bloodwood (*Corymbia gummifera*) usually present as a subdominant (Thomas *et al.*, 2000b).

**Figure 1.8 Example of dense vegetation, present throughout the site at Parnell.**

There is a moderately dense heathy shrub layer dominated by sandstone broad-leaved hakea (*Hakea dactyloides*), the banksias (*Banksia paludosa* and *B. spinulosa*), *Lambertia formosa*, and rough-barked tea-tree (*Leptospermum trinervium*). The groundcover comprises *Lepyrodia scariosa* and *Entolasia stricta*. The second vegetation type (NCTWH), Northern Coastal is a tall, wet sedge shrubland, potentially up to 3 metres high. It is comprised of an open cover of tall shrubs such as *Hakea teretifolia*, *Allocasuarina distyla*, *Leptospermum attenuatum*, *L. squarrosum* and *Xanthorrhoea resinosa*. The diverse intermediate shrub layer is made up of smaller shrubs including *Sprengelia incarnata*, *Banksia paludosa*, *Dillwynia floribunda* ssp *floribunda*, *Baera rubioides*, *Sprengelia incarnata*, *Epacris obtusifolia*, *E. microphylla* ssp *microphylla*, *Darwinia leptantha*, as well as herbs e.g. *Actinotis minor* and sedges such as *Lepidosperma filiformis* and *Restio fastigiatus*. This site also features regions with shrub/fern forest (NCSS/F). This third vegetation type is a forest in which *Eucalyptus pilularis* and *C. gummifera* dominate. There are also some occasional patches of Turpentine. *Elaeocarpus reticulatus*, *Banksia serrata*, *Monotoca elliptica*,

and *Acacia longifolia* are the principal components of the shrub layer. At ground level mainly sedges such as *Lomandra longifolia* and *Lepidopserma laterale* are present, but graminoids *Enolasia stricta*, *Dianella caerulea* var *caerulea*, and *Patersonia glabrata* also feature. The site in Jervis Bay National Park was located adjacent to a trail that extended from Parnell Road. For this reason, for convenience, this site is henceforth referred to as ‘Parnell’.

#### 1.6.2.4 Jerrawangala National Park

The trapping site at Jerrawangala National Park was constructed around a 132kV powerline easement, as distinct from the other three sites, which feature a narrower (~25m) easement. The easement at Jerrawangala measured approximately 40m wide (Fig. 1.9).

**Figure 1.9 Trapping site located within Jerrawangala National Park, on the South Coast of New South Wales, featuring a 132kV powerline easement.**

This site was also quite different in terms of its plant community, having a taller, more open forest with dense patches of acacia. Vegetation communities present at this site

were: (1) Southern Turpentine Forest, (2) Coastal Lowlands Cycad Dry Shrub Dry Forest and (3) Northern Coastal Hinterland Heath Shrub Dry Forest. The first of these, Southern Turpentine Forest, is described as a rather dense eucalypt forest with an open shrubby understorey. Tree species present include *Syncarpia glomulifera*, *Eucalyptus piperita*, *E. scias* and *Corymbia gummifera*. *Banksia spinulosa* and *Persoonia linearis* feature at shrub level, with *Dianella caerulea*, *Entolasia stricta*, *Pteridium esculentum* and *Lepidosperma urphorum* present at ground level (Tindall *et al.*, 2004). Coastal Lowlands Cycad Dry Shrub Dry Forest is a medium to tall forest 25 –30 metres in height. *Corymbia maculata* dominates, with *Eucalyptus paniculata ssp paniculata* and *E. muelleriana* sometimes present as co-dominants. The shrub layer comprises the cycad *Macrozamia communis* with patches of *Allocasuarina littoralis*, *Breynia oblongifolia*, and *Persoonia linearis*. The ground layer comprised grasses *Entolasia stricta*, *Imperata cylindrica*, and *Microlaena stipoides* intermixed with herbs and twiners such as *Desmodium varians* and *Dianella caerulea var caerulea*. Sedges present in this community were *Lepidosperma laterale*, *Lomandra longifolia* and *Lomandra multiflora ssp multiflora*. Finally, Northern Coastal Hinterland Heath Shrub Dry Forest has been described for this area (Thomas *et al.*, 2000a). This is an ecosystem dominated by *Eucalyptus sclerophylla* (Scribbly Gum) with *Corymbia gummifera* (Red Bloodwood) often present as a subdominant, and is also present at Parnell, (Section 1.6.2.3). This site, located in Jerrawangala National Park is henceforth referred to as ‘Jerrawangala’.

## 1.7 Thesis Outline

Powerline easements are likely to have extensive ecological impacts, as explained above, but these are poorly understood. In Chapter 2, I present a range of simulations using Geographic Information Systems (GIS) in which the best and worst case impact scenarios are estimated. Focusing on land tenures of particular ecological value, I examine these scenarios in the context of the actual landscape, which is already highly fragmented by roads and other anthropogenic developments.

Studies in the past have found that roads represent a barrier to the movement patterns of small mammals, as previously described. However, the degree to which this is true for powerline easements has not been widely documented and not at all in the southeast of

Australia. In Chapter 3, I describe an extensive mark-recapture program reporting the rate of easement crossing at four powerline easements on the South Coast of New South Wales. Also described is a related study in which the possibility of competition as an explanation for the low crossing rate is investigated.

As a first step towards improving the passage of small mammals between habitat fragments separated by powerline easements, in Chapter 4 I examine habitat use by my study species at a fine scale using the spool-and-line technique. By comparing their choice of habitat features with the proportions of those features in the background habitat, I determine the categories of habitat features that are chosen preferentially by the animals as they move through their habitat.

Building on the knowledge gained in Chapter 4, Chapter 5 describes an experiment in which habitat ‘linkages’ were constructed which physically connected the opposing sides of powerline easements. I fitted captured animals with miniature thread spools and released on these habitat linkages. I then followed their paths and recorded the tortuosity of their paths described in terms of angles or ‘turns’ in three different regions of the powerline easement. Tortuosity as an indicator of behaviour and of habitat quality is discussed.

To examine some of the responses of released animals described in Chapter 5, in Chapter 6 I report on an analysis of the flight response behavioural adaptation that has been associated with captured animals. Chapter 6 also gives an account of the translocation studies undertaken in this project whereby animals were released on the opposite side of the easement from which they were captured. I describe their habitat use and movement patterns compared to animals in ‘familiar’ habitat.

Finally, in Chapter 7, I bring together the results of these investigations and discuss the impacts of powerline easements on small mammals that I’ve identified. I describe the movement behaviour of the study species and the role of vegetation in determining this behaviour. Finally, I suggest improvements for the management and design of powerline easements, and with a view to enhancing conditions for native small mammal fauna, suggest possible avenues for future research.

## Chapter 2 – Powerline Easements: Impact Magnitude

### 2.1 INTRODUCTION

#### 2.1.1 Direct and Indirect Effects

In Australia, 75% of the population of 19.5 million people live in urban areas (ABS, 2004). The most densely populated region is the coastal southeast of the country. This urban development and the provision of associated communications, energy and transport infrastructure have occurred in an area of significant biological diversity, causing a conflict between development and conservation needs.

As explained in Chapter 1, vegetation growing in powerline easements is regularly cleared in order to control the regrowth that would interfere with power supply and increase potential for ignition of bushfires (Brown, 1995). This results in long strips of mowed vegetation that are in stark structural contrast with the surrounding bushland. Structural discontinuities such as this are associated with the inhibition of movement of a range of taxa (Section 1.1.1.2 & Chapter 3). The most obvious result of powerline easement construction and maintenance in bushland is the direct replacement of natural habitat (direct effects). In addition to this, the physical and biological changes in forest regions adjacent to disturbance such as forest clearance are collectively known as edge effects (Murcia, 1995) (indirect effects) (see Section 1.1.1.3). This term refers to disruptions in ecological processes and patterns such as predation (Paton, 1994), seed dispersal (Landenberger & McGraw, 2004), species abundance (Luck *et al.*, 1999), animal movements (Oxley, 1974; Goosem, 2001), and seedling recruitment (Curran *et al.*, 1999). Estimates of the extent of edge effects quoted in the literature vary widely, depending on experimental objectives, location and species or phenomenon under investigation (Table 2.1).

**Table 2.1 A selected range of examples of edge-extent estimates.**

Extent of edge effects (m)	Location	Habitat type & context	Reference
50m	Pennsylvania & Delaware, USA	Oak-chestnut forest, mature regrowth: Microenvironment at edges	(Matlack, 1993)
100m	Southern Appalachian Mountains, USA	Mountane forest: Edge effect from roads on forest macroinvertebrates	(Haskell, 2000)
50-100m	New Zealand	Lowland temperate rainforest: Effect of edges on plants, animals, and microclimates	(Norton, 2002)
40-120	British Columbia, Canada	Mature and regenerating trees: effects of clearcutting on trees	(Burton, 2002)
200-500m	Tropical North Queensland, Australia	Complex notophyll vine-forest fragments: Edge effects on floristic and physiognomic variables	(Laurance, 1991b)
600m	Massachusetts, North America	Deciduous forest with evergreen. Effects of highway on wetlands, road salt, exotic plants etc	(Forman & Deblinger, 2000)
200-300m	Amazonia	Tropical rainforest: Edge and isolation effects on fragments	(Lovejoy <i>et al.</i> , 1986)
1-5km	Amazonia	Tropical rainforest: Habitat fragmentation	(Skole & Tucker, 1993)

### 2.1.2 Estimates of Impact Magnitude

Estimates of edge extent vary in magnitude depending on many factors, such as location, species of interest and ecological process. Table 2.1 features a sample of estimates which have been reported. The table also illustrates the variation in estimates of extent of the edge effect, as well as the differing geographical locations and ecological contexts to which they refer. Edge effects are extremely diverse (Murcia, 1995; Laurance, 2000) and the potentially large-scale level at which these ecological processes occur make the phenomenon inherently difficult to study (Laurance, 2000).

Roads are well-recognised as a cause of habitat loss and direct mortality of wildlife (Andrews, 1990; Forman & Alexander, 1998; Spellerberg, 1998; Hourdequin, 2000; Trombulak & Frissell, 2000). Forman and Deblinger (2000) described a region of edge effects or a 'road effect zone' that averages 600m in width for a highway in North America. Another study (Forman, 2000) estimated that, collectively, roads affect almost

20% of land in the United States. Powerline easements, however, are quite different from roads in form and function and thus are likely to give rise to different ecological impacts. There have been some investigations into the possible edge effect zone of powerline easements. For example Goldingay & Whelan (1997) reported the presence of exotic predators (cats and dogs) 50-200m inside the forest. In moist open forest in southeastern Australia, Baker *et al.* (1998) reported a lower mean species richness and total abundance of birds at margin (25-125m from the easement). Pohlman *et al.* (*in press*) described abiotic impacts within 20-25m of the edge of the powerline easement, reporting that in the dry season, understorey near powerline edges was warmer and drier than the forest interior at her rainforest study sites. One isolated study estimated the extent of ecological disturbances caused by powerline easements in a region of Tropical North Queensland, Australia (WTMA, 1999). Based on an assumption that ecological effects extend for 200m away from the powerline easement into adjacent forest, this study calculated that 12,960ha of rainforest was affected (WTMA, 1999). Aside from these studies, more generalised assessments of the nature and extent of edge effects caused by powerline easements have not yet been made, either in Australia or elsewhere. Despite their prevalence in the landscape, these features have attracted surprisingly little research attention, such that even the extent of easements across various land tenures in Australian landscapes is unknown.

Powerlines are most common in urban areas where the demand for electricity is highest. These areas, where the network of powerlines is composed mostly of many minor and subsidiary electricity feeders, are also regions of high anthropogenic activity and intensive land use. Ecological impacts are likely to be most severe therefore, where powerlines transect otherwise intact areas of habitat -such as National Parks.

### **2.1.3 GIS: A Tool in Conservation Biology**

GIS has become an indispensable tool for resource managers in accumulating information and modelling the potential effects of all sorts of habitat modification (Treweek & Veitch, 1996; Clevenger *et al.*, 2002). GIS is also used to predict the presence of animals based on physical and environmental characteristics of the habitat (Gibson *et al.*, 2004a; Gibson *et al.*, 2004b). These studies provide an example of how the increasing availability of digital data on habitat suitability, biogeographical features

and landscape composition can contribute to ecological assessment and subsequent conservation management. Because GIS facilitates comparisons between real and theoretical landscapes (With, 1997), this tool can be applied to generate scenarios of the potential impacts of anthropogenic landscape features.

#### **2.1.4 Study Aims**

Powerline easements provide the context for my investigations into the impacts of habitat fragmentation on small mammals. In subsequent chapters, I examine the impact of these features on fine-scale patterns of movement and habitat use. As a precursor to that, I take a broader, landscape approach in this chapter. I seek estimates of the magnitude of direct and indirect effects of powerline easements on a 5,735km<sup>2</sup> area of coastal New South Wales that features extensive human populations, as well as large tracts of biologically rich native habitat.

The aim of this phase of the study was firstly to quantify the linear extent of powerline easements across various land tenures using GIS. Next, I aimed to quantify the direct effects of powerline easements by assessing the area of habitat in each tenure that is directly replaced by the easements, and by using GIS modelling to estimate the magnitude of the edge effects caused by the powerline easements.

Powerlines were the primary concern for this study. However, given the prevalence of roads in the region, a more realistic assessment of their ecological effects in the landscape context would also acknowledge the impact of roads. I therefore estimated the direct impacts of sealed and unsealed roads on habitat, and combined them with estimates of direct and indirect effects of roads and powerline easements, to evaluate the maximal potential ecological impact of these combined linear features in my study area.

## **2.2 METHODS**

### **2.2.1 Study Area**

The 5,735km<sup>2</sup> study area is located on the South Coast of the state of New South Wales (Fig. 1.3), 80km south of Sydney. Urban developments are concentrated in coastal

regions, with the remaining area dominated by National Parks and other natural habitats such as State Forest. The study area was chosen as a good example of land use conflict because of the juxtaposition of urban expansion, fertile agricultural land and extensive areas of National Park, State Forest and Crown Land, (which I refer to collectively as ‘reserved lands’).

### 2.2.2 GIS Methods

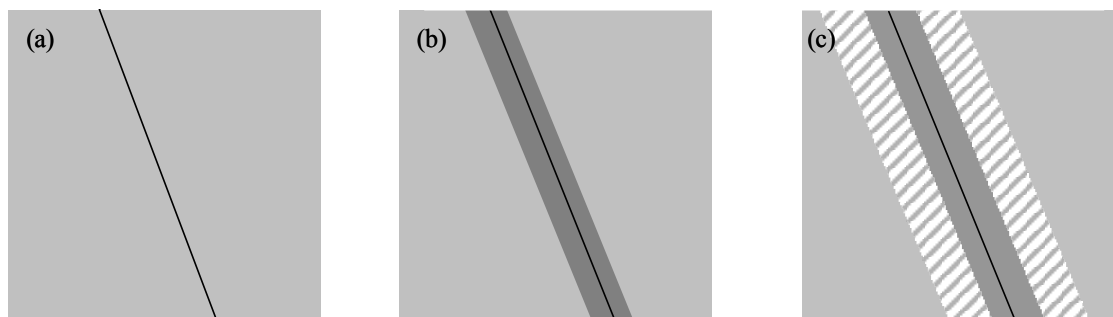
Using a vegetation map provided by The Department of Environment and Conservation (DEC, 2004) I extracted a layer of data that contained all regions of potential habitat in the study area. This was based on the presence of native vegetation. I then overlaid the co-ordinates for the boundaries of National Parks, State Forests and Crown Lands onto this layer (Table 2.2). Regions of habitat that fell outside of the three tenures were defined as ‘Other Habitat’. All other land in the study area was classed as ‘Non-Habitat’, which included developed areas, agricultural land and otherwise modified land.

Associated with the urban development in the area is an extensive network of powerline easements that runs through all land tenures (Fig. 2.1). While these structures frequently follow the course of roads, they also cut paths through otherwise intact habitat, and this provided the context for my study. The two electricity providers in the area supplied the geographic coordinates of powerpoles. I entered these onto the map, and then joined them up to represent the powerlines. I focused on the easements for the three most common voltages that transect habitat outside developed areas: 33kV, typically 25m wide; 132kV, approximately 40m wide; and 330kV, 90m wide. I established these measurements in conversation with representatives from Integral Energy and Transgrid, who own and operate the powerlines, and later confirmed the measurements in the field. Higher voltage powerlines require larger pylons and therefore, a wider vegetation clearance (Stephen Douglas, Integral Energy, pers comm.).

**Table 2.2 Source and description of datasets incorporated into the map of the study area, subsequently used in GIS simulations.**

Data description	Source	Year	Projected coordinate system	Scale
Description and location of habitat regions in study area	New South Wales National Parks and Wildlife Service (Now Department of Environment and Conservation (DEC))	2004	AGD 66 AMG Zone 56	1:25,000
Boundaries of State Forests	State Forests of New South Wales	2004	AGD 66 AMG Zone 56	1:25,000
Boundaries of National Parks	DEC (see above)	2004	AGD 66 AMG Zone 56	1:25,000
Boundaries of Crown Lands	NSW Department of Lands	2000	AGD 66 AMG Zone 56	1:25,000
Location of powerpoles	Integral Energy and Transgrid	2004	AGD 66 AMG Zone 56	n/a

Using ArcMap, I calculated the length of powerlines in each of the land type categories, and combined these results with the above values for width to produce totals for area of land occupied by easement. This was achieved by creating a ‘buffer’ of the appropriate width around the powerline easement, which in the map is a dimensionless linear feature (Fig. 2.1(b)). I refer to this measure as ‘Direct Effects’.



**Figure 2.1 Explanation of buffering process, which enabled the calculation of estimates of direct and indirect effects of powerline easements.**

(a) Powerline easement (dimensionless black line) located in a region of habitat (■), (b) Buffer applied to powerline to represent area occupied by powerline easement (■), (c) Buffer applied to both sides of (b) to represent area subject to indirect effects (shaded pattern).

To estimate the area of land indirectly affected by powerline easements, I added further buffers (Fig. 2.2(c)) on either side of the existing ones, to represent the edge effect zone. Two different edge effect scenarios were created. In the first, I assumed that all

easements would impact upon adjacent habitat to an equal extent (constant width assumption) (Table 2.3). For the second scenario, I assumed that wider easements would lead to edge effects which extend further into the adjacent habitat than narrower easements (variable width assumption). Both scenarios were assessed at two possible magnitudes; small and large (Table 2.3).

**Table 2.3 Explanation of buffer widths applied to powerline easements of three different voltages (widths) using GIS.**

‘Small’ and ‘Large’ refer to the contrasting conservative and upper-limit estimates ecological effects. ‘Constant’ and ‘Variable’ present potential scenarios where the magnitude of effects is independent of easement width (constant) or dependent on it (variable). Combinations of ‘Small’ and ‘Large’ with ‘Constant’ and ‘Variable’ provided the basis for four simulations.

Powerline Voltage	Small		Large	
	Constant Width	Variable Width	Constant Width	Variable Width
	(m)	(m)	(m)	(m)
33kV	25	25	100	50
132kV	25	40	100	80
330kV	25	100	100	200
Scenario	A	B	C	D

Values for these measures in the two scenarios were derived from the wide range of existing estimates of edge effect distances reported in studies of various systems, in different geographical locations and biological contexts (Table 2.1).

To appreciate the contribution made by powerlines to existing fragmentation in the landscape, I included roads in the GIS map of my study area. Best- and worst-case impact scenarios were generated by adding buffer zones to the roads, which, as explained above with regard to powerline easements, represented edge effect zone\*. The extent of the edge zone was conservatively based on existing reports of road-generated edge effect distances (Appendix 1). Buffers of different widths were applied to sealed and unsealed roads (Table 2.4), as the latter tend to be narrower and were assumed to represent less of a contrast with the natural surroundings compared to the asphalt

\* With the assistance of Dr. Marji Puotinen of The School of Earth and Environmental Sciences, University of Wollongong.

surface and heavier traffic volumes of sealed roads, and therefore to have less extensive edge effects.

**Table 2.4 Buffer widths applied to two road types using GIS.**  
Buffers represent edge effect zones.

<b>Road type</b>	<b>Average road width (m)</b>	<b>Best-case buffer width (m)</b>	<b>Worst-case buffer width (m)</b>
<b>Sealed</b>	30	100	200
<b>Unsealed</b>	8	25	50

Once the total area of land directly and indirectly affected by powerline easements under each scenario had been calculated, the same was done for roads, again using ArcGIS. The worst-case scenario for both roads and powerline easements was then combined to yield an estimate of maximum impact magnitude. Results were assessed in terms of area of habitat affected (ha), as well as proportion (%) of habitat in each of the tenures, and in the whole study area.

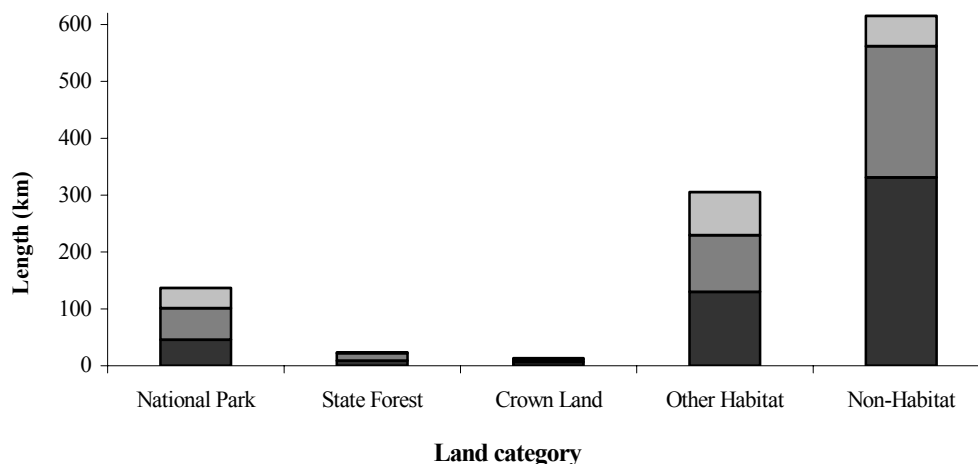
## 2.3 RESULTS

### 2.3.1 Length

The majority of the 1,093km of powerline easements in the study area are located outside the National Parks, State Forests and Crown Lands (Fig. 2.2). If the powerlines were evenly distributed across land tenures, 52.5% of their total length would fall within National Park, State Forest and Crown Lands. In reality, just 15.9% (174km) of the powerlines in the study area located within these three land tenures. However, when all land that contains potential habitat, regardless of tenure (i.e. including non-reserved lands that contain native vegetation), is included in this analysis, 43.8% of the total length of powerlines occurs in reserves or other natural vegetation (Other Habitat), with the remainder located in land classed as ‘Non-Habitat’.

33kV powerlines are the most common voltage in Non-Habitat and Other Habitat, comprising 53% and 42% respectively of the total easement length for these two land tenures. 132kV is most common in State Forests and National Parks, making up 55% and 41% of the total powerline length respectively, in those tenures. Although there are

more easements in ‘Non Habitat’ in terms of total length, a higher percentage (46%) of the powerlines that occur in Crown Lands are 330kV, the widest of the powerlines easements found in this study area. 26% of the easements in National Parks are in the 330kV category. By contrast, just 6% of the powerlines located in ‘Non Habitat’ (Fig 2.3(b)), which has less native vegetation and therefore reduced habitat potential, are 330kV.

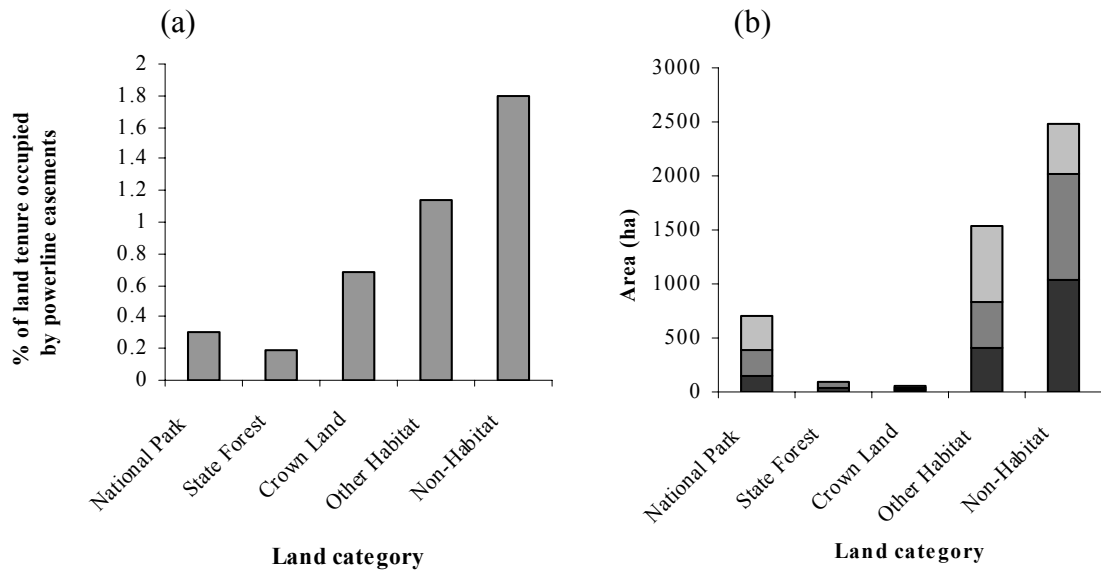


**Figure 2.2 Length of powerlines (km) of three voltages in each land category in this study.**

■ = 33kV, ■ = 132kV, ■ = 330kV

### 2.3.2 Area

Relative to total area of each of the land tenures, the greatest proportion of any land category occupied by easements was in the ‘Non Habitat’ category (1.8%). Other Habitat contains the second highest proportion of powerline easements (1.14%). Less than 0.4% each of National Parks, State Forest and Crown Land are occupied by powerline easements (Fig. 2.3(a)). In the case of National Park, this amounts to 696ha of habitat and approaching twice as much as that in Other Habitat (1,176) directly replaced by easements (Fig. 2.3(b)). Although the powerlines of each voltage vary in total length overall, the easements they occupy replace roughly similar amounts of land – between 1,522ha and 1,717ha. Throughout the study area, almost 50% (2,386ha) of the land that is occupied by easements in all land categories (4,870ha) was in categories that were classified as potential habitat.



**Figure 2.3 Area of land categories occupied by powerline easements.**

(a) Area of easements as a proportion (%) of total area of each land category (b) Area (ha) of each land category occupied by powerline easements: ■ = 33kV, ■ = 132kV, ■ = 330kV.

### 2.3.3 Edge Effects

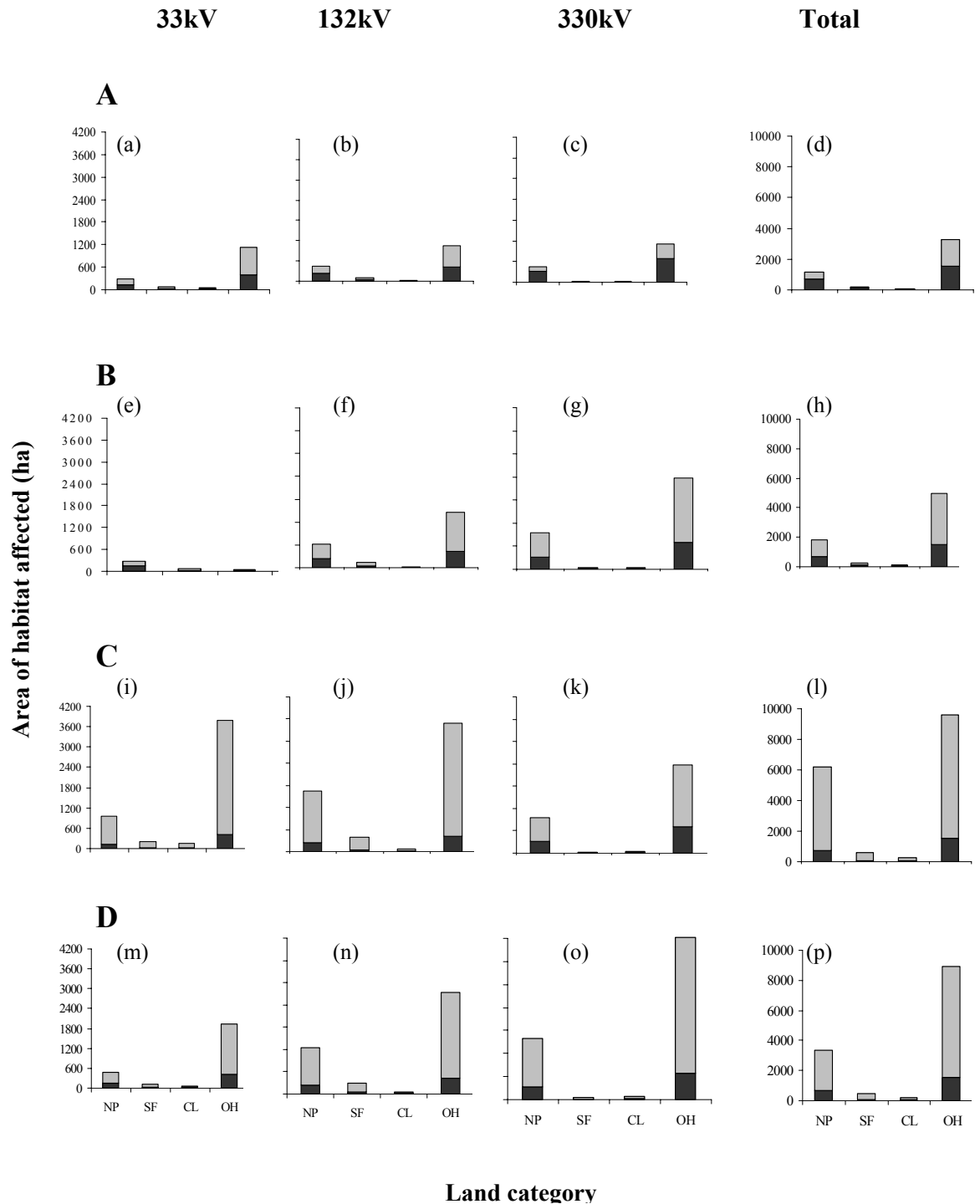
The total impact of powerline easements depends on the relationship between easement width and indirect (edge) effects, as well as the linear extent of easements through a particular habitat type. As indirect effects are not known, simulations give an indication of the range of potential impact magnitude. The simulations showed that over the three reserves and Other Habitat, the maximum and minimum estimates of direct and indirect effect magnitude differed by more than 9,353ha, from 4,717ha for the most conservative estimate, to a potential maximum of 14,070ha.

The most realistic scenario, where the edge effect zone is scaled according to easement width (powerline voltage), showed that 330kV easements contribute disproportionately to area of land affected. There are more 33kV easements (192km) than 330kV (114.6km) located in reserves and Other Habitat in the study area in terms of length (Fig 2.2). Despite this distribution, simulations that scaled edge effects according to width showed that 330kV easements, for both minimum and maximum estimates (3,381ha and

5,954ha respectively), have a greater impact on habitat in the area than 33kV easements (1,521ha and 2,608ha respectively) (Fig. 2.4(g) & (o)).

The greatest impact of powerline easements in the study area was in the Other Habitat category, which is also the category with the second greatest linear extent of easements (305km). Only Non-habitat, where most urban developments in the area are concentrated, contained more easements (614km), most of which (331km) are the narrowest 33kV powerlines. With an estimated minimum impact (direct and edge effects combined) of 3,280ha (Fig. 2.4(d)) and maximum of 9,621ha (Fig. 2.4(p)), more land in the Other Habitat category is affected by powerline easements than all the reserved lands combined.

Focusing on National Parks, which are of particularly high conservation value with regard to their size and secure future, the magnitude of direct effects of powerline easements appears very low, amounting to replacement of 696ha of land (Fig. 2.4(b)). However, when combined with a conservative estimate of edge effects, the magnitude of effects was more than doubled (1,849ha) (Fig. 2.4(h)). Furthermore, in a worst-case scenario, the total impact of powerline easements on this tenure is almost three times this amount, 3,555ha (Fig. 2.4(p)).

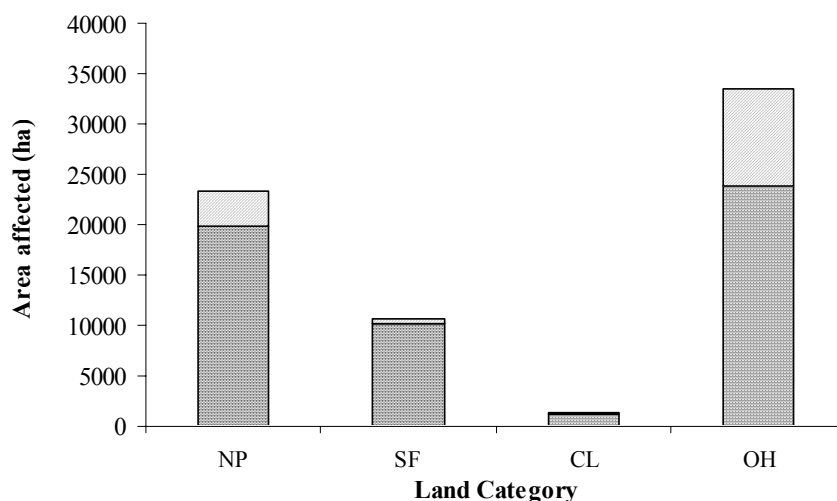


**Figure 2.4 Estimates of direct and indirect ecological effects (ha) of powerline easements in four land categories, based on four potential impact scenarios (see Table 2.3).**

(a) – (d) = small impact, constant width, (e) – (h) = small impact, variable width, (i) – (l) = large impact, constant width, (m) – (p) = large impact, variable width. Effects on three voltages (33kV, 132kV and 330kV) are shown, in addition to total effects for each simulation for all three easement voltages. NP = National Park, SF = State Forest, CL = Crown Land, OH = Other Habitat. Direct effects = ■; indirect effects = ▒.

### 2.3.4 Contribution to Existing Fragmentation

Adding roads to a hypothetical unfragmented landscape resulted in a reduction of total habitat in reserves and Other Habitat by 8.41% in a best-case scenario, and 14.61% in a worst-case scenario. Incorporating powerlines into these predictions of habitat loss resulted in little substantial change to this in terms of percentage. For the worst-case scenario, pristine habitat in the study area was reduced by powerline easements by a further 1.76% amounting to a total reduction of 16.37% of all unaffected habitat across the study area, when roads and powerlines were combined. This represents 7,421ha of land potentially impacted by powerline easements in addition to the 61,609ha of habitat affected by roads alone in a worst-case scenario. Another expression of this result is, that in a worst-case scenario involving both roads and powerline easements, 12% of the habitat ecologically affected was a result of the powerlines. In National Parks, the best and worst-case scenarios predicted that 5.2% and 9.4% respectively of habitat in this tenure was subject to direct and indirect effects due to roads alone. In a worst-case scenario, up to 8.75% of these direct and indirect (edge) effects in National Parks (2,047) resulted from the presence of powerline easements (Fig. 2.5). By contrast, the ecological impacts of powerline easements in State Forest and Crown Land are negligible relative to the impact of roads (Fig. 2.5).



**Figure 2.5 Estimations of relative contribution of powerlines and roads to direct and indirect effects on habitat within four land categories in the study region.**

Values based on a worst-case scenario, using upper estimates of possible extent of indirect effects. NP = National Park, SF = State Forest, CL = Crown Lands, OH = Other Habitat. Powerline easements (1,093km) represented by diagonal pattern, roads (9,297km) represented by brickwork pattern.

## 2.4 DISCUSSION

### 2.4.1 Impact on Habitat Area

The South Coast of New South Wales is a biologically rich and diverse part of Australia (Section 1.6). It is also home to a large proportion of the total population of the State, which explains the dense network of infrastructure including powerlines. While these 1,093km of powerlines themselves occupy a tiny proportion (1.15%) of the habitat in my 5,735km<sup>2</sup> study area, their cumulative indirect impact on adjacent land may be vast. I estimated that they potentially affect more than 14,070ha of habitat altogether. Even in a best-case scenario, my simulations predict that 4,717ha of land of potential conservation significance is subject to direct and indirect effects, in addition to the land ecologically effected by roads. In a worst-case scenario, when combined with upper estimates of the ecological impacts (direct and indirect) of roads in the area, up to 69,030ha, or 16.4% of all habitat may be subject to disturbance resulting from these two linear landscape features. In comparison to the magnitude of the edge effects, the direct effects (i.e. habitat loss) appear very minor but as Fahrig (1997) stressed, the relative ecological impacts of habitat loss are much greater than that of habitat fragmentation.

### 2.4.2 Assessing Impacts Based on Edge Effects

Laurance and co-authors, working in tropical forests, emphasised the importance of the perpendicular distance that edge conditions penetrate into reserves (Laurance & Yensen, 1991). Estimates of this distance vary in magnitude, depending on many factors, such as location, species of interest and ecological process (see Table 2.1). Harper *et al.* (2005b) contended that it is the contrast in composition and structure between opposing sides of an edge which will affect the distance and magnitude of edge influence. This observation is extremely relevant for this study, given the abrupt transition from mowed powerline easement to forest or woodland that is a feature in many regions of my study area. Without large-scale assessment of edge effects for a range of taxa in varying habitats, it is not possible to confidently predict the magnitude of edge effects. Additionally, Johnson *et al.* (1979) observed that, while more information on impacts at what is referred to as the 'tract' level (easement level), is useful, the potentially larger effect of the construction of linear features on landscape dissection, forest island size and biotic richness needs special attention. In the absence of more accurate values, using different scenarios of potential scales of edge effects can give an indication of

this, which in turn can contribute to landscape-level management decision-making. Assessing the total habitat area affected by powerline easements is just the first step in the large-scale assessment process. Landscape spatial structure, though more complex, is a more ecologically meaningful measure of habitat fragmentation. This is because ecological processes in a given ecosystem are, in part, a function of the landscape structure (Tscharntke *et al.*, 2002). As Fahrig and Merriam (1994) observed, not all habitat patches are of equal size, nor are all populations within the patches equally accessible to dispersers. Therefore, understanding the spatial arrangement of patches in the landscape matrix is essential in explaining for effects of habitat fragmentation on population survival. Reed *et al.* (1996) and Andrén (1994) also stressed the role of habitat patches on the impacts of habitat fragmentation. Andrén (1994) explained that, in highly fragmented landscapes, patch size and isolation complement the effects of habitat and species loss alone.

The next step in the impact assessment process would be to measure fragmentation itself using selected indices such as average patch size and number, core:area ratio, and patch shape. Using the study area described here, these measures have been estimated, which, together with the impact in terms of area, give a more realistic impression of the extent of fragmentation of the landscape (Stevens & Puotinen, unpublished data).

### **2.4.3 Land Tenure**

The public perception is that National Parks are pristine habitats. While they do provide secure habitat for biodiversity in general and for many threatened species, my research has shown that even national parks are subject to ‘internal fragmentation’, the subdivision of natural habitat and fauna populations by linear features associated with major powerlines, as described by Goosem (2002). State Forests and Crown Lands, are similarly fragmented. Furthermore, they lack the long-term security with regard to biological conservation that is associated with National Parks. The State Forests and Crown Lands in my study, although considered valuable habitat, are actually liable to be cleared for development. Additionally, these regions are fragmented by almost 36.9km of powerline easements and 1,029km of roads. In a worst-case scenario, roads and powerlines may ecologically impact upon more than 18% of these regions combined.

In my study area, the largest easements (330kV) affected more habitat than 33kV or 132kV easements, both of which are greater in terms of linear extent. This would suggest the wider easements should not feature in areas of high biodiversity value. Contrary to this however, my investigations revealed that more than 35km of high voltage easements run through National Park, which is almost exactly the same length as for regions of my study area without any viable habitat.

Perhaps it is wrong to assume that because of their size, permanent status and restrictions on permitted recreational activities, National Parks *ipso facto* provide higher quality habitat than other land tenures. For example, Burgman and Lindenmayer (1998) explained that national park status in most countries has been allocated on an *ad hoc* basis. They described how the development of reserve systems has been driven by a clear social or political mandate, targeting land that is unlikely to be productive, particularly for agriculture. Additionally, Pressey and Taffs (2001) made the point that conservation priorities that are identified in terms of richness, rarity or threat for example, are basically predictions, and are not useful or realistic without a clearly defined goal (e.g. achieving a target percentage of natural vegetation cover within a park) and subsequent testing of the prediction. Climatic extremes, resulting in drought or flooding for example, can influence politicians and legislators to adopt measures aimed at easing landholders' economic hardship resulting from such conditions. One recent example of this is the proposal in New South Wales to allow grazing of livestock in National Parks\*. It is intended that this would relieve the pressure on the drought-affected agricultural landscapes. National Parks therefore, may not necessarily guarantee the protection and habitat quality with which they are traditionally associated, emphasising the need to conserve habitat and limit fragmentation in regions of habitat in all land tenures. This further reinforces the need for a spatial approach to assessment of the impacts of habitat fragmentation in different land tenures, in combination with ecological investigations of edge effects for a range of flora and fauna.

In urban settings, powerlines through otherwise continuous vegetation can degrade the aesthetic value of the landscape (Anderson & Schroeder, 1983). This may partly explain

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\* Proposal made by Peter Debnam MP, Liberal Party leader in New South Wales (2007).  
See <http://abc.net.au/news/items/200701/1822835.htm?nsw>

the locating of larger powerlines out of visual range of centres of population (e.g. in National Parks), a practice that would also reduce the incidence of deliberate interference with pylons and conductors. However, as stressed by Luken *et al.* (1991a), planners and designers must take into account ecological factors when siting these features. For example, non-afforested areas, or existing edges and corridors would be preferable locations. For practical and commercial reasons, roads tend to follow the straightest line between two points. This re-emphasises the economic sense in siting easements alongside roads.

#### 2.4.4 Existing Fragmentation

My results demonstrate that, cumulatively, the edge and direct effects of powerline easements potentially affect thousands of hectares of habitat in my study region. However, these impacts are still dwarfed by the sum total of land subject to the ecological effects of roads. Roads, tracks and trails in my study area amount to 9,297km and are a pervasive and obvious component of the landscape, with well-documented ecological effects (Forman & Alexander, 1998; Trombulak & Frissell, 2000). While few major roads are located in the three reserved lands in my study area, (National Park, State Forest and Crown Land), fire trails, tracks and unsealed roads collectively measure 2,559km. The negative ecological effects of forest roads on various taxa have been reported (Bakowski & Kozakiewicz, 1988; Burnett, 1992; Haskell, 2000; Marsh *et al.*, 2005). Given their extensive length throughout all tenures, roads are the dominant cause of habitat fragmentation in these regions, and powerline easements must be considered in the context of this existing fragmentation. The magnitude of their combined impacts was shown here to amount to a substantial area, which reinforces the need to devise strategies to reduce this. Whilst road impacts are not readily mitigated, the negative impacts of powerline easements may offer more potential for this. For example, in an effort to reduce the total number of linear features, perhaps more frequent combining of recreational tracks and trails with powerline easements could be explored? While this does occur in some regions of my study area where quite a number of unsealed roads are sited within powerline easements study (e.g. 1,013ha in National Parks), further development of this practice would call for greater integration of management bodies locally responsible for the powerlines, for the reserves, and for recreational pursuits. A further obstacle is likely to be public aversion to activities close to powerlines, for aesthetic and safety reasons.

### 2.4.5 Impact Mitigation

Locating powerlines underground eliminates the need for powerline easements and appears to offer a solution to negative ecological impacts discussed in this chapter. However, to date the practice has been restricted by rocky terrain, high cost and maintenance complications. Less than 5% of all powerlines in my study area are located underground for these reasons.

Research has shown that even narrow linear barriers of as little as 12m in rural or forest locations can impede the crossing of small mammals (Swihart & Slade, 1984; Burnett, 1992; Goosem, 2001). Other taxa whose movement can be inhibited by narrow forest roads include amphibians (Chan-McLeod, 2003) and invertebrates (Haskell, 2000). Thus, both minor powerlines such as 33kV, which are in easements only 30m in width, and major 330kV powerlines that are typically 90m, will similarly reduce dispersal of these animals. Therefore, if electricity companies need to extend a powerline network or increase the voltage carried, it may seem preferable from a conservation perspective to focus on widening existing easements rather than clearing land for new ones. However, based on the evidence of extensive direct and indirect effects resulting from the widest of the easements (Fig. 2.5), widening easements may not in fact be wise from a conservation perspective. Ultimately, the management decision will depend on whether the mitigation priority is to reduce the number of movement barriers, or to reduce the magnitude of direct and indirect effects. Factors such as the local habitat quality, species targeted for conservation, and land availability will also influence the decision.

Because easements are dynamic features in terms of growth, and are regularly in need of maintenance, they provide an opportunity for investigation of alternative management regimes. Integrated Vegetation Management (IVM) may offer further potential for compromise between the needs for powerline easement maintenance and for reduction of negative environmental impacts. In Canada for example, it has been suggested that a strategy of optimising treatment cycle lengths and clearing only what is necessary establishes compatible plant communities in the easements (Wells *et al.*, 2002). Wagner (1994) similarly suggested that IVM provides a superior means of controlling weed species and the composition of the stand by means of selective removal of undesirable species. As Luken *et al.* (1991a) explained, repeated mowing

selects for species with high resprout rates. Therefore, the policy of mowing currently implemented at all of my sites is rather counter-productive. Furthermore, Mercier *et al.* (2001) noted that the disturbance caused by mowing jeopardizes natural resistance to tree invasion, and may also stimulate the production of new shoots, which is the means by which many trees survive the mowing. Johnstone (1990) reported that IVM in rights-of-way, which include powerline easements, is attractive from both commercial and conservation perspectives. Some evidence of the ecological benefits of a more established vegetation layer is presented and discussed in Chapter 3. Selective treatment of incompatible plant species in the right of way with pesticides resulted in reduced overall maintenance costs in addition to superior wildlife habitat with concurrent benefits for landscape aesthetics and site access (Johnstone, 1990). Perhaps, as Gascon *et al.* (2000) explained in the rainforest context, the regeneration of a vegetation stand, albeit a controlled, low-growing one as in a powerline easement, may also act as a buffer against microclimatic changes associated with edge effects. The merits of tall shrub cover in ‘border zones’ (Fig. 2.6) of powerline easements are discussed by Yahner (2002), as well as Yahner and Hutnik (2005). They discussed the ‘wire-border zone method’, where a short stand of grass and shrubs is established under the wires, with shrubs present in zones that border adjacent forest. This produces a powerline with economic, aesthetic and wildlife benefits (Yahner & Hutnik, 2005). It is considered by powerline operators that a mowed powerline easement can act as a fire-break in landscapes subject to bushfire (Stephen Douglas, Integral Energy, pers comm.). However, evidence suggests that large fires can move at great speed covering considerable distances, aided by spotting (ignition caused by mobile embers (CSIRO, 2001). This phenomenon can cause a fire to ‘jump’ a distance far greater than the width of a powerline easement.

**Figure 2.6 Illustration of the ‘wire-border zone method’, with its gradual vegetation gradient from trees at the easement border, to short vegetation under the powerlines.**

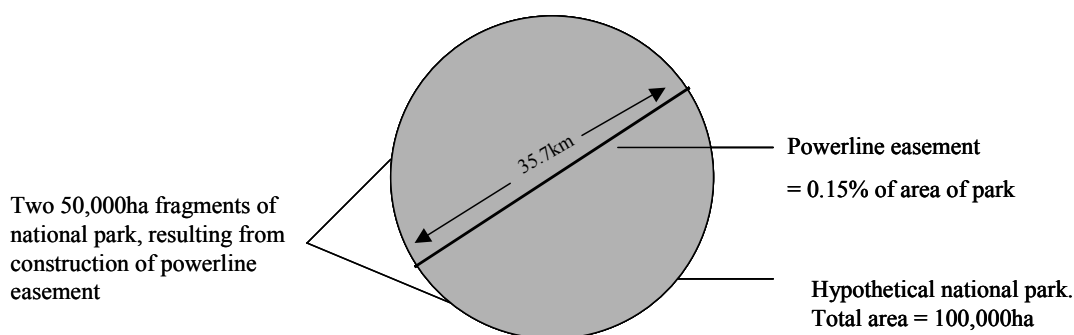
As an alternative to mowing of the entire easement, this design offers economic, aesthetic and wildlife benefits. Diagram taken from Yahner & Hutnik (2005).

Evidence suggests that habitat corridors linking isolated blocks of land can provide the connectivity necessary for population survival (Fahrig & Merriam, 1985; Collinge, 1998; Tewksbury *et al.*, 2002). Furthermore, Australian research shows that gullies between forest fragments can benefit some ground-dwelling and arboreal mammals (Soderquist & Mac Nally, 2000). More specifically, with regard to powerline easements, Goosem and Marsh (1997) described how gullies linking the two sides of a powerline easement were inhabited by rainforest-dwelling small mammals. These findings indicate that for small mammals at least, preserving natural connections between forest fragments such as gullies, or constructing artificial structural linkages, may reduce the effects of fragmentation caused by powerlines. In Chapter 5, I explore this theory, based on habitat utilisation information gathered in Chapter 4. Through physical manipulation of easement conditions at four sites, I attempt to assess the efficacy of artificial corridors in enhancing movement of animals across powerline easements.

#### **2.4.6 Conclusions**

Powerline easements may appear to affect a very small area of the total landscape. However, my study shows that ecological implications of locating of powerline easements in regions of natural habitat may be extensive. Interpreting the impact of powerline easements as a percentage of total habitat available is not necessarily meaningful. As explained in Section 2.4.2, my simulations suggest that powerline

easements could reduce the area of pristine habitat in the study region by nearly 2%, which is the equivalent to a substantial area of land (7,421ha). Furthermore, assessing the results in terms of area and percentages of total habitat available ignores the possibility that the habitat directly or indirectly affected may contain key ecological requirements such as movement corridors, food resources, and access to mates or nesting sites. For a visual representation of this, I present the following simplified example: If a powerline easement is constructed in an otherwise pristine national park of 100,000ha, the powerline itself (e.g. 40m in width, as in the case of a 132kV powerline) will measure 35.7km in length (Fig. 2.7).



**Figure 2.7 Example of the effect of a powerline easement on an otherwise pristine hypothetical national park.**

Whilst the area of the powerline is negligible, compared to the total area of the park (100,000ha), the formerly continuous park area is subdivided into two 50,000ha fragments.

The area of the easement would be, therefore, approximately 145ha, or 0.15% of the total area of the park. However, if the easement is an effective barrier, the park now consists of two separate 50,000ha fragments, neither of which may be viable for species isolated from key habitat, food or other resources as a result of the barrier. This visualisation assumes that no other forms of fragmentation (e.g. roads or forest tracks) are found in the park, which is unlikely given the extensive nature of these features in my study area, for example. In the context of climate change, with the current ranges of biota in Australia (and elsewhere) expected to shift or contract (Hughes, 2003), these factors together highlight the disparity between the direct impact of powerline easements and their wide-ranging ecological implications.

Hourdequin (2000) explained, in relation to roads, that the challenge for ecologists and policy makers lies in achieving a balance between human needs for access and mobility, and the continued existence of diverse and healthy ecosystems. Like roads, powerlines are also a necessary part of modern infrastructure, but it is important that they are recognised as a significant contributor to habitat fragmentation in natural landscapes.

The magnitude of edge effects, the focus of this chapter, is one of the main ecological consequences of powerline easements, as well as other forms of disturbance. A second and related indirect impact is the creation of a barrier effect, whereby movement behaviour of many species of fauna is inhibited. In Chapter 3, I investigate the magnitude of the barrier effect for two species of native small mammal. Over a period of two years I quantify the rate of easement crossing, and also examine typical movement patterns of the small mammals at four sites, where powerline easements occur in otherwise intact bushland. As explained in Section 2.4.2 however, this approach is the necessary preliminary phase of a more detailed spatial and ecological investigation required for a thorough assessment of habitat fragmentation caused by powerline easements.

## Chapter 3 – The Barrier Effect of Powerline Easements

### 3.1 INTRODUCTION

It is almost an article of faith among conservation biologists that dividing native habitats into discontinuous patches harms both flora and fauna (Beier & Noss, 1998). Small mammals are an important component of many ecosystems and landscapes (Pasitschniak-Arts & Messier, 1998), because they play a role in the community dynamics and energy flow of forest ecosystems (Hamilton & Cook, 1940). They are involved in ecological processes such as pollination (Goldingay *et al.*, 1991; Carthew, 1994; van Tets & Whelan, 1997; Goldingay, 2000; Wooller & Wooller, 2003), seed dispersal and predation (Brewer & Rejmanek, 1999), as well as predation on invertebrates (e.g. Haythornthwaite, 2005). They also represent a food source for larger predators. The role of these animals is, therefore, considerable and their ability to move freely through habitat is important for ecosystem function. The potential impacts of habitat fragmentation on biodiversity are numerous and complex, as outlined in Section 1.1.1. In this chapter I address the issue of isolation, or more specifically, isolation of small mammals as a result of the ‘barrier effect’ caused by powerline easements.

#### 3.1.1 Causes of the Barrier Effect

Much of the existing evidence of this phenomenon is derived from studies of road ecology. An abrupt contrast in vegetation composition and structure between two contiguous landscape elements can act as a barrier to dispersal of wildlife. For example, highways as well as minor forest roads have been found to inhibit the movement of small mammals (e.g. Oxley, 1974; Wilkins, 1982; Mader, 1984; Swihart & Slade, 1984; Merriam *et al.*, 1989; Burnett, 1992; Goosem, 2001), as well as a range of other taxa (Thurber *et al.*, 1994; Haskell, 2000; Bélisle & Cassady St. Clair, 2001; Bhattacharya *et al.*, 2003; Keller *et al.*, 2004; Marsh *et al.*, 2005).

Powerlines can also inhibit the dispersal of small mammals (Goosem & Marsh, 1997). They reported that movements of rainforest species in tropical Australia across a predominantly grassy powerline easement were almost completely inhibited. However,

the generality of this barrier effect in other habitats, and for other species, has not been explored. Given that powerlines are widespread through all plant communities and land tenures, a clearer understanding of their impacts is essential in order to devise appropriate conservation measures for all regions.

### 3.1.2 Impacts of the Barrier Effect

Dispersal is a fundamental process in natural landscapes, with profound consequences for populations (Peakall *et al.*, 2003). Patterns of extinction, recolonisation, and gene flow are influenced by dispersal (Dieckmann *et al.*, 1999). It has been reported that in some fragmented landscapes, isolated small mammal populations can lack genetic variation (Gaines *et al.*, 1997; Peakall *et al.*, 2003) as a result of reduced gene flow (Mader, 1984). A further consequence of reduced dispersal of individuals in isolated populations is greater susceptibility to extinction (Fahrig & Merriam, 1985), as a result of lower immigration rates. The severity of the barrier effect can vary depending on the composition of the barrier (McDonald & Cassady St. Clair, 2004), the habit of the species under investigation (Oxley, 1974), and degree of similarity between the barrier and the adjacent habitat (Wilkins, 1982). In order to estimate the degree of isolation of a population, it is necessary to understand the extent and direction of their movement patterns (Szacki & Liro, 1991).

### 3.1.3 Investigating the Barrier Effect

Radio tracking is a popular method of measuring home range (Harris *et al.*, 1990) and habitat selection patterns of a variety of mammal species ranging from wolves (Jedrzejewski *et al.*, 2001) to voles (Tallmon & Scott Mills, 1994). However, this technique is not always feasible, such as in very dense habitats (Anderson *et al.*, 1988), or where the study species is highly sensitive to sound and movement (e.g. Garavanta *et al.*, 2000). Radio-tracking, use of fluorescent pigment or tracking of prints or trails, though invaluable tools in detailed studies of individual animals, fail to provide the broad scale assessment of movements in a population. The mark-recapture technique reveals patterns of distance and direction of the movements of small mammals, and can also provide information on population structure (e.g. Dickman, 1982) and species composition (Szacki & Liro, 1991; Sekgororoane & Dilworth, 1995; Gentile & Fernandez, 1999; Bowman *et al.*, 2001a). Though not without its shortcomings (see

Section 3.4.1), the method does avoid invasive or harmful procedures and allows a number of sites to be studied at once. For these reasons, I implemented the mark-recapture technique to investigate the barrier effect of powerline easements. The trapping described in this chapter also provided individuals that were involved in subsequent investigations described in Chapters 4, 5 and 6.

### 3.1.4 Study Predictions and Aims

The primary objective in this part of the study was to quantify the degree of crossing of powerline easements by two species of small mammals; *Rattus fuscipes*, and *Antechinus stuartii*. I predicted low rates of crossing where easement vegetation was sparse, but increased frequency where more established vegetation provided some shelter for small mammals. This was investigated over the course of eight trapping sessions, using trapping grids at four sites, each of which featured a powerline easement.

A secondary objective of the trapping sessions was to document the abundance and diversity of small mammal species present in habitat adjacent to powerline easements in my study area. Where trap success was high, I expected that individual home ranges would be smaller and therefore predicted that distances travelled between captures would be short, and vice versa.

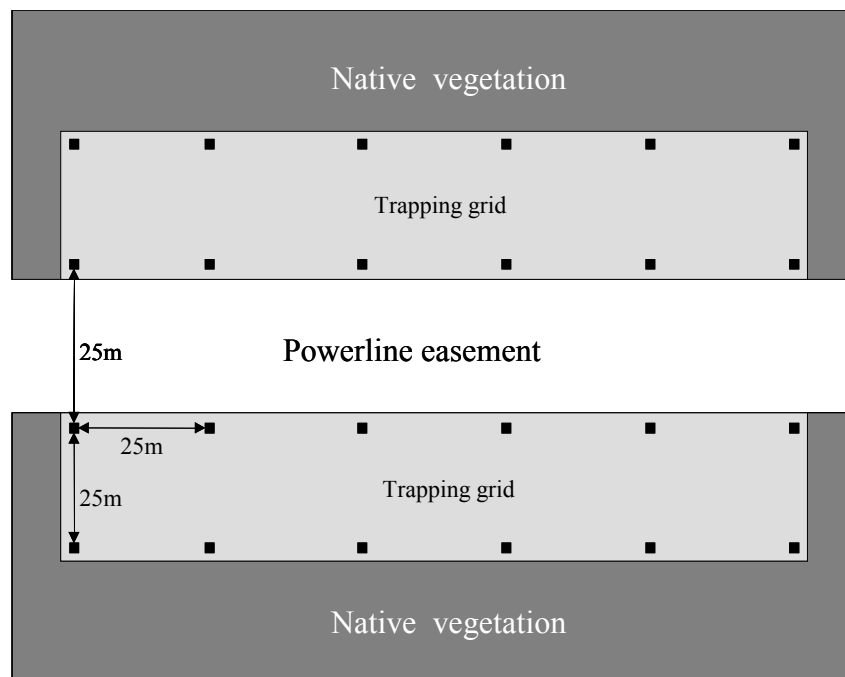
Finally, I predicted that interference competition, resulting from the presence of small mammal communities in the powerline easement, could be a possible explanation for infrequent easement crossing by these animals. To test this, I established a trapping grid in the open easement at each site with trap-spacing to mirror that in the grids in the adjacent habitat.

## 3.2 METHODS

### 3.2.1 Mark-recapture Program

#### 3.2.1.1 The Trapping Grid

I established a trapping grid (25m x 125m) on either side of the powerline (Fig 3.1). Each grid had 12 trap stations at 25m intervals, except at Jerrawangala NP where the interval between stations was 40m. The inter-trap distances were determined by the width of the easement at each site, such that the distance between two adjacent traps was the same (i.e. regular trap spacing), whether the two traps were on opposite sides of the easement or were on the same side. The 12 trap stations were divided into two parallel rows of six stations. I set up the first row immediately inside the habitat at the boundary between the forest and the powerline easement (Fig. 3.1). I set up the second row parallel to this, 25m into the forest.



**Figure 3.1 Trapping grid layout for the mark-recapture study.**

This design was repeated at the four sites: Currumbene SF, Conjola NP, Parnell NP and Jerrawangala NP. ■ = trap stations.

#### 3.2.1.2 Trapping

I positioned each trap within 2m of the predetermined trap stations (Fig. 3.1) at a suitable microhabitat location, such as alongside a fallen log, and marked the site with brightly coloured flagging tape to facilitate the location of the traps later in the study. I

scraped vegetation and leaf litter aside or flattened a small area of ground so that the trap would be flush with the ground and stable. Two Elliott Type A (33 x 10 x 10cm) live-traps were placed at each station and baited with a mixture of rolled oats, peanut butter and honey. This was done at all sites except Parnell, where just one trap was used per station owing to the exceptionally high capture rate. There were two reasons for this; at least two hours were required to process all the captured animals, and secondly, two sites were processed each morning. Although processing of animals began before sunrise, travel time between the sites and the time required to process all captures at both sites took several hours. For this reason fewer traps were deployed at Parnell to avoid the risk of animals overheating in traps as the daytime temperature rose. I added non-absorbent cotton wool to each trap for insulation, along with a generous handful of leaf litter, in order to provide bedding material. This measure has been reported to reduce stress (Tasker & Dickman, 2002) and mortality (Statham & Harden, 1982). I then placed each trap in a plastic bag, except the hinged door, to provide additional protection in wet conditions. This precaution has been taken in previous studies (e.g. Statham & Harden, 1982) to reduce mortality on cold nights.

Before trapping was commenced, I described both the ground and shrub vegetation in the easement as (i) low, (ii) medium, (iii) high or a combination of two of these measures if borderline. Traps were kept closed during the day to avoid capturing diurnal birds and reptiles, and were opened just before dusk. The following morning, at first light, I inspected all traps for captures. These times were chosen for trap opening and inspection because this study and others (e.g. Wood, 1970) found peak activities of *A. stuartii* at dusk and dawn. When I encountered a trap containing an animal, the animal was removed from the trap at the site of capture. Species, sex, reproductive status, capture site, date, weather conditions and any existing markings were noted.

I used a marking system that combined both permanent and temporary markings, as each system alone was found to be inadequate. I identified captured animals and marked each one with a unique combination of two permanent V-shaped ear notches made on either the upper or lower ear pinna (University of Wollongong Animal Ethics Committee, Permit AE03/). Ear notches removed approximately 2mm<sup>2</sup> of the pinna in the case of *A. stuartii* and 4mm<sup>2</sup> in the case of *R. fuscipes*. Dettol<sup>®</sup> antiseptic cream was applied immediately after the notching procedure. Generally, the notches could be made

without causing bleeding. In addition to this, up to 5 ‘tailbands’ were applied to the base of the tail with a permanent black marker (Fig. 3.2). These marks remained visible for the period of one trapping session. When animals were recaptured, I reapplied the tailbands to keep the markings clearly visible and released the animals at the site of capture<sup>1</sup>. Each evening, when resetting the traps, I removed and replaced the bedding in the traps that had contained animals the previous night.

**Figure 3.2 Photograph of *Antechinus stuartii*, showing four tail-bands, made with a permanent outdoors marker.**

These tailbands complemented ear notches to provide a reliable marking system.

The four nights of trapping were divided into two, two-night sessions separated by an interval of one night. Other studies of *Antechinus* spp. (e.g. Ford *et al.*, 2003) have taken similar precautions to avoid continuous trapping when trapping pregnant or lactating females, which are highly susceptible to stress if captured repeatedly. *Antechinus stuartii*, although attracted by the scent of the bait, do not eat it once inside the trap (pers. obs.). Owing to the high capture rate and the considerable distance between sites, only two sites were trapped at a time: Currumbene SF and Conjola NP in the first week, Jerrawangala NP and Jervis Bay NP in the second week. These trapping sessions were conducted in September and November of 2004 and 2005, February and April of 2005 and 2006 and June of 2006 (Appendix 2). No trapping was conducted in winter months in my study to reduce the risk of animals dying from exposure on particularly cold or

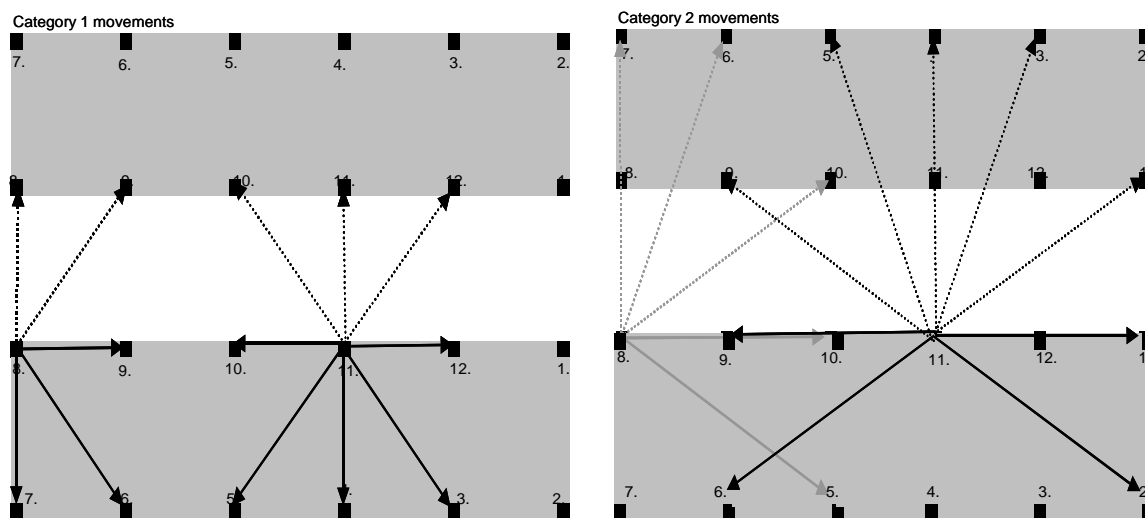
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<sup>1</sup> Animals captured in the course of this mark-recapture study were also involved in a concurrent spool-and-line study, described in Chapter 4

wet nights. All traps were cleaned thoroughly with water and a scrubbing brush before trapping at the second two sites the following week began.

### 3.2.1.3 Data Analysis

Whilst *R. fuscipes* and *A. stuartii* were the target species for this study, data from a small number of captures of *Cercartetus nanus* (eastern pygmy possum), *Sminthopsis murina* (common dunnart) and *Rattus lutreolus* (swamp rat) were included in analyses. The total number of easement-crossing events was calculated by comparing locations of captures and recaptures. Recaptures of individuals at the same trap as previous capture were not included in analyses, as they provided no information on distance and direction of travel. All other recaptures were categorised based on distance moved between recaptures. Movements to the nearest trap horizontally in the grid (25m) or diagonally (35.5m) were defined as Category 1 (Cat 1) movements (Fig. 3.3).



**Figure 3.3 Examples of possible Category 1 and Category 2 movements between traps.** Solid lines indicate ‘same side’ movements, and dotted lines movements across the powerline easement. For clarity, Category 3 movements are not included (see Appendix 3).

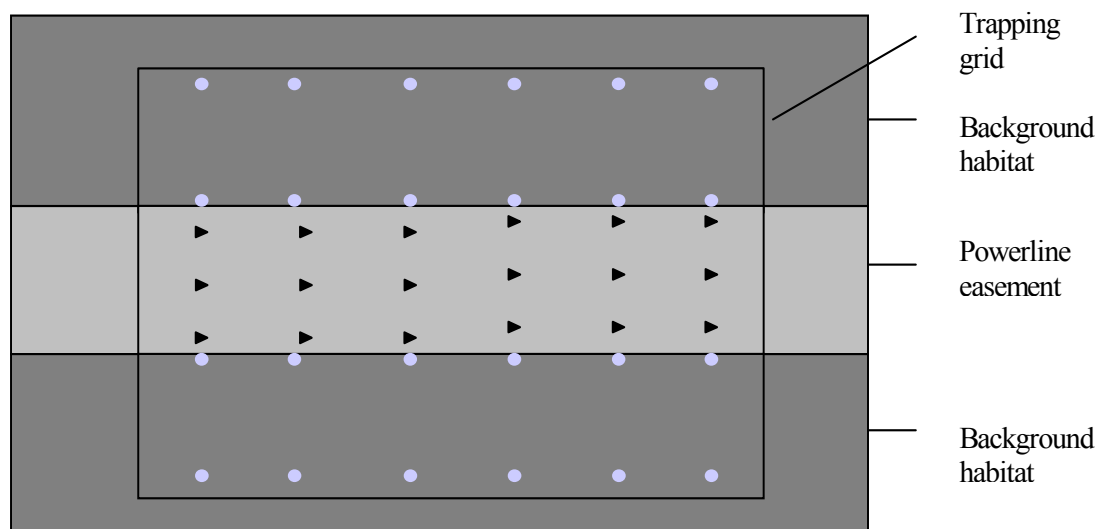
Horizontal movements to traps two stations away (50m i.e. 2\*25m) or diagonally (55.9m) were termed Category 2 (Cat 2) movements (Fig. 3.3). Finally, Category 3 movements (Cat 3) were those that measured 75-79.1m (Appendix 3). In the absence of knowledge of the exact movement paths of the study animals, these categories allowed recapture data to be statistically analysed. As the vast majority (80%) of the movements made by the animals were in Categories 1-3, statistical analyses were performed on these categories only.

For each of the 12 trap stations in a grid, the potential number of both easement-crossings and movements on the same side of the grid were calculated (see Fig. 3.3) and combined to produce an overall expected ratio of crossings with respect to same-side movements. This was completed for all three categories of movements (Appendix 4). For example, from Trap 11, there are five potential category 1 movements to traps on the same side, and three potential category 1 movements to traps on the other side of the easement. Projected movements that originated at stations in the trapping grid but ended outside of the grid were not included in calculations. A  $\chi^2$  goodness-of-fit test was used to compare observed and expected numbers of same-side and cross-easement movements. This was done firstly for category 1, category 2 and category 3 movements separately, then for all categories combined. Finally, I drew maps of all recaptures at each of the four sites.

### 3.2.2 Trapping within Easements

#### 3.2.2.1 Potential Competition Interference

Three rows of traps were established in the powerline easement (except for Parnell, where the slightly narrower easement restricted trapping to just two rows). Each row was set parallel to the easement-habitat boundary (Fig. 3.4).



**Figure 3.4** Layout of traps within the easement, relative to the trapping grid established in adjacent habitat.

Traps were positioned at each site to explore the presence of potential inter/intra specific competition as an explanation for infrequent occurrence of easement crossing by small mammals. ■ = background habitat, ■ = area within the powerline easement, ► = traps within the easement, ● = trap stations in the habitat.

Traps within each row were spaced at 25m intervals, in line with the trapping grid in the adjacent habitat. Three rows were established so that the number of captures in the two rows closer to the easement-habitat boundary could be compared with the row in the centre of the easement. Trapping within the easement was conducted at all four sites (Parnell, Currumbene, Conjola and Jerrawangala) commencing in late summer 2006 (Table 3.1).

**Table 3.1 Trap nights conducted at each trapping location investigating the presence of small mammals within the powerline easement.**

Date	Location	Trap Layout	Total # Traps	Trap Nights
February-06	Currumbene	3*6 rows	18	114
April-06	Currumbene	3*6 rows	18	132
February-06	Conjola	3*6 rows	18	132
April-06	Conjola	3*6 rows	18	132
February-06	Jerrawangala	3*6 rows	18	132
April-06	Jerrawangala	3*6 rows	18	132
February-06	Parnell	2*6 rows	12	48
April-06	Sussex	3*5 rows	15	45
<b>Total</b>				<b>867</b>

### 3.2.2.2 Effect of Dense Easement Vegetation

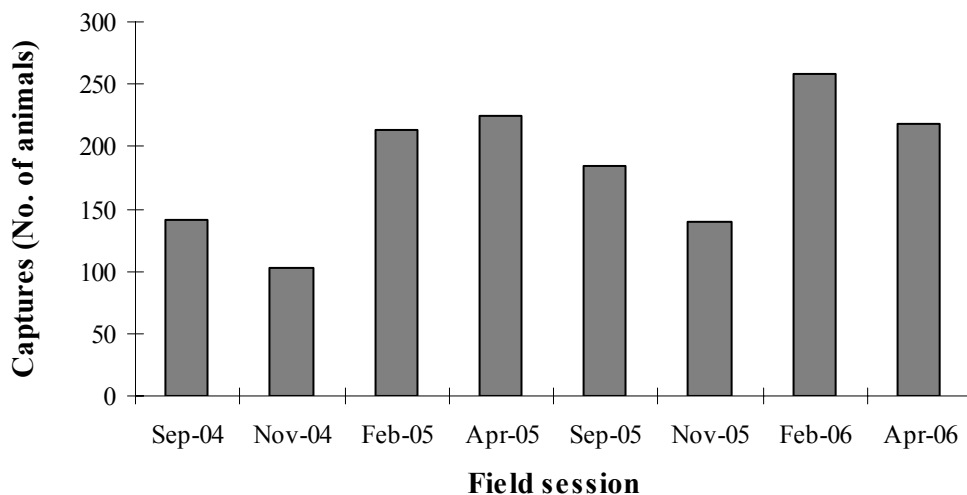
In addition to the trapping described in Section 3.2.2.1, a brief study was conducted at the Sussex Easement trapping site (Fig. 1.4). Located near to the trapping site at Conjola, but on a wider (40m) 132kV easement, this site was selected for its well-established vegetation regrowth within the easement. It therefore provided an opportunity to explore the presence of small mammals in an easement without a recent history of mowing. Five parallel rows of traps were established in the easement, and a brief period of trapping conducted (Table 3.1), following a similar trapping and animal-handling routine as described in Section 3.2.1.2.

### 3.3 RESULTS

#### 3.3.1 Mark Recapture Study

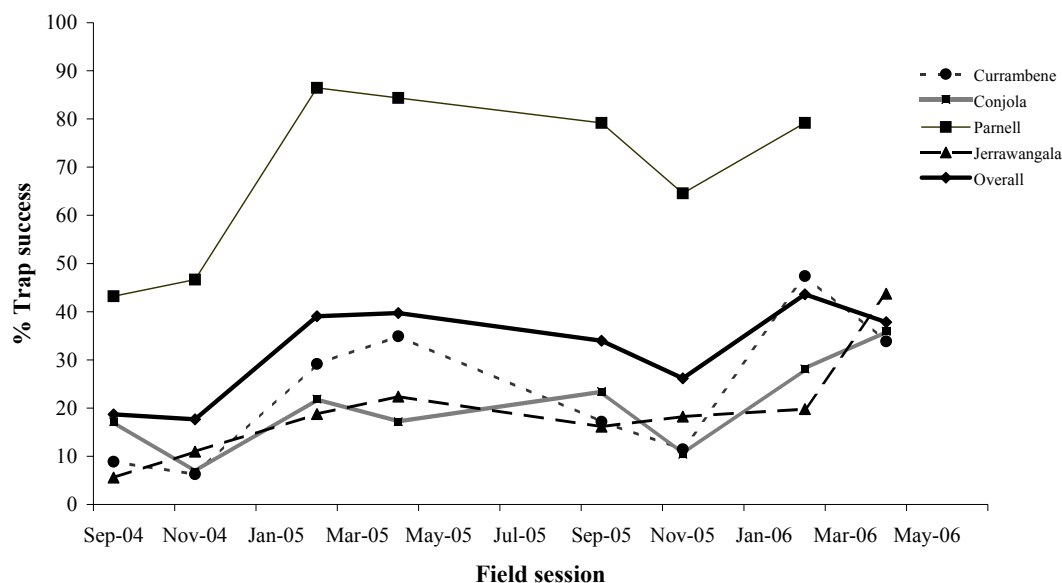
##### 3.3.1.1 Trap Success

The 5,352 trap nights in this phase of the study yielded 1,485 captures of small mammals. Total captures varied in each of the eight trapping sessions (Fig. 3.5). Trap success was maximal in the months of February and April and lowest in September and November each year. February 2006 yielded the greatest number of captures, with 259 captures made in eight nights of trapping. This contrasts with November 2005, when just 102 captures were made in the same time period with the same trap effort.



**Figure 3.5** Total number of captures of small mammals during each of eight field sessions.

The overall trap success at the four sites for the study period was 27.75%. Trap success was greatest in the months of February and April, which always recorded values of >27% (Fig. 3.5 & Fig. 3.6). The lowest trap success was recorded in November 2004 (14.9%), in contrast to a maximum of 33.3% in April 2005. Trap success between the four sites varied, with Parnell repeatedly registering the highest trap success, averaging almost 70%, more than twice as high as any other site (Fig. 3.6). Of the other three sites, Conjola and Jerrawangala had similar overall trap success of 22.4% and 22.8% respectively. At 23.6%, overall trap success at Currambene was only slightly higher.

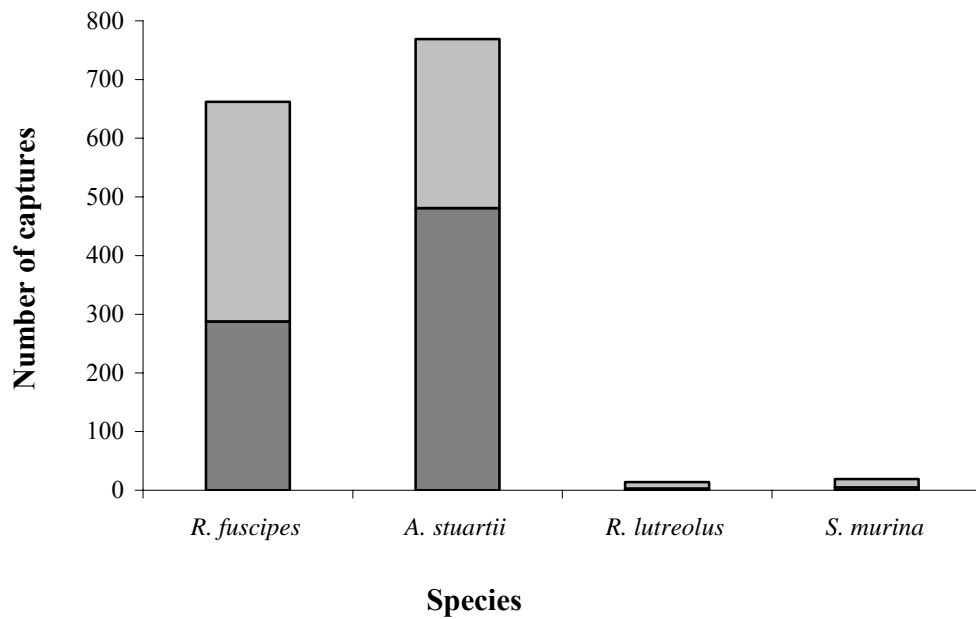


**Figure 3.6** Trap-success during trapping period from September 2004 to April 2006.

Eight two-week trapping sessions were conducted in this time resulting in 5,352 trap nights and 1,485 captures at four trapping sessions.

### 3.3.1.2 Species Captured

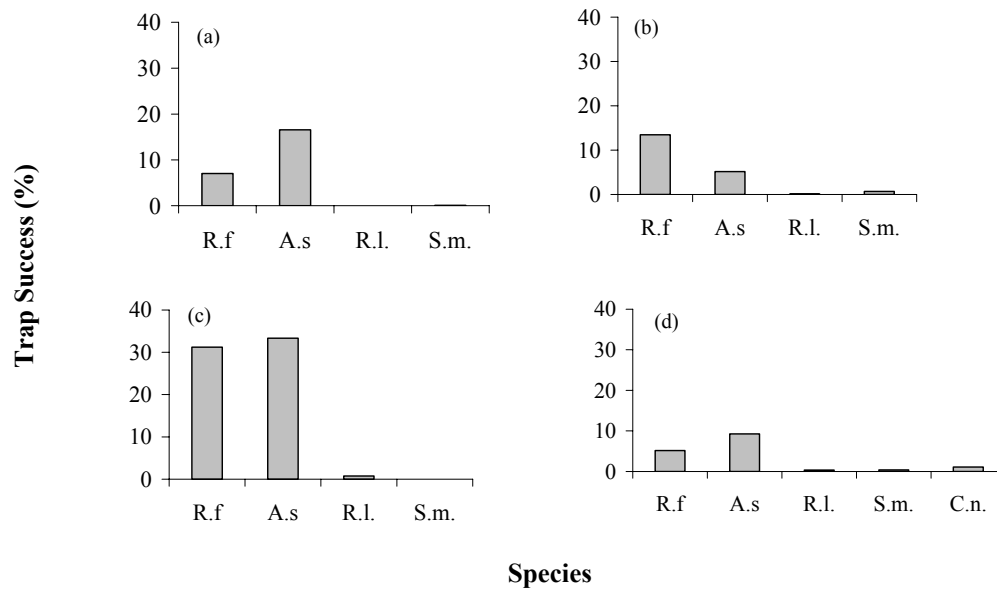
Of the 1,485 animals captured, the most common species in this study was *A. stuartii*, which was captured 769 times (Fig. 3.7), yielding an overall trap success for this species of 13.4%. Owing to the annual die-off of males after mating, only 288 (37.5%) of the *A. stuartii* captures were males, with the remaining 481 (62.5%) females. A more even sex ratio was achieved with the 662 *R. fuscipes* captured (11.5% trap success across all sites), of which 288 (43.5%) were male and 374 (56.5%) female (Fig. 3.7). Captures of *S. murina* and *R. lutreolus* were also both dominated by females. Almost 4 times as many female (11) than male (3) *R. lutreolus* were captured. Similarly, almost 3 times as many female (14) *S. murina* were captured compared to male (5). However, the total number of these species was too low for a conclusive explanation of this pattern.



**Figure 3.7 Total number of captures of each sex and species made in 5,352 trap nights in this study**

■ = female, ■ = male

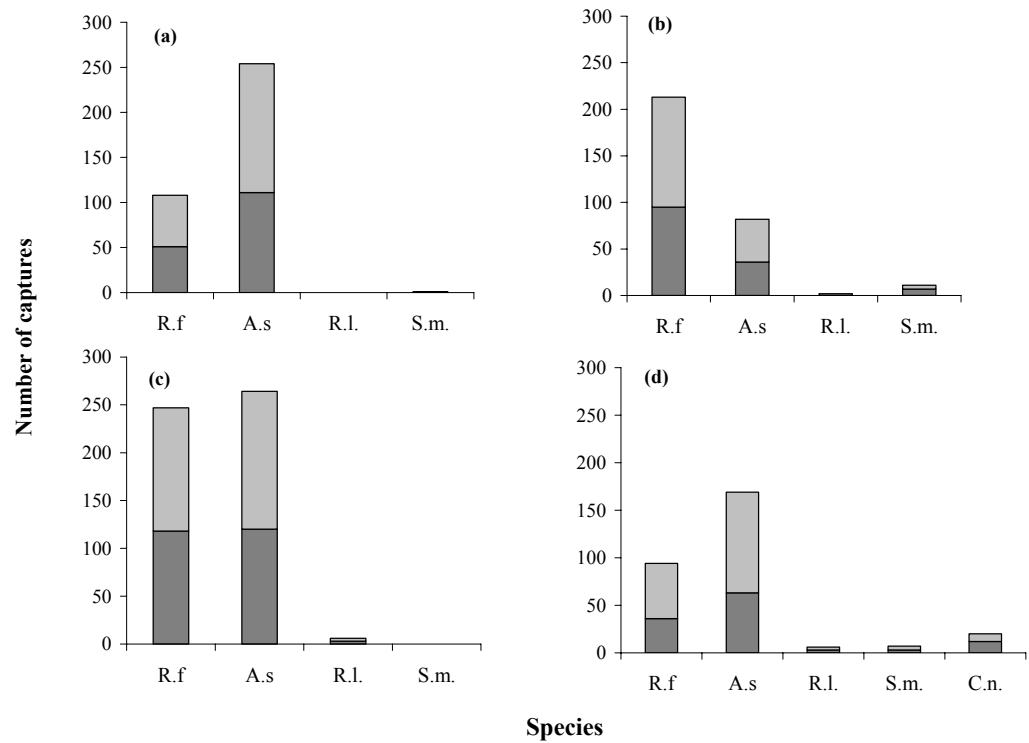
There were clear differences in the proportions of species captured at each of the sites. At Parnell NP for example, there were approximately equal numbers of *R. fuscipes* and *A. stuartii* captured, 31.2% and 33.3% respectively (Fig. 3.8). At Currumbene SF, *A. stuartii* was more than twice as abundant (16.5%) as *R. fuscipes* (7%). Conversely, at Conjola NP, there were approximately three times as many captures of *R. fuscipes* (13.7%) as for *A. stuartii* (5.5%) (Fig. 3.8). Captures of *Sminthopsis murina*, *Rattus lutreolus* and *Cercatetus nanus* were relatively infrequent or absent at all locations. Of these species, the highest trap success was of *C. nanus* at Jerrawangala NP, though even at that site captures were very infrequent (<1% trap success).



**Figure 3.8 Average trap success (%) recorded during the eight field sessions at four trapping sites (a) Currambene State Forest (b) Conjola National Park (c) 'Parnell' and (d) Jerrawangala National Park.**

R.f. = *Rattus fuscipes*, A.s. = *Antechinus stuartii*, R.l. = *Rattus lutreolus*, S.m. = *Sminthopsis murina*, C.n. = *Cercatetus nanus*. Total number of captures = 1485, total number of trap nights = 5,736.

At all of the sites, the recapture rate of both *R. fuscipes* and *A. stuartii* was approximately 50% (Fig. 3.9). An exception to this however, were the recapture rates of *A. stuartii* and *R.fuscipes* at Jerrawangala which were 65.7% and 63.3% respectively. *Sminthopsis murina* and *C. nanus* had recapture rates of less than 40%.



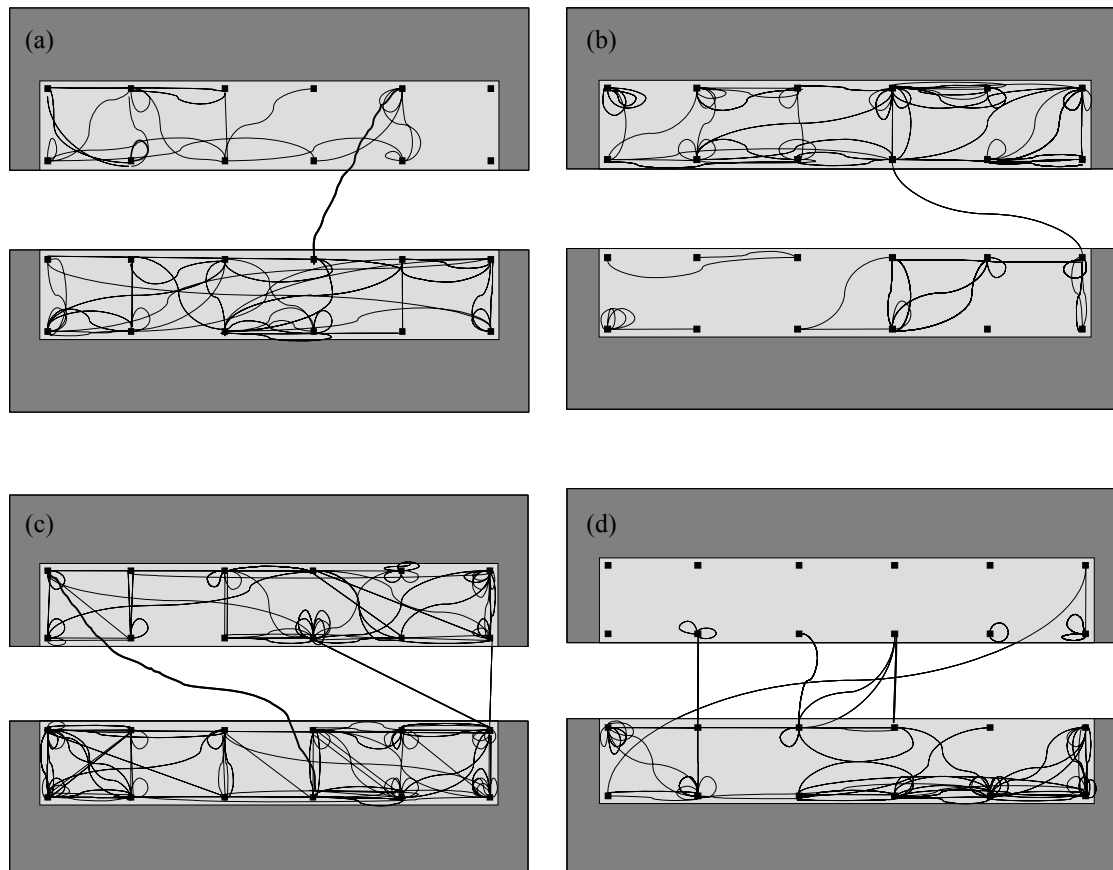
**Figure 3.9 Total number of captures of individuals and recaptures of each species of small mammal at four trapping sites**

(a) Currumbene State Forest (b) Conjola National Park (c) Parnell (Jervis Bay National Park) (d) Jerrawangala National Park. R.f. = *Rattus fuscipes*, A.s. = *Antechinus stuartii*, R.l. = *Rattus lutreolus*, S.m. = *Sminthopsis murina*. ■ = individuals, ■ = recaptures (This includes multiple captures of the same individual)

### 3.3.2 Easement Crossing

The number of easement crossings was determined by comparing the recapture location of an individual with its original trap location. There were 823 recaptures made during this study. 230 (30%) of all recaptures were made at the same trapping station as the previous capture. Assuming random movement in relation to the easement, and based on the length and direction of the movements, 330 (40%) of the 823 recaptures would be expected to have been across the easement. However, there were only 15 easement crossings across the eight field sessions at four different sites. The majority, (408 or 68%) of the recaptures were Category 1 movements (see Section 3.2.1.3). There was less than a quarter as many Category 2 movements (111) and just 33 Category 3 movements. Statistical analysis based on potential crossings of each distance category provided overwhelming grounds for rejection of the null hypothesis of no difference between the potential and actual number of easement crossing events (see Fig. 3.10). The goodness-of-fit test for Category 1 movements returned a  $\chi^2$  value of 243.12 (df = 1,  $P < 0.0001$ ). Equivalent values for Category 2 movements were  $\chi^2 = 103.15$  (df = 1,

$P < 0.0001$ ), and Category 3 were  $\chi^2 = 18.89$  ( $df = 1$ ,  $P < 0.0001$ ) respectively. These results demonstrate the infrequency with which small mammals crossed powerline easements in this study.



**Figure 3.10** Recapture pattern for *Rattus fuscipes* and *Antechinus stuartii* during the first four trapping sessions in grids established on either side of a powerline easement at (a) Conjola National Park, (b) Currumbene State Forest, (c) Jervis Bay National Park (Parnell), (d) Jerrawangala National Park.

Black lines are used to represent the distance traveled by individuals between recaptures. The 11 easement crossing events recorded at this time are also shown. Only data from the first four sessions has been shown, which is taken to be representative of the movement patterns exhibited by the animals. To avoid overcrowding the figure, data relating to the four subsequent fieldwork session is not shown. Exact path taken by animals between recaptures is not known. Sketches serve to illustrate typical movement directions observed and the proportion of easement crossings relative to other inter-trap movements.

A total of 15 easement crossings were recorded across the 4 sites during the study period (Table 3.2). No clear patterns regarding species or sex bias were observed.

Similar numbers of *R. fuscipes* and *A. stuartii* were found to have crossed the easement (6 and 8 respectively). Two of the easement crossings were made by *C. nanus* (Fig. 3.11), which, although few in number, represent 25% of all recaptures of *C. nanus*. By

contrast, just 1.66% of the recaptured *R. fuscipes* crossed the easement. The equivalent figure for *A. stuartii* was 1.6%. One *S. murina* individual crossed the easement though a second that was captured in the easement was later recaptured in the habitat adjacent to the powerline easement.

**Figure 3.11 Vulnerable species *Cercartetus nanus* captured at Jerrawangala**

This species was captured 12 times at Jerrawangala during eight trapping sessions and was observed to cross the easement twice, though only when vegetation in the easement was dense

**Table 3.2 Record of easement crossing events by *Rattus fuscipes* and *Antechinus stuartii* at four trapping sites, September 2004-July 2006**

Table only includes the crossing events that were independent of any spooling activities. Species abbreviations marked with \* indicate the recapture of the same individual as listed immediately above. Crossing #16 and #17 were recorded by Bennett (2006) after my fieldwork sessions were completed. ^Denotes easement crossing events recorded after the installation of linkages in the easements (See Chapter 5). High, medium and low refer to easement vegetation density, not height. Some animals captured in this mark-recapture study were also involved in a concurrent spool-and-line study (Chapter 4) during which traps were checked two hours after dusk. Therefore, fractional time intervals (0.5 day) were possible because traps were checked both after dark and at dawn i.e. the time interval for an animal captured first in the morning and then recaptured the next day but in the evening would be 1.5 days.

Crossing #	Fieldwork session	Location	Species	Sex	Direct distance (m)	Distance category	Time interval (days)	Easement ground vegetation density	Easement shrub vegetation density
1	Sep-04	Conjola	R.f.	M	~50m	2	2	Low	Medium
2	Nov-04	Parnell	A.s.	F	~75m	3	1	High	None
3	Feb-05	Jerrawangala	C.n.	M	~45m	2	1	High	High
4	Feb-05	Parnell	R.f.	F	~30m	1	1	High	Low-Medium
5	Feb-05	Jerrawangala	A.s.	F	~50m	2	1	High	High
6	Feb-05	Jerrawangala	As*	F	~45m	2	0.5	High	High
7	Feb-05	Jerrawangala	C.n.	M	~100m	5	5	High	High
8	Feb-05	Curumbene	A.s.	M	~50	2	2	Low-Medium	Low-Medium
9	Apr-05	Parnell	A.s.	M	~50m	2	2	High	Low-Medium
10	Apr-05	Jerrawangala	A.s.	F	~45m	2	0.5	High	High
11	Apr-05	Jerrawangala	S.m.	M	~45	2	1	High	High
12^	Sep-05	Conjola	R.f.	M	~75	3	0.5	Low	Low
13^	Sep-05	Conjola	R.f.*	M	~75	3	1	Low	Low
14^	Nov-05	Parnell	R.f.	F	~30	1	4.5	High	Medium-High
15^	Feb-06	Conjola	R.f.	M	~75	3	2.5	Low	Medium
16*^	Jul-06	Conjola	A.s.	M	~75	3	9*	Low	Medium
17*^	Jul-06	Curumbene	A.s.	M	~75	3	2	Low	Low

Ten of the 15 crossings occurred when there was a thick cover of ground vegetation. Eleven were made when shrub vegetation cover was at least in the medium density category. Six crossings occurred when both ground and shrub vegetation were maximal, only two crossings were recorded for conditions with minimal levels of these features.

Though males are traditionally perceived as the dispersers in the population, in this study almost equal numbers of males and females were recorded to have crossed the easement (nine and seven respectively). Similarly, at the species level, there was no apparent trend for sex-biased easement crossings, i.e. two of the six *R. fuscipes* that crossed were females, while four of the seven *A. stuartii* that crossed were female. However, such low numbers made statistical interpretation of results impossible.

Easement crossings were most frequent at Jerrawangala (6) and least common at Currambene (1). Equal numbers of easement crossings were recorded for both Parnell and Conjola (4). It is worth noting that the six crossings recorded for Jerrawangala occurred when vegetation cover in the easement was maximal.

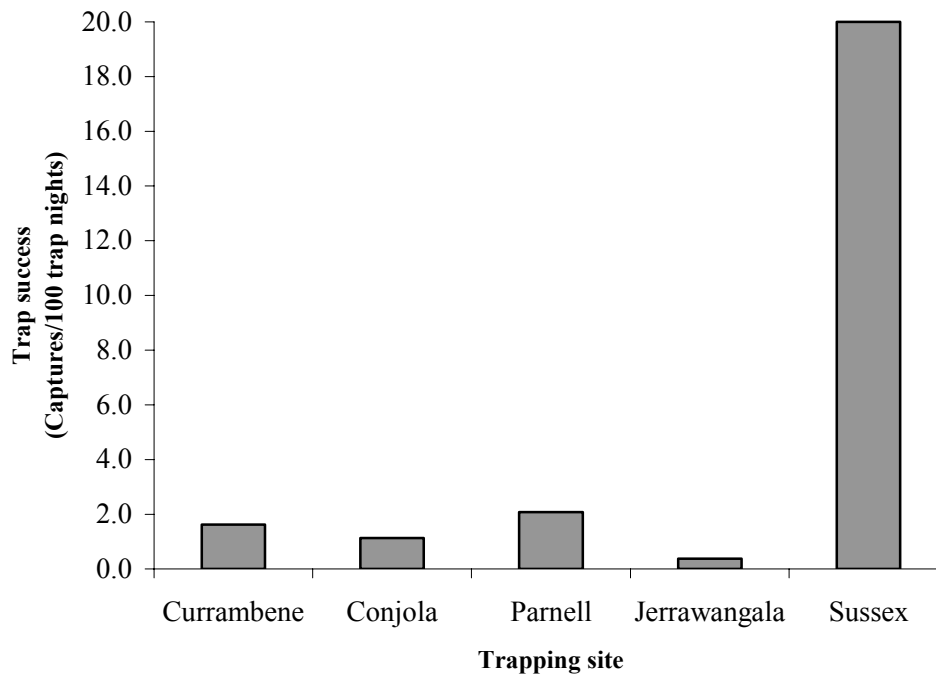
Half (6) of the crossings occurred in late summer, (February), with a similar number of crossings (2-3) recorded in the other three trapping periods, April, September and November. February was also a month when trap success was at its maximum (Section 3.3.1.1)

A study conducted at the same sites shortly after my fieldwork concluded, recorded two further easement crossing events (Table 3.2) during a total of 816 trap nights (Bennett, 2006). Combined with this study, the entire investigation of easement crossing yielded 17 crossing events and 823 recaptures in a total of 6,552 trap nights.

### 3.3.3 Easement Captures

The 867 trap nights in this phase of the study resulted in a total of 25 captures within easements (Appendix 5), 18 of which were different individuals. This corresponds to an

overall trap success of 2.88%. However, at individual sites, trap success varied greatly (Fig. 3.12).

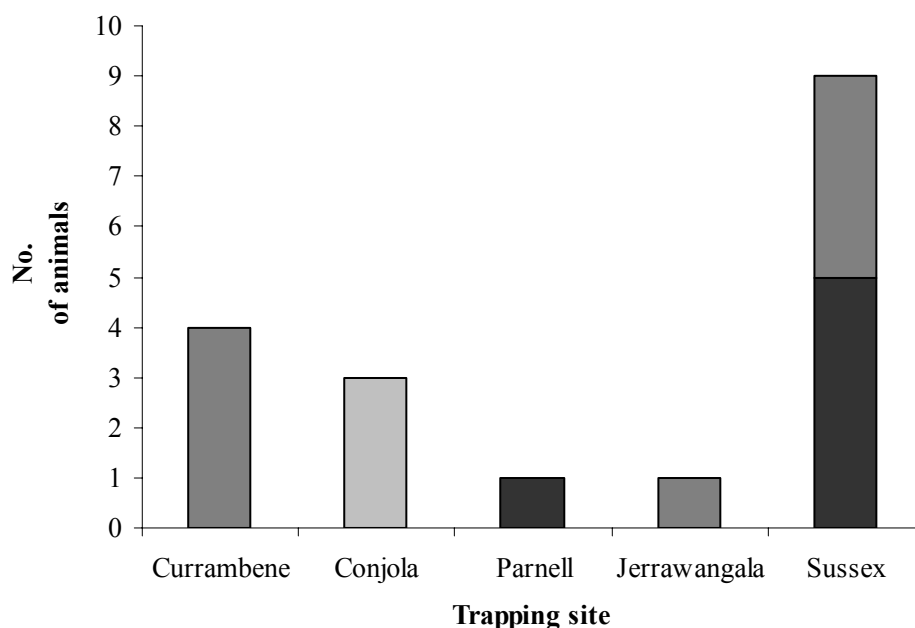


**Figure 3.12 Percent (%) trap success (Number of captures per 100 trap nights) within the powerline easement at each trapping site.**

The greatest number of captures (15) in this phase of the study was made at Sussex easement, where trap success in the easement was almost ten times that of any of the other sites. This was also the site that had the most dense vegetation cover at the time of trapping (Fig. 3.13)

**Figure 3.13 Dense vegetation cover present in Sussex Easement, the site where most in-easement captures were recorded in the study.**

Insufficient captures were made at the other sites to reach any confident conclusions about the small mammal species that occupy powerline easements. Relative to the total number of *S. murina* captured in the study (19), this species was more likely to be captured in the easement than any other species. However, this result is to be treated with caution because this species was only captured in the easement in Conjola. 15% of all *S. murina* in this study were captured in the easement, compared to 1.81% and 1.3% for *R. fuscipes* and *A. stuartii* respectively. Species of small mammal captured at each of the sites varied (Fig. 3.14). No species was consistently captured in the easement at all of the five sites, though *R. fuscipes* was captured in the easement at three of the five sites and *A. stuartii* at two of the five.



**Figure 3.14 Total number of individuals captured within the easement at each trapping site.**

■ = *R. fuscipes*, ■ = *A. stuartii*, ■ = *S. murina*

### 3.4 DISCUSSION

#### 3.4.1 Small Mammal Abundance

The high overall trap success of small mammals recorded in this study (25%) was indicative of healthy populations. One factor that may explain this is the regular implementation of 1080 poison baiting by National Park and State Forest authorities directed at *Vulpes vulpes*, the red fox, which is present in the Jervis Bay area (Dexter & Meek, 1998; Meek & Saunders, 2000), and throughout southeastern Australia. Elsewhere on the South Coast of New South Wales trap success has been in the region of 8-10% (e.g. Goldingay & Whelan, 1997). Interspecific competition can cause an inverse correlation in abundance between two species occupying the same macrohabitat (Songer *et al.*, 1997). There was some suggestion of this at Currambene where *A. stuartii* was more than twice as numerous as *R. fuscipes* and the reverse was true at Conjola. However, the numbers of these species were almost equal at Parnell and not substantially different at Jerrawangala

The abundance of native species is in some respects surprising given the extent of habitat fragmentation in the region. The Jervis Bay area features several National Parks including Jervis Bay National Park, Booderee National Park, Jerrawangala National Park and a collection of State Forests and smaller reserves and is also a popular tourist destination. The area is therefore characterised by high seasonal and permanent human populations. Furthermore, it features a dense network of roads, including the main arterial road on the South Coast of Australia, the Princes Highway. Currambene was considered the most disturbed site. This is because the northern side of this site was within 200m of a road and, though unsealed and with relatively low traffic volume, was, during daytime, within audible range of heavy trucks in transit to and from a nearby quarry. Horseback and dirtbike riders also frequently used this site (pers. obs). Considering the anthropogenic disturbance in the area, what was also surprising was the absence from the trapping grids of exotic rodents (with the exception of occasional captures of *M. musculus* at Conjola and Jerrawangala).

### 3.4.2 The Barrier Effect

Very occasionally at all sites animals were recaptured at the opposite end of the trapping grid (approximately 125m away) from the previous capture. Also, there was a total of 33 Category 3 movements (55.9-79m). The distance covered in these movements demonstrates that the animals are physically capable of travelling the required distance to cross the easement but, instead, chose to move parallel to the easement. In a study by King (1978), conducted not far from this study area, *A. stuartii* was found to travel more than 500m. Wilson (1986) reported movements by this species of up to 450m. Generally in this study individuals were recaptured either at the same trap as on the previous occasion, or within 50m of it. Szaki & Liro (1991) considered that individuals may become accustomed to traps and thus be soon recaptured at the same location. Tasker and Dickman (2002) described how dirty or scented traps may capture animals in greater numbers more quickly. This supports the findings of Boonstra & Krebs (1976), who reported that voles entered dirty traps significantly more frequently than clean traps. Trapping by Drickamer (1984) also revealed a strong heterosexual odour preference in deermice. Cunningham *et al.* (2005) similarly reported a greater probability of trapping a male *R. fuscipes* if a conspecific had been captured at that trap the previous night. Additionally, they reported that the capture of *A. stuartii* had a similar effect on *R. fuscipes*. However, dirty traps are also known in some cases to deter

animals from entering traps (Stoddart, 1982) and in other cases to have no apparent effect (Monamy, 1996). In my study, excessively dirty traps were cleaned between recaptures to minimise the impact of odour on subsequent captures. Furthermore, all traps were thoroughly scrubbed before re-use at the same or other trapping sites. The failings of this technique are acknowledged, but in the absence of any definitive evidence of the impact of odour on small mammals, recapture data were used in their entirety. Towards the end of each trapping session, the capture of new individuals became infrequent, suggesting that the majority of the trappable population had been captured at least once. Furthermore, some individuals were recaptured numerous times (maximum of six). These observations may reveal a tendency by animals to revisit a location associated with food or refuge or, alternatively, may be a reflection of small home range. It is possible that abundant food supplies within the immediate habitat may reduce the impetus for dispersal (Garavanta *et al.*, 2000), which would explain the infrequent movements between opposing sides of the easement.

Typically males to move longer distances than females e.g. Price *et al.* (1994); Lunney & Leary (1988), and are associated with dispersal movements (e.g. Diffendorfer & Slade, 2002), though many other studies of small mammals have detected no difference between males and females (Wood, 1970; Laidlaw *et al.*, 1996; Bowman *et al.*, 2001a; Morris & Diffendorfer, 2004). I found no difference in distances moved by males and females either in respect of captures or with regard to easement-crossings.

A large number of studies have used the linear distance between recaptures of small mammals to describe movement patterns (e.g. Wood, 1970; Szacki & Liro, 1991; Price *et al.*, 1994; Laidlaw *et al.*, 1996; Diffendorfer & Slade, 2002). This measure is widely used where the recording of precise individual movement distance is neither practical nor possible. The principal disadvantage of the technique is that it only provides a value for the minimum possible linear distance from previous capture. The results from mark-recapture studies are, nonetheless, accepted as approximations of movement distance and are supported by results from studies such as by Laidlaw *et al.* (1996) which found no significant difference in distance estimates derived from radio-tracking points and those from trapping distances.

Bowman *et al.* (2001a) explained that trapping grids are frequently too small to detect long-distance movements ( $>125\text{m}$ ). Indeed, it is possible that animals in my study travelled distances of that length and more, but could not be recaptured because of the limited size of the trapping grid. However, such extensive movements in this study were thought to be rare, given that the vast majority of recaptures (77.5%) were made at the same trap or the nearest to it in the grid. This is consistent with the findings of Bowman *et al.* (2001a), who also recorded fewer longer distance movements than shorter movements.

### 3.4.3 Exploring the Barrier Effect

Diffendorfer (1999) observed that when patches of habitat are smaller than home ranges, individuals must move between patches to satisfy daily foraging needs. Owing to the infrequency of easement-crossing events recorded in the study and to the very low trap success in the easements, movements by small mammals across the easements are not likely to be regular transits through a home range. There are a number of possible driving forces behind movements such as the crossing of powerline easements, one of which is dispersal. Dispersal is a key process in the life history of many organisms but the cues to which dispersing animals respond are poorly understood (Haughland & Larsen, 2004). The size, shape and distance between patches may all influence dispersal between patches, as does the local population density (Diffendorfer *et al.*, 1999).

#### 3.4.3.1 Philopatry

Philopatry may explain the infrequent easement crossings observed as small mammals have been shown to exhibit strong attraction to their home range (Schreiber & Graves, 1977). Without continuous, longer-term data regarding the movements of the animals in my study, it is difficult to predict if the easement crossings were transits between habitat patches within a home range, true dispersal events, or short-term exploratory movements. The lack of seasonal or sex bias to the few crossings recorded suggests that they may not be true dispersal events. Some authors have contended that, in the case of fine-grained mosaics and high mobility of animals, every home range may incorporate many habitat types of varying quality (e.g. Szacki & Liro, 1991). Thus movements across easements may not be connected to dispersal but, rather, represent transit of animals through different habitats. Perhaps the high population densities observed in my

study are the driving force behind the easement-crossing events observed and that, in spite of the rich supply of resources, individuals are forced to seek home ranges elsewhere due to high population density. Small mammal ecology literature reports positive, negative and neutral effects of population density on dispersal so this question remains unanswered (Diffendorfer *et al.*, 1999).

#### 3.4.3.2 Competition with Easement Specialists

Regular mowing of the regrowth vegetation maintains a short, grassy habitat in a powerline easement. Previous studies have reported regular captures of grassland species of small mammal in powerline easements that were not detected in adjacent habitat (Johnson *et al.*, 1979; Goosem & Marsh, 1997). It has also been suggested that as a landscape becomes increasingly fragmented, populations are increasingly vulnerable to invasion of species from anthropogenic habitats (Janzen, 1983). In the case of southeastern Australia this would include exotic rodent species such as *Rattus norvegicus*, the brown rat (or ship rat), *Rattus rattus*, the black rat and *Mus musculus*, the house mouse. These generalist species may be capable of occupying the powerline easements. I therefore sought to explore competition interference exclusion as an explanation for the rarity of easement crossing events by native small mammals recorded in my study. I detected populations of exotic species in the powerline easements (*Mus musculus*, the house mouse) at two of my four sites (Conjola and Jerrawangala). However, these captures in the easement were matched by occasional, irregular captures in adjacent habitat. No exotic rats were captured in the duration of the study. The grassland mammal species detected in the powerline easements in Tropical North Queensland, where Goosem and Marsh (1997) conducted their study, are not found in coastal south eastern New South Wales, where my study was carried out, nor are there species with comparable habitat preferences. Of the frequently captured small mammals in my study region, only *S. murina* is known to prefer open habitats (Menkhorst & Knight, 2004), and a high proportion of the captures of this species were, indeed, in the powerline easement. However, the total number of easement captures was very low (3), and these captures were all made at the same site, Conjola. These observations did not support the theory of competitive exclusion, caused by native or exotic species, as a possible explanation for the barrier effect indicated in this study.

### 3.4.4 Vegetation Structure

The impacts of vegetation on the habitat use patterns of small mammals have been extensively researched and documented e.g. (Barnett *et al.*, 1978; Fox & Fox, 1981; Catling, 1986; Goodyear, 1989; Bennett, 1993; Stevens & Husband, 1998; Gentile & Fernandez, 1999; Monamy & Fox, 1999; Sutherland & Predavec, 1999; Bowman *et al.*, 2001b; Lindenmayer *et al.*, 2001; Stokes *et al.*, 2004; Wells *et al.*, 2004; Monamy & Fox, 2005). Interactions between physical and floristic composition of the habitat and ecological processes such as predation, foraging, competition and dispersal are highly variable and species specific. Accounts of the basic ecology and habitat use patterns of all small mammals in my study describe an affinity for physical structure and complexity (e.g. Wood, 1970; Wood, 1971; Barnett *et al.*, 1978; Dickman, 1982; Statham & Harden, 1982; Robinson, 1987; Lazenby-Cohen & Cockburn, 1991; Lindenmayer *et al.*, 1994). Johnson *et al.* (1979) maintained that increased levels of cover and density offered by low-growing vegetation in a right-of-way provided small mammals with protective runways and nesting sites. In a previous study of small mammals in a powerline easement on the south coast of New South Wales, captures inside a powerline easement were only made in one easement where a dense stand of vegetation was established (Goldingay & Whelan, 1997). Research based in the USA reported that richness of forest-dwelling species of small mammal was lower in clearcuts than in other, less highly modified, regions of the landscape (Lomolino & Perault, 2000). Additionally, recent research by Clarke *et al.* (2006) reported that unlike early-seral-stage vegetation, mid-seral-stage vegetation in powerline easements provided habitat for native species that were rare in adjacent forests. All of the easements in my study were mowed at least once at different times in the course of my fieldwork, with the result that at a given point in time the density of regrowing vegetation varied from site to site. The majority of easement crossing events in my study, though few in total number, occurred when vegetation in the easement was medium or high at the time of trapping. However, my study has also shown that even in locations where thick vegetation is present in the easement, these species cross powerline easements infrequently. Therefore, lack of vegetation *per se* fails to explain the inhibition observed.

The contrast in structure and composition between vegetation communities on either side of a habitat boundary is thought to influence the extent of the edge effect (Harper *et al.*, 2005b). As described by Forman (1995) management techniques can lead to the generation of ‘hard edges’. Hard edges are a result of contrast between early-successional vegetation, which is low in structural complexity, and the surrounding matrix. Perhaps, the lack of a steady biotic and abiotic gradient between the habitat and the powerline has an inhibitory effect on small mammals. Studies of dispersal in some small mammals has shown that individuals originating in more closed-canopy forest did not venture to explore more open forest with lower tree densities, though the converse was true for individuals from open forest habitat (Haughland & Larsen, 2004). This may apply to the animals in this study that did not enter the open conditions of the powerline easement.

**Figure 3.15 Example of structural contrast between mowed powerline easement and adjacent habitat**

This photograph was taken in September 2005 at Jerrawangala trapping site, which features a 132kV powerline

At all of my study sites, with the exception of Parnell, the ground vegetation in the easement remained very sparse, even several months after mowing. At this stage isolated patches of shrub such as acacia and eucalyptus regrowth were approaching 1m or more in height. Such poor growth of ground vegetation may be explained by stony,

infertile soil, which was a feature of my sites. Exposure to high light and wind intensity may further limit establishment of a denser layer of ground vegetation. Chemical analysis of soils from eucalypt woodlands has shown that under-canopy soils have higher nutrient levels than outside canopy soils (Jackson & Ash, 2001). This may further explain the sparse ground vegetation observed in powerline easements in my study.

At a broad level, easement vegetation had little effect on the number of easement crossings. When easement vegetation was medium, or high (Table 3.2), the number of crossing events was very still low, compared to the potential number of crossings. However at a finer scale, the majority of crossings were across easements with medium or high levels of vegetation cover. The small number of crossings at all four sites made it impossible to statistically associate likelihood of crossing with particular combinations of shrub and ground level vegetation.

### **3.4.5 Microclimate Effect**

In July 2006 Bennett conducted a related study of the ecological effects of powerline easements (Bennett, 2006). The study explored the possibility that microclimate differences between the easement and the habitat might explain the scarcity of easement crossings. In her investigation, miniature temperature loggers (Tinytalk Miniature Temperature Loggers) were installed at three sites used in my study; Conjola National Park, Currumbene State Forest and Jerrawangala National Park. The loggers were placed in 3 locations within each easement; the linkage (corridor of logs and branches established later in my study that linked the opposite sides of the powerline easement, see Chapter 5), the open easement and the habitat adjacent to the easement. For a period of almost two days, they recorded the temperature fluctuations at these regions at five-minute intervals.

The results illustrated that all three regions follow the same daily temperature change pattern (Fig. 3.16). The only slight deviation from this was from noon to early afternoon, when the average temperature in the open easement was approximately 5°C than the habitat, and approximately 2.4°C warmer than in the linkages. This may be because of the shade provided by the canopy in the habitat. Alternatively it may be

because in the habitat, and to a lesser extent the linkages, the warm air does not circulate widely owing to the presence of denser vegetation, radiant heat is therefore greater in the open habitat. Since the study species are nocturnal or nocturnal-crepuscular, this observation is unlikely to explain the infrequency with which they venture into the easement.

Microclimate at the edges of forest fragments can vary with respect to air temperature and light intensity (Murcia, 1995). Few studies have addressed the variation in microclimate specifically caused by powerline easements. Pohlman *et al.* (2007) found that in the dry season understorey near powerline edges was warmer and drier than the forest interior at her rainforest study sites. There are few other studies that report the abiotic changes associated with powerline easements, and therefore the impact on fauna is also poorly documented. The two principal species in my study have a widespread geographical distribution (Menkhorst & Knight, 2004), and occupy a range of habitats in terms of structural and floristic composition. It is therefore unlikely that the reported contrasts in abiotic factors such as temperature (Bennett, 2006) or soil moisture (Pohlman *et al.*, 2007) between powerline easements and forest consistently explain the low incidence of easement crossing recorded at all four trapping sites in this study.

**Figure 3.16 Plot of daily temperature fluctuation recorded at three regions of the powerline easement at Conjola National Park.**  
Taken from Bennett (2006).

Recently exposed trees at edges lack the lateral crown spread typical of natural edge specimens, and thus permits deep penetration of atmospheric conditions (Matlack, 1993). However, at the edges of newly created forest, trees can respond to increased light intensity through development of the lateral canopy (Mourelle *et al.*, 2001). This suggests that atmospheric edge effects at newly created powerline easements may become somewhat attenuated over time.

### 3.4.6 Behaviour

Several researchers have reported a barrier effect in spite of the presence of corridors and habitat connections that presented the small mammals with the potential to cross barriers (Schreiber & Graves, 1977; Burnett, 1992). Burnett attributes this to psychological and sociological factors rather than the physical barrier itself, explaining that small mammals have a tendency to align their home ranges with physical or environmental barriers. In the case of *A. stuartii*, Wood (1970) attributed low dispersal rates to strong site attachment by the animals. Goosem and Marsh (1997) argued that social and psychological factors still fail to explain either the low rates of dispersal across powerline easements or the poor response to inducement experiments. Schreiber and Graves (1977) suggested that movement inhibition is species-specific. With a small sample size for all species in this study, applicability of this to my study could not be explored statistically.

### 3.4.7 Risk of Predation

Fear of predation can cause some small mammals to seek more dense microhabitats (Bennett, 1993). In these regions habitat structure may be used to reduce the risk of predation (Stokes *et al.*, 2004) as vegetation provides small mammals with shelter (Spencer *et al.*, 2005). The reverse may therefore also be true, namely that the absence of vegetation (e.g. in a mowed powerline easement) may act as a deterrent to small mammals, because of inadequate shelter from predators. Diffendorfer (1999) postulates fear of predation as a possible explanation for reduced movement between patches in his investigation. Behaviour of prey species is complex however, and is likely to be subject to the influences of a range of factors including habitat configuration, risk of predation, availability of resources (Brinkerhoff *et al.*, 2005) and perceptual range (Zollner & Lima, 2005).

Potential predators of small mammals present in on the South Coast of New South Wales include owls (Family Strigiformes) and *Podargus strigoides*, the tawny frogmouth, (Family Podargidae) (Moorcombe, 2000), and also introduced carnivores, *Felis catus*, the domestic cat and *Vulpes vulpes*, the red fox (Dexter & Meek, 1998). Isolated reports of the native carnivore, *Dasyurus maculatus*, the spotted quoll, also exist (DEC, 2006). Furthermore, whilst foxes will forage and move through dense vegetation, they are believed to favour roads and tracks for transit through bushland (Meek & Saunders, 2000). Other studies actually confirm sightings of foxes in powerline easements (Goldingay & Whelan, 1997). I did not sight any foxes during the course of this study but I did observe pawprints at Jerrawangala and Parnell despite fox baiting programs in operation at both locations aimed at controlling the numbers of this feral predator. Owls sightings were frequent, as was the number of occasions on which these birds were heard calling at night.

Studies have shown that rodents will alter their foraging behaviour in response to direct cues of predation risk (Orrock *et al.*, 2004; Brinkerhoff *et al.*, 2005), though Brinkerhoff *et al.* (2005) note that the perception of predation risk may not reflect the actual rate of predation. The exposed nature of the open easement suggests that predation on small mammals in this region would be elevated, though powerline easements are a little-studied habitat and research has not confirmed this assumption. However, existing literature does suggest that predation rates can be elevated at edges (Andrén & Angelstam, 1988), which are a feature of easements, and also that perceived predation risk is higher in clearcuts (areas where vegetation has been cleared) (Bakker & Van Vuren, 2004).

### **3.4.8 Potential Impacts of the Barrier Effect**

#### *3.4.8.1 Demographic Impacts*

The powerline easements in this study appeared to inhibit the movement of small mammals. In the absence of an accompanying genetic evaluation of populations on either side of the powerline easement, the true magnitude of the barrier effect is not known. Whilst records of easement crossing events in this study are few, they demonstrate that the powerline easement is somewhat permeable. Furthermore,

although many trap nights were conducted (5,736), this was over a period of two years. Some easement crossings occurred in the timeframe of my two-week trapping sessions, so it is likely that further such movements occurred outside of the trapping period.

#### 3.4.8.2 Genetic Impacts

Genetic analysis has shown that in cases of extreme habitat fragmentation, small mammal populations become depauperate of genetic variation (Gaines *et al.*, 1997). It has also been suggested that very few immigrants into the population are required to provide genetic variation and prevent the process of genetic drift (Mills & Allendorf, 1996). Kozakiewicz (1993) has also described how even low-frequency exploratory movements of animals can be very important for gene flow. However, some authors have explained that the impact on genetic diversity is related to the degree of habitat fragmentation. For example, Marsh *et al.* (2005) estimated that a 50% reduction in dispersal is unlikely to effect genetic diversity. With more fragmentation, dispersal is greatly reduced, and is likely to have much stronger effects. Similarly for birds, Bélisle & Cassady St. Clair (2001) concluded gaps that thwart movement may have a cumulative effect at the landscape scale. Couvet (2002) also described how low population size in a fragmented landscape, together with infrequent migration, raises the likelihood of detrimental genetic effects on population survival. Such a phenomenon may be very relevant for populations in my study given the highly fragmented character of the landscape in which my study was conducted (see also Section 7.4).

#### 3.4.9 Powerline Easement Vegetation Management

An argument supporting the establishment of limited vegetation in powerline easements arises from an observation made by Lima and Dill (1990) that structural complexity afforded by denser microhabitats hinders the efficiency of pursuit predators. More recently, Short (2004) explained that mammal populations in mesic woodland, forest and coastal scrub are probably protected from extensive predation by cats by the presence of the dense vegetation in these habitats. My study also provides some evidence that easement crossing occurs more readily in dense vegetation. These arguments, together with the observation by Meek and Saunders (2000), that foxes prefer to move along roads and pathways, strengthens the case for permitting the

establishment of a shrub layer in powerline easements. While Integrated Vegetation Management, IVM, is a growing area of study in the United States (Johnstone, 1990; Wagner, 1994), similar research into vegetation management policies applied to powerline easements in Australia has not yet been undertaken despite the threatened status of many Australian mammal species and potential conservation applications of such research. IVM research in Canada is also relevant for powerline management in Australia. For example, Wells *et al.* (2002) noted that optimising treatment cycle lengths and clearing only what is necessary establishes compatible plant communities in the easements. Research by Brown (1995) also showed that growth of some crops in rights-of-way (easements) can alter plant community composition in the early stages of development, and may inhibit the establishment of trees. Furthermore, Johnstone (1990) found that a shift from traditional regular mechanical mowing of powerline easements, towards more selective mowing and spraying resulted not only in improved wildlife habitat but also enhanced aesthetics, accessibility and environmental protection. The effects of contrasting chemical and physical management techniques on Australian vegetation and native fauna have not yet been explored (but see Clarke *et al.* (2006)).

For access and practical reasons, powerline operators do not mow in gullies, i.e. where the topography dips for a short period before returning to previous height. Unlogged gullies have been shown to provide both arboreal mammals (Lunney, 1987) and ground dwelling small mammal species with valuable habitat (Goosem & Marsh, 1997; Soderquist & Mac Nally, 2000). Areas with level topography or with more gently sloping undulations will lack such habitat connections. Therefore gullies alone, cannot be relied upon to eliminate the barrier effect for mammals in fragmented landscapes

Discussions with employees of the two main power companies (Integral Energy and Transgrid) on the South Coast of New South Wales revealed reluctance on the part of the operators to modify the current vegetation management policy. Regular clear-cut mowing of easements is seen as the conventional and optimal strategy with regard to maintaining powerline access and preventing the spread of bushfire (Steve Douglas, Integral Energy, pers. comm.). Until a more cost effective alternative is proposed, there is little motivation for change. This realisation drove me to explore manmade connections across powerline easements as a possible solution to the barrier effect so

evident in this part of the study. My study species are physically capable of moving distances far greater than the width of the easement but are clearly inhibited by one or more factors. As a first investigatory step I needed to understand how small mammals in this study used the features in their habitat. To achieve this, I tracked *R. fuscipes* and *A. stuartii* using the spool-and-line technique, recording the habitat features they utilised. This process, and the subsequent analyses are described in Chapter 4. In Chapter 5, I then explain how the results of the spool-and-line studies were employed to design habitat linkages constructed to mitigate the barrier effect caused by powerline easements. The responses of animals to the linkages are also described. To further test the strength of the barrier effect, I subsequently conducted translocations; these are described in Chapter 6.

## Chapter 4 – Habitat Use

*“Like most dilemmas we face in this world, there is likely no unique and probably no universally acceptable solution to any one of them, and we may have to accept therefore some compromises if we are to proceed constructively in resolving these apparent antitheses”*

(Anderson, 1981)

### 4.1 INTRODUCTION

The associations between animals and various features of their habitat are generally referred to as ‘habitat preferences’ (Newsome & Catling, 1979; Fox & Fox, 1981; Ford *et al.*, 2003). However, the question of whether animals display ‘habitat preference’ is controversial. It has been argued that patterns of distribution with respect to microhabitat do not necessarily reflect ‘preferences’, but instead are a reflection of various processes underlying the interactions between a species and its habitat (Crowe & Underwood, 1998). I approached this phase of the study by describing the habitat use of two native Australian small mammals and then exploring how this may be influenced by biotic and abiotic factors. I acknowledge that these animals may be associated with certain habitat features not because they are ‘preferred’, but because there may be other forces acting upon them.

#### 4.1.1 Factors Affecting Habitat Use

Theoretically, the paths that animals make while moving through habitat ensure that the costs (e.g. predation, competition) are outweighed by the benefits (e.g. gaining energy, nutrients, territories or mates) (Haythornthwaite, 2005). Habitat use patterns are, therefore, a reflection of the trade-offs between these costs and benefits, and will vary with species and habitat. Greater variation in patterns of habitat use result from the heterogenous composition of forest vegetation (Catling & Coops, 1999). Factors such as individual species’ characteristics (see Harper *et al.* (2005a)), site bushfire history (see Fox *et al.* (2003); Monamy & Fox (2005)) and land use (Bennett, 1990b) can further affect the habitat use patterns of resident small mammals.

### 4.1.2 Measuring Habitat Use

Research projects combining vegetation classification/description with small mammal studies are numerous, and are used to answer a wide range of ecological questions. These include questions regarding species diversity (August, 1983; Stevens & Husband, 1998; Williams & Marsh, 1998; Williams, 2002), movement patterns (Stapp & Van Horne, 1997), species interactions (Fox, 1982a), species abundance (Catling & Burt, 1995; Bowman *et al.*, 2001b), habitat use (Stewart, 1979; Wells *et al.*, 2004; Haythornthwaite, 2005; Monamy & Fox, 2005; Bakker, 2006), and response to habitat fragmentation (Laurance, 1994; Bentley *et al.*, 2000; Cox *et al.*, 2004; Pardini *et al.*, 2005). The list of possible attributes that can be used for vegetation classification is very extensive (Anderson, 1981). I opted for a scoring system that incorporated many of the habitat components that have been associated with small mammals such as logs, leaf litter and shrub vegetation. Various methods have been used to measure vegetation structure, though many are subjective, labour-intensive or disturb the vegetation (Fox, 1979). I sought to determine the association between two small mammal species and the features of their habitat that are influenced by the disturbance associated with the establishment and maintenance of powerline easements. My protocol was designed to achieve a compromise between measurement of the fine-grain detail of vegetation features and the efficiency required to simultaneously estimate the background habitat and movement paths of animals

### 4.1.3 Study Predictions and Aims

Both *R. fuscipes* and *A. stuartii* have been the focus of habitat use studies in the past (Barnett *et al.*, 1978; Braithwaite, 1979; Dickman, 1982; Statham & Harden, 1982; Bennett, 1993; Whelan *et al.*, 1996; Cox *et al.*, 2004). However, investigations that link ecological patterns with management or conservation measures are more rare. Conservation planning for species residing in habitat fragments must take into account their autecologies (McCoy & Mushinsky, 1994). Detailed investigation of habitats used by animals can provide invaluable information for such conservation and management (Cox *et al.*, 2000). In this phase of my research, I sought to identify the preferred habitat features of these two species in areas of native bushland adjacent to powerline easements, which are a major source of habitat fragmentation (see Chapter 2).

Based on preliminary observations, I predicted positive associations with structural features such as logs, but the interactions with other habitat features such as leaf litter and shrub vegetation were unknown. I further predicted that *R. fuscipes* and *A. stuartii* would exhibit different habitat associations, given their differing body size and food requirements. I envisaged fewer captures of small mammals at the edge of the habitat immediately adjacent to the powerline easement, and expected that less favourable habitat characteristics in these areas would help to explain the phenomenon. The primary aim of this phase of my research was to determine the habitat features most commonly associated with *R. fuscipes* and *A. stuartii* that are also potentially manipulable in amelioration programs. The findings of this investigation could then be incorporated into ensuing habitat manipulation experiments, directed at increasing the movement of small mammals across powerline easements.

## 4.2 METHODS

### 4.2.1 Pilot study

A pilot study assessing spooling success was conducted prior to the formal data-gathering sessions. During this period, it was established that some spool trails measured 80m or more in length but that the average length of thread expended prior to shedding of the device or snagging of the thread was 35m. For this reason, spools containing 120m of thread were deemed to be adequate for the spool-and-line study. Spools were composed of fine white nylon (Quilting thread bobbin 140/2, Size 8, Danfield Ltd., Sydney, New South Wales) and weighed 3g when encased in white electrical tape. This casing served to improve adhesion of the spool to the fur and ensured that the spool remained intact while on the animal and did not snag on vegetation.

### 4.2.2 Spooling of Animals

This spool-and-line study was run concurrently with the investigation of the barrier effect caused by powerline easements described in Chapter 3. Traps were inspected approximately two hours after dusk and animals trapped at this stage were included in the spool-and-line study, provided that they had not been spooled before. Animals were

removed from the trap at the site of capture, and then measured and marked as described in Section 3.2.1.2. Using round-ended scissors, a small area of fur between the shoulder blades of the animal was trimmed. A thin trail of cyanoacrylate ('superglue') was delivered onto half of the long side of the prepared spool. The spool was then quickly placed onto the trimmed area of fur and held in place for one minute while the glue dried (Fig. 4.1(a) & (b)). Throughout the entire procedure, a cloth bag covered the animal's eyes in order to minimise distress. The end of the thread was secured to a nearby stem or log and the animal gently released. Following the practice of Miles *et al.* (1981), the observer remained still until the animal had moved away, or withdrew quietly to avoid causing the animal to flee in any particular direction. Traps without animals were left open, inspected once again in the morning and then finally closed off for the diurnal period. No spools were affixed to animals in the morning because the study animals are nocturnal, and would, therefore, return directly to their nests rather than proceed with foraging. The trapping routine for this part of the study is summarised in Table 4.1. This routine was carried out at four sites for *R. fuscipes* and at three sites for *A. stuartii*.

**Figure 4.1 (a) Affixing a spool to a *Rattus fuscipes* individual. (b) *Antechinus stuartii* fitted with a spool.**

The spool is placed between the shoulder blades, but owing to the loose nature of the skin, the spool in this case appears to have fallen to one side. (Photograph: Sue Carthew)

Spooling of *R. fuscipes* was conducted in September and November 2004 and February and April 2005 (Appendix 2). Spooling of *A. stuartii* began later, and was carried out in February and April of 2006. This was to allow development of the technique on larger, more manageable animals (i.e. *R. fuscipes*). Secondly, recording of spools was a time-

consuming process, hence, only a limited number could be processed in each field session. Finally, these months were chosen for spooling of *A. stuartii* to ensure there were males present in the population, and also to avoid the phase of the year when females are pregnant or lactating.

**Table 4.1 Trapping routines at each of four trapping sites in this study**

Time	Day 1	Day 2	Day 3	Day 4	Day 5	Day 6
AM		Empty and close all traps	Empty and close all traps		Empty and close all traps	Empty and remove all traps
PM 1	Set up trapping grid	Record spools	Record spools	Rebait and set traps	Record spools	Record spools
PM 2	Inspect traps Spool animals	Inspect traps Spool animals	No spooling	Inspect traps Spool animals	Inspect traps Spool animals	Finish

### 4.2.3 Recording Spool Data

In daylight, I revisited the locations where spooled animals had been released the previous night. The path of the thread laid down by the animal as it proceeded through the habitat was followed and sketched to produce a map of the animal's movement pattern. At 3m intervals along the course of the thread path the habitat features of 'Logs', 'Leaf Litter', 'Branches', 'Ground Vegetation' and 'Shrub Vegetation' were scored within a 1m radius of each point, as described in Table 4.2. Each of the habitat features was subdivided in to measures (e.g. Leaf0-20%) which described the abundance of each of the features. Care was taken in the course of my study to ensure that the subjective determination of measures of habitat were clear-cut, well-defined.

Canopy strata were not considered biologically important for this investigation, as described in Sutherland & Predavic (1999). Where an animal moved up a tree of any width, and more than 1m tall, I described the animal as being 'in a tree' and other habitat features were not recorded. Logs use by *R. fuscipes* was described according to Table 4.2. Later in the study when recording habitat utilisation by *A. stuartii* I incorporated more detail; following the thread, I noted when *A. stuartii* was moving along, under or inside a log or trunk. I also noted if the surface of the log along which the animal was moving was at ground level. Recordings of all other habitat features (e.g. leaf litter etc.) were made only if the log or trunk the animal had proceeded along was within 30cm of the ground. For *A. stuartii*, adjacent habitat features were not

recorded when an animal was off the ground. This was because, as the study progressed, I felt that when the animal was off the ground, inside or under a log or trunk, other habitat features were either not present in the immediate vicinity, or of secondary importance, particularly given the scale relevant to an animal of this small size. When recording spools from both *R. fuscipes* and *A. stuartii*, I followed each spool and scored the features until the animal shed the spool, or the thread came to an end because it was snagged in the vegetation.

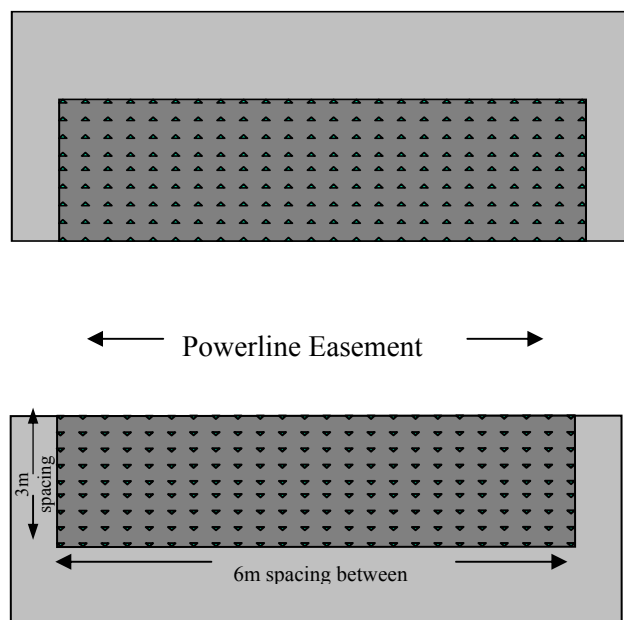
**Table 4.2 Explanation of habitat features and corresponding measures recorded at data points on spool trails and background vegetation grids**

Habitat feature	Measure	Explanation for circular area 1m out from data point
<b>Logs</b>	NoLogs	No logs seen at all
	Logs10	Log diameter 5-10cm
	Logs20	Log diameter 10-20cm
	Logs>20	Log diameter 20-50cm
	Trunk	Log diameter >50cm including trunks
<b>Leaves</b>	Leaf0-20	0-20% of ground covered with leaf litter
	Leaf20-40	20-40% of ground covered with leaf litter
	Leaf40-60	40-60% of ground covered with leaf litter
	Leaf60-80	60-80% of ground covered with leaf litter
	Leaf80-100	80-100% of ground covered with leaf litter
<b>Branches</b>	BranchL	Zero or just a few branches (<5cm diameter) present
	BranchM	Several branches present
	BranchH	Network of branches/fallen tree
<b>Ground Veg</b>	GrVeg0-20	0-20% of ground has veg <30cm in height
	GrVeg20-40	20-40% of ground covered with veg <30cm in height
	GrVeg40-60	40-60% of ground covered with veg <30cm in height
	GrVeg60-80	60-80% of ground covered with veg <30cm in height
	GrVeg80-100	80-100% of ground covered with veg <30cm in height
<b>Shrub Veg</b>	ShVeg0-20	0-20% of ground covered with shrubs >30cm in height
	ShVeg20-40	20-40% of ground covered with shrubs veg>30cm in height
	ShVeg40-60	40-60% of ground covered with shrubs veg>30cm in height
	ShVeg60-80	60-80% of ground covered with shrubs veg>30cm in height
	ShVeg80-100	80-100% of ground covered with shrubs veg>30cm in height

Individuals were spooled only once during each field session. This was to ensure independence of each spool and also to minimise the stress to the animals. Furthermore, I found that recaptured individuals that had been spooled tended to have a small bald spot between the shoulder blades where the spool had been affixed. This made affixing of a new spool to the animal difficult and potentially harmful. Whilst the ear notching marking system was permanent, the complimentary tail-banding was not (Section 3.2.1.2). For this reason, it is possible that the same individuals may have been spooled in subsequent field sessions, since their fur, removed during a previous spooling event, may have regrown. However, I believe that repeated spooling of individuals in successive field sessions was rare because individuals with distinctive physical characteristics such as old injuries to the tail, feet or ear pinna were rarely recaptured in successive sessions (pers. obs.).

#### 4.2.4 Recording Background Habitat Data

I conducted a survey of the ‘background’ habitat in the trapping area, which provided a comparison dataset for the spooling data. One hundred and ninety eight points composed of 22 parallel rows throughout the trapping grid were surveyed (Fig. 4.2).



**Fig 4.2 Background habitat survey grid, composed of 198 points where five habitat structural features were scored.**

■ = trapping grid area, ■ = surrounding habitat. Triangles represent points at which habitat variables were recorded. The background habitat was scored in this way at each site on two occasions in the course of this study, in June 2005 and again in December 2005 - January 2006.

Points were spaced at 3m intervals on rows perpendicular to the easement, with rows spaced 6m apart. I determined the location of the points using a measuring tape, and scored the habitat variables described in Table 4.2.

#### 4.2.5 Data Analysis

##### 4.2.5.1 Temporal Change of Background Habitat Proportions

To determine whether the composition of the background habitat changed significantly during this period, I compared datasets for each time period (June 2005 and in December 2005 - January 2006) using  $\chi^2$  tests of independence. I discovered significant differences at all sites (Appendix 6) although the patterns of change were not consistent between sites. For example, while branches and ground vegetation were significantly different in abundance at all sites one year to the next, shrub vegetation only varied significantly at Currumbene ( $\chi^2 = 68$ ,  $df = 1$ ,  $P < 0.001$ ). Based on these results, I decided to compare spools with the most recent measurements of the background habitat.

##### 4.2.5.2 Use of Habitat Features Relative to Availability

Initially, I summarised all the habitat use data to the spool level. To do this, the scores for each habitat measure were summed and divided by the number of points recorded for each spool. I subtracted the proportions of habitat features present in the background from these proportions (Appendix 7). These calculations were location-specific, so, for example, I compared spools from the South side of the easement at Currumbene to the background values from the South side only. I then used the results of the subtractions to produce box plots, which portrayed the animals' habitat preferences relative to availability of each habitat feature. In compositional analysis, as described by Aebischer *et al.* (1993), the values obtained are normally analysed using multivariate analysis of variance (MANOVA). However, I used an alternative technique to analyse the habitat use data. This is because when records from spools which are composed of many points are averaged, much of the detail present in the complete dataset is lost. Following advice from Dr. Robert Clark (Statistical Consulting Service, School of Mathematics and Applied Statistics) I used simple logistic regression analyses to determine the habitat preferences of the animals in my study. Logistic regression is a useful way to determine the probability that a described resource unit is used during a

period of selection, given information that describes the study area (Manly *et al.*, 2002). Logistic regression returns ‘*B* values’, which reflect the strength and direction of the relationship under examination. The analysis also yields ‘odds ratios’ ( $\text{Exp}(B)$ ), which is a measure of selection likelihood. Selection of statistical techniques is discussed further in Section 4.4.4.

Analysis of habitat for *A. stuartii* involved a similar use of logistic regression, albeit slightly different than for *R. fuscipes*. I believe that given the very small size of *A. stuartii*, once an animal was above ground level (app. 50cm) and proceeding along a large log or trunk, then other habitat features at ground level would not impact greatly on its choice of movement paths. For example, I observed animals following the entire length of a log, regardless of the changes in microhabitat that occurred adjacent to the log. For these reasons, when *A. stuartii* was moving along a large trunk or log, I did not record other habitat features. For the logistic regression, the points that exclusively reported large log/trunk use were not included. This amounted to 252m in total, or 11.4% of all spool data (not including arboreal sections) for *A. stuartii*. The effect of this approach on results was to underestimate the use of logs. Therefore, I analysed log use by this species in a separate logistic regression, in which I compared the measures of logs as revealed by spools, with the records for logs present in the background habitat grid. Additionally, analysis of use of logs, branches and trunks by this species, relative to the proportions of these features in the background habitat, is described in Section 4.2.5.4.

For both *A. stuartii* and *R. fuscipes*, all sites were initially analysed together to detect overall trends, and then separately, to determine the consistency of trends among sites. Data recorded during several field sessions at each site were pooled. In order to justify combining background data from both sides of the easement in the logistic regressions, I performed a  $\chi^2$  analysis on both easement sides. Results showed that, for the majority of features, there was a significant difference between the vegetation composition in the opposing sides of the easement. To test whether these significant differences were a reflection of actual, large differences in proportions habitat features (or merely a reflection of very slight but consistent differences in two large datasets), histograms of the average proportion of habitat features of each side were constructed (Appendix 8).

After analysing the histograms, which a great deal of similarity between the two sides of the easement at each site, I decided that it was appropriate to combine background habitat recorded from both sides of the easement. However, I noted that results needed to be interpreted carefully for leaf litter and ground veg at Currumbene and Conjola where some substantial differences existed for these features. Furthermore, application of the logistic regression model was deemed valid on the basis of the following assumption; animals are more likely to select a particular habitat measure than another, regardless of whether that measure was more abundant on one side of the easement or not.

#### 4.2.5.3 Associations Between Habitat Features

To determine if animal movements were related to certain combinations of habitat features, I analysed habitat use datasets from each site (with the assistance of Dr. Robert Clark) using the robust linear model. As with simple logistic regression, this method utilises all the data points recorded in the study, but is superior because it returns data regarding interactions between different habitat features, and provides more accurate estimates of standard error. I discuss the use of statistics in this phase of the study further in Section 4.4.4.

#### 4.2.5.4 Arboreality and Log Use

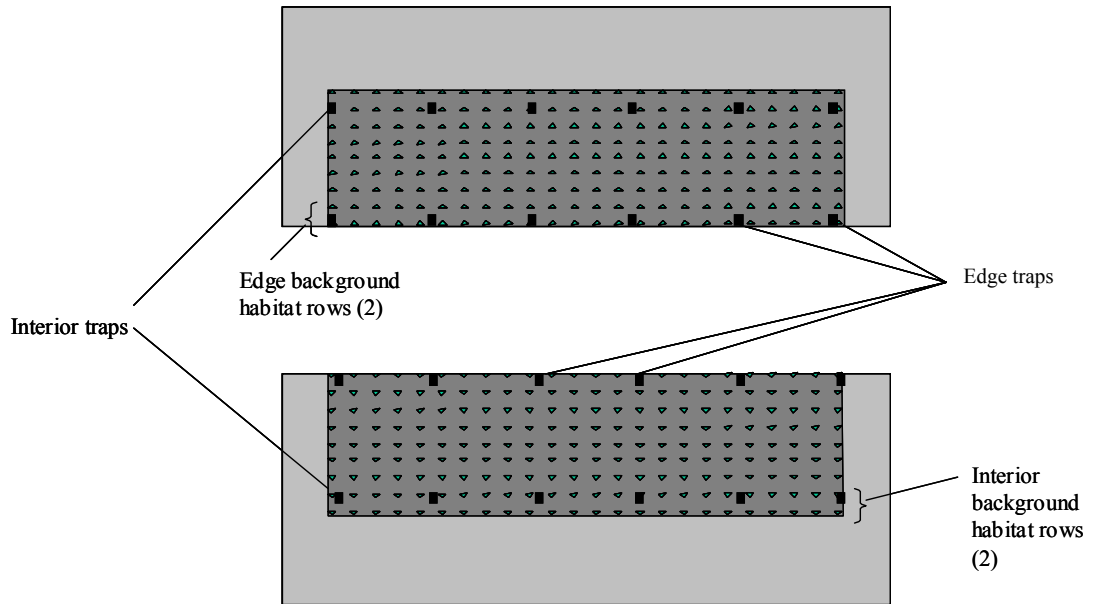
Preliminary analysis of spools suggested that tree-climbing activity by *A. stuartii* was sufficiently common to merit investigation separately from the main body of habitat use data. The proportion of the spool length for which an animal was in a tree was estimated for each site by dividing the number of points that were on trees by the total for the spool. This method was also applied to log use, described below. *Rattus fuscipes* did display arboreal tendencies but this was not quantified because it was infrequent and, in many of the spools, did not occur at all. Analysis of log use by *R. fuscipes* was based on spool data that featured the records of log size category selected. Proportions of usage of each size category were graphically compared with proportions in the background dataset. For *A. stuartii*, three forms of log use were identified:

1. Movement along logs at ground level, where logs were immediately adjacent and on the same level as other habitat features (leaves, ground vegetation and shrub vegetation);

2. Movement along logs or branches more than 50cm off the ground -this occurred where the log or trunk was large enough to elevate the animal above the ground and the level of ground vegetation;
  3. Movement along branches, usually slender arcing branches, off the ground.
- Averages and totals were then calculated for each spool and each site.

#### 4.2.5.5 Edge Preference

There were two phases to this investigation. Firstly, the number of captures recorded at all the edge traps was compared to the number at interior traps (Fig. 4.3). The edge was defined as the row of six trap stations situated just inside the habitat, where the bushland borders the powerline easement. Interior traps were those located in the row parallel to this 25m from the easement-habitat boundary (Fig. 4.3). The number of captures at both locations within the grid was compared directly for each side of each site. This was possible because equal numbers of traps were located at the edge and interior at each site. Similarly, the number of trap nights was identical for edge and interior traps. Initially, to determine if there was a difference in the number of captures at the edge versus the interior, I compared captures for each session across all sites using a  $\chi^2$  goodness-of-fit test. To do this, the observed number of captures of *R. fuscipes* and *A. stuartii* individuals at the edge and interior trapping stations was compared with the numbers of expected captures had there been no difference in trap-success at the two regions. I then applied the same test to edge and interior captures for each session at the site level. The numbers of individuals and recaptures were analysed separately to ensure that certain animals captured repeatedly at the edge or interior did not confound the results. Results from different trapping sessions were not pooled because it was likely that some of the animals captured in a session were the same individuals captured during a previous occasion.



**Figure 4.3** The location of ‘edge’ and ‘interior’ traps in the trapping grid, and ‘edge’ and ‘interior’ rows of the background habitat at each site.

The number of captures at the edge and interior were compared at each site (Section 4.2.5.6) to investigate if small mammals exhibited an ‘edge preference’. Habitat features at edge and interior rows of ‘background habitat’ were subsequently compared to test if the two regions differed in composition.

Following the investigation of numbers of edge and interior captures, in the second part of this exploration I compared the proportions of the five habitat features (recorded during the background habitat study) in the two edge rows, with the interior rows, by examining overlap in 95% confidence intervals in the graphs. I then used a 3-way analysis of variance (ANOVA) (JMP statistical package, Version 5.1) to compare the habitat features in the edge and interior rows, in terms of site and side of the easement. ‘Site’ (Currambene, Conjola, Parnell and Jerrawangala), ‘Side’ of easement and ‘Location’ (edge or interior of trapping grid) were the factors included in this analysis. The dependent variables were the five habitat features; logs, leaf litter, branches, ground vegetation and shrub vegetation. Measures for each of these features (see Table 4.2) were converted to a score (e.g. Leaf0-20 = 0, Leaf20-40 = 1, Leaf40-60 = 2 etc.). Each habitat feature was analysed separately.

## 4.3 RESULTS

### 4.3.1 Spool-and-line Tracking Study

Between September 2004 and April 2006 a total of 102 spools were recorded at the four trapping sites, yielding 5,255m of thread trails. Almost twice as many *R. fuscipes* (66) were spooled as *A. stuartii* (36).

The 66 *R. fuscipes* individuals spooled produced 2,474m of thread trails, with an average length of 37.9m. Parnell yielded the greatest number of spools (24) and also had the greatest average spool length (44.4m). Fewest spools were recorded at Jerrawangala (6), but the spools there were of almost the same average length as those recorded at Parnell (42.2m). Approximately the same number of spools was recorded in each fieldwork session (~20) with the exception of November 2004, when there were just 10.

Thirty six *A. stuartii* were spooled at three sites in this phase of the study, in the months of February and April of 2006, amounting to 2,781m of data. Most spools (16) were recorded at Currumbene and fewest at Conjola (8), though the average length of spools at these two locations was almost identical. On average, the 12 spools recorded at Jerrawangala were much shorter (54.2m) than those from Conjola or Currumbene. In general, spools recorded from *A. stuartii* were more than twice as long as those for *R. fuscipes*.

### 4.3.2 Habitat Use

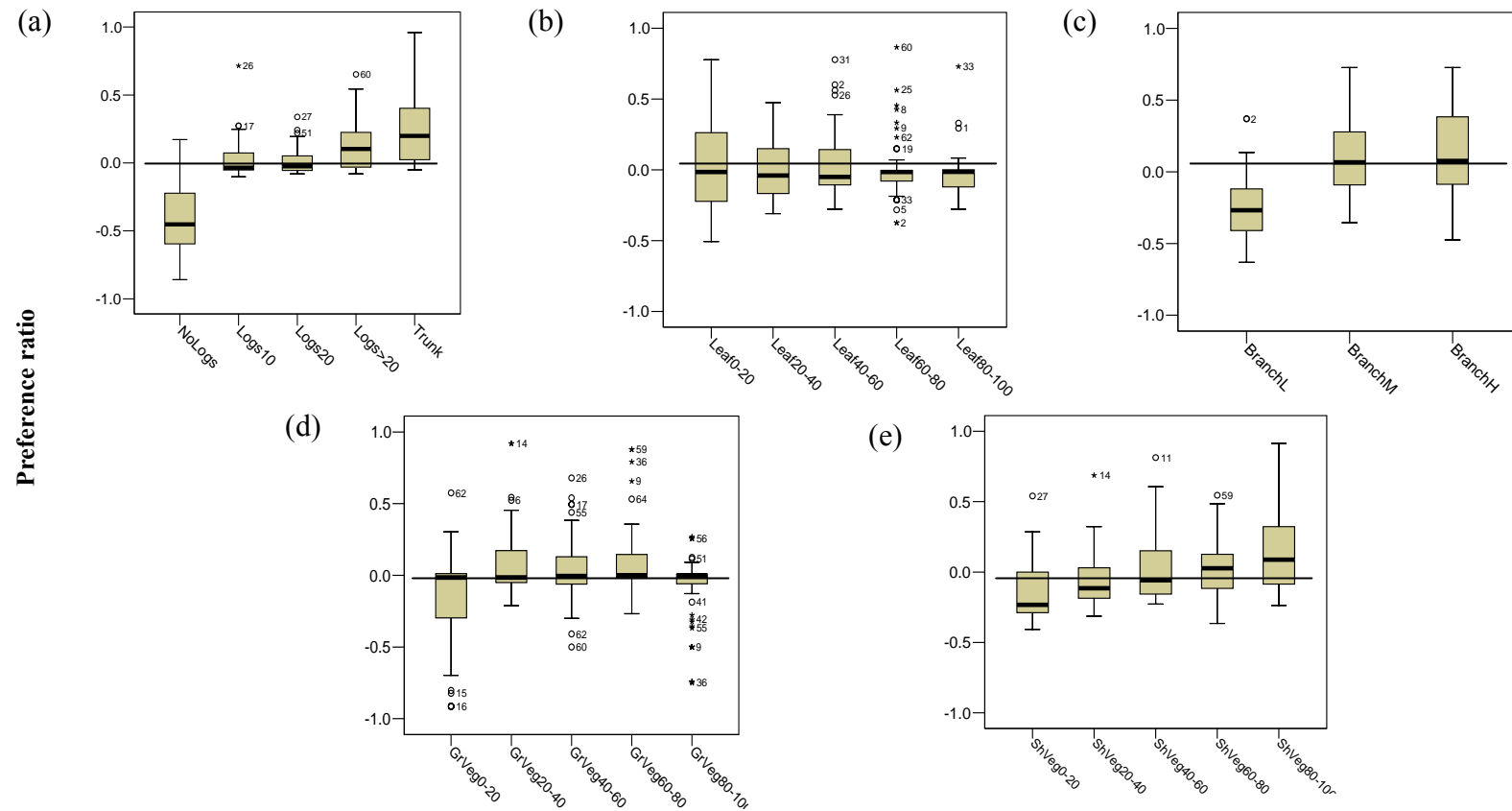
#### 4.3.2.1 *Rattus fuscipes*

Across the four sites ('All Sites'), *R. fuscipes* showed strong positive associations with two habitat features in particular; Logs and Branches (Fig. 4.4 (a) – (e)). This was supported by binary logistic regression of data from All Sites, with uniformly high statistical significance of  $P < 0.01$ .  $B$  values greater than 1 indicated that the animals were preferentially using a particular feature, relative to its abundance in the background habitat. Logs in particular returned high  $B$  values, as did the measures for denser Shrub Vegetation (Table 4.3). *Rattus fuscipes* was 6.14 times more likely select a

movement path that features logs which are greater than 20cm in diameter (Logs20), than one with no logs (NoLogs). Similarly, animals were 3.1 times more likely\* to be found at a point with high (H) measures for branches. Results from this logistic regression also show that regions with densest vegetation cover were 8.66 times more likely to be selected by *R. fuscipes* than regions where Shrub Vegetation was minimal (ShVeg0-20). Boxplots derived from differences between average values for spools and background data did not reveal any clear patterns of habitat use regarding 'Leaf', 'Ground Vegetation' or 'Shrub Vegetation' (Fig.s 4.4 (b), (d) & (e)). In each case the results tended to be evenly spread around 0. However, the more detailed analysis produced by logistic regression relating to 'All Sites' reveals negative *B* values, indicating that the animals are less likely to chose a path featuring leaf litter densities of more than 0-20%. Results relating to ground vegetation (GrVeg) are less conclusive. Whilst boxplots suggest that the animals tend to avoid regions with low degrees of ground vegetation cover, the *B* values from the logistic regression are all less than one. Although the chances the animals selecting ground vegetation densities of 20-40% were twice as high as selecting 0-20%, this was less convincing than other habitat features such as logs or branches, where the odds ratios (Exp(*B*)) values were considerably higher and there was a steadier increase towards the higher measures of ground vegetation.

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\* Here and elsewhere, '3.1 (etc.) times more likely' is actually an expression of probability, meaning 3.1 times the odds ratio. Though '3.1 times more likely' is not strictly accurate in statistical terms, it is applied here for linguistic simplicity.



**Figure 4.4 Associations between *Rattus fuscipes* movements and five habitat features: (a) Logs, (b) Leaf Litter, (c) Branches, (d) Ground Vegetation (GrVeg) and (e) Shrub Vegetation (ShVeg), relative to availability of those features in the habitat at ‘All Sites’: Currumbene, Conjola, Parnell and Jerrawangala.**

Positive values for preference ratio(y-axis) indicate an association with that measure of habitat feature. Negative values indicate an avoidance of the measure. Values close to zero indicate no association was detected. Results are derived from 66 different spools recorded over 1 year, with a total length of 2,474m (825 data points). Outliers are represented by symbols (° and \*). Numbers next to these symbols refer to the spool from which the data was sourced. Habitat features are shown on the x-axis.

**Table 4.3 Results of logistic regression testing for associations between *Rattus fuscipes* and habitat features.**

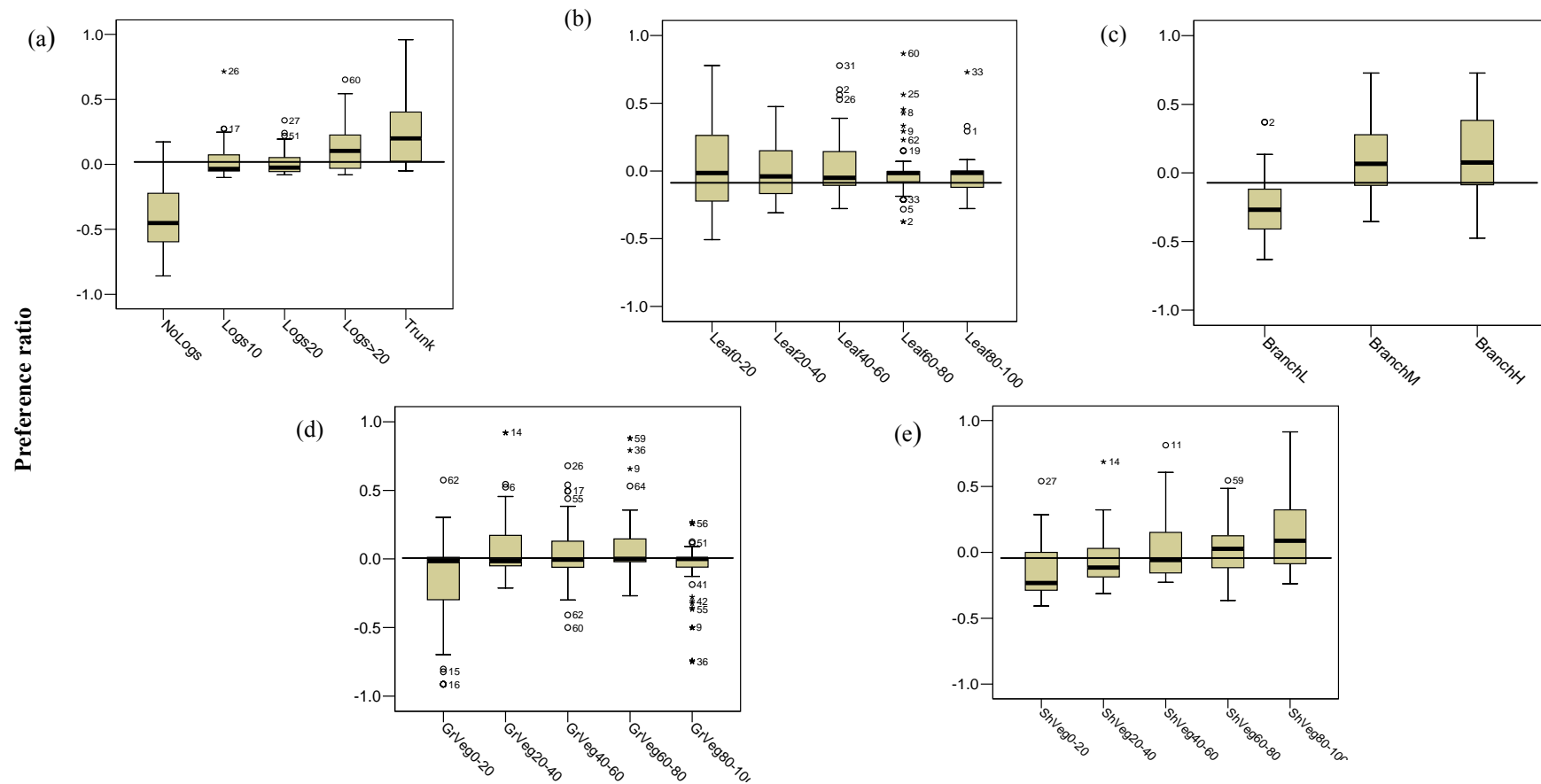
Data were derived from a spool-and-line study, in which 66 animals were spooled, yielding 2,474m of data. Currambene = 292m, Conjola = 857m, Parnell = 1066m, Jerrawangala = 253m. In this analysis, measures of each habitat feature (Leaf20-40%, Leaf40-60% etc.) were compared to the first measure for that feature (e.g. Leaf0-20% etc). For this reason, results for the first measure are n/a or 1. Elsewhere n/a indicates that there were no records for that measure. Entries in italics signify the absence of any records for the measure in question either in the spool or in the background dataset. Significant results are shown in bold. Exp(B) = odds ratio. *P* = significance level.

		Currambene			Conjola			Parnell			Jerrawangala			All Sites		
		<i>B</i>	<i>P</i>	Exp (B)	<i>B</i>	<i>P</i>	Exp (B)	<i>B</i>	<i>P</i>	Exp (B)	<i>B</i>	<i>P</i>	Exp (B)	<i>B</i>	<i>P</i>	Exp (B)
<b>Logs</b>	No Logs	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1
	Logs10	<i>0 records in spools</i>			1.018	0.007	<b>2.767</b>	1.522	<0.001	<b>4.582</b>	-0.025	0.982	0.975	1.021	<0.001	<b>2.777</b>
	Logs20	0.887	0.236	2.429	1.061	0.008	<b>2.890</b>	1.845	<0.001	<b>6.327</b>	1.497	0.017	<b>4.467</b>	1.220	<0.001	<b>3.388</b>
	Logs>20	1.210	0.005	<b>3.355</b>	1.104	0.001	<b>3.016</b>	2.809	<0.001	<b>16.588</b>	2.481	<0.001	<b>11.949</b>	1.815	<0.001	<b>6.138</b>
	Trunk	1.964	<0.001	<b>7.131</b>	1.296	<0.001	<b>3.656</b>	2.129	<0.001	<b>8.404</b>	2.431	<0.001	<b>11.376</b>	1.510	<0.001	<b>4.526</b>
<b>Leaf</b>	Leaf0-20%	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1
	Leaf20-40%	0.179	0.740	1.195	0.161	0.584	1.175	-0.712	0.010	0.491	1.152	0.009	<b>3.165</b>	-0.204	0.158	0.815
	Leaf40-60%	-0.380	0.455	0.684	0.090	0.746	1.094	-1.050	0.077	0.350	0.784	0.112	2.191	-0.490	0.002	0.612
	Leaf60-80%	-0.684	0.182	0.504	-0.387	0.223	0.679	-1.498	0.281	0.224	-0.218	0.694	0.804	-1.051	<0.001	0.350
	Leaf80-100%	-1.165	0.039	0.312	-0.331	0.424	0.718	<i>0 records in spools</i>			<i>0 records in spools</i>			-1.620	<0.001	0.198
<b>Branches</b>	BranchL	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1.000
	BranchM	-0.360	0.193	0.695	1.297	<0.001	<b>3.658</b>	2.045	<0.001	<b>7.727</b>	-0.385	0.274	0.681	0.870	<0.001	<b>2.386</b>
	BranchH	0.005	0.989	1.005	1.221	<0.001	<b>3.391</b>	1.784	<0.001	<b>5.953</b>	-1.969	0.116	0.140	1.133	<0.001	<b>3.104</b>
<b>GrVeg</b>	GrVeg0-20%	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1.000
	GrVeg20-40%	0.936	0.073	2.550	1.496	<0.001	<b>4.463</b>	-2.465	0.012	0.085	-1.432	0.126	0.239	0.755	<0.001	<b>2.127</b>
	GrVeg40-60%	0.653	0.210	1.921	2.271	<0.001	<b>9.688</b>	-1.502	0.102	0.223	-2.174	0.014	0.114	0.240	0.186	1.271
	GrVeg60-80%	0.879	0.089	2.409	2.498	<0.001	<b>12.163</b>	-0.591	0.419	0.554	-1.110	0.199	0.330	0.435	0.011	1.545
	GrVeg80-100%	-0.004	0.994	0.996	<i>0 records in B/Gr</i>			-2.134	0.002	0.118	-0.846	0.364	0.429	-0.683	<0.001	0.505
<b>ShVeg</b>	ShVeg0-20%	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1
	ShVeg20-40%	0.787	0.249	2.196	0.549	0.065	1.731	0.294	0.528	1.341	0.104	0.780	1.109	0.433	0.014	1.541
	ShVeg40-60%	1.904	0.003	<b>6.712</b>	1.098	<0.001	<b>2.999</b>	1.032	<0.001	<b>2.807</b>	-0.492	0.312	0.611	1.162	<0.001	<b>3.197</b>
	ShVeg60-80%	1.833	0.005	<b>6.252</b>	1.278	<0.001	<b>3.588</b>	1.962	<0.001	<b>7.111</b>	-1.746	0.036	0.174	1.497	<0.001	<b>4.469</b>
	ShVeg80-100%	1.106	0.133	3.023	1.531	<0.001	<b>4.622</b>	2.910	<0.001	<b>18.361</b>	0.367	0.692	1.444	2.159	<0.001	<b>8.658</b>

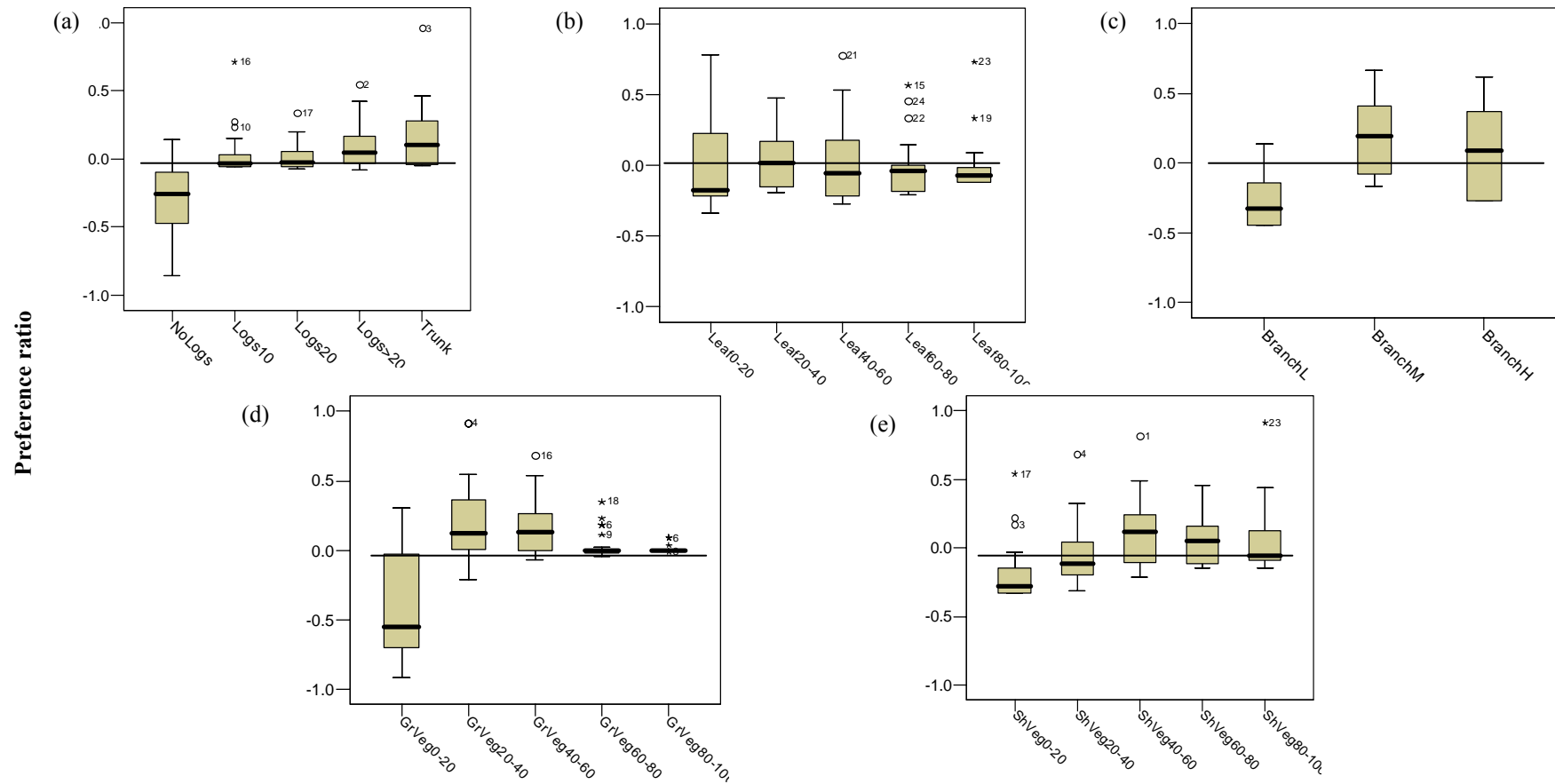
There was also some evidence of an association between *R. fuscipes* and higher values of shrub vegetation (Table 4.3). For example, *R. fuscipes* was more than eight times more likely to be detected in maximal shrub vegetation (80-100%), than in minimal shrub vegetation cover of 0-20%. However, this was less distinct in the box plots (Fig. 4.4(e)).

These same patterns of habitat use also emerged at the individual site level (Fig. 4.5, Fig. 4.6, Fig. 4.7, Fig. 4.8). For example, at Currumbene National Park, once again the animals favoured larger logs (Fig. 4.5(a)) and higher measures of branches (Fig. 4.5(c)). They also showed evidence of a negative association with lower values of shrub vegetation, and the lowest value for ground cover. The results from Conjola were very similar (Fig. 4.6), although intermediate values for branches appear to be favoured. Secondly, at Conjola, the negative association with the lowest measure for ground vegetation was particularly evident (Fig. 4.6(d)).

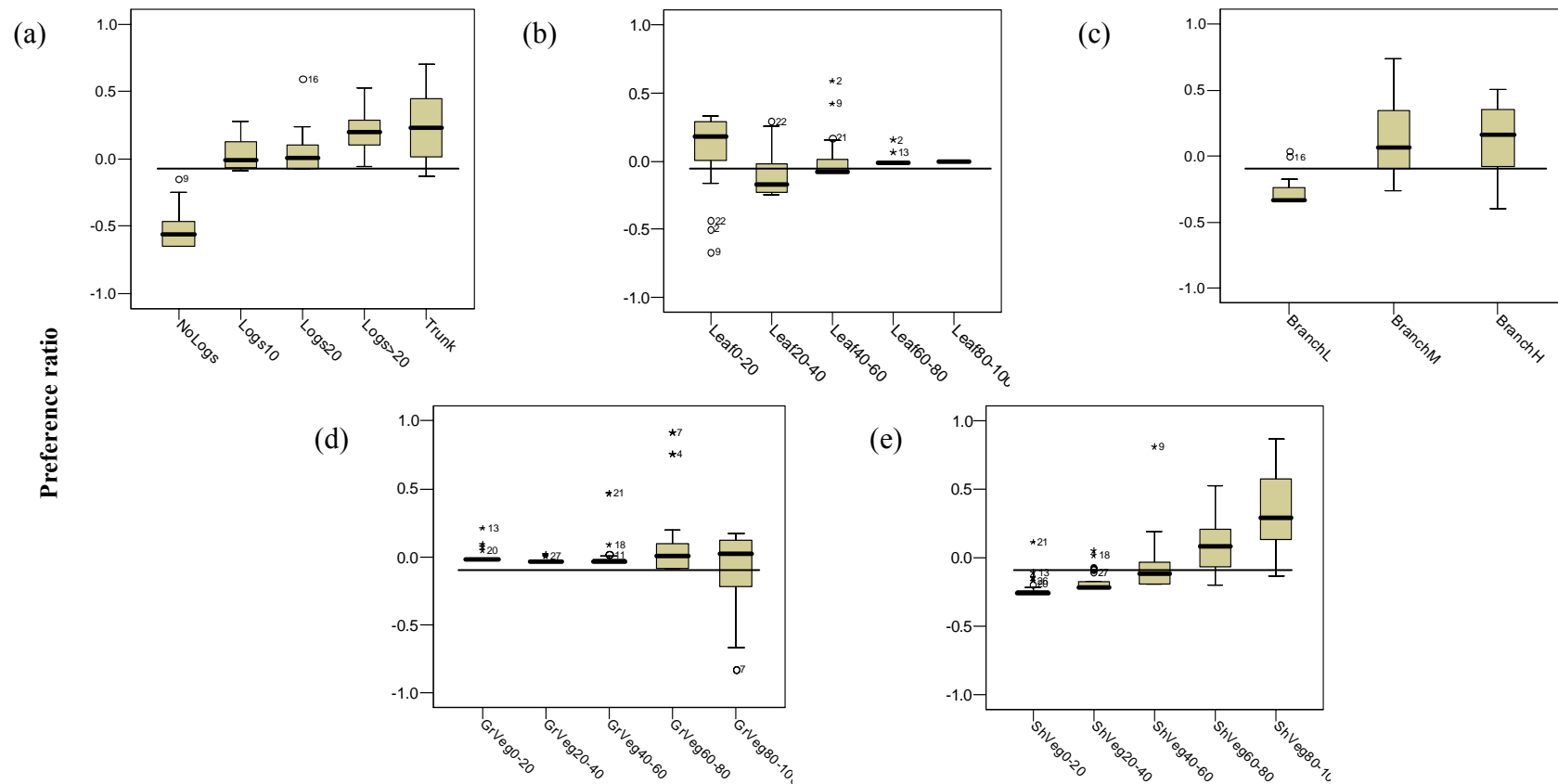
This pattern of association with larger logs and greater volumes of branches was continued at Parnell (Fig. 4.7), where a strong positive relationship with dense shrub vegetation was also apparent (Fig. 4.7(e)). Of the four sites, only Jerrawangala did not exhibit any relationship between *R. fuscipes* and branches (Fig. 4.8(c)), although positive association with logs was evident (Fig. 4.8(a)).



**Figure 4.5 Associations between *Rattus fuscipes* and five habitat features: (a) Logs, (b) Leaf Litter, (c) Branches, (d) Ground Vegetation (GrVeg) and (e) Shrub Vegetation (ShVeg), relative to availability of those features in the habitat at Currumbene State Forest**  
 Positive values for preference ratio (y-axis) indicate an association with that measure of habitat feature. Negative values indicate an avoidance of the measure. Values close to zero indicate no association was detected. Results are derived from 10 different spools recorded over 1 year, with a total length of 292m (98 data points). Outliers are represented by symbols (° and \*). Numbers next to these symbols refer to the spool from which the data was sourced. Habitat features are shown on the y-axis.

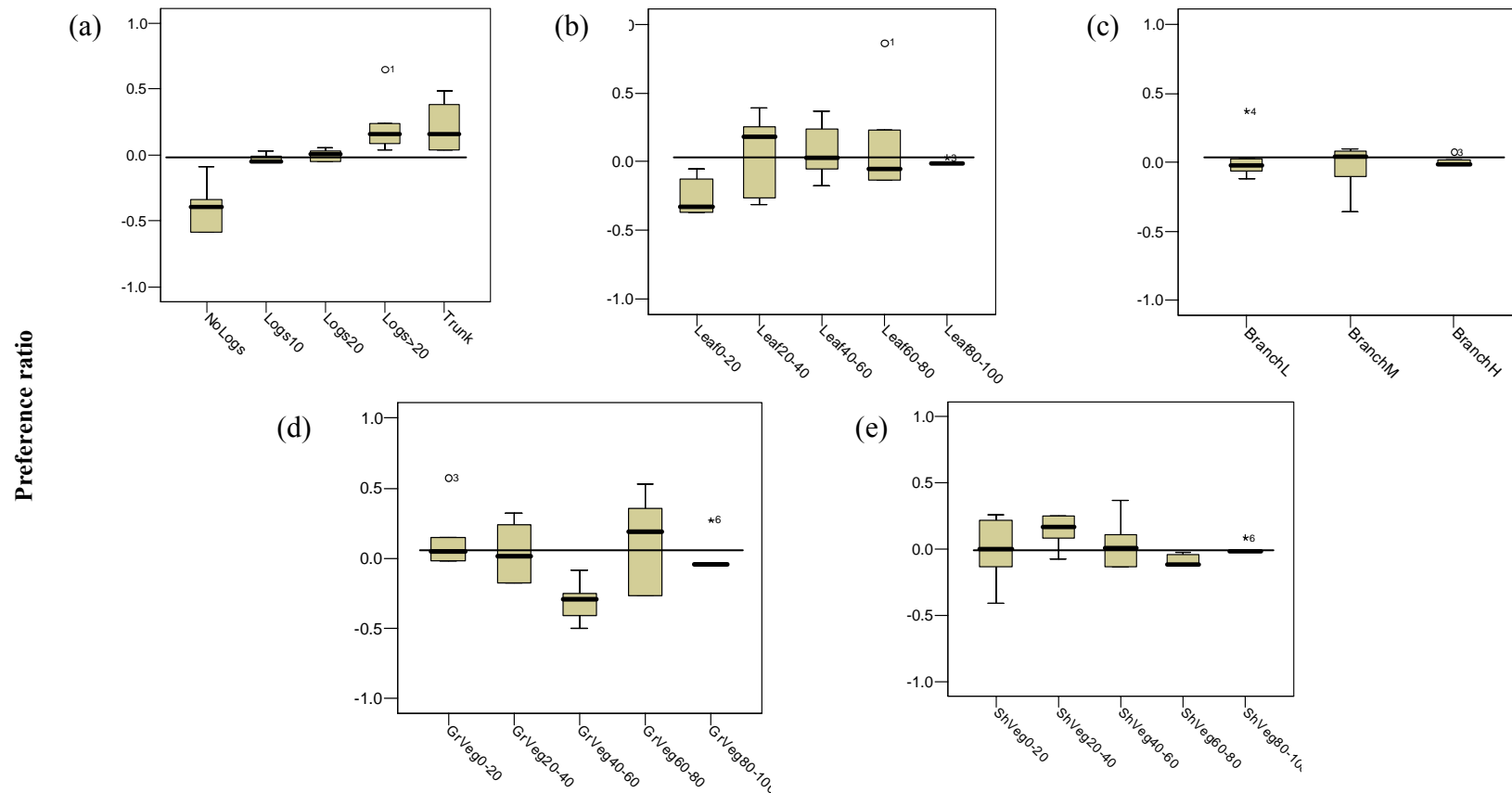


**Figure 4.6 Associations between *Rattus fuscipes* and five habitat features: (a) Logs, (b) Leaf Litter, (c) Branches, (d) Ground Vegetation (GrVeg) and (e) Shrub Vegetation (ShVeg), relative to availability of those features in the habitat at Conjola National Park**  
 Positive values for preference ratio (y-axis) indicate an association with that measure of habitat feature. Negative values indicate an avoidance of the measure. Values close to zero indicate no association was detected. Results are derived from 26 different spools recorded over 1 year, with a total length of 857m (286 data points). Outliers are represented by symbols (° and \*). Numbers next to these symbols refer to the spool from which the data was sourced. Habitat features are shown on the x-axis.



**Figure 4.7 Associations between *Rattus fuscipes* and five habitat features: (a) Logs, (b) Leaf Litter, (c) Branches, (d) Ground Vegetation (GrVeg) and (e) Shrub Vegetation (ShVeg), relative to availability of those features in the habitat at Jervis Bay Park ('Parnell')**

Positive values for preference ratio indicate an association with that measure of habitat feature. Negative values indicate an avoidance of the measure. Values close to zero indicate no association was detected. Results are derived from 24 different spools recorded over 1 year, with a total length of 1,066m (355 data points). Outliers are represented by symbols (° and \*). Numbers next to these symbols refer to the spool from which the data was sourced. Habitat features are shown on the x-axis.



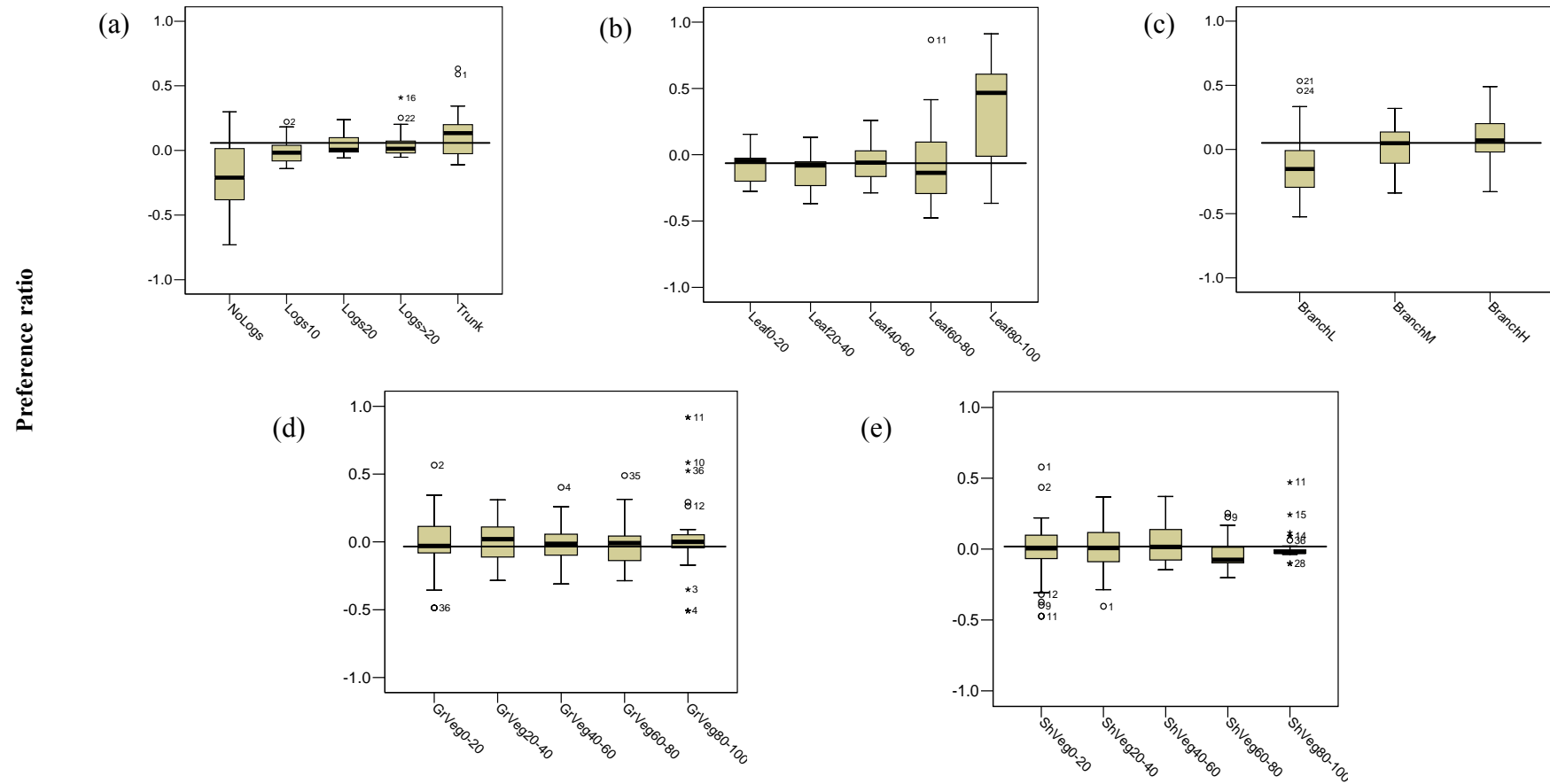
**Figure 4.8 Associations between *Rattus fuscipes* and five habitat features: (a) Logs, (b) Leaf Litter, (c) Branches, (d) Ground Vegetation (GrVeg) and (e) Shrub Vegetation (ShVeg), relative to availability of those features in the habitat at Jerrawangala National Park**

Positive values for preference ratio (y-axis) indicate an association with that measure of habitat feature. Negative values indicate an avoidance of the measure. Values close to zero indicate no association was detected. Results are derived from 6 different pools recorded over 1 year, with a total length of 253m (843 data points). Outliers are represented by symbols (° and \*). Numbers next to these symbols refer to the pool from which the data was sourced. Habitat features are shown on the x-axis.

#### 4.3.2.2 *Antechinus stuartii*

Across the three sites where *A. stuartii* was spooled, the habitat feature that showed consistent patterns was leaves. *Antechinus stuartii* showed a high degree of preference for this feature (Fig. 4.9(b)). Another pattern that consistently emerged was apparent avoidance of regions with no logs and fewest branches (Fig. 4.9 (a) & (c)). These observations were supported by the statistical analysis (Table 4.4). For example, across all three sites, the animals were 14 times more likely to be recorded in areas with the most leaf litter than the least ( $P < 0.001$ ). The tendency to avoid the lowest measure for branches, though suggested by the boxplots, was not statistically significant. An association with regions featuring larger logs was clear. *Antechinus stuartii* was at least 2.3 times more likely to select regions with the three larger measures for logs, these trends were all statistically significant. Furthermore, as explained in Section 4.2.5.2, the result for trunk use is likely to be an underestimate. No strong associations with other measures of branches, or with shrub or ground vegetation, were detected across all sites (Fig. 4.9).

Additional patterns were apparent at the individual site level. At Currumbene there was statistically significant evidence of use by *A. stuartii* of habitat with higher measures of ground vegetation (GrVeg60-80% and GrVeg80-100%,  $P < 0.001$ ) (Fig. 4.10(d)). At Conjola, there were statistically significant associations once again with larger logs (though, curiously, not trunks). As before, the strongest statistically significant overall ‘preference’ was for abundant leaf litter (Fig. 4.11). *A. stuartii* was more than four times more likely to be detected in Leaf40-60%, Leaf60-80% and Leaf80-100% than Leaf0-20%,  $P < 0.001$ . While shrub vegetation and branches had no obvious effect on the animals’ movement paths (Fig. 4.11(e)), there was a statistically significant association with two of the three higher measures of ground vegetation (Fig. 4.11(d)), (GrVeg40-60%:  $B = 0.829$ ,  $P = 0.011$ ,  $\text{Exp}(B) = 2.292$ . GrVeg80-100%:  $B = 2.313$ ,  $P = 0.012$ ,  $\text{Exp}(B) = 10.107$ ). At Jerrawangala, there was no clear association between *A. stuartii* and ground vegetation, branches or shrub vegetation (Fig. 4.11). However, the animals showed significant association with two of the three larger log size classes (Fig. 4.11(a)). Dense leaf litter had the strongest effect on *A. stuartii* movement paths; regions with maximal values for leaf litter (Leaf 80-100%) were more than six times more likely to be selected than Leaf 0-20% (Fig. 4.11(b)) ( $P < 0.001$ ).



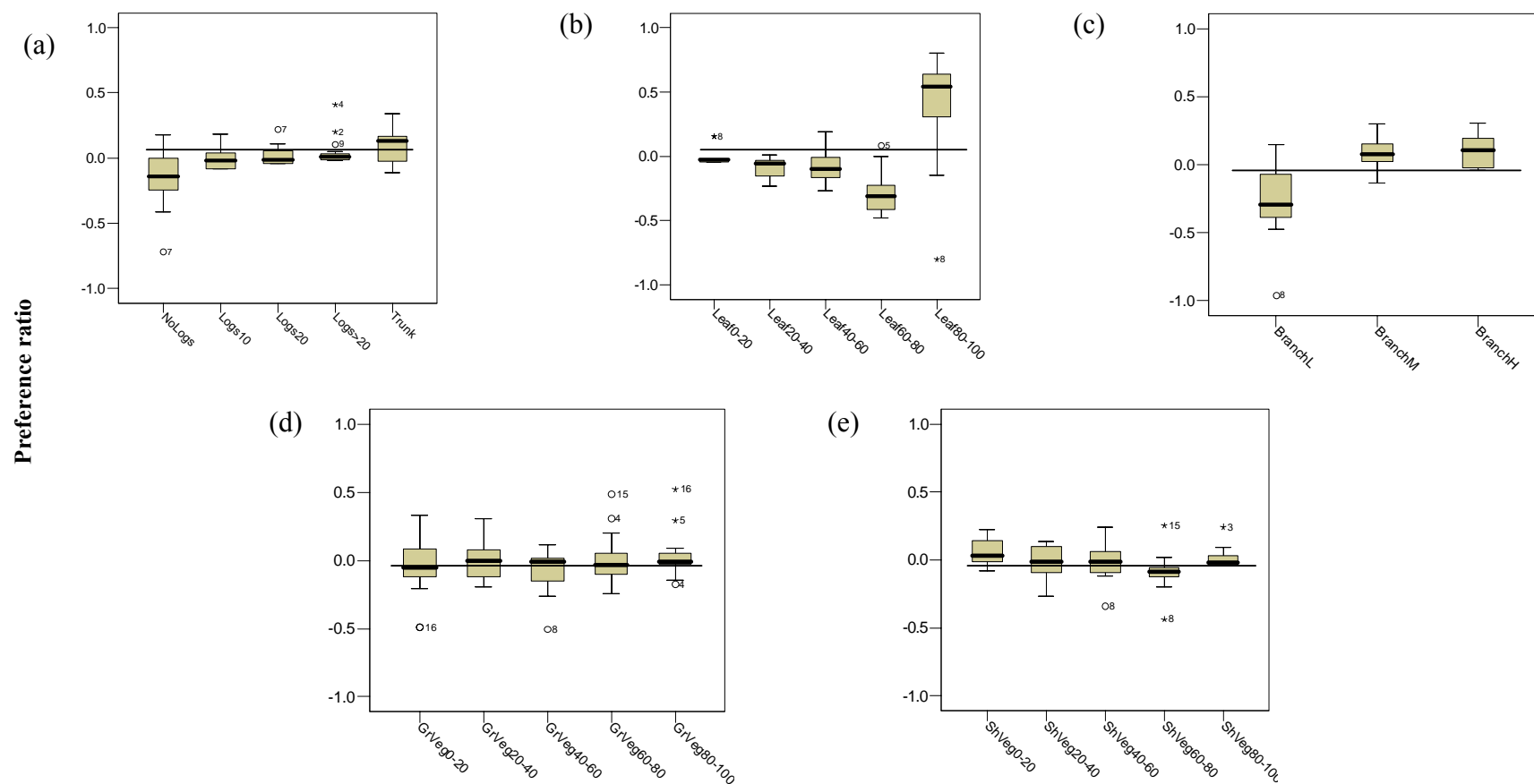
**Figure 4.9 Patterns of habitat use of *Antechinus stuartii* across all 3 sites ('All Sites') in Autumn of 2006, as revealed by spool-and-line technique (a) Logs, (b) Leaf Litter, (c) Branches, (d) Ground Vegetation (GrVeg) and (e) Shrub Vegetation (ShVeg).**

Average values for the 5 vegetation features (a) – (e) in the background habitat were subtracted from average values for 36 spool records (2,218m, = 893 measurement points, arboreal portion subtracted). Therefore, preference ratio >0 indicates use of a habitat measure by *A. stuartii* more frequently than that feature occurs in the background habitat. Negative values reflect apparent avoidance of those habitat measures. Outliers are represented by symbols (° and \*). Numbers next to these symbols refer to the spool from which the data was sourced. Habitat features are shown on the x-axis.

**Table 4.4 Results of logistic regression testing for associations between *Antechinus stuartii* and habitat features**

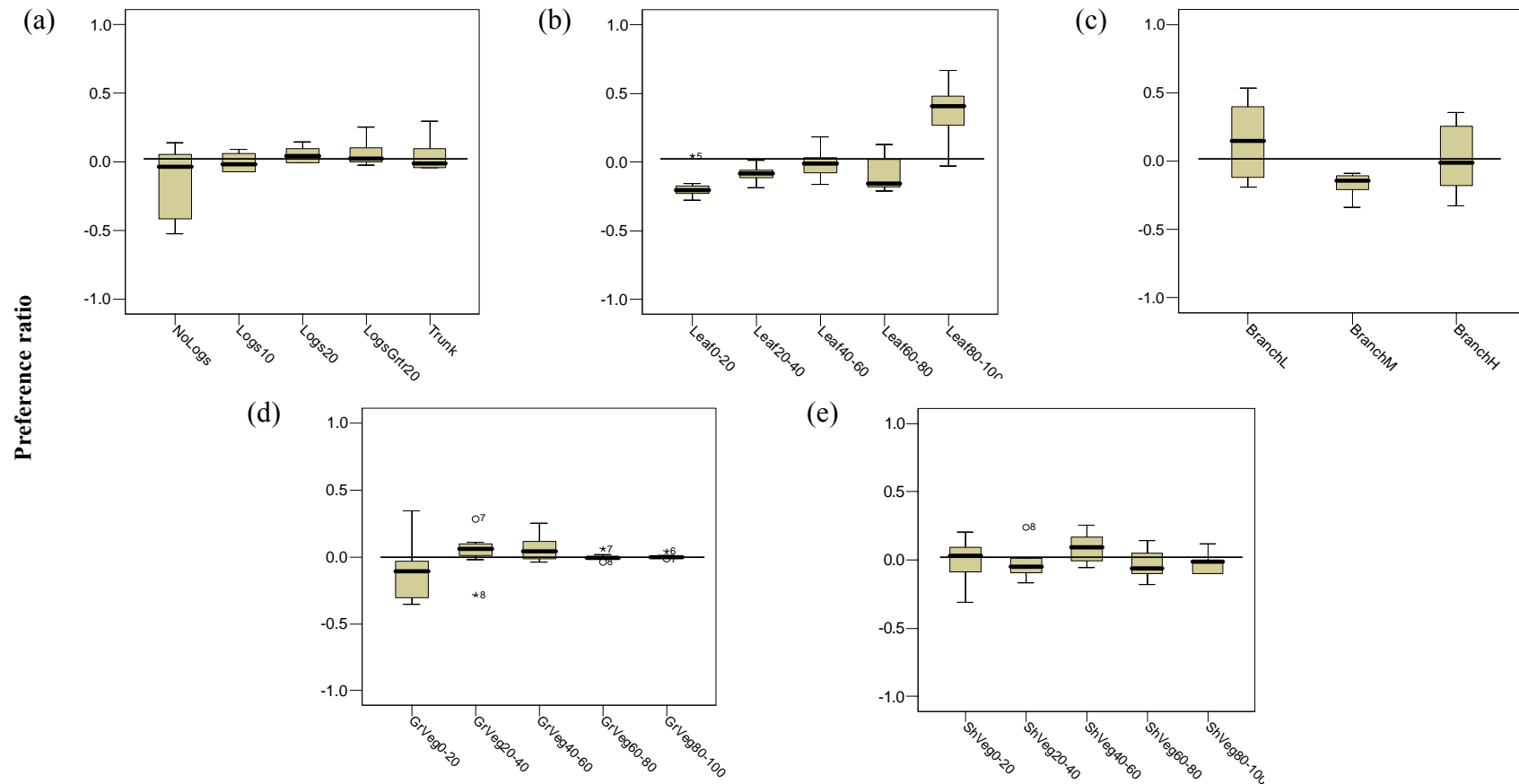
Data were derived from a spool-and-line study, in which 36 animals were spooled, yielding 2,218m of data (arboreal portion subtracted). Currumbene = 1,091m, Conjola = 568m, Jerrawangala = 559m. Measures of each habitat feature (Leaf20-40%, Leaf40-60% etc.) were compared to the first measure for that feature (e.g. Leaf0-20% etc). For this reason, results for the first measure are n/a or 1. Elsewhere n/a indicates that there were no records for that measure. Exp(B) = odds ratio. *P* = significance level. Significant results are shown in bold.

		Currumbene			Conjola			Jerrawangala			All Sites		
		<i>B</i>	<i>P</i>	Exp (B)	<i>B</i>	<i>P</i>	Exp (B)	<i>B</i>	<i>P</i>	Exp (B)	<i>B</i>	<i>P</i>	Exp (B)
Logs	No Logs	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1
	Logs10	0.632	0.111	1.882	0.506	0.199	1.659	0.622	0.067	1.862	0.424	0.036	1.528
	Logs20	0.826	0.101	2.283	1.544	0.011	<b>4.681</b>	1.218	0.004	<b>3.381</b>	1.030	<0.001	<b>2.801</b>
	LogsGtr20	1.724	0.003	<b>5.606</b>	1.331	0.019	<b>3.785</b>	0.634	0.143	1.885	1.085	<0.001	<b>2.959</b>
	Trunk	0.913	0.006	<b>2.491</b>	0.183	0.743	1.201	0.853	0.004	<b>2.346</b>	0.857	<0.001	<b>2.357</b>
Leaf	Leaf0-20%	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1
	Leaf20-40%	0.073	0.924	1.075	0.675	0.152	1.963	-0.030	0.959	0.970	0.378	0.22	1.460
	Leaf40-60%	0.675	0.344	1.964	1.662	<0.001	<b>5.271</b>	0.776	0.159	2.174	1.125	<0.001	<b>3.079</b>
	Leaf60-80%	0.507	0.470	1.661	1.492	<0.001	<b>4.446</b>	1.665	0.002	<b>5.288</b>	1.208	<0.001	<b>3.346</b>
	Leaf80-100%	3.119	<0.001	<b>22.631</b>	3.119	<0.001	<b>22.633</b>	1.802	<0.001	<b>6.061</b>	2.662	<0.001	<b>14.320</b>
Branches	BranchL	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1
	BranchM	0.965	<0.001	<b>2.624</b>	-0.917	<0.001	0.400	0.459	0.046	1.583	0.297	0.014	1.346
	BranchH	1.985	<0.001	<b>7.278</b>	-0.409	0.158	0.665	0.378	0.396	1.459	0.688	<0.001	<b>1.990</b>
GrVeg	GrVeg0-20%	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1
	GrVeg20-40%	0.263	0.341	1.301	0.170	0.494	1.185	-0.940	0.044	0.391	0.137	0.363	1.147
	GrVeg40-60%	0.635	0.025	1.888	0.829	0.011	<b>2.292</b>	-1.267	0.004	0.282	0.332	0.037	1.394
	GrVeg60-80%	1.072	<0.001	<b>2.920</b>	-0.217	0.765	0.805	-1.566	<0.001	0.21	0.203	0.244	1.225
	GrVeg80-100%	1.963	<0.001	<b>7.122</b>	2.313	0.012	<b>10.107</b>	-2.061	<0.001	0.13	0.220	0.243	1.246
ShVeg	ShVeg0-20%	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1	n/a	n/a	1
	ShVeg20-40%	-0.201	0.431	0.818	-0.259	0.344	0.772	0.302	0.217	1.353	-0.063	0.648	0.939
	ShVeg40-60%	-0.226	0.401	0.798	-0.369	0.216	0.692	0.465	0.149	1.592	0.088	0.557	1.092
	ShVeg60-80%	-0.555	0.108	0.574	-1.577	<0.001	0.207	0.302	0.514	1.353	-0.520	0.009	0.595
	ShVeg80-100%	0.337	0.604	1.401	-3.451	0.001	0.032	0.542	0.520	1.719	-0.629	0.066	0.533



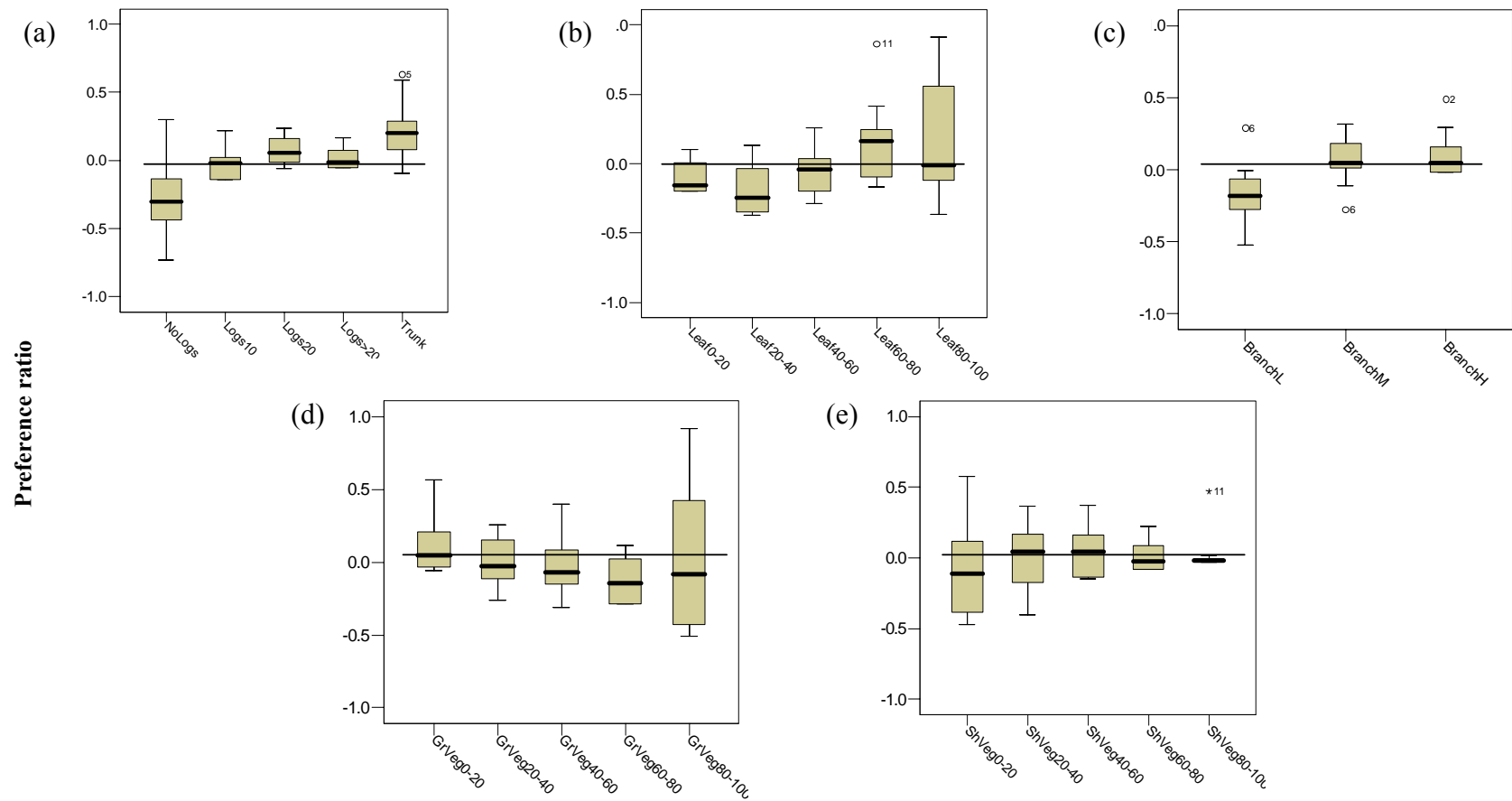
**Figure 4.10 Patterns of habitat use of *Antechinus stuartii* at Currumbene in Autumn of 2006, as revealed by spool-and-line technique (a) Logs, (b) Leaf Litter, (c) Branches, (d) Ground Vegetation (GrVeg) and (e) Shrub Vegetation (ShVeg).**

Average values for the 5 vegetation features in the background habitat were subtracted from average values for 16 spool records (1,419m, = 473 measurement points). Therefore, preference ratio (y-axis) >1 indicates use of a habitat measure by *A. stuartii* more frequently than that feature occurs in the background habitat. Negative values reflect apparent avoidance of those habitat measures. Outliers are represented by symbols (° and \*). Numbers next to these symbols refer to the spool from which the data was sourced. Habitat features are shown on the x-axis.



**Figure 4.11 Patterns of habitat use of *Antechinus stuartii* at Conjola in Autumn of 2006, as revealed by spool-and-line technique (a) Logs, (b) Leaf Litter, (c) Branches, (d) Ground Vegetation (GrVeg) and (e) Shrub Vegetation (ShVeg).**

Average values for the 5 vegetation features in the background habitat were subtracted from average values for 8 spool records (715, = 238 measurement points). Therefore, preference ratio (y-axis) >1 indicates use of a habitat measure by *A. stuartii* more frequently than that feature occurs in the background habitat. Negative values reflect apparent avoidance of those habitat measures. Outliers are represented by symbols (° and \*). Numbers next to these symbols refer to the spool from which the data was sourced. Habitat features are shown on the x-axis.



**Figure 4.12** Patterns of habitat use of *Antechinus stuartii* at Jerrawangala in Autumn of 2006, as revealed by spool-and-line technique (a) Logs, (b) Leaf Litter, (c) Branches, (d) Ground Vegetation (GrVeg) and (e) Shrub Vegetation (ShVeg).

Average values for the 5 vegetation features in the background habitat were subtracted from average values for 12 spool records (545m = 182 measurements). Therefore, preference ratio (y-axis)  $>1$  indicates use of a habitat measure by *A. stuartii* more frequently than that feature occurs in the background habitat. Negative values reflect apparent avoidance of those habitat measures. Outliers are represented by symbols (° and \*). Numbers next to these symbols refer to the spool from which the data was sourced. Habitat features are shown on the x-axis.

#### 4.3.2.3 Comparison of *R. fuscipes* and *A. stuartii*

Both species showed an association with logs. There was also a trend for both to preferentially use branches while moving through habitat, though evidence for this was weaker for *A. stuartii* than for *R. fuscipes*. While *R. fuscipes* used regions with higher measures of shrub vegetation, the same pattern did not emerge for *A. stuartii*. The latter was strongly associated with leaf litter at all sites, a habitat use characteristic not recorded for *R. fuscipes*.

#### 4.3.4 Associated Habitat Features

The robust logistic regression of habitat use by *R. fuscipes* revealed some significant associations between logs and shrub vegetation, though clear, consistent patterns in the results were not obvious. Use of larger logs tended to be significantly associated with low measures of shrub cover (e.g. for Logs20 and Shrub20-40%,  $B = -2.260$ ,  $t = -3.989$ ,  $P = 0.0001$ ), i.e. *R. fuscipes* tended to be more attracted to logs in the absence of shrub vegetation (Appendix 9(a)).

Robust logistic regression applied to habitat utilisation data recorded from *A. stuartii* showed an association between ground vegetation and leaf litter. I found that in the absence of leaf litter, regions of the habitat with higher measures of ground vegetation were preferentially used (Appendix 9(b)). There was also some evidence of an association between ground vegetation and shrub vegetation, such that attraction to regions of habitat with abundant ground vegetation increased when shrub vegetation is also abundant (Appendix 9(c)). The final significant result of the robust logistic regression was that regions of the habitat with a combination of little leaf litter and few branches are particularly unattractive to *A. stuartii* (Appendix 9(d)).

#### 4.3.5 Arboreality

*Rattus fuscipes* occasionally left the forest floor, following a path along branches or fallen trunks. However, evidence of vertical ascents of trees was uncommon and typically not greater than a 1.5m off the ground. For this reason arboreality was not quantified. *Antechinus stuartii* displayed strong arboreal tendencies (Fig. 4.13 & Fig. 4.14(a) & (b)). Almost 20% (567m) of the habitat use records for this species (2,785m) referred to movement in trees (Table 4.5).

**Table 4.5 Summary of tree climbing activity (arboreality) by *Antechinus stuartii* at three trapping sites in summer and autumn 2006.**

Recorded from 36 *A. stuartii* individuals at Conjola, Currumbene and Jerrawangala. Standard deviation is shown in brackets.

Site (no. of spools)	Total distance in a tree (m)	Average no. tree climbs/spool (Total = 8)	Average length (m) of tree climb	Average distance (m) between climbs	Total no. points on spool	Overall % of spool points in trees
Conjola (n=8)	150	2.38 (1.51)	7.9 (4.5)	26.3 (31.2)	718	20.9
Currumbene (n=16)	330	2.38 (1.78)	8.7 (6.7)	18.4 (20.7)	1421	23.2
Jerrawangala (n=12)	87	1 (1.21)	7.6 (7.2)	23.4 (14.4)	646	13.5
<b>Total</b>	<b>567</b>	<b>69</b>	<b>567</b>	<b>891</b>	<b>2785</b>	
<i>Average for all three sites</i>	189	1.92	8.1	22.7	928.3	19.2
Standard deviation of all values	46.29	1.71	6.2	23.9	46.3	

n=number of spools recorded per site.

The number of tree climbs in each spool largely depended on the length of the spool and varied between individuals. There were more than twice as many tree-climbs per spool (average = 2.38) at Conjola and Currumbene than at Jerrawangala (1) (SD = 1.71) (Table 4.5). The length of tree-climbs varied ranging from 3m to 30m, averaging approximately 8m (SD = 6.21). Average distance travelled by animals between separate tree climbs also varied greatly (Appendix 10), and was shortest at Currumbene (18.36m) and greatest at Conjola (26.25m). Some climbs extended considerable distances (up to 20m) into the canopy (Fig. 4.13).

**Figure 4.13** *Antechinus stuartii* was frequently observed to climb trees to a considerable height.

This climb into a eucalypt tree measured more than 20m and was recorded at Currumbene in February 2006.

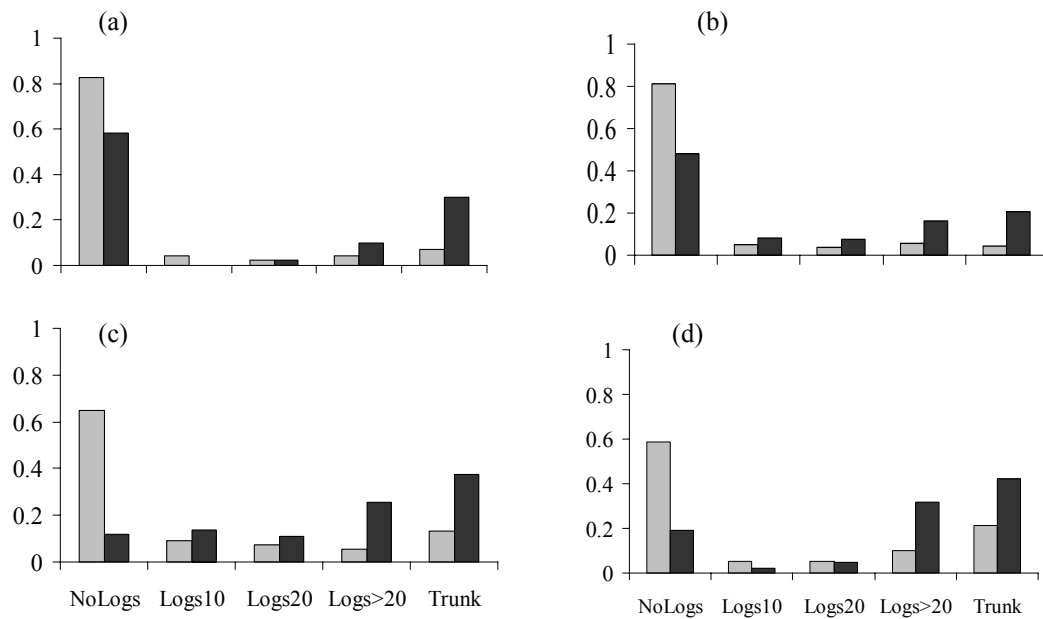
**Figure 4.14 (a) & (b) The spool-and-line technique revealed strongly arboreal tendencies in *Antechinus stuartii*.**

(a) Evidence of the ascent of a banksia tree at Currumbene (b) The animal's path on a branch of a eucalypt tree at Jerrawangala.

### 4.3.6 Log Use

#### 4.3.6.1 *Rattus fuscipes*

Early in the study, details on the nature of the log use (e.g. on a trunk off the ground versus along log at ground level) and branch use were not recorded, though the decision was made to record this detail once spooling of *A. stuartii* was commenced later in the study. Although 11% of the data describing the background habitat featured trunks, approximately 32% of all *R. fuscipes* spool data referred to movement along these features. There was a similar threefold difference for the second largest log size category. These trends were also clear at the site level (Fig. 4.15). Differences between log use by *R. fuscipes*, and log availability were less distinct for the small log size classes although, for every site, it was clear that areas without any logs were used less commonly by *R. fuscipes*.



**Figure 4.15 Comparison of the proportion of logs of each size category in the background habitat versus the spool dataset recorded from *Rattus fuscipes*.**

(a) Currambene, (b) Conjola, (c) Parnell (d) Jerrawangala ■ = proportions in the background habitat, ■ = proportions in the spool dataset.

#### 4.3.6.2 *Antechinus stuartii*

The main logistic regression conducted to investigate habitat associations of *A. stuartii* excluded portions of log use where the animals were off the ground (Section 4.2.3), therefore the actual log use in this analysis was consequently underestimated. The subsequent separate regression of all log use (independent of other habitat features) provided a more realistic impression of log use. In this analysis across all sites, the three largest log categories were over three times more likely to be selected by *A. stuartii* than areas with no logs ( $P < 0.001$  in all cases) (Table 4.6). At the site level, the same pattern emerged; *A. stuartii* showed a significant association with logs 10-20cm (diameter), logs 20-50cm and trunks. The only exception to this was at Currambene, where the trend was there but not statistically significant.

**Table 4.6 Results of logistic regression of all log use data recorded from *Antechinus stuartii* in a spool-and-line study at four sites.**

The length of spool data recorded at each site varied. Currumbene (Cur) = 16 spools (1,421m), Conjola (Cnj) = 8 spools (718m), Jerrawangala (Jer) = 12 spools (646m). In this analysis, measures of each feature are compared to the first (i.e. No Logs). For this reason, results for the first measure are n/a or 1. Exp(B) represents the likelihood of a measure being selected relative to 'NoLog'. Significant results are in bold.

	NoLog			Logs10			Logs20			Logs>20			Trunk		
	B	P	Exp(B)	B	P	Exp(B)	B	P	Exp(B)	B	P	Exp(B)	B	P	Exp(B)
<b>Cur</b>	n/a	n/a	1	0.110	0.710	1.120	0.720	0.080	2.050	1.300	0.010	<b>3.630</b>	1.280	<0.001	<b>3.600</b>
<b>Cnj</b>	n/a	n/a	1	0.380	0.260	1.480	2.000	<0.001	<b>7.390</b>	1.660	0.001	<b>5.280</b>	1.090	0.001	<b>2.990</b>
<b>Jer</b>	n/a	n/a	1	0.571	0.056	1.770	1.690	<0.001	<b>5.400</b>	1.320	<0.001	<b>3.760</b>	1.730	<0.001	<b>5.630</b>
<b>All</b>	n/a	n/a	1	0.280	0.120	1.330	1.350	<0.001	<b>3.850</b>	1.270	<0.001	<b>3.570</b>	1.400	<0.001	<b>4.050</b>

On average, 13.4% of the total length of the 36 *A. stuartii* spools involved movement along logs, branches and trunks (Table 4.7) and more than half of this referred to movement on logs or trunks off the ground. This, however, varied greatly from spool to spool (Appendix 11). Animals at Jerrawangala used these features most commonly, with 29% of the total length of all spools composed of log, branch and trunk (LBT) use. This was more than twice as much as the LBT use at Currumbene (Fig. 4.16).

**Table 4.7 Composition of log use data from 36 *Antechinus stuartii* involved in a spool-and-line study at three trapping sites (Conjola, Currumbene and Jerrawangala) in February and April 2006.**

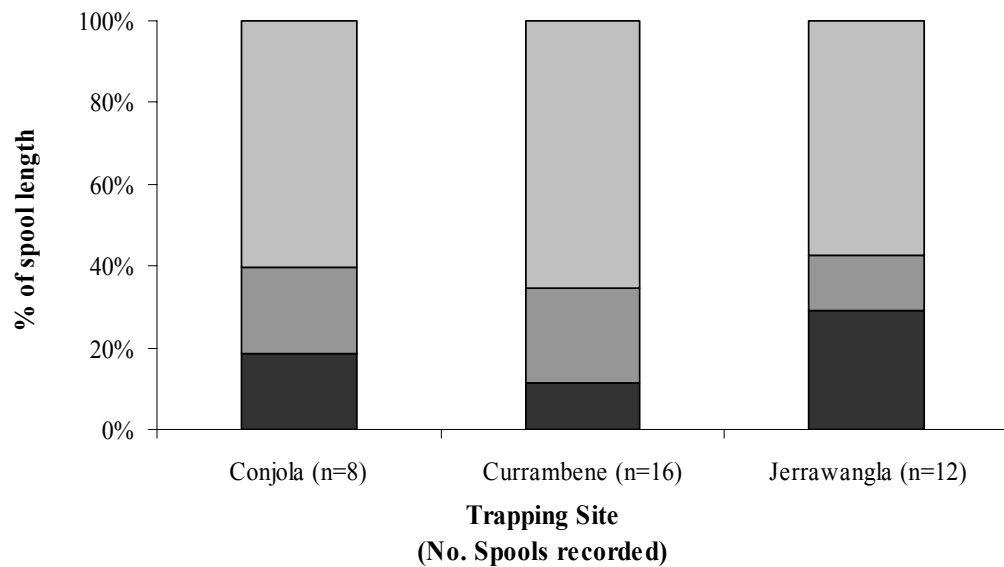
The values are the percentage (%) of total length of spool data (m) recorded at each site.

Site (n = No. of spools)	% Following log at ground level	% On log/trunk off the ground	% On branch off the ground	Total log/branch use (% all spools)
<b>Conjola (n=8)*</b>	5.0	8.4	5.2	18.5
<b>Currumbene (n=16)#</b>	2.5	5.9	2.7	11.2
<b>Jerrawangala (n=12)^</b>	7.4	16.7	5.1	29.3
<i>Site Average</i>	<b>5.0</b>	<b>10.3</b>	<b>4.3</b>	<b>19.7</b>
<i>All Spool Average</i>	3.3	7.0	3.0	13.4

\*Total length = 712m, # = 1419m, ^ = 650m

For *A. stuartii*, log use and arboreality combined accounted for a substantial portion of the total length of all spools. Furthermore, when data from each site were pooled, there was remarkable consistency in the composition of the spools; at Currumbene, Conjola

and Jerrawangala, approximately 40% of all spool data from *A. stuartii* described movement in trees or along logs, branches and trunks (Fig. 4.16).



**Figure 4.16 Composition of spool data with regard to log use and arboreality by *Antechinus stuartii* as revealed by 2,781m of spool-and-line data recorded at three sites (Conjola, Currumbene and Jerrawangala.**

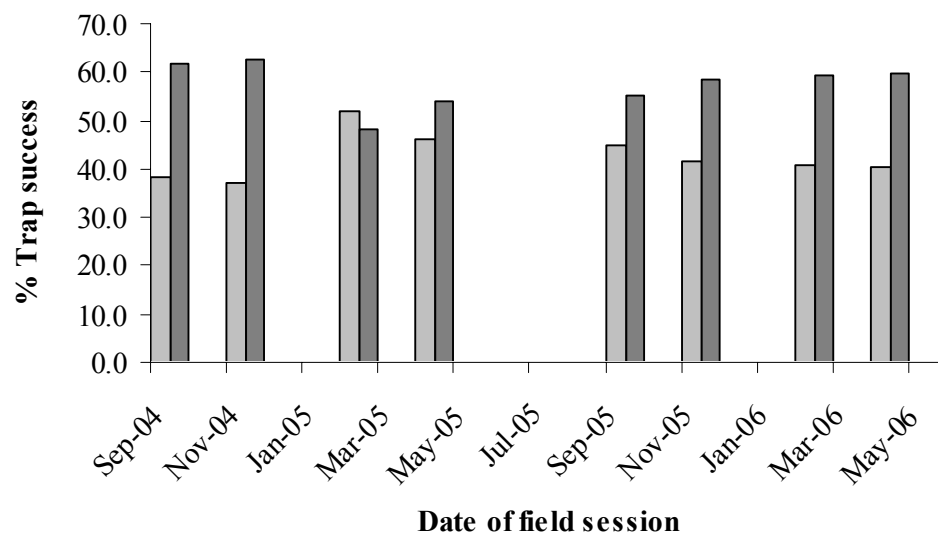
■ = % of all spools at ground level, ■ = % in tree, ■ = % along logs or trunks or branches. n = number of spools recorded at each site.

Though informative about the composition of LBT use, these measures are more meaningful when examined in the context of the availability of each of the habitat features at each site (Section 4.3.2.2). General patterns of log use are supported by my earlier findings that *A. stuartii* favour larger logs (Fig. 4.9 (a) & Table 4.4) and tend not to be recorded in regions lacking these features.

**Figure 4.17 Evidence of typical behaviour of *Antechinus stuartii* moving amongst and between logs in its habitat at Jerrawangala trapping site.**  
(Photograph: Victoria Bennett, April 2006)

#### 4.3.7 Edge Preference

There were proportionally more captures in the interior than at the edge for seven of the eight trapping sessions (Fig. 4.18). If each session at each side of each site is considered a 'case', there were more captures in the interior in 28 of the 32 cases (eight trapping sessions, four sites, two sides per site). When recaptures were excluded from the analysis, the pattern still held true, with more individuals captured at the interior than at the edge for both *R. fuscipes* and *A. stuartii*. There was just one exception to this (at Conjola) where equivalent numbers of *R. fuscipes* were captured in the edge and interior regions. For *R. fuscipes* at Currambene, significantly more animals were captured at the interior ( $\chi^2=5.78$ ,  $df=1$ ,  $P=0.016$ ), while for *A. stuartii*, the same pattern was evident and significant at both Parnell ( $\chi^2=5.78$ ,  $df=1$ ,  $P=0.016$ ) and Jerrawangala ( $\chi^2=6.34$ ,  $df=1$ ,  $P=0.012$ ).



**Figure 4.18** Trap success (%) of *Rattus fuscipes* and *Antechinus stuartii* at the edge and interior regions of the trapping grid during each of eight trapping sessions.

■ = edge captures, ■ = interior captures.

Analysis of variance revealed that of the five habitat features, logs, leaves and shrub vegetation showed the most meaningful patterns of variation among easement sites, sides and location (edge or interior) (Appendix 12). Logs were generally bigger at the edges, with the exception of Jerrawangala, where little difference was found. Shrub vegetation also tended to be denser at the edges at each site except Jerrawangala (Appendix 13), where the difference between the edge and the interior shrub vegetation depended on the side ( $P < 0.001$ ). Conversely, there tended to be more leaf litter in the interior, except for at Conjola where there was little difference (Appendix 13).

There was a significant effect of site ( $P = 0.004$ ) and location ( $P < 0.001$ ) on logs, as well as a site\*location effect, meaning that the magnitude of the location effect is site-dependent. For leaves, all of the main effects, with the exception of the 3-way interaction (site\*side\*location), were significant. In other words, the amount of leaves at the edge and interior varied with location (more leaves in interior regions), except at Conjola where no difference was recorded. Furthermore, the magnitude of the difference between the edge and interior depended on the side of the easement.

Analysis of branches revealed a similar pattern, the key difference being that for this habitat feature, the 3-way interaction returned a significant result ( $P=0.002$ ). This result indicates that the effect of side depends on the site and the effect of location depends on both side and site. This 3-way interaction also applied to ground vegetation ( $P=0.018$ ), although the location effect was not significant ( $P=0.136$ ).

Finally, there was more shrub vegetation at the edge of all sites except at Jerrawangala, where there was less at the edge. This pattern of more shrub vegetation at the edge tended to be more pronounced on one side of the easement than the other (Appendix 13).

#### 4.3.8 Other Field Observations of Habitat Use

A tuft of fur, originating from where the spool had been stuck to the animal, was often present when I recovered a spool (Fig. 4.19(a)). Typically, spooled animals would eventually remove the entire spool and casing, which I would then encounter while recording the spool trail. On other occasions, the animal appeared to have stopped at a secluded place in the habitat, removed fragments of the plastic spool casing and drawn out the thread from the spool (Fig. 4.19(b)). Other places where spools removed by the animals were most commonly found are under logs, in recesses or hollows, and inside hollow trunks (e.g. Fig. 4.20 & Fig. 4.21). A further observation made while spooling was that *A. stuartii* made regular visits to the inflorescences of *Banksia spinulosa* (Fig. 4.22).

**Figure 4.19 Examples of spools that had been removed by *Rattus fuscipes* and *Antechinus stuartii*.**

(a) Evidence of fur remaining on the spool where it was stuck to the animal. (b) Thread drawn out of the casing as the animal attempted to remove the spool, fragments of plastic casing to the left of the thread.

**Figure 4.20 Location of a spool, removed by *Antechinus stuartii* - in a recess or hollow.**

Thread trail at the edge of this hollow trunk reveals the path of the animal just before the spool was shed.

**Figure 4.21 Location of a spool, removed by *Antechinus stuartii* - inside a hollow trunk.**

**Figure 4.22 *Antechinus stuartii* showed frequent evidence of feeding on nectar-rich plants, such as this *Banksia spinulosa* inflorescence.**  
(Photograph: Victoria Bennett)

Additionally, animals clearly made a habit of entering hollows at ground level as well as tree crevasses, sometimes re-emerging and continuing with a movement path (Fig.

4.23(a) & (b), Fig. 24(a) & (b)). *Rattus fuscipes* in particular was given to skirting around tree trunks. In both *R. fuscipes* and *A. stuartii*, the spools showed evidence of doubling back and zig-zagging just before removal of the spool (Fig. 4.25).

**Figure 4.23 Spool trails were frequently found to enter crevasses and hollows (a) in living and dead tree trunks, and spools were by times discarded at these locations (b).**

**Figure 4.24 (a) & (b) Photographs show the typical behaviour of *Antechinus stuartii* of entering hollows while moving through the bush.**

This was more common in *A. stuartii*, though *Rattus fuscipes* occasionally showed similar behaviour

**Figure 4.25** Example of log use by *Rattus fuscipes*, including evidence of ‘doubling back’ (several parallel strand of thread), that frequently occurred just before the spool was shed.

A further field observation regarding the movement patterns of small mammals was the regular use of common tracks and trails, particularly by *R. fuscipes*. A tendency for these tracks and trails to skirt the edge of the habitat adjacent to the easement was observed. There were clear ‘runways’ in the bush that were repeatedly used both by the same individual and other conspecifics. Finally, some spooled animals were, on occasion, encountered in traps with the spool recently removed and lying in the trap, or, with the spool still adhering.

#### 4.4 DISCUSSION

*Rattus fuscipes* and *A. stuartii* both showed a positive response to the presence of logs. They strongly avoided areas without any logs and tended to use areas featuring logs of a wider diameter. *Rattus fuscipes* was positively associated with branches and denser measures of shrub vegetation, though similar patterns were not detected for *A. stuartii*. Regions of the habitat with a high percentage cover of leaf litter were preferentially used by *A. stuartii* but not *R. fuscipes*. Additionally, the paths of *A. stuartii* revealed a significant arboreal tendency. Both species showed slight edge aversion, though this

was not easily explained by local vegetation characteristics such as logs, ground vegetation or leaf litter.

#### 4.4.1 Habitat Use by *R. fuscipes*

A number of recurring patterns of habitat use were encountered in the course of recording the 66 *R. fuscipes* spools. The first of these was the preference for areas of dense vegetation, as reflected in the positive association with dense shrub vegetation (>30cm) at all but one of the sites. This did not come as a surprise given the reports in the literature of selection by this species of areas with forest (Newsome & Catling, 1979), structural complexity (Barnett *et al.*, 1978; Catling, 1991) or simply vegetation cover (Stewart, 1979; Cox *et al.*, 2004). The highest trap success also correlated with the most structurally dense site, Parnell, which concurs with the finding of Catling (1991), that greater forest complexity is usually associated with higher abundance and species richness of mammal fauna. However, *R. fuscipes* is wide-ranging in its habitat associations and its response to habitat can vary with food niche which is subject to change both seasonally and regionally (Barnett *et al.*, 1978). Therefore the relationship between this species and habitat is not straightforward.

Contrary to previous reports (Lunney & Ashby, 1987; Menkhorst & Knight, 2004) which have shown an association between *R. fuscipes* and ground vegetation, my results did not generally reveal this pattern. Only one of the sites, Conjola, displayed significant selection by *R. fuscipes* for areas with abundant ground vegetation. This result may be related to interactions with other habitat features or plant types present at Conjola but not at the other sites in this study. The general lack of any association between *R. fuscipes* and ground vegetation at Conjola is not entirely unsupported by existing studies. For example, Tasker and Dickman (2002) report that *R. fuscipes* actually avoided dense vegetation <30cm in height. Cases of negative association with ground vegetation were occasionally detected in my study, though none were significant. Perhaps, as Bakker (2006) suggests, dense vegetation may be more energetically expensive to move through because the animals must physically push aside stems or follow a more tortuous path to avoid them. It is possible that dense ground vegetation may impede the movement of *R. fuscipes* (Dickman & Steeves, 2004), unlike taller vegetation, which has tall stems that do not impede movement, yet still provides shelter.

Few studies report an association between *R. fuscipes* and litter. My study similarly failed to detect any relationship. One study that does describe use of (deep) litter by *R. fuscipes* is that by Catling (1986), though in this study it is specified that this was in the heathland context, where shrubs were tall. A second study by Dickman and Steves (2004) also investigated the relationship between *R. fuscipes* and litter, though the focus in that investigation was on the depth, rather than the % ground cover of leaves, as in my study. Although Dickman and Steeves (2004) found that *R. fuscipes* generally favoured sites with leaf litter, amongst other features, no consistent patterns were found.

The association detected between logs and shrub cover (Section 4.3.4) may stress the importance of logs in the movement paths of *R. fuscipes*. As outlined in Section 4.3.2.1, *R. fuscipes* showed a preference for regions of habitat featuring abundant shrub vegetation. In the absence of this feature however, it appears that use of an alternative preferred habitat feature (logs) is increased. Research has often shown a preference of *R. fuscipes* to travel along logs, a pattern that also was recorded in my study. Logs are used by *R. fuscipes* for shelter by day (Dickman & Steeves, 2004) and for foraging and cover by night (Stewart, 1979; Dickman, 1991). However, Stewart (1979) reported an exception to this, suggesting that logs become less important in the presence of abundant ground cover. In my study there was a statistically significant preference for logs by *R. fuscipes*, even at Parnell where ground cover was extremely high. In a study of *Peromyscus leucopus* in Maryland USA, Barnum *et al.* (1992) showed that this species favoured logs as a movement medium. They went on to suggest that this may be attributed to the silent passage afforded by the hard, solid surfaces of logs, thus potentially minimising detection by predators (Barnum *et al.*, 1992). Alternatively, as suggested by McMillan & Kaufmann (1995) structural features such as logs provide paths that are more easily travelled and remembered. These observations may also explain the high levels of log use by *R. fuscipes* in my study.

A further interesting phenomenon revealed by the spool-and-line technique was the use of ‘runways’ or regularly used pathways through the bush. This is consistent with the findings of Stewart (1979). A similar habit has also been reported for the closely related *Rattus lutreolus* (Catling, 1986).

Unlike *A. stuartii*, which regularly exhibited arboreal behaviour, (often to a considerable height), *R. fuscipes* generally remained at ground level, occasionally coursing along networks or logs or branches within a metre of the ground. Wood (1971) also found that they rarely left the forest floor. Dickman and Steeves (2004) explained that *R. fuscipes* is a poor climber. Although they reported that tree hollows have been used by this species, they also note that such hollows are not consistently required and that the use observed may be more a reflection of selection for other habitat components such as leaf litter.

*Rattus lutreolus* and *R. fuscipes* were both captured at Parnell. These species have similar habitat use characteristics and both often feature in the same trapping studies (e.g. Barnett *et al.*, 1978; Friend, 1979). *Rattus lutreolus* is associated with wetter, more swampy regions (Monamy & Fox, 1999), while *R. fuscipes* tends to occupy woodland habitats (Maitz & Dickman, 2000). Secondly, research has shown that although similar in some aspects of their ecology, their diet does not necessarily overlap even where they co-exist (Cheal, 1987). At the study site in Victoria where Cheal conducted his study, *R. fuscipes* favoured fleshy fruit, seed and arthropods in summer, while *R. lutreolus* fed predominantly on grasses and herbs. In contrast to this, experimental removal of *R. lutreolus* led to a 6.5-fold increase in the capture of *R. fuscipes* in a field enclosure containing both sedge and woodland, indicating intense interference-mediated competition (Maitz & Dickman, 2000). However, as with *S. murina*, the total number of captures of *R. lutreolus* was infrequent and the species was absent from some of my sites, unlike *R. fuscipes*, which was relatively common at all sites. For these reasons, I do not consider that *R. lutreolus* had a significant impact upon the patterns of habitat use recorded for *R. fuscipes*. Attempts were made to spool *R. lutreolus*, though these attempts were largely unsuccessful for a number of reasons. Firstly, *R. lutreolus* has more wiry, less dense hair than *R. fuscipes*. This may explain the poorer adhesion of the spools. On the rare occasions that this species was captured, the behaviour was more aggressive than *R. fuscipes*. Spooled animals were observed to stop to remove the spool immediately after release, unlike *R. fuscipes*, which tended to bound away and remove the spool later.

#### 4.4.2 Habitat Use by *A. stuartii*

There was a number of differences in the microhabitat use by *A. stuartii* compared with that of *R. fuscipes*. Broadly speaking, *A. stuartii* is associated with dense undergrowth and a large number of logs (Statham & Harden, 1982). However, Statham & Harden (1982) also noted that, for *A. stuartii*, the concept of habitat is very complex. For example, in their study vigorous growth of the shrub layer was not matched by a concurrent increase in numbers of *A. stuartii*. Furthermore, the literature describing habitat preferences of this species is often conflicting, suggesting there are several factors that may influence how *A. stuartii* uses habitat. Some studies, for example, have failed to find any association with habitat features such as logs, previously recognised as important to this species (Stewart, 1979; Wilson *et al.*, 1986). Stewart (1979) conceded that this result may be attributable to the existence of associations with other unrecorded variables. Statham and Harden (1982) cautioned however, that the recording of more variables may not necessarily help to solve the problem because different factors can come into play at different times and at intensities.

In my study, there was compelling evidence for an association between *A. stuartii* and leaf litter. Reports of preference for this habitat feature in the literature are surprisingly uncommon (but see Cunningham *et al.* (2005) and Barnett (1978)) given that *A. stuartii* is known to feed on litter invertebrates (Fox *et al.*, 1979; Dickman *et al.*, 1983; Green, 1989). The importance of leaf litter to *A. stuartii* as a habitat feature was supported by robust logistic regression (Section 4.3.4), in which interactions between leaf litter and other habitat features were found. Although leaf litter is the habitat feature with which *A. stuartii* were most strongly associated, in the absence of litter, a preference for ground vegetation was detected. Perhaps this is indicative of a hierarchical system of habitat preferences, in which alternative habitat features are utilised if the most favoured feature is absent. Both Branches and Leaf Litter were associated with *A. stuartii* to varying degrees (Table 4.4). It is not surprising therefore, that habitat regions lacking the combination of these features were negatively associated with *A. stuartii* (Section 4.3.4).

Though exceptions do exist, as mentioned above, one habitat feature consistently reported to be important for *A. stuartii* is logs (Barnett *et al.*, 1978; Knight & Fox, 2000;

Cox *et al.*, 2004). I detected a positive relationship between *A. stuartii* and larger categories of logs, and a negative relationship with areas without any logs. Settle & Croft (1982) suggest that logs may provide *A. stuartii* with nesting sites. In addition to this, research has shown that in Tropical North Queensland, logs can provide a valuable refuge for invertebrates (Braithwaite, 1979) and may in turn provide an important food source for *A. stuartii*. Research conducted in Sydney has reported that two families of beetle (Carabidae and Leiodidae), both likely food items for *A. stuartii*, were associated with logs, amongst other habitat features (Lassau *et al.*, 2005). Litter arthropods have also been shown to be a major component of the diet of *R. fuscipes* (Warneke, 1971). Dunnarts have been shown to follow trails that feature more numerous and larger sources of invertebrate prey (Haythornthwaite, 2005). *Antechinus stuartii* may be using a similar strategy when following logs through habitat. Logs may provide *A. stuartii* with noiseless transit through habitat (Barnum *et al.*, 1992) as suggested for *R. fuscipes* in Section 4.4.1. Though this theory seems plausible, it is, nonetheless, curious that in my study, the habitat feature that was repeatedly selected for most strongly at each site was leaf litter, a ‘noisy’ travel medium. Perhaps there is a trade-off between the increased predation risk incurred while traversing regions with leaves, and the rich food reward that may be gained in the form of invertebrate prey. A final possible explanation for log use by *A. stuartii* is that the logs themselves may serve as refuges (Barnett *et al.*, 1978).

According to Knight & Fox (2000), a tall and even understorey is an important element of structure for *A. stuartii*. Barnett (1978) and Bennett (1993) both reported significant associations between *A. stuartii* and vegetation of lower height classes. This pattern did not emerge in my investigations, as only at Currambene was there evidence of a significant preference for dense ground vegetation. In all habitats surveyed by Statham and Harden (1982), a thick shrub layer was a feature at the capture locations of *A. stuartii*. In my study, logistic regression failed to detect a significant association with shrub vegetation at any site. The only association with shrub vegetation detected was in combination with ground vegetation, as revealed by robust logistic regression (Section 4.3.4). This is peculiar given the reports that a complex understorey, which is highly correlated to taller understorey, is important to *A. stuartii* for the provision of a heterogenous food source as well as nesting habitat (Knight & Fox, 2000). One theory

which may explain this lack of a significant association with shrub vegetation is the presence at my sites of nectar-bearing shrubs and trees, as well as numerous dead, hollow trees, or trees with hollows (pers. obs.). Furthermore, a history of bushfire in the region may explain the accumulation of logs, branches and other debris at ground level. These factors combined may accentuate the use of logs, branches and trees relative to shrub or ground vegetation. Also relevant to this discussion is the observation by Statham and Harden (1982) of the spatial and temporal variability of observed patterns of habitat use by *A. stuartii*.

*Antechinus stuartii* is known to nest in tree hollows (Dickman, 1982). In a study by Dickman and Steeves (2004), tree hollows emerged as statistically significant predictors of abundance of this species. In these studies, and in mine, *A. stuartii* is likely to be seeking invertebrate prey in the boughs and hollows of the trees, or, depending on time of year, to be raising young in these locations. The arboreal tendencies of *A. stuartii* previously reported are based on captures made in trees (Wood, 1970; Lazenby-Cohen & Cockburn, 1991), on spool-and-line studies (Carthew, 1994), and on records of nesting in the hollows of trees (Dickman, 1982). I found that *A. stuartii* would occasionally climb into and around the branches of shorter trees and tall trees such as *Banksia* spp. as well as climb straight up tall eucalypts up to 20m into the canopy. This mirrors the findings of Wood (1970), who reported capturing two *A. stuartii* individuals in a tree at a height of approximately 24m from the ground. I observed that *A. stuartii* frequently climbed trees, of varying height and foliage-cover, and then entered crevasses and hollows in the trunk (Fig. 4.23). It was not uncommon for a thread trail to disappear into the upper reaches of a tree, apparently without returning to ground level, suggesting the spool was shed by *A. stuartii* while in the tree. Wood (1970) found no preference for tree size or the degree of cover on the tree, though he did report that more arboreal activity took place in winter than in summer. Because the phase of my study in which *A. stuartii* was spooled was in late summer/early autumn only, seasonal patterns in arboreality could not be detected.

A combination of anatomical mal-adaptation and larger body size is likely to limit the tree-climbing activity of *R. fuscipes*. As Wells *et al.* (2006) explain, dissimilarities in body size and morphology can account for differences in observed movement patterns

of non-congeneric species. While captures of *R. fuscipes* and *A. stuartii* in my study certainly confirmed some macrohabitat overlap and similarities in habitat selection, they are unlikely to be in direct competition. Both species will eat arthropods, but *R. fuscipes* will also feed on fungi, seeds and fruit (Menkhorst & Knight, 2004). Spool-and-line studies revealed differences in microhabitat preferences that are likely to further explain the co-existence of these species. Results from my study support the findings of Lindenmayer *et al.* (1994), who also reported a degree of partitioning of the use of the forest environment by the two species. Similarly, (Wells *et al.*, 2006) describe how in species-rich communities, segregation of small mammals along vertical strata can favour coexistence of small mammals. Specific manipulative experiments at my sites would be required to investigate how the habitat selection patterns of one of these species are affected by the abundance of the other species with similar habitat requirements.

*Sminthopsis murina*, also captured in this study, is a nocturnal, insectivorous dasyurid with similar dietary requirements to *A. stuartii* (Fox, 1982a). Once again, direct interference competition is not suspected to be a key explanation for the observed habitat use patterns of *A. stuartii*. This is because, consistent with previous findings (Fox, 1995; Monamy & Fox, 2005), *S. murina* was captured infrequently and at two sites only. This is thought to reflect low population densities and may also be related to the reported reciprocal abundance of these two species (Fox, 1982a). Perhaps also, the evidence that *S. murina* has the ability to switch microhabitat preference if necessary (Monamy & Fox, 2005) indicates that interference competition between the two species may be avoided.

The discovery that logs are used preferentially by both *R. fuscipes* and *A. stuartii* is useful from a conservation perspective given the amenability of this feature to manipulation in management projects. However, knowledge of the attributes of particular species before such action is implemented is important, because as McCay (2000) explained, similar small mammals can exhibit quite different habitat use patterns.

#### 4.4.3 Disturbance

After a fire, the two most important elements that drive faunal communities are habitat and floristics (Sutherland & Dickman, 1999). All four of my study sites burned in the very severe summer bushfires of 2000-2001. How the populations of small mammals at my sites were affected by the 1999-2000 bushfires in the area is not known, though trap success at all sites, and particularly at Parnell, indicate substantial current populations. Furthermore, the gradual accumulation of burnt and partially burnt branches, trunks and logs may actually enhance the habitat for my study species. Many species of small mammal are positively associated with habitat complexity (Newsome & Catling, 1979). For example, at Parnell, the habitat was almost impenetrable in places, such was the density of debris dating from the bushfire event. At all sites there was frequent evidence of the use of fallen material and burnt logs for shelter and as part of movement pathways.

Anthropogenic disturbance generally has a negative effect on biodiversity (e.g. Kemper, 1990; Dunstan & Fox, 1996; Watkins *et al.*, 2003; Cox *et al.*, 2004; Wayne *et al.*, 2005). Laurance (1991a) suggested that habitat disturbance and isolation may act in synergy to exacerbate the impacts of fragmentation on forest dependent species. Because powerlines are known to inhibit the movement of small mammals, efforts need to be focused on reducing other forms of disturbance where they occur (see Section 2.4.4).

One inherent feature of habitat fragmentation is the generation of extensive tracts of edge habitat (Laurance & Yensen, 1991). As described in Chapter 2, large areas of edge-habitat are generated by the construction of powerline easements. Though traditionally considered valuable habitat for wildlife (Leopold, 1933), it is now recognised that edge habitat can negatively impact on wildlife communities (Yahner, 1988; Murcia, 1995; Temple, 1998; Maina, 2003). Stevens & Husband (1998) reported lower species abundance and diversity of small mammals closer to edges. At each site in my study fewer captures were made at the edge than the interior. This was almost always the case for both *R. fuscipes* and *A. stuartii*, and in some instances was statistically significant. I did not quantify abiotic factors such as air temperature and relative humidity, though previous studies have suggested that abiotic gradients from

the edge to the forest interior may explain observed abundance patterns (e.g. Stevens & Husband, 1998). Multivariate analysis of habitat features including logs, branches and shrub vegetation failed to identify consistent patterns that would explain the higher incidence of captures at interior regions of the grids. In fact, curiously, the results indicated that shrub vegetation and larger logs tended to feature at edge versus interior regions of the grid. These were both features to which *R. fuscipes* in particular responded positively. However, the multivariate analysis did confirm that, in general, leaf litter tended to be more abundant in the interior. *Antechinus stuartii* was strongly associated with this feature, which may be related to the greater number of interior captures for this species.

In contrast to my evidence of slight avoidance of edges, studies elsewhere report both neutral (Crooks, 2002) and positive (Harding & Gomez, 2006) effects of edges. Furthermore, the strength of the edge effect can vary depending on the matrix structure (Ewers & Didham, 2006). In conclusion, as Heske (1995) cautioned, definitive statements regarding edge effects must be restricted to a limited sample of species. To assess the generality of the edge effect in mammal communities, replicated, comparative studies are required (Yahner, 1988).

#### 4.4.4 Comment on Statistical Technique

An example of a simple preference index to compare proportional microhabitat use and availability was provided by Haythornthwaite (2005). She calculated proportional microhabitat use and availability using percentage difference in mean distances travelled by *Sminthopsis youngsonii* through each habitat. My analysis was similar to this initially, in order to produce boxplots that provided visual representations of patterns. Negative values showed avoidance of a particular habitat feature, positive values indicated the opposite trend. In compositional analysis, these data are subjected to a multivariate analysis of variance (MANOVA). This approach is quite common in ecological studies involving animal tracking (e.g. Pendleton *et al.*, 1998; Bos & Carthew, 2003). As mentioned in Section 4.2.5.2, there are a number of weaknesses with this analytical strategy. Compositional analysis is best applied when there is a small number of categories and when the sample area is clear-cut. Furthermore, analytical complications arise when habitats are not available to animals, or when

habitat is available, but is not used (i.e. zero values in the dataset). Finally, when the data are summarised to the site and individual animal level respectively, in order to deal with the issue of correlated data points, much of the detail contained within the data is lost.

For the majority of my analyses of habitat utilisation, I therefore used simple logistic regression. In the logistic regression I conducted, the dependent variable was Source (Source = 1 = spool data; Source = 0 = background data) (Appendix 7). A further advantage of this technique is that all recorded points are utilised, instead of aggregating to the individual animal level. There are, however, some weaknesses associated with this method. Firstly, autocorrelation, meaning that each step taken by a wandering animal is correlated to the previous one (Elston *et al.*, 1996; Benhamou, 2004).

Autocorrelation describes the degree to which an animal's position at a given time is dependent on the position of the animal at some previous time (Bell, 1991). For example, because spools in my study recorded represent only a portion of the foraging done in the course of the night, the trail cannot traverse the full extent of the grid. Therefore these points are close in distance and thus likely to be quite similar, which may result in an underestimate the standard error. Secondly, animals may differ slightly in their preferences for the available microhabitat, so points on the path made by one animal may be more similar than points chosen a different animal. An advance on simple logistic regression is the robust linear model, which was used with the assistance of Dr. Robert Clark (Centre of Statistical and Survey Methodology - UOW), to investigate possible associations between habitat features used by the animals in this study. This analysis yields clearer results regarding interactions between habitat features and more accurate standard errors than simple logistic regression. However, the underestimates of standard error would only impact upon overall results in the case of borderline significance/lack of significance (e.g.  $P = 0.04$  or  $P = 0.06$ ). Furthermore, as the name suggests, simple logistic regression is more widely accessible in statistical software packages and easier to apply. To confirm the validity of the results returned by the simple logistic regression, some habitat utilisation data were analysed using the robust linear model (with the assistance of R.C.). This test revealed that both analyses (simple logistic regression and robust linear model) returned similar results regarding habitat preferences, with no discrepancies in the patterns of statistical significance in the

results. Together, these reasons justified the application of simple logistic regression as the statistical analysis technique used in this part of my study.

#### 4.4.5 Conclusions

*Rattus fuscipes* and *A. stuartii* responded to different habitat features, with the former showing particular affinity for logs and the latter for leaves. To varying degrees, both showed an aversion to areas with no logs or branches. From the perspective of management or conservation initiatives, leaves are difficult to work with, being light and thus subject to displacement by wind. Shrub vegetation may provide solutions to counteract the barrier effect in other contexts, but in this study establishment of swathes of shrub vegetation was both unacceptable to easement operators, and too lengthy in terms of time investment. For these reasons I chose to work with logs and branches, which were shown to be ecologically relevant, are manipulable and readily available in my study region. Chapter 5 describes the experiment in which I tested the efficacy of habitat connections that I constructed from vegetation features associated with my study species, as identified in this chapter. Building on this, Chapter 6 then briefly examines the question of flight response as a possible explanation for observed patterns, and explores the movement of translocated individuals with respect to path tortuosity and habitat utilisation.

## Chapter 5 – Use of Habitat Linkages

### 5.1 INTRODUCTION

#### 5.1.1 Habitat Corridors

The term ‘habitat corridor’ describes the natural or artificial connections between otherwise isolated patches of habitat. Because of the potential role of corridors in conducting species across fragmented or inhospitable landscapes (Tischendorf & Wissel, 1997), investigations into factors determining their effectiveness have become more common. The primary ecological benefit of corridors is the facilitation of dispersal between otherwise isolated populations (Kozakiewicz, 1993; Tewksbury *et al.*, 2002; Haddad *et al.*, 2003). This in turn ensures connection between subpopulations in a metapopulation, enhancing population persistence through: (i) exchange of genetic material (Tewksbury *et al.*, 2002; Haddad *et al.*, 2003) (ii) providing access to resources distributed throughout the habitat (Bennett, 1990a) and (iii) reversal of local extinction (Fahrig & Merriam, 1985). However, there is no general consensus on the efficacy of corridors in providing these benefits. Instead, studies have concluded that the importance of corridors will depend on the ecology and behaviour of a species and on the nature of the surrounding matrix (Bowne *et al.*, 1999). Indeed for some plant systems, fragment isolation has little impact on extinction risk relative to the impact of the landscape matrix (Williams *et al.*, 2006). Other factors that influence the use of corridors by wildlife include microhabitat conditions, structural and spatial attributes of the retained linear strips, the forest type (Lindenmayer *et al.*, 1994) and the physical composition of the corridors (e.g. width and continuity) (Andreassen *et al.*, 1996).

The conflicting views on the effectiveness of corridors (Section 1.2) confound the design and implementation of management projects (Simberloff *et al.*, 1992). The paucity of direct measurements of corridor use compounds these difficulties (Merriam & Lanoue, 1990). Such uncertainty regarding the effectiveness of corridors calls for closer examination of the assumption that corridor presence is correlated with increased movement rates for particular species in a range of circumstances (Mabry & Barrett, 2002).

In order to understand the function of corridors, it is essential to identify what constitutes a high quality corridor for a particular species (Bennett *et al.*, 1994).

Focusing on two common native species of small mammal, I address this issue in this chapter, through replicated survey and experimental techniques. Little is known about the movement behaviour of mammals moving on unfamiliar ground, despite the fact that this information may be critical to assessing and enhancing landscape connectivity (Bakker, 2006).

### 5.1.2 Animal Movement Patterns

Understanding movement behaviour can contribute to the resolution of many ecological questions (Wiens *et al.*, 1995), and can be used as a basis for designing biodiversity conservation measures. Movement path characteristics can be a reflection of habitat quality. One such characteristic is tortuosity (Etzenhouser *et al.*, 1998), the turning frequency in the movement path of an animal. For example, some research has shown that small mammals preferred shrub microhabitats and thus where shrubs were scarce, their movement paths were relatively straight (Stapp & Van Horne, 1997). Similarly, for a small mammal exposed in a barren, unfamiliar environment, one might expect a straight movement path as the individual proceeds directly towards an area offering better shelter. The behaviour of small mammals is affected by landscape configuration as well as the risk of predation, and these factors can have interactive effects (Brinkerhoff *et al.*, 2005). Therefore, the provision of preferred habitat features in an environment that would usually be perceived as hostile because of high predation risk, may encourage more foraging, and thus result in a more tortuous travel path.

Movement behaviour of small mammals may also be modified by food availability, which in turn can interact with landscape configuration, habitat structure and predation risk. For example, in a structurally complex habitat with abundant but dispersed food supplies, an animal may exhibit a movement path that is tortuous as it navigates a path through the physical components of its environment. The same path may also be expected to feature straight sections, where the animal is in transit between food sources, perhaps through regions with less abundant cover. Whilst the relationships between the factors that can influence movement behaviour are complex, a closer investigation of these interrelated factors must begin with predictions based on prior

observations, knowledge of the species and habitat in question and sound ecological theory. I attempted to incorporate all of these elements into the predictions outlined in the following section.

### 5.1.3 Study Predictions and Aims

In this experimental phase of my study, I investigated whether the construction of habitat ‘linkages’ connecting the two sides of mowed powerline easements would increase the frequency of easement crossing by *R. fuscipes* and *A. stuartii* (i.e. reduce the barrier effect). Given the association between my study species and logs, and to a lesser degree branches (see Section 4.3.2), I expected that the inclusion of these features in the easement would encourage the animals to move more frequently between the opposing sides of the easement. I predicted that, following the construction of the linkages, there would be an increase in the number of individuals trapped that had previously been captured on the opposite side of the easement.

The second component involved releasing captured animals on constructed habitat linkages to monitor their use of these corridors, and record their movement through the use of the spool-and-line technique. I predicted that paths of individuals released on linkages would more closely resemble the paths of animals recorded in familiar habitat, than those released in the open easement. By contrast, I predicted that animals released in the open easement, particularly where vegetation cover was sparse, would follow a direct path to more sheltered habitat adjacent to the powerline easement, thereby resulting in lower path tortuosity than in the familiar habitat.

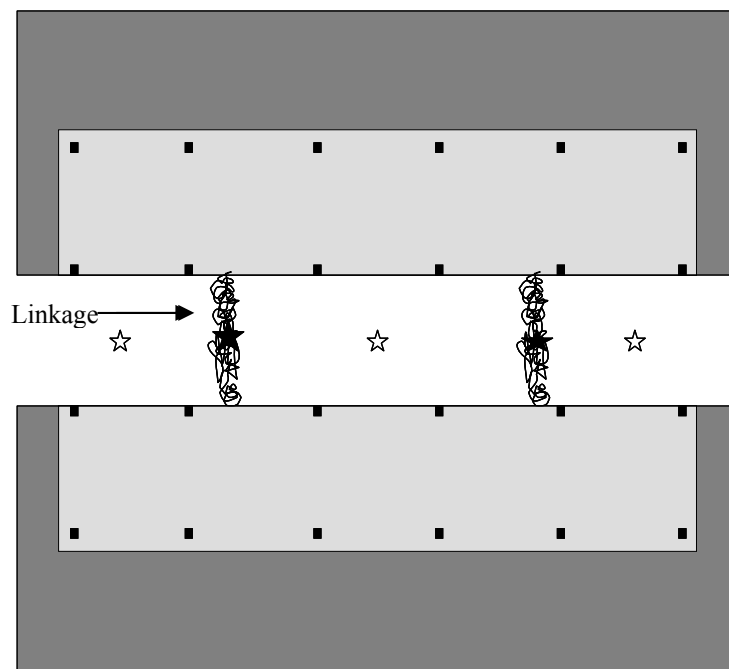
## 5.2 METHODS

### 5.2.1 Establishing Habitat Linkages

Spooling of *R. fuscipes* revealed a preference for logs and branches (Section 4.3.2.1). This pattern was less well defined for *A. stuartii*, though it was clear that regions with more of these two features were used preferentially, compared to areas with little or none of them. Based on this knowledge, in early September 2005, ‘linkages’ were constructed in the powerline easements at the four trapping sites; Parnell, Jerrawangala, Conjola and Currumbene. Logs and branches were accumulated from regions of

bushland away from each of the trapping sites. This material was conveyed to the easement and arranged in a row connecting the opposing sides of habitat on either side of the easement as shown (Fig. 5.1 (a) & (b)). Outsourcing of materials was necessary, because removal of these features would alter the habitat in which the target animals were present. Two linkages were established at each of the four sites, to double the number of locations at which animals could be released (Fig. 5.2).

**Figure 5.1 (a) & (b) Examples of linkages constructed from logs and branches connecting opposing sides of the powerline easement.**



**Figure 5.2** Trapping grid used at the four trapping sites, and the approximate locations of linkages.

★ = release points on the linkage. ☆ = release points in the open.

### 5.2.2 Trapping Procedure

Animals involved in this investigation were captured in a concurrent mark-recapture study (Chapter 3). As described in Chapter 3, traps were checked two hours after dusk. In this instance, however, the animals were not released *in situ*, but rather conveyed to the release site of release in the easement while still in the Elliott trap. Figure 5.2 illustrates the range of release sites either in the 'open' or in the 'linkage'. The animals were processed and fitted with a spool as before, but with the free end of the thread tied to either a log in the linkage or anchored to vegetation nearby. When the animal was slowly released, the handler remained still and silent (as described by Miles (1981)) to prevent influencing the animal's choice of direction, as described by Miles. All releases of animals were in the middle of the easement, whether in the open or on the linkage, to ensure that the direction the animal chose to move was not simply the nearer region of forested habitat. The release of spooled animals in the open easement provided comparison with individuals released on the linkage. Efforts were made to achieve equal numbers of releases at both open and linkage sites. No more than five animals

were spooled in the easement on any one night, to avoid confusion of different spool trails. An attempt was made to dye the white thread spools, so that a number of colours could be used in the same location, but attempts to dye the thread proved to be ineffective. This phase of spooling investigations was conducted in September 2005 only for *R. fuscipes*.

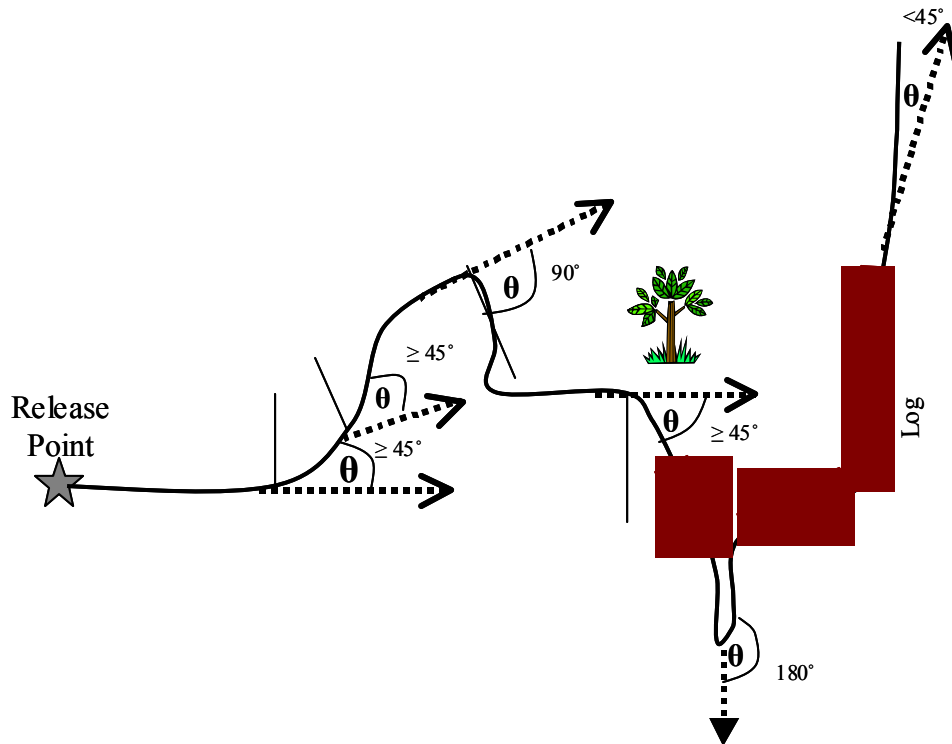
### 5.2.3 Data Recording

As before, the path of the spool was traced the following morning but, in this instance, the nature of the path itself was the focus of the study, rather than the habitat feature utilisation. The trail was assumed to reflect actual path use, as in Barnum *et al.* (1992) who used fluorescent powder to track small mammals. Research has shown that the spool-and-line provides an accurate reflection of the path followed by an animal in my study sites (Bennett, 2006).

Each spool traversed up to two regions; 'Open' and 'Habitat' when the animal was released in the open, or else 'Linkage' and 'Habitat' when the animal was released in a linkage. Spool data were classified as 'open' when the animal was released in the open easement, not close to a linkage (>10m away, as explained in Section 5.2.2). Spool data gathered from an animal that was released on the linkage was referred to as 'Linkage' data. Spool data relating to an animal released on a linkage but subsequently straying from it were also included in this category. Finally, 'habitat' referred to the portion of the spool after the animal had left the easement or linkage, and had entered the adjacent bushland. 'Open', 'linkage' and 'habitat' are referred to as 'regions'.

At 1m intervals, I recorded the number of turns of each of four size classes; (i) <45°, (ii) 45-90°, (iii) 90-179° and (iv) 180° (Fig. 5.3). For simplicity I henceforth refer to these categories as <45°, >45°, 90° and 180°. Angle size was determined by comparing previous direction with new direction after the turn. The number of each of these angles per 1m of spool trail in the open and the linkage (or 3m in the habitat) was recorded until the end of the spool trail was reached. Simultaneously, I noted the degree of ground and shrub vegetation present in the easement. Ground vegetation was defined as <30cm in height, shrub vegetation >30cm. In cases where the animal was released on a linkage, the distance (m) of the spool from the linkage was also estimated at each 1m interval. The maximum value estimated for this was >4m. Beyond 4m, a more precise

measurement was not possible without the use of a tape measure and this bore the risk of inadvertently disturbing the spool trail.



**Figure 5.3** Schematic diagram of a spool trail, as typically made by *Rattus fuscipes* or *Antechinus stuartii* in this study, illustrating method by which angle size was determined. The sketch also includes examples of movement along logs, which was also recorded. Shaded rectangles represent logs used for movement.

A sketch was made of the spool trail. As long as the thread trail was within the open easement and within 4m of the linkage, the distance (m) from the linkage was recorded. Once the trail left the easement and entered the habitat, angle recording was continued, but only at 3m intervals. As path tortuosity was of primary interest, only angle recordings were made once the animal entered the habitat. Animal handling and data recording procedures were the same for *R. fuscipes* and *A. stuartii*, except that for the latter, it was not necessary to clip the fur prior to affixing the spool. This was because the fur tended to be much shorter than with *R. fuscipes*, hence attempts to clip ran the risk of cutting the soft and flexible skin.

#### 5.2.4 Altered Linkage Layout

It emerged that straight linkages failed to provide insight into path choice by small mammals following release in the easement. This was because it was unclear if the released animals were following the linkages because they preferred the conditions these structures provided, or whether they were merely following the shortest straight line to the habitat. For this reason, it was considered that a more informative test would be to incorporate bends or 'kinks' into the linkages. Two kinks were built into each linkage (Fig. 5.4 (a) & (b)). In this way, regardless of the direction that the animal chose to move upon release, it would encounter a kink in the linkage.

**Figure 5.4 (a) & (b) Examples of kinks built into habitat linkages to explore the preference of small mammals for the linkages, as opposed to the open habitat when released in the easement**

Spools were sketched and recorded as before. Both *R. fuscipes* and *A. stuartii* were involved in this study. Fieldwork sessions for this were conducted in November 2005, February and April 2006 for *R. fuscipes* and in April and June of 2006 for *A. stuartii* (Appendix 2).

#### 5.2.5 Data Analysis

##### *Easement Crossing*

In Chapter 3 I reported the number of easement crossing events throughout the study period, including all eight trapping sessions. Because the number of trapping sessions and the trapping effort were the same both before and after the installation of the

linkages (four sessions for each), I simply compared the number of easement crossings recorded during these two phases.

### *Angle Analysis*

The number of angles per metre of each angle size class in the open, the linkage and the habitat regions were first plotted on histograms. The proportion of turns in each angle size class relative to all the turns in each region was also investigated. In a simple preliminary analysis, I conducted a  $\chi^2$  test of independence on data pooled from the four sites to investigate if the relative frequencies of turns in different angle categories were independent of region.

I then used a univariate ANOVA to test whether (i) the mean number of angles per metre, and (ii) the mean proportion of angles in each angle class varied among regions. Before the ANOVA was applied to the proportions of angles, the values were arcsine transformed (Kasuya, 2004). The angle proportion dataset was also weighted for length (m), in order to control for the fact that some spools were longer than others and would otherwise yield disproportionate values for the proportions of angles. In these two ANOVAs the response variable was either the number of angles per metre or the arcsine of the proportion of angles per metre respectively. The explanatory variable in each case was easement region as defined above. Nine spools recorded by Bennett (2006), at two of my sites (Conjola and Jerrawangala) after completion of my fieldwork were included in this analysis. All of these spools were recorded from *A. stuartii*. The nine spools she recorded (2 at Conjola and 7 at Jerrawangala) that were included in my analysis contributed 497m of data (375m in habitat, 77m in open, 45 in linkage) to the 882m that I recorded in April 2006.

### *Impact of Kinks on Distance from Linkage*

This investigation tested whether the presence of kinks in the linkages influenced the average and maximum distances that *R. fuscipes* strayed from the linkage into the easement after release. This investigation did not apply to *A. stuartii* because spooling of this species only began after kinks had been incorporated into the linkages. The average distance (per spool) that the animals moved from the linkage while in the easement was calculated. Using an Independent Samples t-test (SPSS, Version 12.0.1), I

then compared the average distance moved from the linkage with, and without, the kinks present. The maximum distance moved from the linkage during the course of each spool was also recorded<sup>\*</sup>, and once again analysed using a t-test to compare patterns with and without the kinks present in the linkage.

#### *Impact of Vegetation on Distance from Linkage*

This analysis was only possible for *R. fuscipes* (30 spools) owing to the comparatively small number of spools recorded for *A. stuartii* (10 spools) released on linkages. I investigated the association between (i) ground vegetation and (ii) shrub vegetation density on the distance that the released animals tended to venture away from the linkage. Ground vegetation and shrub vegetation in the easement were categorised as either high or low. Using an Independent Sample t-Test, the average distance (per spool) from the easement was compared for low versus high ground vegetation. The same analytical approach was implemented for the comparison of maximum distance from the linkage when ground vegetation was low versus high. This process was repeated to investigate the associations between shrub vegetation and distance strayed from the linkage while in the easement.

### **5.3 RESULTS**

#### **5.3.1 Spool-and-line Records**

72 animals were spooled and released, of which 51 were *R. fuscipes* and the remainder (21) *A. stuartii* (Table 5.1). A maximum of 19 spools was recorded in any field session owing to practical limitations of tracing several spool trails through dense habitat. *R. fuscipes* was spooled most frequently at Parnell (19), a site which was not used for angle analysis of *A. stuartii*. Jerrawangala returned the greatest number of spools for *A. stuartii* (11). The 72 spools yielded a total of 3,923m of data (Table 5.1).

Average spool length at each site ranged from 43m at Parnell for *R. fuscipes* to 102m at Conjola for *A. stuartii*. Spools recorded from *A. stuartii* were, on average, 6.9% longer than those from *R. fuscipes*. For *R. fuscipes*, the average portion of the spool data

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<sup>\*</sup> The largest record in the dataset for maximum distance from linkage was >4. For statistical purposes these records were converted to 5. Hence results are likely to represent a conservative estimate. Given the narrow spatial confines of the easement, very high values for distance from linkage were rare.

recorded in the easement at each site ranged from 20.1% at Parnell to 43.9% at Jerrawangala. The spools varied greatly in total length and in the portion of spool present in the easement.

For both *R. fuscipes* and *A. stuartii*, across all of the sites, the highest proportion of the spool data that was located in the easement was at Jerrawangala (43.9% and 31.5% respectively), which compared with just 26.1% and 13.4% respectively at Conjola. However, compared to *R. fuscipes* (30.7%), the proportion of the *A. stuartii* spools in the easement (22.8%) relative to the total length of the spools, was lower at all sites (Table 5.2).

**Table 5.1 Results of spool-and-line study of *Rattus fuscipes* and *Antechinus stuartii* in which the tortuosity of the path and use of habitat linkages was investigated.**

This includes spools recorded from animals released on linkages and those released in the open easement

<i>Rattus fuscipes</i>											
	Currumbene		Conjola		Parnell		Jerrawangala		Total		
Fieldwork session	No. spools	Total length (m)	No. spools	Total length (m)	No. spools	Total length (m)	No. spools	Total length (m)	No. spools	Average length (m)	Length for session (m)
Sep-05*	1	13	6	247	9	306	3	85	19	34.3	651
Nov-05	4	225	3	196	8	303	2	60	17	46.1	784
Feb-06	6	332	5	407	2	209	1	50	14	71.3	998
Apr-06	0	0	0	0	0	0	1	111	1	111.0	111
<b>Total</b>	<b>11</b>	<b>570</b>	<b>14</b>	<b>850</b>	<b>19</b>	<b>818</b>	<b>7</b>	<b>306</b>	<b>51</b>		<b>2544</b>
<i>Average</i>		<i>52</i>		<i>61</i>		<i>43</i>		<i>44</i>		<i>66</i>	
<i>Antechinus stuartii</i>											
	Currumbene		Conjola		Parnell		Jerrawangala		Total		
Fieldwork session	No. spools	Total length (m)	No. spools	Total length (m)	No. spools	Total length (m)	No. spools	Total length (m)	No. spools	Average length (m)	Length for session (m)
Apr-06	5	340	3	315	0	0	4	227	12	74	882
Jun-06**	0	0	1	103	0	0	7	300	8	50	403
Jul-06**	0	0	1	94	0	0	0	0	1	94	94
<b>Total</b>	<b>5</b>	<b>340</b>	<b>5</b>	<b>512</b>	<b>0</b>	<b>0</b>	<b>11</b>	<b>527</b>	<b>21</b>		<b>1379</b>
<i>Average</i>		<i>68</i>		<i>102</i>				<i>47</i>		<i>72</i>	

\*This session was conducted when there no kinks present in the linkages, kinks were a feature in the linkages in all other sessions.

\*\*These spools were recorded by Bennett (2006)

**Table 5.2 Summary of total spool length data gathered at each site the in angle analysis study of the paths of *Rattus fuscipes* and *Antechinus stuartii*.**

The % of the length in the easement is the sum of all sections of spool trails recorded before the animal enters the habitat. In some cases the spool was shed before the animal reached the habitat adjacent to the easement. In these cases the data relating to movement in the easement were still included in the analysis

	Study Site				Total
	Currambene	Conjola	Parnell	Jerrawangala	
<i>R. fuscipes</i>					
Length, all sessions (m)	570	850	818	306	2544
Portion of spools in easement, all sessions (m)	206	220	171	135	732
% of length in easement	36.1	25.9	20.9	44.1	28.8
<i>A. stuartii</i>					
Length, all sessions (m)	340	512	n/a	527	1379
Portion of spools in easement, all sessions (m)	71	56	n/a	166	293
% of length in easement	20.9	10.9	n/a	31.5	21.3
Total for both species					
Length, all sessions (m)	910	1362	818	833	3923
Portion of spools in easement, all sessions (m)	277	276	171	301	1025
% of length in easement	30.4	20.3	20.9	36.1	26.1

The average distance that an animal travelled away from a linkage in the easement after release varied greatly. Of the 31 *R. fuscipes* individuals that were released on the linkage, 11 (35.5%) followed the path of the linkage ('Followed') (Table 5.3). Of 10 animals released on straight linkages, 7 of them followed the linkage straight to the adjacent habitat. When the kinks were present, a much lower proportion of the animals, just 4 of the 21, closely followed the linkage all the way to the habitat (Fig. 5.5).

**Table 5.3 Summary of outcomes of the release of *Rattus fuscipes* on habitat linkages at four sites in the study.**

% of all spools with each outcome is shown. Values in parentheses indicate records that are included in the total, but that related to outcomes when no kinks were present.

	Currambene	Conjola	Parnell	Jerrawangala	All sites	% of all spools
<b>Followed</b>	1	4	5	1	<b>11 (7)</b>	<b>35.5</b>
<b>Strayed</b>	3	5	3	3	<b>14 (3)</b>	<b>45.2</b>
<b>Strayed &amp; returned</b>	3	0	3	0	<b>6</b>	<b>19.4</b>
<b>Total</b>	<b>7</b>	<b>9</b>	<b>11</b>	<b>4</b>	<b>31</b>	

**Figure 5.5 Yellow tape (location indicated by orange arrows) traces the spool path taken by one *Rattus fuscipes* individual as it followed the linkage after its release in the centre of the linkage.**

Animals that ‘strayed but returned’ did not follow the linkages, but their paths were nonetheless quite straight, so that they rejoined the linkage after the kink (5.6 & Appendix 14(c)). This behaviour applied to 6 (19%) of the releases on the linkages. 14 (45%) of all the animals released on linkages ‘strayed’ away from it to a distance greater than 2m and did not return to the linkage (Fig. 5.7).

**Figure 5.6 Example of where one *Rattus fuscipes* released on a linkage ‘strayed but returned’.**

Pink tape highlights the path followed. By maintaining a straight path, the animal returned to the linkage after the kink.

**Figure 5.7 Example of where one *Rattus fuscipes* released on a linkage ‘strayed’ from it, and did not return to it but, instead, entered the adjacent habitat.**

Pink tape highlights the path followed.

The 9 *A. stuartii* spools that were recorded from animals released on linkages revealed a strong tendency to remain on the linkage for at least half of the portion that the spool was present in the easement. The spools revealed that five of the nine animals remained on the linkage from the point of release until the adjacent habitat was reached. Upon

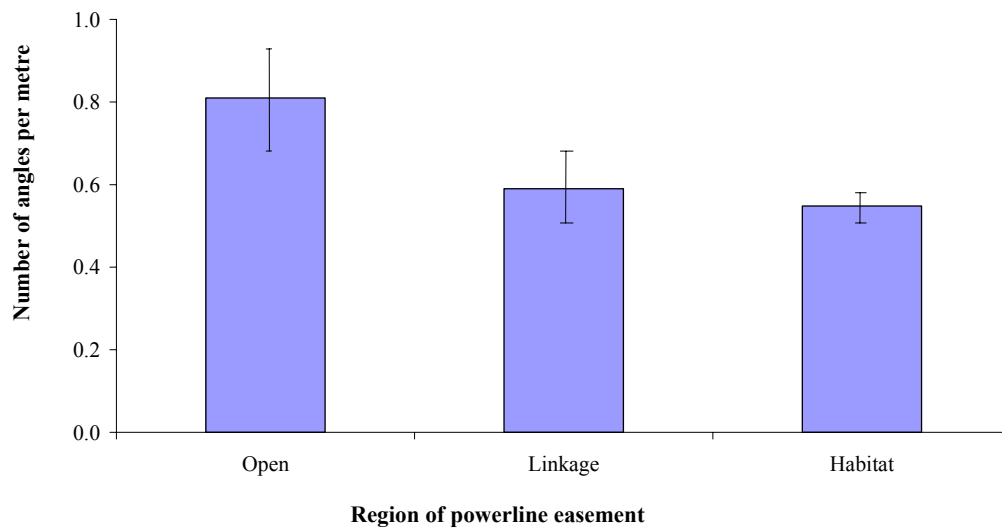
entry into the habitat, animals showed a tendency to skirt the edge of the habitat adjacent to the easement (Appendix 14(b)). Three of the animals progressed along the linkage for 2-3 metres, then ventured into the open easement and on towards the nearest habitat edge (Appendix 14(c)). One individual left the linkage almost immediately and then later returned to it before entering the habitat.

### 5.3.2 Easement Crossing

Easement crossing events in the four field sessions during which the linkages were present were very few. Just four such events were recorded (Table 3.2). This was seven fewer than were recorded for the period prior to the establishment of the linkages, which involved the same trapping effort. The total number of crossings was too low to permit any formal statistical analysis.

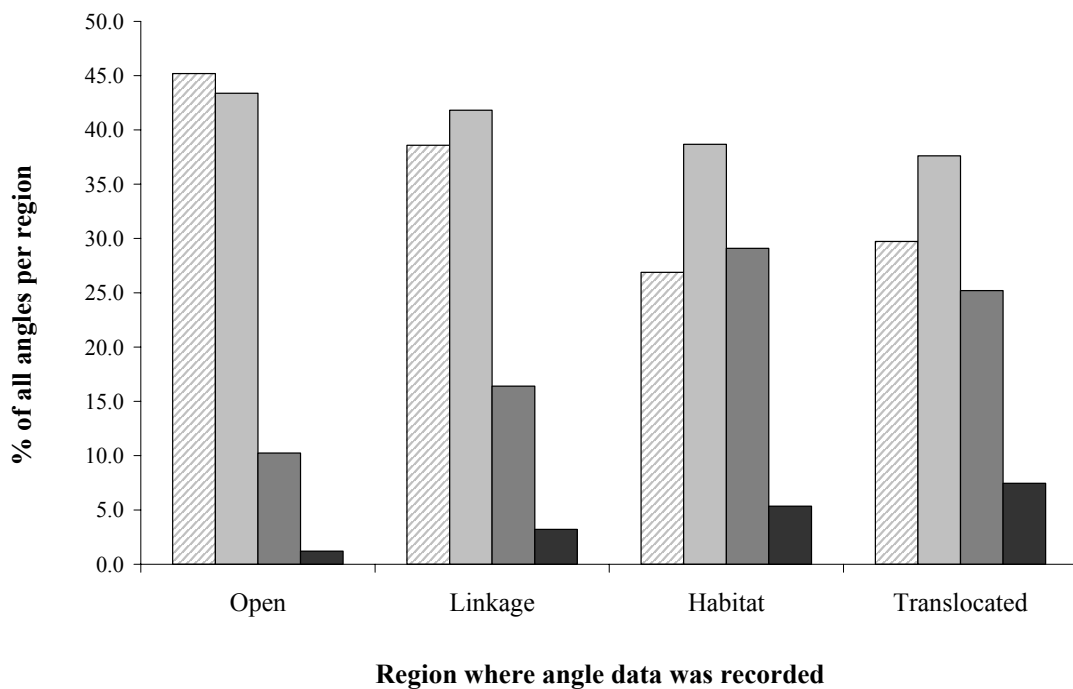
### 5.3.3 Tortuosity of the Movement Path – *R. fuscipes*

Data were pooled from the four sites, which totalled 1,465 turns (angles) in 51 movement paths, recorded between September 2005 and April 2006. Animals made the greatest number of turns per metre when released in the open easement, on average 0.8 (Standard error, (SE) = 0.102) turns per metre (Fig. 5.8). They made fewest turns while in the habitat, 0.56 per metre (SE = 0.048). The number of turns made per metre after release on the linkage was almost exactly half way between the values for the open and habitat regions 0.59 turns per metre (SE = 0.08).



**Figure 5.8 Average numbers of angles (turns) per metre ( $\pm$  standard error) made by *Rattus fuscipes* in each of three regions following release in the powerline easement.** Total length of spool data in the open = 205m (20 spools), on the linkage = 550m (31 spools) and in the habitat = 1,786m (41 spools), featuring 1,456 angles altogether.

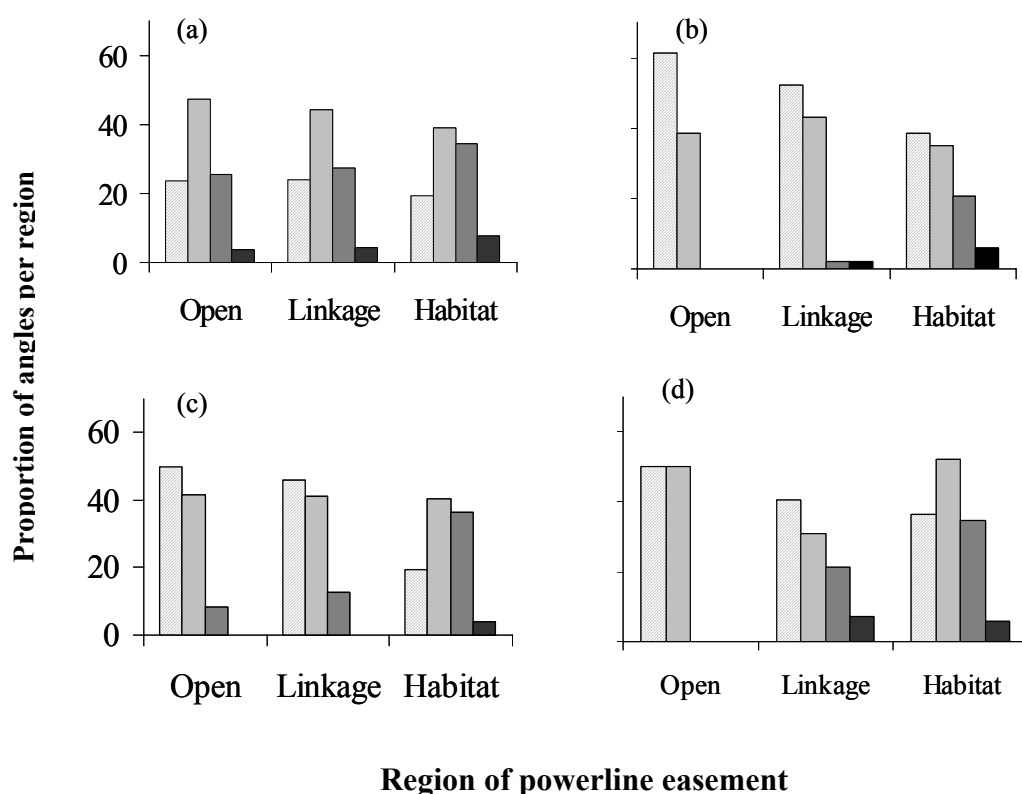
The proportion of small angles ( $\leq 45^\circ$ ) was greatest (45.2%) in the open and lowest where the animal was in the habitat (26.9%). Conversely, higher proportions of the larger angles (both  $\geq 90^\circ$  and  $180^\circ$ ) were found in the habitat region (Fig. 5.9). For example, just 10.2% of the angles recorded in the open were  $\geq 90^\circ$ , whereas the same figure was almost three times as high (29.1%) in the habitat.



**Figure 5.9 Percentages (%) of angles of each size class in three regions (Open, Linkage and Habitat) where spool-and-line data were recorded for *Rattus fuscipes*.**

Diagonal pattern = angles  $\leq 45^\circ$ ,  $\square$  =  $\geq 45^\circ$ ,  $\blacksquare$  =  $\geq 90^\circ$ ,  $\blacksquare$  =  $180^\circ$ . Total length in each region: Open = 207m, Linkage = 459m, Habitat = 1,786m. 51 spools were recorded.

These same patterns were discernable, though less distinct, at the site level (Fig. 5.10). At all sites, the medium and large ( $>90^\circ$  and  $180^\circ$ ) angles were most frequent in the habitat. For example, more than 4%, and up to 7.5% of the angles in the habitat at each site were  $180^\circ$ . By contrast, there were no  $180^\circ$  angles in the open at three of the sites. Conversely, angles of the smallest angle size class ( $\leq 45^\circ$ ) were least frequent in the habitat, compared to in the open or on the linkage. The proportion of angles  $<45^\circ$  in the habitat at the sites ranged from 19-38%, compared to 23-61% in the linkage and open regions. With the exception of Currambene, movement in the open easement was characterised by small and medium angles only (Appendix 14(a)). Overall, the proportions of angles in the linkage were similar for to those in the open easement, though  $90^\circ$  and  $180^\circ$  angles were more frequent in the former than in the open (Fig. 5.10).



Region of powerline easement

**Figure 5.10** Proportion of angles (turns) made by *Rattus fuscipes* at each site, in three easement regions, open, linkage and habitat.

(a) Currambene (b) Conjola (c) Parnell (d) Jerrawangala. Diagonal Pattern = angles  $\leq 45^\circ$ , ■ =  $\geq 45^\circ$ , ■ =  $\geq 90^\circ$ , ■ =  $180^\circ$ . Total length in each region: Open = 207m, Linkage = 459m, Habitat = 1,786m. 51 spools were recorded.

The number of angles per metre in the open easement was significantly different from that in the habitat for all angle size classes ( $F = 6.08$ ,  $B = 0.24$ ,  $P = 0.02$ ) (Table 5.4). The two smaller angle size classes ( $<45^\circ$  and  $>45^\circ$ ) were significantly less common in the habitat, (0.15 and 0.21 per metre respectively), than in the open (0.37 and 0.35 per metre). The reverse was true of the two larger angle size classes ( $90^\circ$  and  $180^\circ$ ); in the habitat, there were 0.16 and 0.08 angles per metre respectively, which compared with 0.08 and 0.01 per metre in the open. Similarly, the proportions of all of the angle sizes differed significantly between the habitat and the open, with the exception of angles  $>45^\circ$  (Table 5.5).

Significant differences between the open and the linkage in terms of angles were absent. Only when all angles were considered together did the regions differ markedly, bordering on statistical significance ( $F = 3.87$ ,  $P = 0.06$ ). While a significantly greater

proportion of 180° angles was recorded in the linkage (3.22%) than the open (1.2%), the significance in this case was also only borderline ( $F = 3.87$ ,  $P = 0.05$ ), which may reflect the small total number of turns of this size made.

**Table 5.4 Results of analysis of variance used to compare the number of angles per metre of each angle size class made by *Rattus fuscipes* in the open, linkage and habitat regions of powerline easement.**

Data are pooled from four trapping sites and four trapping sessions conducted between September 2005-April 2006. Total length in each region: Open = 207m, Linkage = 459m, Habitat = 1,786m. Fifty one spools were recorded. Significant results are highlighted in bold.

	Angle size category				
	<45	>45	90	180	All
<b>Open Vs Linkage</b>					
<b>F</b>	3.23	1.46	0.002	1.65	3.87
<b>P</b>	0.08	0.23	0.96	0.21	0.06
	More in Open	More in Open	More in Open	More in Linkage	More in Open
<b>B</b>	0.14	0.09	0.02	-0.01	0.3
<b>Habitat Vs Linkage</b>					
<b>F</b>	2.23	0.08	<b>7.62</b>	<b>6.56</b>	0.04
<b>P</b>	0.14	0.78	<b>0.007</b>	<b>0.01</b>	0.85
	More in Linkage	More in Linkage	Fewer in Linkage	Fewer in Linkage	Fewer in Linkage
<b>B</b>	0.07	0.02	<b>-0.1</b>	<b>-0.02</b>	-0.02
<b>Habitat Vs Open</b>					
<b>F</b>	<b>9.9</b>	<b>5.83</b>	<b>5.46</b>	<b>8.38</b>	<b>6.08</b>
<b>P</b>	<b>0.003</b>	<b>0.02</b>	<b>0.02</b>	<b>0.005</b>	<b>0.02</b>
	More in Open	More in Open	Fewer in Open	Fewer in Open	More in Open
<b>B</b>	<b>0.21</b>	<b>0.105</b>	<b>-0.08</b>	<b>-0.03</b>	<b>0.24</b>

When angles in the linkage and the habitat were compared, the overall trend was for fewer angles per metre in the linkage (0.59) than in the habitat (0.55), though this was not significant ( $F = 0.42$ ,  $P = 0.53$ ) (Table 5.4). Larger angles (90° and 180°) were significantly less common in the linkage than the habitat ( $F = 7.62$ ,  $P = 0.007$  and  $F = 6.56$ ,  $P = 0.01$  respectively). No significant trends for the smaller angle size classes were detected. Proportions of each of the angle size classes echoed the patterns observed for the number of angles per metre when analysed statistically, with more of the smallest angles and fewer of other angles in the linkage. However, not all of these trends were significant (Table 5.5).

**Table 5.5 Results of analysis of variance used to compare the proportion of each angle size class in the open made by *R. fuscipes* in the linkage, open and habitat regions of powerline easements.**

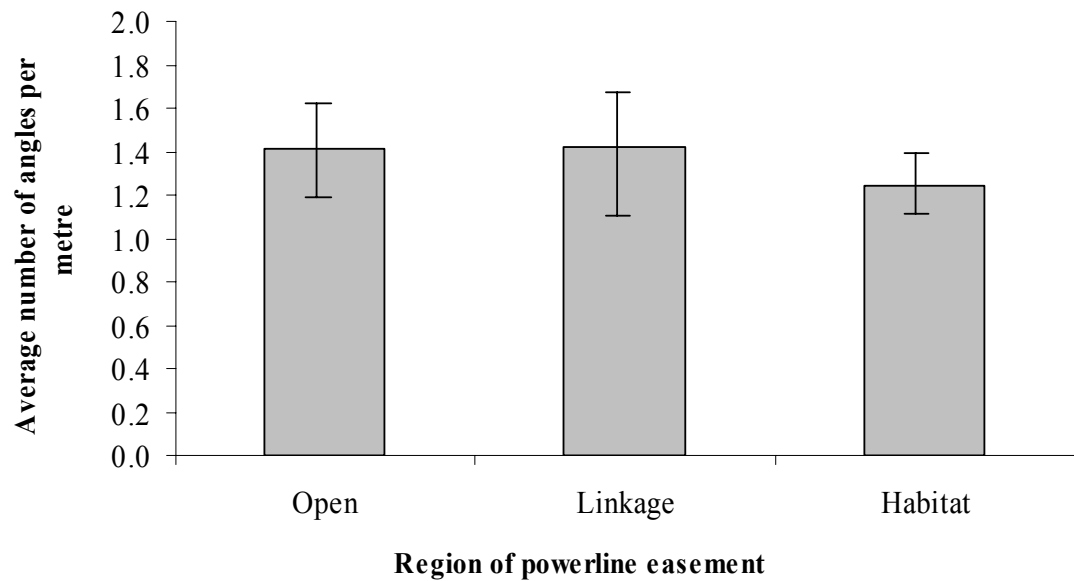
Data were pooled from four trapping sites and four trapping sessions conducted between September 2005-April 2006. Total length in each region: Open = 207m, Linkage = 459m, Habitat = 1,786m. Fifty one spools were recorded.

<i>Angle size category</i>				
	<45	>45	90	180
<b>Open Vs Linkage</b>				
<i>F</i>	0.15	1.3	0.51	<b>3.97</b>
<i>P</i>	0.71	0.26	0.48	<b>0.05</b>
	More in Open	More in Open	Fewer in Open	<b>Fewer in Open</b>
<i>B</i>	0.04	0.11	-0.04	<b>-0.03</b>
<b>Habitat Vs Linkage</b>				
<i>F</i>	<b>7.11</b>	1.83	<b>10.93</b>	0.83
<i>P</i>	<b>0.01</b>	0.18	<b>0.001</b>	0.36
	<b>More in Linkage</b>	Fewer in Linkage	<b>Fewer in Linkage</b>	Fewer in Linkage
<i>B</i>	<b>0.17</b>	-0.06	<b>-0.16</b>	-0.02
<b>Habitat Vs Open</b>				
<i>F</i>	<b>7.46</b>	0.88	<b>7.86</b>	<b>2.84</b>
<i>P</i>	<b>0.01</b>	0.353	<b>0.01</b>	<b>0.01</b>
	<b>More in Open</b>	More in Open	<b>Fewer in Open</b>	<b>Fewer in Open</b>
<i>B</i>	<b>0.212</b>	0.06	<b>-0.2</b>	<b>-0.05</b>

#### 5.3.4 Tortuosity of the Movement Path – *A. stuartii*

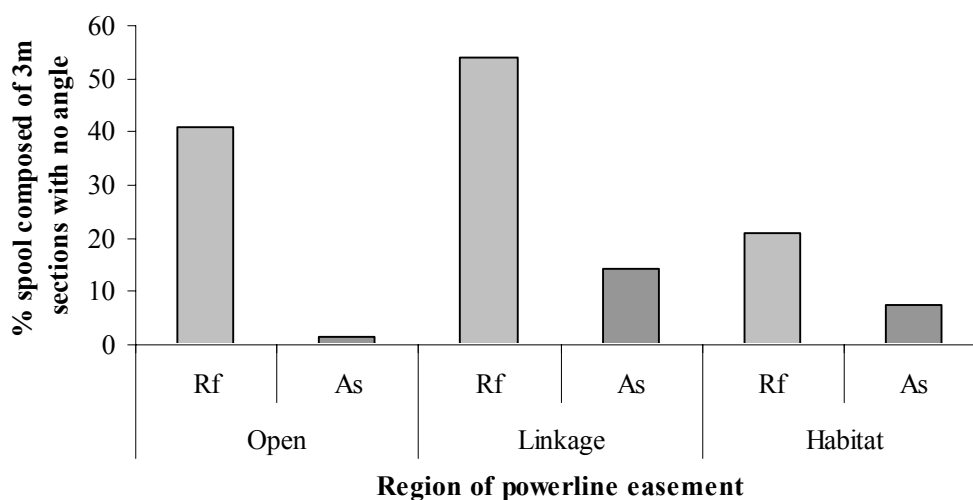
On average, *A. stuartii* made more turns per metre than *R. fuscipes* in each of the regions where spools were recorded. For example, *A. stuartii* made on average 1.4 turns (SE = 0.204) per metre in the open, compared to 0.8 (SE = 0.102) for *R. fuscipes*.

*Antechinus stuartii* made approximately the same total number of turns per metre in the open easement, in linkage regions (1.42 per metre) and in the habitat (1.24 per metre) (Fig. 5.11), though the proportions of each angle size in each region varied.



**Figure 5.11 Average numbers of angles (turns) per metre made by *Antechinus stuartii* ( $\pm$  standard error) in each of three regions following release in the powerline easement.** Total length of spool data in the open = 124m (9 spools), on the linkage = 208m (10 spools) and in the habitat = 792m (13 spools), featuring 1,472 angles altogether. As = *Antechinus stuartii*.

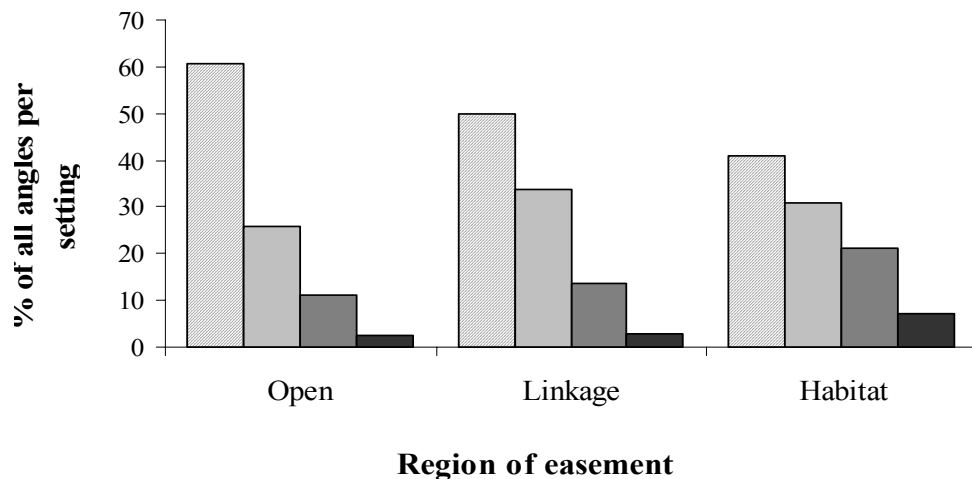
Three metre sections without any angle comprised more than 42.7% and 54% of the spool data in the open and linkage regions respectively for *R. fuscipes*, while 3m sections without any angles in these easement regions for *A. stuartii* were much lower, at 2% and 30% respectively (Fig. 5.12) -i.e. *A. stuartii* turned more frequently than *R. fuscipes*. The same pattern was true in the habitat; the proportion of *A. stuartii* paths that were composed of 3m sections (7.6%) was approximately a third of that recorded for *R. fuscipes* (20.9%).



**Figure 5.12 Percentage (%) of spools in each easement region composed of 3m sections with no angle (turn).**

*Rattus fuscipes* (Rf) (■) is compared with *Antechinus stuartii* (As) (■). Total length in each region: Open = 207m, Linkage = 459m, Habitat = 1,786m. Fifty one spools were recorded.

Although *A. stuartii* showed a higher overall turning frequency than *R. fuscipes*, the number of angles per metre, and the proportions of angles in each size class followed similar trends to those recorded from *R. fuscipes* spools. There was more of the smallest angle size ( $<45^\circ$ ) per metre in the open (0.87) than in the habitat (0.52). Conversely, larger turns ( $90^\circ$  and  $180^\circ$ ) were more frequent (per metre) in the habitat (0.26 and 0.09 respectively) than in the open (0.17 and 0.04 respectively). These same patterns were found when proportions of each angle size in the three easement regions were considered;  $<45^\circ$  angles were most common in the open easement (60.6%) and least common in the habitat (40.9%), while the reverse was true of the two larger angle sizes (Fig. 5.13). For example, 7.03% of the angles in the habitat were  $180^\circ$ , while the equivalent figure in the open easement was 2.5%. The number of angles per metre of each size class in the linkage lay between the values recorded for the open and the habitat with the exception, however, of  $>45^\circ$  angles, which at 33.8% were proportionally more abundant than in the open (25.9%) or the habitat (30.8%). There was an insufficient number of spools to compare the trends at each site separately.



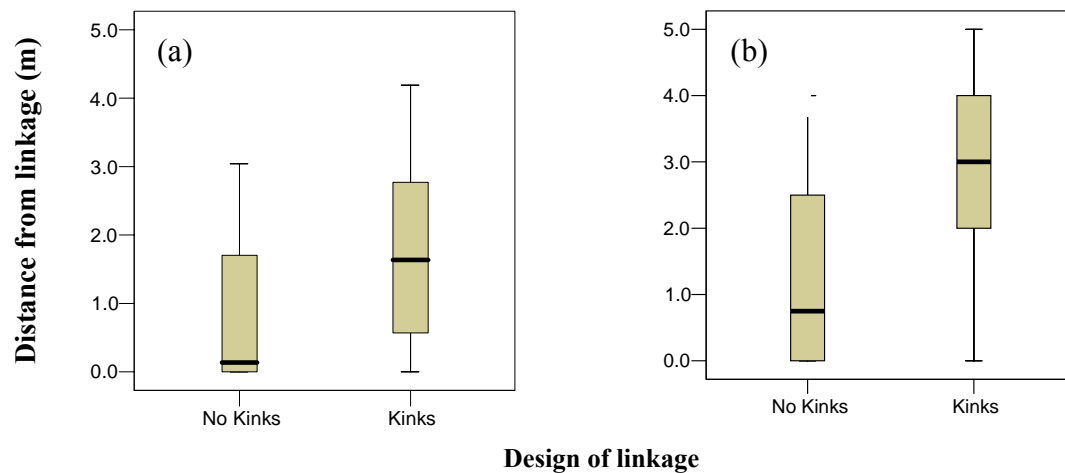
**Figure 5.13 Proportions (%) of angles of each size class recorded in three regions (open, linkage and labitat) where spool-and-line data was recorded for *Antechinus stuartii*.**

Diagonal pattern = angles  $\leq 45^\circ$ ,  $\square$  =  $\geq 45^\circ$ ,  $\blacksquare$  =  $\geq 90^\circ$ ,  $\blacksquare$  =  $180^\circ$ . Total length of spool data in the open = 124m (9 spools), on the linkage = 208m (10 spools) and in the habitat = 792m (13 spools), featuring 1,472 angles altogether.

Despite the patterns revealed by graphical interpretation of results (Fig. 5.13), differences in the number of angles per metre and proportions of angles of each size category were rarely significant. The same was true of the proportions of angles per metre. The difference between the number of angles per metre ( $<45^\circ$ ) in the open compared to the habitat was of borderline significance ( $F = 4.165$ ,  $P = 0.055$ ,  $df = 1$ ). Similarly the difference in the proportion of  $<45^\circ$  angles in the spools recorded in the open and those recorded in the habitat was almost significant ( $F = 4.067$ ,  $P = 0.057$ ,  $df = 1$ ). In both cases, more turns of this size were made in the open than the habitat.

### 5.3.5 Effect of Kinks on Linkage Use

There was a difference between linkages with and without kinks in both the average and maximum distance that the animals strayed from them (Fig. 5.14(a) & (b)). The average distance from a linkage without kinks was 0.76m (SE = 0.36), compared to 2.1m with kinks (SE = 0.36). A similar pattern was seen for maximum distance from linkage: when kinks were absent, the maximum distance that the released animals moved from the linkages was 1.25m (SE = 0.48) but was greater when kinks were present (3.28m, SE = 0.41). These differences were statistically significant for both average ( $t = -2.36$ ,  $P = 0.03$ ,  $df = 28$ ) and maximum ( $t = -3.02$ ,  $P = 0.01$ ,  $df = 28$ ) distance from easement.

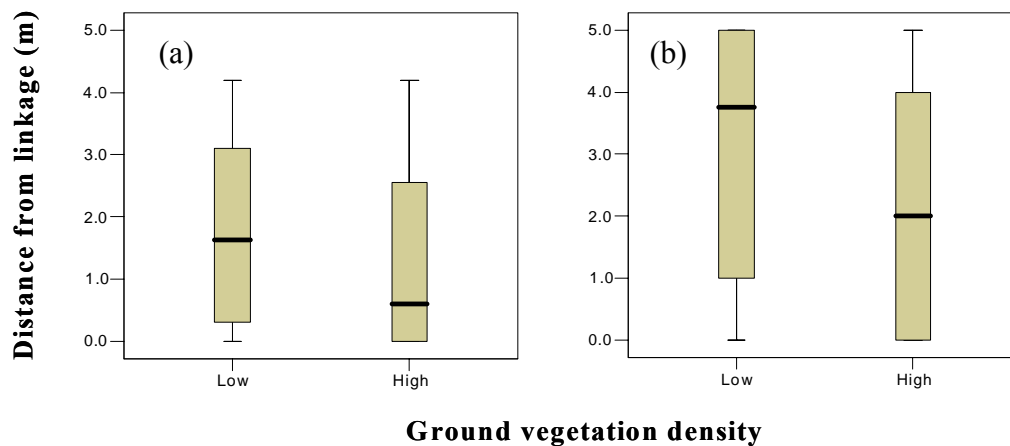


**Figure 5.14** Range of distances between spool trail and the linkage, where *Rattus fuscipes* was released on linkages with and without kinks.

(a) Average distance (b) Maximum distance (n=30).

### 5.3.6 Effect of Vegetation on Linkage Use

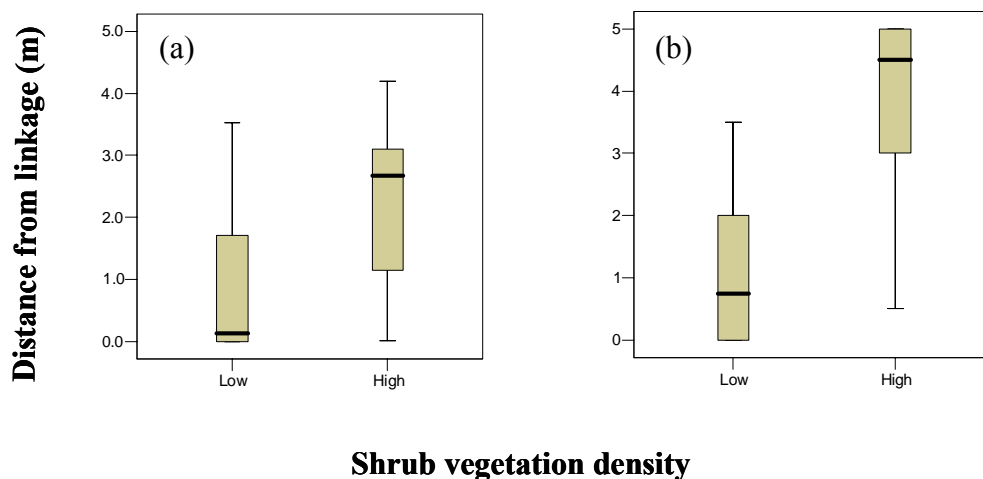
Boxplots constructed from average values for distance from easement showed no obvious association with the degree of ground vegetation cover (Fig. 5.15(a) & (b)). Statistical analysis confirmed this lack of significant association for both average distance from linkage (Fig. 5.15(a)), and maximum distance from (Fig. 5.15(b)). The average distance from the linkage when ground vegetation was low was 1.84m (SE = 0.39), which was not statistically different ( $t = 0.59$ ,  $P = 0.56$ ,  $df = 28$ ) from the distance when the ground vegetation was high (1.49m).



**Figure 5.15** Relationship between ground vegetation and distance of spools from linkages where *Rattus fuscipes* were released during spool-and-line study (n=30).

(a) = Average distance (b) = Maximum distance.

Similarly, the mean maximum distance of the spools from the linkage did not vary significantly with density of ground vegetation ( $t = 1.25$ ,  $P = 0.22$ ,  $df = 28$ ). When ground vegetation was low the maximum distance that the animals moved from the linkage was 3.07m (SE = 0.51), compared to 2.19m (SE = 0.49) when ground vegetation was high. Animals tended to follow a movement path that was further from the linkage when shrub vegetation was denser (Fig. 5.16). For example, when shrub vegetation was low, the average distance of the spools from the linkage was 2.32m, compared to 3.32m when the shrub vegetation was high. Statistical investigation subsequently confirmed this pattern. The average distance that *R. fuscipes* moved away from the linkage was marginally greater when higher shrub vegetation was present but this was not statistically significant ( $t = -1.7$ ,  $P = 0.1$ ,  $df = 28$ ). The difference in maximum distance from linkage in the presence of low versus high shrub vegetation density was statistically significant ( $t = -2.74$ ,  $P = 0.01$ ,  $df = 28$ ).



**Figure 5.16 Relationship between shrub vegetation and distance of spools from linkages, where *Rattus fuscipes* were released during spool-and-line study (n=30).**  
(a) = Average distance (b) = Maximum distance.

## 5.4 DISCUSSION

These investigations of the movement paths of both *R. fuscipes* and *A. stuartii* have revealed compelling evidence of response patterns of these species to their immediate environment. When *R. fuscipes* was released in an open powerline easement, movement paths were characterised by numerous small changes in direction with few large deviations from a straight path (Appendix 14(d)). By contrast, these animals reached the

habitat, they made fewer minor turns but significantly more abrupt changes in direction of 90° degrees or more (Appendix 14(a)). Anderson *et al.* (1988) suggested that such movement behaviour, featuring many twists and turns, is indicative of foraging behaviour. The provision of habitat linkages constructed from preferred habitat features failed to alter significantly the tortuosity of animals' paths in the easement. Contrary to expectation, animals frequently left the linkage where they had been released and ventured for some distance into the open easement before returning to the habitat, regardless of the easement vegetation and the presence of kinks. *Antechinus stuartii* behaved in a similar way to *R. fuscipes*, making many small turns and few large turns while in the easement and the reverse pattern in the habitat adjacent to the linkage although these trends were rarely statistically significant. In the following sections I discuss these movement patterns with reference to species, scale, vegetation levels, perceptual ability, and experimental effects.

#### 5.4.1 Extent and Distribution of Spool Data

Research has shown that the spool-and-line technique provides an accurate reflection of the path followed by a small mammal as it moves through its habitat (Bennett, 2006). Therefore, in this study the observed thread trail was assumed to reflect actual path use, as in Barnum *et al.* (1992) who used fluorescent powder to track small mammals. The increase in average spool length from the earliest to the final field session may reflect an increased proficiency in animal handling and spool-fitting skills. The average length of spools also varied between sites, and may be explained by the density of the habitat.

The proportion of the spool data that was in the easement is likely to be more of a reflection of the width of the easement rather than of a higher level of activity by animals while in the easement at these sites. Of all the powerline easements in this study, Jerrawangala is the widest (because it contains a powerline with higher voltage – 132kV rather than 33kV), almost twice as wide as that at Parnell. This mirrors the proportions of the spools present in the easement at these sites.

### 5.4.2 Use of Linkages

#### *Easement Crossing*

Contrary to expectation, the number of easement crossing events was no higher in the four trapping sessions when linkages were present, than in the four prior to the installation of the linkages. In fact, the opposite of what I expected occurred; less than half the number of crossings was recorded after the linkages had been put in place. As discussed in Section 3.4, there is a number of possible explanations for this barrier effect. These include risk of predation, philopatry, home range boundaries along habitat edges, competition exclusion and vegetation structure. Furthermore, Jerrawangala, the site at which six of the easement crossing events were recorded before the linkages were installed, was mowed before the start of the trapping phase involving the linkages. This may have had an impact on the number of crossings. Nonetheless, the presence of linkages, which were composed of habitat features positively associated with the study species, failed to increase the crossing rate. Referring to the trade-off between predation risk and ecological requirements discussed by Lima & Dill (1990), I conclude that the risks associated with easement crossing, even with the assistance of linkages, outweighed the urge to cross the easement (except where animals had been translocated, see Chapter 6).

Another possible explanation for the continued low rate of easement crossing is that the construction of the linkages was too recent to allow the animals time to familiarise themselves with these potential movement corridors; two of the four trapping sessions for which the linkages were present were conducted less than three months after the construction of the linkages. Furthermore, although linkages were left in place in the easement between field sessions, a condition of powerline operators was that logs and branches be removed from the utility track in the easement. Had the animals explored the linkages during the intervals between trapping sessions, they would have been required to cross the narrow dirt road. Research has shown that even narrow tracks and trails can represent a deterrent to movement for small mammals (Bakowski & Kozakiewicz, 1988; Burnett, 1992; Goosem, 2001).

It is clear that the issues of corridor use and quality are more complex than may appear, and that the original predictions about their efficacy (Section 5.1.3) were naïve. Animals released on linkages responded to factors that extended beyond the simple habitat preferences which were recorded in habitat settings more familiar to them.

### *Linkages as Corridors*

In the early stages of this study, the linkages lacked kinks. Therefore, when an animal followed a straight path to the habitat, it was unclear whether it was preferentially using the linkage as a travel path, or whether the linkage was simply beneath their straight movement path, which was selected for another reason. The incorporation of kinks addressed this conundrum, providing evidence of a tendency by the animals to follow the linkage either partially or entirely, with or without the kinks present in the linkage.

Although there was some evidence of linkage use by released animals, this was inconsistent because animals did not always follow the linkage to the adjacent habitat but, rather, would sometimes leave the linkage and venture into the open easement. Because linkages were constructed from preferred habitat features, it would seem likely that once on the linkage, animals would remain on the log/branch rather than move into the open easement. This is supported by evidence that the movement activity of both *R. fuscipes* (Barnett *et al.*, 1978; Catling, 1991) and *A. stuartii* (Statham & Harden, 1982) is associated with structural complexity. Evidence of avoidance of regions with little vegetation is also present (Chapter 4). Both *A. stuartii* and *R. fuscipes* frequently used at least part of the linkage for movement while in the easement, but overall, spools recorded from *A. stuartii* were more likely to exhibit linkage-use behaviour than *R. fuscipes*. Five of the nine *A. stuartii* released on linkages followed a path along the entire linkage that led to the natural habitat, which compared with eleven of the thirty-one *R. fuscipes* individuals. This may be explained by a higher tolerance of the latter to open, less structurally complex habitat conditions, or may reflect a more vigorous response to the handling process. In some cases, following the handling procedures, an animal would dart towards habitat adjacent to the easement directly away from the source of any light, human scent or noise, regardless of the nature of the vegetation (pers. obs.) suggesting that the urges to seek shelter or avoid predators overrule typical habitat utilisation behaviour. While this experimental phase of my study indicates some

degree of selective use of habitat features by released animals, evidence of voluntary use of linkages would add greater weight to the case for corridors as a conservation tool.

#### *Impact of Easement Vegetation*

Both *R. fuscipes* and *A. stuartii* have been associated with dense vegetation (Barnett *et al.*, 1978; Statham & Harden, 1982). Therefore, it would seem likely that if these species were to leave the easement, they would do so most frequently in easements with denser vegetation. This was confirmed in Chapter 3, where there were more crossings recorded in the easements with denser vegetation. It was therefore not surprising that, in this phase of the study, the denser the shrub vegetation, the more *R. fuscipes* moved away from the linkage and into the easement. This ties in with the findings from Chapter 4, which describe how *R. fuscipes* showed a statistically significant preference for denser shrub vegetation. Previous researchers have also reported an association between higher measures of vegetation cover and the presence of *R. fuscipes* (e.g. Stewart, 1979; Cox *et al.*, 2004). Based on the evidence of an association with shrub vegetation, it was perhaps surprising that no association between ground vegetation and linkage use was found. This may be related to results from Chapter 4, where no preference for any measure of ground cover was detected for *R. fuscipes*. The small number of spools recorded for *A. stuartii*, as well as the fact that several *A. stuartii* individuals did not leave the linkage while in the easement, prevented me from drawing parallels between easement vegetation and linkage use for this species.

The average distance that released animals moved away from the linkage and into the easement was typically no more than 4 metres. One explanation for this is that the total width of the easement is not vast (approximately 25m at Conjola, Currumbene and Parnell, 40m at Jerrawangala). While progressing away from the linkage, the animal, could, potentially, reach the adjacent habitat within 10-15m, depending on the width of the easement in question and the angle of the trajectory on which it moved away from the point of release on the linkage.

It was observed that the average and maximum distances that *R. fuscipes* moved away from the linkage were lower when there were no kinks present. This may either be an

experimental artefact, or an indication of preference for a straight path on the linkage. For example, after release on a linkage, an animal might simply follow a direct path to the habitat region adjacent to the easement. Attempts were made in the field to overcome this artefact by randomly assigning the orientation of the animal upon release, instead of actively directing it towards the habitat on every occasion. When kinks were incorporated, the tendency was still for both *R. fuscipes* and *A. stuartii* to remain on the linkage, for a few metres at least immediately after release. One potential refinement of this technique would be to release animals within 1-2 metres of the linkage and then to monitor whether they tended to gravitate towards the linkage and use it as a travel medium through the easement. There was no indication that animals released in the open easement behaved in such a way. This may be because the nearest linkage was further away than the habitat. A second explanation may be that the animals could not see the linkage at that distance.

After release, some of the animals released on linkages, moved to the opposite side of the easement from where they were captured. It was usually revealed later in the course of the spool that these individuals moved back across the easement to the origin side (Appendix 14(e)). Why they should at first have chosen to move in the opposite direction from their habitat of origin is unclear. It may be because they darted away in any direction solely to put distance between themselves and the perceived danger of the handler. A similar behavioural response by animals was recorded in the study by Sutherland and Predavic (1999). Alternatively, it may have been because from their vantage point on the linkage immediately after release, they could not perceive the familiar habitat they occupied. Forest edge was typically between 10 and 20m away, depending on the width of the easement. Perceptual ability can influence the path selected by small mammals (Zollner & Lima, 1997; Mech & Zollner, 2002; Schooley & Wiens, 2003; Zollner & Lima, 2005) (see also Section 5.4.5).

### 5.4.3 Path Tortuosity

In a study by Stapp & Van Horne (1997), paths of mice tended to be straight where there were few shrubs, with path tortuosity increasing with shrub cover. Results from my study resembled their results, in that the movement paths of both *R. fuscipes* and *A. stuartii* in the barren, open easement had very few large angles (90° and 180°), and were

more tortuous once in the dense habitat. As with the mice, the patterns I observed may be related to the absence of protective vegetation. The direct nature of these movement patterns may be related to the observation by Vásquez *et al.* (2002), that movement speed in *Octodon degus*, the degu, a diurnal rodent, was greatest in the open, which has been linked with higher perceived predation risk in such habitats.

Barnum *et al.* (1992) found that log use by small mammals was particularly high when vegetative cover was sparser (Barnum *et al.*, 1992). They suggested that this was anti-predatory behaviour. Logs tend to be straight, which may in turn result in an overall straighter movement path in these regions. However, this fails to explain the low tortuosity of the paths in my powerline easements, where both vegetation and logs were rare.

Another factor that may cause increased path tortuosity is foraging. For example, Vernes & Haydon (2001) found that *Bettongia tropica* (the northern bettong) made more frequent and more acute turns immediately before and after the recovery of its preferred food item. Perhaps a lack of food in powerline easements may further reduce the likelihood of a more tortuous path in this region. However, food availability for small mammals in powerline easements has not been investigated.

Despite the structural similarities that the linkages bore to the habitat regarding the key habitat features, the movement patterns of *R. fuscipes* and *A. stuartii* in the linkages more closely resembled the patterns recorded from animals in the open easement; no statistical differences in path tortuosity were found between the open and the linkage. This suggests that factors other than physical structure alone influence linkage use by these animals, and therefore management actions directed at reducing the barrier effect in future require a better understanding of small mammal behaviour.

#### **5.4.4 Path Tortuosity in a Fragmented Landscape**

In one respect the results from the animals released on linkages matched my expectations; the paths showed very few large turns. However, spools recorded in the open easement were characterised by many smaller turns which was contrary to expectation. The movement of small mammals in a fragmented landscape is clearly not

as predictable as it may appear. The ability of animals to move through areas of disturbance and anthropogenic activity can determine the extent to which habitat fragmentation will impact upon their dispersal and therefore ultimately on their population viability and survival (With & Crist, 1995; Brooker & Brooker, 2002). Some animals (e.g. ruminants and small mammals) maximise foraging efficiency in high-quality habitats by simultaneously reducing foraging speed while increasing the tortuosity of their movement path (Etzenhouser *et al.*, 1998; Gillis & Nams, 1998). Conversely, behavioural responses from other animals (e.g. butterflies and wolves) indicate that in disturbed habitats, lower tortuosity may be predicted (Schultz, 1998; Whittington *et al.*, 2004). Just as perceptual range can influence the orientation of the movement path of *Peromyscus leucopus*, the white-footed mouse (Zollner & Lima, 1997), it is likely that it may also influence the more fine-scale components, or tortuosity, of the movement path of small mammals.

#### 5.4.5 Habitat Perception

I used simple geometry to provide a measure of tortuosity with which to explore the relationship between the movement paths of *R. fuscipes* and *A. stuartii* and measures of habitat quality of different regions of powerline easements. This analysis is confounded by the fact that understanding an animal's perception of, and response to its environment may be influenced by use of arbitrary measurement scales (Etzenhouser *et al.*, 1998). For example, my perception of 'distance from easement' may have been quite different from the assessment made by a small mammal, due to different perceptions of distance.

In patchy environments, the search behaviour of individuals and their perceptual range are key determinants of the functional connectivity of the landscape (Schooley & Wiens, 2003). Some small mammals (e.g. *P. leucopus*) have a remarkably low perceptual range (<10m) when it comes to detecting their forest habitat, if released in a location with little vegetation (Zollner & Lima, 1997). This is of particular relevance to this study, where animals released on linkages or on the opposite side of the easement (Chapter 6) are required to locate habitat patches in a landscape fragmented by powerline easements. Species with limited perceptual range have restricted information from which they can make movement decisions (Zollner & Lima, 1999a; Schooley & Branch, 2005). These animals therefore may not display habitat use patterns typically

associated with animals in familiar habitat. Additionally, Mech and Zollner (2002) identified a significant positive relationship between perceptual range and body mass. This finding may be relevant for my study and for *A. stuartii* especially which is a particularly small mammal. Animals released on linkages in my study usually followed a path towards the adjacent habitat, albeit not always a direct path. This suggests that the animals could perceive or ‘see’ the habitat. Interestingly, exceptions to this occurred at Jerrawangala, where animals were seen to travel down the middle of the easement for some distance before either shedding the spool or, finally, turning towards the habitat. This may be related to the fact that at Jerrawangala, the width of the easement was considerably larger than any of the other sites, 40m as opposed to a maximum of 25m.

#### 5.4.6 Measuring Corridor Use

The question of how best to measure corridor use was raised by Merriam and Lanoue (1990). They made the observation that the relationship between the distance moved and time taken for movement may not be linear. One drawback of the spool-and-line technique used in my study is that it does not record the temporal element of the animal’s movements. However, the scarcity of large changes in direction (turns) exhibited by both *R. fuscipes* and *A. stuartii* in the easement suggests that a more direct, probably ‘faster’ route was taken when in the easement, perhaps to minimise time spent in a perceived high-risk environment. In this study, therefore, distance moved is unlikely to be a useful gauge of predation risk and corridor use.

Corridor use can also be measured in terms of availability, a point made by Merriam and Lanoue (1990). The mark-recapture phase of my study revealed that animals were capable of travelling the distance to either of the linkages positioned along the grid. Therefore, the evidence of infrequent voluntary use of linkages is unlikely to reflect inadequate provision of easement crossing opportunities.

There have been relatively few empirical tests of the value of corridors to threatened species that were not subject to the confounding effects of other variables (Inglis & Underwood, 1992). They offered suggestions to overcome experimental inadequacies, such as increased replication and use of controls but they also conceded that, in some

cases, practical obstacles may stand in the way of these measures. In light of the practical obstacles of time and human resources, as well as uncontrollable factors such as weather and trap success, this study nevertheless sought a balance between test replication and site replication. My research took the form of a progression from preliminary investigation, to experimentation and habitat manipulation. This approach provided a sound framework for the final conclusions

Flight response may play a role in the movement patterns observed (Section 6.1.3). Every effort was made to minimise distress for study animals. This included not speaking, avoiding sudden, rough movements or using bright lights while handling the animal. Spooled animals were released in darkness and in silence with just one handler present. The handling procedure, which included a period of trap confinement the time required for me to attach a spool to the backs of the individuals, must nonetheless have been traumatic for the captured animals. The extent to which this affected the behaviour of individuals immediately after release is not known but could be addressed through replicated experimentation that followed the procedures used in this study. Preliminary investigation of this issue was undertaken in this study through experimentation and statistical analysis as described in Chapter 6.

Lack of response by a small mammal to a corridor was reported by Haddad *et al.* (2003). They explained that this may indicate that the landscape manipulations were too small to be perceived as corridors by their study species, *Sigmodon hispidus*. This problem arises if a corridor is not perceived by the species in question to be of the same scale as the habitat it occupies. I do not consider this a potential explanation for the infrequent use of linkages in my study. This is because the animals' use of logs and branches in the habitat was used as a model for the construction of the linkages with respect to layout, height, width and composition.

#### **5.4.7 Statistical Analysis of Path Tortuosity**

Because the dataset relating to the angles (turns) made by spooled animals was categorical, and referred to data derived from three easement regions,  $\chi^2$  analysis seemed an appropriate means of making preliminary investigations of angle proportions in each region. However, the assumptions of this test are violated by my dataset,

because the technique does not take into account that the data points on which it is based come from different animals. Furthermore, each data point potentially contains records for several angles size classes and this further confounds the analysis. This prompted me to opt for the ANOVA as an alternative means of analysing my data. Although this method makes less use of the data, since it uses fewer data points, it avoids the violation of statistical assumptions. The arcsine transformation was applied to the proportions of angles of each size class in my dataset. Arcsine transformation, as outlined by (Dobson & Gebski, 1986) can be used for analysis of proportions and, so, is appropriate here. The weakness of this transformation is that it can cause a large deviation of the expected value or mean if the sample size is not the same for all proportions analysed (Kasuya, 2004). It can also decrease differences among means and reduce the variance thereby decreasing the power to detect differences among groups (Dexter & Chestnut, 1995). Use of this method did, nevertheless, detect a number of statistically significant effects.

#### **5.4.8 Conclusions**

The finding that the linkages provided in this study failed to substantially increase the number of easement crossings does not invalidate the implementation of habitat corridors as a biodiversity management tactic. Rather, it highlights the complexity of the issue and directs research towards further modification and experimentation of wider, taller, more structurally complex linkages.

A closer examination of the flight response issue, perhaps through the use of a remote trap release mechanism, may help to account for some of the behavioural patterns observed in my study. Additionally, I would suggest that a longer-term study where linkages are left permanently intact be undertaken. Building on the findings of Goosem & Marsh (1997) which reported that vegetated corridors are occupied by forest-species, I suggest that the role of habitat features not included in the linkages here such as shrub vegetation be investigated, where possible.

The effectiveness of corridors depends on a wide range of complex interacting factors, many of which are outlined in this chapter. It is important, therefore, that corridors are

assessed individually in the context of the entire landscape mosaic (Perault & Lomolino, 2000). Given the potential ecological benefits that corridors can provide in certain situations, investigations into their efficacy are of great value. However, it is imperative that such experiments be robust in terms of design (Inglis & Underwood, 1992) and, additionally, incorporate processes of habitat selection and movement (Chetkiewicz *et al.*, 2006). In Chapter 6, I build on the information gathered thus far regarding linkage use and movement patterns. I carry out translocations of *R. fuscipes* to investigate the incidence and manner of return to the original side of the easement. I also test whether patterns of habitat utilisation show any evidence of a flight response by my study animals.

## Chapter 6 – Translocation Study

### 6.1 INTRODUCTION

#### 6.1.1 Translocation and Homing

Transferring animals from one location to another can serve a range of purposes in conservation biology. For example, the objective may be to assist the recovery of locally extinct species (Priddel & Wheeler, 2004), to restock populations that have undergone dramatic decline (Arrendal *et al.*, 2004; Dullum *et al.*, 2005) or to relocate wildlife that have become pest species (Mosillo *et al.*, 2002). Translocation studies have also been used to assess the impacts of landscape barriers, both natural (Klee *et al.*, 2004) and man-made (Bakowski & Kozakiewicz, 1988), on small mammals. In this phase of the study, translocation of *R. fuscipes* provided an opportunity to test the ability of this species to move between areas of habitat separated by a powerline easement. In a fragmented landscape, the ability to move between patches is essential in driving population dynamics (Zollner & Lima, 1999b) and also in reducing the loss of genetic diversity resulting from population isolation (Mills & Allendorf, 1996). In combination with the fine-scale data provided by spool-and-line technique, translocation studies can reveal much about the patterns and mechanisms that explain species responses to unfamiliar habitat. This information can then be used in the development and future application of conservation measures such as habitat restoration or wildlife relocation projects.

Several factors can influence how a translocated animal returns home. For example, homing plays a role in determining the movement paths of animals (Étienne *et al.*, 1985). Under laboratory conditions, small mammals have the ability to construct a direct homebound path after a more convoluted outbound journey to a feeding place (Seguinot *et al.*, 1993). This is done through the accumulation of cues and signals from the outbound journey by a process known as path integration (Étienne *et al.*, 1996). In other circumstances, where such cues have not been gathered, animals may depend on perception to direct them to suitable habitat (e.g. Zollner & Lima, 1997; Schooley &

Branch, 2005). As Hodara and Busch (2006) explained, success at finding favourable habitats also depends on search strategy. Analysis of the movement paths of translocated animals may provide an insight into the characteristics of these search paths. Finally, as Zollner and Lima (2005) explained in the case of dispersing mammals, patterns observed will be the product of the trade-off between movement and predation risk.

### 6.1.2 Flight Response

If handling of study animals alters behaviour such that it becomes erratic and abnormal, then results describing the activities of these animals may not be valid. As explained in Section 5.4.6, the trapping and handling process was likely to have caused a certain degree of trauma for the wild animals I handled, despite efforts to minimise distress. In a study of *S. younsoni* by Haythornthwaite (2005), it was found that animals sheltered immediately after release and then subsequently resumed their movement through the habitat. Because animals were not pursued or radio-tracked in my study, it is not possible to say if this occurred. Instead I chose to use the data gathered from animals spooled during the study of habitat utilisation (Chapter 4), to investigate this question.

### 6.1.3 Study Predictions and Aims

The results reported in Chapter 3 confirmed that powerline easements represented a very strong barrier effect for the two small mammal species I studied. Some individuals did use linkages installed in the easements, when released on them, though the linkages did not substantially affect the number of easement crossing events. I translocated 18 *R. fuscipes* individuals and spooled them aiming to explore the magnitude of the barrier effect. For those that did return I also wished to examine the path by which they returned to their side of origin, for those that did return.

Based on the evidence from Chapter 3, I predicted low rates of return by translocated individuals to their side of origin. I also predicted that if return journeys did occur, they would be likely to use the linkages provided, rather than traverse the open easement. In Chapter 5, I investigated the responses of small mammals to manmade habitat linkages, and discovered that, compared to the open easement, the paths of animals in natural

habitat featured larger, more frequent angles. Based on this, I expected that translocated animals would exhibit a path at least as tortuous as animals in familiar habitat.

There is a vast body of literature describing stress responses in small mammals in laboratory conditions. However, the flight response phenomenon has not received much attention in the ecological literature, despite the plethora of field investigations that involve physical manipulation of captured animals. I aimed to address the question of flight response in recently captured animals by means of statistical analysis of spool data. Given the amount of handling required to spool an animal in my study, and the total time that each individual could be confined in the trap, I envisaged that the first portion (12m) of each spool would represent flight response behaviour, exhibited by an animal darting away from perceived danger. This 12m estimate was based on the findings of Sutherland & Predavic (1999), who reported a flight response of approximately 10m in their study species *Antechinus agilis*. Given the extensive average length of the spools in my study, and the fact that animals were confined for some time while being spooled (and thus possibly causing a longer flight response), a slightly longer portion of 12m was selected for analysis. I predicted that habitat utilisation would be significantly different in the early portion of the spool immediately after release, compared to later in the spool, when the animal had moved away from the trap and the handler and away from perceived danger.

## 6.2 METHODS

### 6.2.1 Translocation of Animals

#### 6.2.1.1 Handling, Release and Spool Recording

Based on extremely low rates of crossing of *R. fuscipes*, described in Chapter 3, I assumed that the home range of the individuals in this study was restricted to one side of the easement only. I refer to this as the ‘origin side’, and to the side where the translocated animal was released as the ‘opposite side’. This part of the study was an extension of Phase 2, described in Chapter 5, in which *R. fuscipes* captured in traps on the grid were released on habitat linkages in powerline easements. In this instance, I gently conveyed animals captured in traps in the grid to the opposite side of the powerline easement, while they were still in the traps. The release location relative to

point of capture was randomly selected, but was always within the area of the trapping grid on the opposite side. I then removed the animal from the trap, identified it, fitted it with a spool and released it as before.

The following day, I followed and recorded the spool trail. At 3m intervals, I noted the habitat features as described in Section 4.2.3. Simultaneously, I also recorded the number of angles of each size class along the spool trail as described in Section 5.2.3. Where the trail entered the easement from the habitat, recordings were made at 1m intervals, this again to maximise the detail in the records from this region. I sketched the path and followed the thread until it was snagged and could no longer be traced, or until the animal had shed the spool.

#### *6.2.1.2 Statistical Analysis*

Although 18 animals were spooled, only 12 of these provided enough data for statistical comparison. Because of this small sample size, data from Conjola, Currumbene and Parnell were pooled. Initially, as with the habitat utilisation data in Chapter 4, I compared the spool data with the background data using logistic regression, to identify which habitat features were selectively used and avoided. Secondly, I compared habitat utilisation by translocated animals with the equivalent dataset from individuals of the same species that were released in familiar habitat (at the point of capture). This was also done by means of logistic regression. I then compared the tortuosity of paths of translocated animals with those from the three other regions i.e. in familiar habitat, in the open easement and on the linkage. To do this, I firstly prepared the data describing the proportions of each angle size category by transforming it using the arcsine transformation (see Section 5.2.5). I then analysed all the angle data, which were summarised to the spool level using ANOVA, with  $\alpha$  set at 0.05.

#### **6.2.2 Flight Response**

I tested the hypothesis that the habitat use of an animal immediately after handling and release was different from that further along the course of the spool trail. To do this I compared the habitat utilisation patterns of first 12m ('flight response portion') of each spool with those from the remainder ('main portion') of each spool. The flight response portion and the main portion of each spool were coded 1 and 0 respectively, and

compared using logistic regression (see Section 4.4.4). Data from all sites were initially pooled, and subsequently analysed individually.

## 6.3 RESULTS

### 6.3.1 Translocation Experiments: Species and Spool Length

18 *R. fuscipes* were translocated in this phase of the study, though two of these spools failed to yield any data. More than half of the translocated individuals had returned to their origin side before the end of the trapping session at each site (max. 5 days) (Table 6.1). Returns to the origin side were recorded at all four sites where translocations were carried out, irrespective of the level of vegetation cover present in the easement.

**Table 6.1 Summary of translocation results for *Rattus fuscipes***

Species	Fieldwork session dates	Sites	Total no. of translocations	Total length of spool	Proportion returned to origin side during session
<i>Rattus fuscipes</i>	February-06, April-06	Currambene	4	285	3/4
		Conjola	8	756	5/8
		Jerrawangala	5	291	3/5
		Parnell	1	102	1/1
Species total			18	1434	12/18 (66.6%)

Spools averaged 80m in length, and yielded 1,434m of data. Of this, 846m described habitat utilisation of 11 translocated *R. fuscipes*. The remaining 588m referred to movement back across the easement and to habitat utilisation once back inside familiar habitat on the opposite side of the easement. More angle data were recorded than habitat utilisation data i.e. the total of 1,434m also featured 955m of angle data recorded from 16 individuals. In some cases, spools recorded from translocated animals revealed their return journey back to their side of origin after a brief and highly convoluted movement path on the ‘wrong’ side of the easement. These journeys tended not to use the linkages, but instead crossed the open easement (Appendix 14(e)). Bennett (2006) reported an interesting exception to this in her study of the response of *A. stuartii* to translocation

across powerline easement at Conjola National Park; one animal completed a return journey to its origin side using the linkage provided (Fig. 6.1).

**Figure 6.1 Diagrammatic representation of a spool recorded from a translocated *A. stuartii* individual that used a linkage to return to its origin side.**

Taken from Bennett (2006)

### **6.3.2 Habitat Preferences of Translocated *R. fuscipes***

Analysis of habitat utilisation data from eleven translocated *R. fuscipes* revealed very little evidence of preferential use of specific habitat features. Animals ‘in situ’ (familiar habitat) avoided open areas, selected for larger logs, and showed associations with dense shrub vegetation and branches (Chapter 4). By contrast, the translocated animals only showed preferences for two measures of logs. There was a significant preference for logs 10-20cm in diameter ( $P = 0.022$ ), as well as logs >20cm ( $P < 0.001$ ).

Translocated *R. fuscipes* were approximately 2.2 and 3.2 times more likely respectively, to select these measures than to select regions with no logs.

*Rattus fuscipes* used large logs significantly less while moving through unfamiliar habitat. Logs 10-20cm in diameter, 20-50cm in diameter and trunks were approximately three times more likely to be used by this species in familiar habitat than when translocated into unfamiliar habitat ( $P = 0.033$ ,  $P = 0.001$  and  $P < 0.001$  respectively). No difference was found in the use of leaf litter between animals in the two contexts. *R. fuscipes* used both medium and high amounts of branches significantly more in their familiar setting ( $P < 0.001$  for both) compared to when translocated. All measures of ground cover, except the highest and lowest measures were significantly more common in the paths of untranslocated animals (Table 6.2). Finally, for animals in familiar habitat, denser shrub vegetation was used significantly more than by animals that were translocated.

**Table 6.2 Significant results from logistic regression that compared habitat utilisation by *Rattus fuscipes* individuals in familiar habitat (4 sites, 66 animals, 2,474m spool data = 824.6 data points), with translocated individuals (3 sites, 11 animals, 846m of spool data = 282 data points)**

Positive values of  $B$  indicate that animals in familiar habitat selected more of the measure than translocated animals. (See Table 4.2 for explanation of habitat measures).  $\text{Exp}(B)$  is a measure of selection likelihood.

Habitat Measure	3 Sites		
	$B$	$P$	$\text{Exp}(B)$
Logs20	0.853	0.033	2.347
Logs>20	1.070	0.001	2.915
Trunk	1.125	<0.001	3.080
BranchM	1.290	<0.001	3.631
BranchH	1.488	<0.001	4.430
GrVeg20-40	1.625	<0.001	5.077
GrVeg40-60	1.641	<0.001	5.163
GrVeg60-80	1.533	<0.001	4.633
ShVeg20-40	0.832	0.008	2.298
ShVeg40-60	1.406	<0.001	4.080
ShVeg60-80	1.774	<0.001	5.897
ShVeg80-100	1.920	<0.001	6.821

### 6.3.3 Path Tortuosity of Translocated *R. fuscipes*

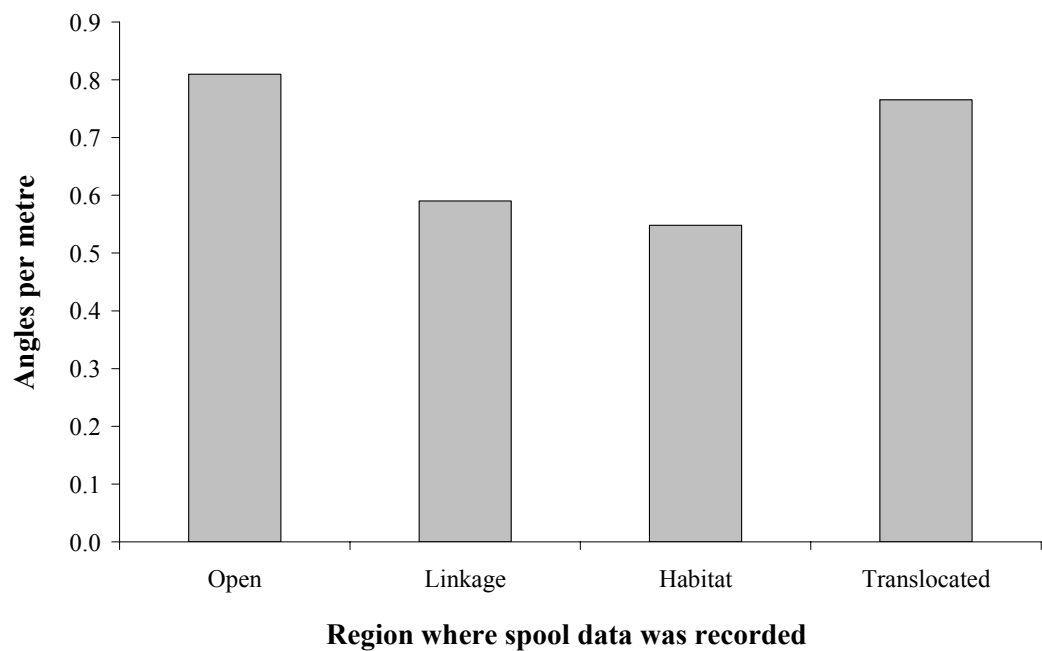
The movement paths of translocated *R. fuscipes* featured significantly more angles per metre ( $F = 5.419$ ,  $df = 1$ ,  $P = 0.024$ ) overall than paths recorded in familiar habitat (Table 6.3). There were also more angles per metre in translocated spool data (0.77) than in the linkage (0.59) (Figure 6.2), though this was not statistically significant. Only spools recorded in the open easement had more angles per metre (0.81) than spools from translocated animals (Fig. 6.2) but not significantly more.

**Table 6.3 Significant results from comparisons of the number of angles per metre made in the movement paths of *Rattus fuscipes* in four easement regions.**

Number of spools in the open easement = 20, the linkage = 31, familiar habitat = 41 spools and unfamiliar habitat (translocated) = 16 spools. Negative values of *B* indicate that animals made more turns when translocated.

Comparison	Familiar habitat versus translocated			Linkage versus translocated		Open versus translocated	
	<45	180	All angles	90	180	90	180
<b>F</b>	4.072	6.586	5.419	8.092	19.4	6.5	17.593
<b>P</b>	0.048	0.013	0.024	0.007	<0.001	0.015	<0.001
<b>Trend</b>	Fewer in habitat	Fewer in habitat	Fewer in habitat	Fewer in linkage	Fewer in linkage	Fewer in open	Fewer in open
<b>B</b>	-0.104	-0.036	-0.203	-0.118	-0.056	-0.116	-0.062

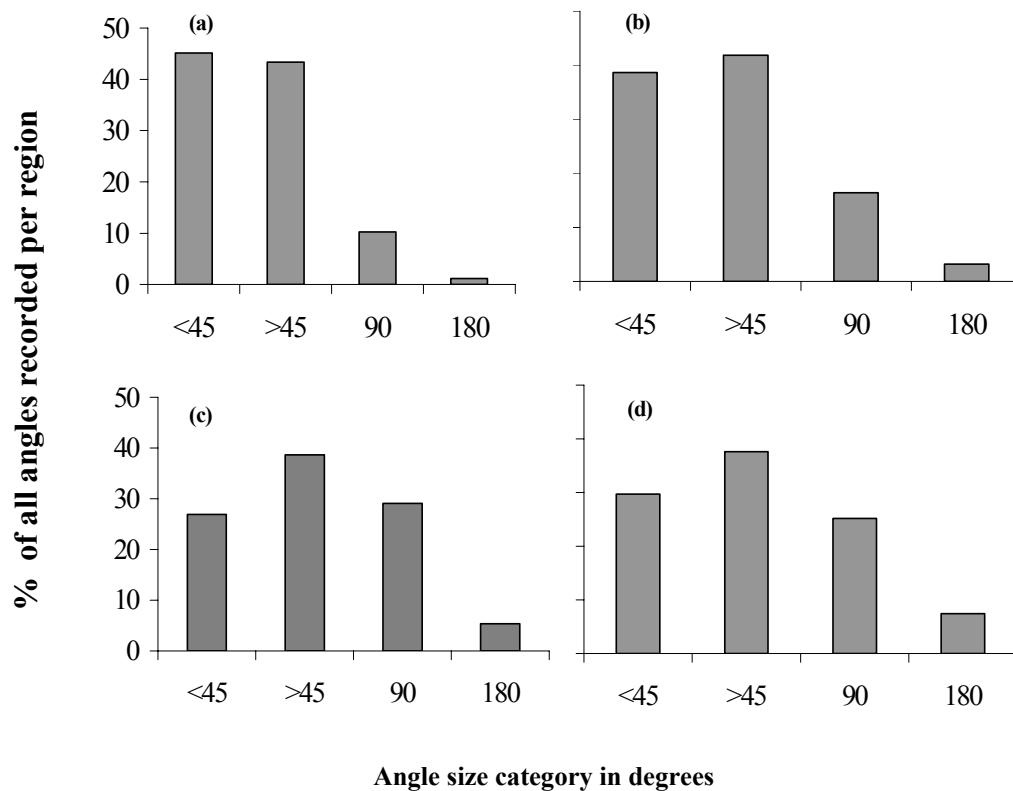
There were also significantly more <45° and 180° turns made by translocated animals than by those in familiar habitat (Table 6.3). Compared to animals moving in the linkage, there were more angles per metre for all angle sizes made by translocated animals (Fig. 6.2), though this was only significant for the two largest angle sizes, 90° and 180° (Table 6.3).



**Figure 6.2** Number of angles per metre ( $\pm$  standard error) recorded for each easement region for *Rattus fuscipes*.

Total length of data analysed 3,599m. Total number of angles included in analysis = 2,273.

Finally, animals in the open easement made significantly fewer 90° and 180° turns per metre than translocated animals (Table 6.3). Differences in the number of smaller angles were insignificant in this case, though indicated a tendency to make smaller turns more frequently in the open. No significant differences were found in the proportions of angle sizes recorded from animals that were in familiar habitat, compared to those that were translocated into unfamiliar habitat i.e. proportions of angles of the four size categories were similar, regardless of whether the animal was in familiar habitat or not (Fig. 6.3).



**Figure 6.3 Proportions of angles (%) of four size classes recorded for *Rattus fuscipes* in four easement regions.**

(a) spools recorded in the open, (b) spools recorded in the linkage, (c) spools recorded in the habitat, (d) spools recorded from translocated animals in the habitat.

However, translocated animals made a significantly higher proportion of 90° and 180° turns in their paths than animals in the open easement ( $F = 12.96$ ,  $df = 1$ ,  $P < 0.001$  and  $F = 8.46$ ,  $df = 1$ ,  $P = 0.006$  respectively) (Fig. 6.3). Relative to path tortuosity in the open, the patterns in the linkage were more similar to patterns from translocated animals.

#### 6.3.4 Flight Response

Based on habitat selection patterns, there was no consistent evidence of flight response from *R. fuscipes* for all sites combined. Habitat use in the first 12m after release was generally not significantly different from that in the remainder of all spools. However, a significant difference was found for certain features at some sites. For example, at both Conjola and Parnell leaf cover of the measures 20-40% and 40-60% was recorded significantly more often in the first 12 m than in the remainder of spools (after 12m). At Parnell and Jerrawangala, as well as overall (all sites), there was significantly more use of tree trunks in the latter portion of spools (Table 6.4). For example, at Parnell and

Jerrawangala respectively, animals were twice and four times more likely to use trunks in the latter portion of their movement paths than in the initial portion.

**Table 6.4 Significant results of logistic regression to investigate the presence of flight response in *Rattus fuscipes* as revealed by habitat use patterns.**

All the measures shown here were selected significantly more in the latter portion of the spool than the initial 12m. Exp(B) is a measure of likelihood that the measure will be selected, the higher the Exp(B), the higher the chance that the measure will be selected. n/a indicates that this measure was absent from the early portion of any spool at this site. Significant results are shown in bold.

Habitat feature	Measure	Currambene		Parnell		Jerrawangala		All Sites	
		<i>P</i>	Exp (B)	<i>P</i>	Exp (B)	<i>P</i>	Exp (B)	<i>P</i>	Exp (B)
<b>Logs</b>	Logs10			<b>0.017</b>	2.760			<b>0.028</b>	1.798
	Trunk			<b>0.037</b>	2.069	<b>0.029</b>	4.313	<b>0.004</b>	1.709
	Leaf20-40%	<b>0.044</b>	6.000			<b>0.012</b>	5.850		
<b>Leaf</b>	Leaf40-60%	<b>0.034</b>	5.833			<b>&lt;0.001</b>	n/a		
	Leaf60-80%							<b>0.038</b>	0.622

Although inconsistent, there was, nonetheless, some evidence of flight response in the paths of *R. fuscipes* based on habitat utilisation patterns. In *A. stuartii*, by contrast, it was almost entirely lacking. No significant differences were found between the initial 12m and the remainder of spools at any of the three sites. When data were pooled from these three locations, only one result with borderline significance was discovered. *A. stuartii* was more than twice as likely to select logs with a diameter of 10-20cm in the later portion of spools ( $B = 0.08$ ,  $P = 0.05$ ,  $\text{Exp}(B) = 2.23$ ,  $\text{df} = 1$ ) than in the first 12m.

## 6.4 DISCUSSION

Examination of fine-scale movements of individual animals can provide insights into mechanisms not available through larger scale studies (Zollner & Crane, 2003). In this part of the study, I discovered that although powerlines represent a significant barrier to the movement of small mammals, translocated *R. fuscipes* can and will still cross them to return home. The spool-and-line technique revealed that translocated individuals of this species do not show the strong habitat associations recorded when in familiar habitat. Although animals show a more tortuous path overall in unfamiliar habitat than familiar habitat, the sizes of turns in either context are very similar. The technique also

illustrated how they will return home across a barren powerline easement very soon after translocation to the adjacent side.

#### 6.4.1 Philopatry

Chapter 3 confirmed a very strong barrier effect for small mammals caused by mowed powerline easements. Based on this finding, I was surprised by how promptly a high proportion of translocated animals returned to their side of origin. Of those that did not return to the origin side, some are likely to have done so subsequent to my trapping session. Studies of small mammals elsewhere confirm that translocated animals will cross back over landscape barriers such as forest roads (Bakowski & Kozakiewicz, 1988) and highways (McDonald & Cassady St. Clair, 2004), distances up to 400m (Fox & Cooper, 1982), as well as over a fifth-order river from an otherwise isolated peninsula (Klee *et al.*, 2004). An attempt by Goosem & Marsh (1997) to induce the crossing of a powerline easement by means of bait inducement was unsuccessful, suggesting that food is not as strong an incentive as returning to home range. The presence of conspecifics detected via olfaction (see Croft (1982)) is likely to be a stimulus for animals outside their home range to return home to avoid intraspecific competition. The proportion of translocated animals that returned to origin in this study, and in those by McDonald & Cassady St. Clair (2004), Schreiber & Graves (1977), and Hodara & Busch (2006) is considered a measure of return ‘success’.

*Rattus fuscipes*, the focal species of this phase of my research, is associated with structural complexity (Barnett *et al.*, 1978; Catling, 1991) and also with logs (Stewart, 1979). However, this species occupies a range of vegetation communities (Menkhorst & Knight, 2004) that include heath, eucalypt woodland and sub-alpine vegetation. MacDonald & Cassady St. Clair (2004) reported that generalist species of small mammal in their study returned to their home range more often than other species. They also suggested that perceptual abilities of the three species in their study may explain apparent differences in philopatry. It is possible, therefore, that species with more specific habitat requirements with regard to vegetation community or structural composition would not show such a high incidence of returning to origin across an inhospitable expanse, particularly if that species also lacked the ability to perceive habitat at some distance. Typically, habitat specificity is a feature of threatened species

(Lunney, 1996), which highlights the concern among conservation biologists for the status of such species in a fragmented landscape.

Although perceptual ability is a key component of navigational skills (see Gillis & Nams (1998)) required by displaced animals, other factors will also influence philopatry. For example, some taxa depend on olfaction to determine orientation (e.g. Schooley & Wiens, 2003), while *Oryzomys palustris*, the marsh rice rat, is known to display anemotaxis (response to wind) (Schooley & Branch, 2005). Barry & Franq (1980) explain the importance of structural features such as logs and rock piles as orientational and navigational aids for *Peromyscus leucopus*, the white-footed mouse. Animals in my study may indeed use recognisable features for navigation when in familiar habitat but would not have had these cues when translocated or in the open easement or linkage. In the latter contexts they must therefore have relied upon other navigational aids.

#### **6.4.2 Habitat Utilisation by Translocated Animals**

Logs were the habitat features with which *R. fuscipes* was most strongly associated, as shown in Chapter 4. It is therefore not surprising that of all the habitat features, measures from the log category were significant in the choice of paths by translocated animals too. This result is not thought to be an artefact of release location because I established the trapping stations (where the animals were released) at points on a grid, the size and layout of which was determined independently of structural composition at the trapping stations. Although these data were derived from 11 animals only, an equal sized dataset recorded from a similar number of animals at Currumbene during the study of habitat utilisation (Chapter 4) did return significant results. This suggests that results here are a genuine reflection of reduced selectivity with regard to habitat features.

Evidence from experiments conducted in Chapter 5, as well as from translocation experiments in this chapter, shows how animals will return to their home range soon after they were displaced. Perhaps this finding, coupled with the highly tortuous paths of translocated animals, indicates that *R. fuscipes* was more preoccupied with returning home than with selecting an optimal movement path as it would do in familiar habitat.

These findings contrast with those of Bennett (2006), who reported that when *A. stuartii* was translocated to the opposite side of a powerline easement, the movement characteristics were not significantly different from those when the animals were in familiar habitat. Bennett (2006) did report, however, that like *R. fuscipes*, *A. stuartii* frequently returned to its origin side following translocation – six of the 15 animals in her study were recaptured on their origin side within days of translocation. For *R. fuscipes*, one plausible explanation for the apparent impetus to return to origin and the lack of habitat preferences when translocated would be high sensitivity to the presence of conspecifics already occupying the unfamiliar habitat. Whilst the relative sensitivities of *R. fuscipes* and *A. stuartii* to the presence of conspecifics have not been documented, unrelated *A. stuartii* individuals are known to nest communally (Lazenby-Cohen & Cockburn, 1991), which is perhaps indicative of greater tolerance to conspecifics than that exhibited by *R. fuscipes*. Inverse relationships in the numbers of different species of small mammals have been reported (e.g. Perault & Lomolino, 2000) but the effects on members of the same species in the context and short timescale of recent translocation are not known. The movement characteristics of *R. fuscipes* within its home range may be determined to a large extent by the presence of specific structural features, whose location relative to the nest or other key habitat features has been learned (see Étienne *et al.* (1996)). In the absence of these cues, movement and habitat selection patterns may be atypical.

#### 6.4.3 Path Tortuosity in Translocated Animals

The movement paths of translocated animals featured almost as many turns overall as paths in the open easement, but notably also featured a far higher proportion of larger turns, including doubling-back (180°). Such tortuous movement patterns are regarded by some (e.g. Anderson *et al.*, 1988) as indicative of searching behaviour, often associated with foraging. Several of the spool records from *R. fuscipes* individuals showed a prompt return from the ‘wrong’ side of the easement back to their side of origin. For this reason, I considered that the highly convoluted paths of translocated animals were more likely to indicate a search for bearings or familiar habitat than for food. This is supported by the findings of Chance and Mead (1955), who discovered rats will delay feeding when part of the environment is unfamiliar.

Several authors have discussed the association between *R. fuscipes* and logs (e.g. Dickman & Steeves (2004), Dickman (1991) and Stewart (1979)). My research also supported these findings. While translocated animals did show a significant preference for two measures of logs, the preference was not as marked as for animals in familiar habitat. Logs tend to be straight and, therefore, animals using them as movement substrates will frequently exhibit straight portions in their movement paths. Perhaps greater path tortuosity exhibited by translocated animals is related to lower usage of logs compared to animals in familiar habitat? The more convoluted movement paths may be explained by the observation, both in my study and elsewhere (Stewart, 1979), that small mammals tend to use established runways. Such runways or well-established pathways tend to be quite straight, possibly to conserve energy and minimise travel time. Translocated animals did not appear to use these runways, perhaps because they were unfamiliar with the terrain, or because there were fewer runways present. This may have contributed to a higher overall path tortuosity.

It has been reported that voles exhibited avoidance behaviour when encountering a barrier edge by incorporating more turns as they approached and evaluated the barrier (McDonald & Cassady St. Clair, 2004). Other studies also suggest distinctive movement behaviour of small mammals at habitat boundaries (Stamps *et al.*, 1987; Bowne *et al.*, 1999; Haddad, 1999). These studies support my finding that animals adopt an unusually tortuous path when translocated into unfamiliar habitat adjacent to a movement barrier and lend credence to the theory that corridors may be beneficial to their movement back to origin habitat.

#### **6.4.4 The Flight Response**

Animals in my study varied in their immediate response to handling. Whilst some slowly progressed through the habitat until out of sight (pers. obs.), others darted away. Research by Sutherland and Predavic (1999) similarly reported that *A. agilis* tended to flee and hide roughly 10m from the point of release. Some habitat features, such as logs, were utilised significantly more by *R. fuscipes* in the latter portion of spools. Overall, however, statistical analysis failed to show any differences in habitat utilisation patterns in the first 12m after release, compared to the remainder of the spool. This mirrors the findings of Bennett (2006) for *A. stuartii*, where only a small number of habitat measures were utilised significantly more in later portions of spools. Possible reasons

for these differing responses may include; varying behavioural characteristics of individuals, the weather conditions, hunger levels, distress or energy levels, and also the time required to affix the spool. It has been confirmed that live trapping induces a physiological stress response in some small mammals (Fletcher & Boonstra, 2006). Literature describing the flight response is very limited and so these conjectures cannot be linked to existing evidence or explanations.

The test for flight response was aimed at eliminating spurious explanations for movement patterns recorded from translocated animals as well as those released in powerline easements. The finding that habitat utilisation immediately after handling and release was, generally, no different from that in later sections of the spool, suggests that my results were more a reflection of other unidentified behavioural traits or of the impact of the immediate physical environment, than of the effect of handling.

## Chapter 7 – General Discussion

*“When we try to pick out anything by itself, we find it hitched to everything in the universe”*

~John Muir (1838-1914)

### 7.1 Significance of the Study

This study has resulted in important discoveries regarding the ecological effects of powerline easements, a poorly understood yet pervasive form of habitat fragmentation. I initially investigated the ecological impacts of powerline easements at the landscape scale, using GIS to estimate impact magnitude: I then adopted a more fine-scale approach, focusing on the movement patterns of native small mammals adjacent to powerline easements. I also incorporated habitat manipulations and replicated experiments involving native species at several sites to test the effectiveness of potential mitigation strategies.

Whilst some of the habitat associations that emerged were as predicted, results elsewhere (e.g. response to linkages created within easements) were less intuitive. My investigations into the responses of native species to artificial habitat corridors have revealed a complex pattern, indicating that previous assumptions regarding habitat utilisation in this context may be naïve. It is clear that the interacting factors which influence the movement behaviour of small mammals in a fragmented landscape are subtle, variable and intricate.

Although elements of this study supported previous findings regarding habitat use (e.g. movement inhibition at habitat boundaries; a preference for logs), elsewhere I have reported both new and contradictory findings about the magnitude of the impact of powerline easements, the use of habitat corridors, flight response, and path tortuosity. In the following section, I summarise the most important findings from each phase of the research conducted during this study.

## 7.2 Overview of Main Findings

### 7.2.1 Magnitude of Ecological Effects of Powerline Easements

The main results of Chapter 2, in which I estimated the magnitude of the ecological effects of powerline easements, were as follows:

- Very little is known about the nature or extent of the ecological impacts caused by the construction and maintenance of powerline easements within regions of natural habitat.
- In my 5,735km<sup>2</sup> study area, there are 1,093km of easements, containing powerlines of one of three possible voltages.
- Powerline easements are present in all land tenures, including National Parks.
- 43.6% of the easements in the study area cut through regions identified as potential habitat which results in the replacement or radical alteration of 2,386ha of natural habitat.
- Using GIS, a range of estimates of the magnitude of indirect (edge) effects was made. Up to 14,070ha of habitat in the study area may be affected either directly or indirectly by powerline easements.
- Together, roads and powerline easements in the study area may ecologically affect up to 69,030ha, (16.37% of all habitat in the area) either directly or indirectly.
- Powerline easements make a substantial contribution to the amount of land subject to disturbance from linear habitat fragmentation.

With the exception of one study in Tropical North Queensland (WTMA, 1999), I believe this study to be the first of its kind to estimate the magnitude of the ecological impacts of powerline easements in Australia. Estimates of the edge effect zone of roads have been undertaken in the United States (e.g. Forman, 2000; Forman & Deblinger, 2000) but comparable investigations of powerline easements have not been made.

The amount of habitat directly replaced by powerline easements is very small when viewed as a percentage of the total habitat in the study area. However, when estimates of edge effect magnitude are added to this, and viewed in the context of a landscape

already highly fragmented by roads, the true impact of these features is very much more extensive.

These results highlight the potential ecological impact of powerline easements and reinforce the need for a more detailed, widespread assessment of their impacts on natural habitat. GIS is a valuable tool in estimating the magnitudes of ecological effects of these landscape features. However, more accurate predictions will require empirical measurements of edge effects that are specific to powerline easements, and will also need to incorporate measures of habitat fragmentation that include the spatial composition of habitat patches.

### 7.2.2 Barrier Effects Caused by Powerline Easements

The main findings of Chapter 3, in which I quantified the barrier effect of powerline easements, were as follows:

- High capture rate in habitat adjacent to easements at all sites, indicative of substantial populations of *Rattus fuscipes* and *Antechinus stuartii*.
- Very low rate of easement crossing (15 out of a potential 330) despite the proven ability of recaptured small mammals to travel at least the equivalent width of the easement. The observed number of crossings was significantly less than expected for both *R. fuscipes* and *A. stuartii*.
- The majority of easement crossings were recorded when vegetation density in the easement was medium to high.
- There was no apparent seasonal, species or sex bias in the records of easement crossing.
- Competition exclusion is unlikely to explain the barrier effect observed, owing to the very infrequent capture of any species of small mammal in the powerline easement itself.
- One site, which featured very dense easement vegetation, was trapped for a short period only. A higher trap success within the easement was recorded at this site than anywhere else in the study region.

These results support the findings of Goosem and Marsh (1997) and Schreiber & Graves (1977), who also reported a barrier effect for small mammals caused by a powerline easement. The discovery of a barrier effect was not surprising given the additional evidence of the inhibitory effects on animal movement caused by a variety of linear features located in areas of natural habitat. This phenomenon has been widely reported for small mammals (e.g. Wilkins, 1982; Mader, 1984; Swihart & Slade, 1984; Bakowski & Kozakiewicz, 1988; Burnett, 1992; Goosem, 2001) as well as other taxa (e.g. Vos & Chardon, 1998; Haskell, 2000; Bélisle & Cassady St. Clair, 2001; Marsh *et al.*, 2005).

Given the exposed nature of a mowed powerline easement, in addition to the well-established association between the small mammals in my study and vegetation structure (Wood, 1970; Barnett *et al.*, 1978; Dickman, 1982; Lazenby-Cohen & Cockburn, 1991; Lindenmayer *et al.*, 1994), the low capture success from trapping in the open easement was as expected. Previously, forest species have been absent from trapping surveys of powerline easements (Goosem & Marsh, 1997) (but see Mansergh & Scotts (1989)) as well as other areas subjected to severe habitat disturbance (e.g. Dunstan & Fox, 1996). The failure to detect small mammals communities within the easement at any site eliminated the possibility of competitive exclusion at the easement edge as a cause of the barrier effect.

There is a number of possible alternative explanations that may explain why some small mammals would avoid movement into open habitats. These include; philopatry (Wood, 1970; Schreiber & Graves, 1977), predation risk (Bennett, 1993; Stokes *et al.*, 2004), the absence of preferred habitat features (e.g. Braithwaite & Gullan, 1978), or the presence of psychological barriers arising from a tendency to align home ranges with habitat boundaries (Barnett *et al.*, 1978). It is difficult to predict which one or combination of these explanations can apply for a particular species in a given context without closer examination of habitat preferences, and subsequent habitat manipulation experiments.

### 7.2.3 Habitat Preferences of *R. fuscipes* and *A. stuartii*

The main findings reported in Chapter 4, in which I investigated habitat use patterns in *R. fuscipes* and *A. stuartii*, were as follows:

- *Rattus fuscipes* showed a significant positive association with logs, and in particular with logs of a large diameter. Across all sites, *R. fuscipes* also showed significant preferential use of regions of habitat featuring abundant branches and shrub vegetation. The same patterns tended to exist at the site level too, though were not always significant.
- There was a significant positive relationship between *A. stuartii* and leaf litter at all sites. This species also exhibited a significant positive response to larger logs with additional evidence of significant associations with branches and ground vegetation at some, but not all sites.
- *Antechinus stuartii* showed strong arboreal tendencies.
- Trap success was consistently higher at trapping stations at the interior of the trapping grid compared to those at the habitat-easement boundary. This was true for both *R. fuscipes* and *A. stuartii*, but in particular for the latter where the pattern was significant at two of the four sites.
- *Rattus fuscipes* and *A. stuartii* were found to coexist at all sites that were trapped.
- Habitat utilisation patterns recorded from *R. fuscipes* suggested that larger logs were used more when shrub vegetation was sparse. Associations between habitat features were also detected for *A. stuartii*; in the absence of leaf litter, regions of habitat with denser ground vegetation were preferentially selected. Furthermore, attraction to regions with abundant ground vegetation increased when shrub vegetation was also abundant.

The habitat preferences of *R. fuscipes* for logs and branches, and also shrub vegetation found in my study are supported by previous studies such as Stewart (1979) and Dickman & Steeves (2004) who reported preferential use of regions with habitat cover and with logs respectively. Unlike other studies that describe preferential use of leaf litter (e.g. Catling, 1986) and ground vegetation (Lunney & Ashby, 1987) by *R. fuscipes*, my investigations did not detect associations with these habitat features. Log

use may maximise silent passage through the habitat (Barnum *et al.*, 1992), or may alternatively be explained by their provision of shelter (Dickman & Steeves, 2004) and food.

Fewer distinct habitat preferences were detected for *A. stuartii* than for *R. fuscipes*. It is not clear why this might be so, although Statham & Harden (1982) commented that the concept of habitat is particularly complex in the case of *A. stuartii* and therefore may be poorly described using the coarse categories I used to describe habitat. The exception to this was a distinct association with regions of the habitat featuring abundant leaf litter. This habitat use characteristic has been previously reported for *A. stuartii* by Barnett *et al.* (1978) and for *Antechinus* spp. by Cunningham *et al.* (2005). Selective movement through regions with abundant leaf litter may reflect foraging behaviour for their prey, invertebrates, (Fox *et al.*, 1979; Dickman *et al.*, 1983), which are often found in leaf litter. *Antechinus stuartii* in my study selected regions with logs, a finding also reported by Statham & Harden (1982), which can be a further source of invertebrates (Lassau *et al.*, 2005). The regular arboreal movements of *A. stuartii* observed in this study mirror the findings of Dickman & Steeves (2004) and also Carthew (1994), and are likely to be related to the search for prey, or may be for nesting purposes (Dickman, 1982).

The lower incidence of captures in the region of the trapping grid closest to easement echoes the findings of Ryan (1999), Laurance (1994) and Dunstan (1996) who variously report lower trap success for forest dwelling small mammals closer to the habitat edges or regions of disturbance. In my study, reasons for this were not easily explained statistically by the distribution of habitat features at each of the sites, thus are likely to involve more complex factors such as interspecific interactions, landscape context, demographic history of the species and avoidance of disturbed regions.

Research has repeatedly shown that at the fine scale, microhabitat segregation exists between species whose range overlaps (e.g. Dueser & Shugart Jr., 1978). As Downes *et al.* (2000) explained, highly complex habitats offer more potential niches than those with lower structural complexity. My sites each provided dense, structurally complex

habitat conditions, which may have permitted the co-existence of *R. fuscipes* and *A. stuartii* that was a feature at all of my sites.

#### 7.2.4 Response to Habitat Linkages

The main findings of Chapter 5, in which I investigated the response of *A. stuartii* and *R. fuscipes* to artificial habitat linkages, were as follows:

- The construction of habitat linkages did not increase the number of easement crossing events by small mammals.
- The spool-and-line technique revealed that animals released on habitat linkages tended to use either some or the entire course of the linkage to return to the habitat. This was particularly evident in *A. stuartii*. However, other individuals of both species strayed from the linkage, and after progress in the easement for some distance, eventually entered the adjacent habitat.
- Animals released in the open easement tended to follow a straight path to the nearest habitat, though not necessarily the shortest path.
- Individuals that progressed towards the ‘wrong’ side (not their side of origin) after release in the easement frequently corrected their error by crossing back over the easement to their origin side.
- *Rattus fuscipes* strayed further from the linkage into the easement when there was more abundant shrub vegetation growing in the linkage. The maximum distance strayed from the linkage while in the easement was significantly higher when shrub vegetation was abundant.
- There was no significant association between ground vegetation and the distance that *R. fuscipes* strayed from the linkage after release.
- Both *R. fuscipes* and *A. stuartii* made more turns per metre in the open easement and the linkage than when in familiar habitat.
- *Rattus fuscipes* made significantly more small turns in the open easement than the habitat and significantly more large turns in the habitat. The same pattern was observed for *A. stuartii*, though the trends were generally not significant.
- There was no significant difference in the tortuosity of spools recorded in the linkage and the open easement. This was true for both *R. fuscipes* and *A. stuartii*

- The paths of *A. stuartii* were more tortuous overall than those of *R. fuscipes*, though the relative proportions of turns of each size were quite similar.

While some reports confirm the use of by small mammals of corridors as links between habitat patches (Laurance & Laurance, 1999; Haddad *et al.*, 2003), others report findings more similar to those presented here (e.g. Andreassen & Ims, 2001), namely that corridors had little impact in increasing the frequency of movements between patches. Possible reasons for the reluctance to use the habitat corridors in this study include lack of familiarity with the linkages, inadequate cover offered by the linkages, philopatry and a perceived predation risk in the easement.

The evidence of linkage usage by the small mammals in this study suggests that these structures provided favourable conditions for movement, which has encouraging prospects for implementation of such linkages for conservation purposes in the future. The tendency of animals to leave the easement contradicted this however, but may be explained in two possible ways: Firstly, the animals' overwhelming need to escape the site of handling may cause them to dart away in the opposite direction, regardless of the suitability of the adjacent linkage for movement. Secondly, perceptual abilities of small mammals are poor (Zollner & Lima, 1999a; Schooley & Branch, 2005). It is therefore possible that the animals were unaware that the linkage on which they were released led to habitat and therefore the promise of shelter.

The abundance of smaller turns ( $<45^\circ$  and  $45^\circ$ - $90^\circ$ ) in the open and linkage may reflect a degree of uncertainty or hesitation as the released animal proceeded towards cover in the habitat adjacent to the easement. This is likely to be related to the observation by Stapp & Van Horne (1997), that in the absence of shelter small mammals adopt a movement path that is largely straight. Larger turning angles ( $90^\circ$  and  $180^\circ$ ) were very infrequent in these same regions, perhaps because of the urgency to avoid any large deviations from a straight movement path, but instead seek cover and thereby minimise predation risk (Stokes *et al.*, 2004).

It is interesting to note that turning frequency of animals in the linkage was not significantly different from that in the open easement. This suggests that while linkages may sometimes be used by small mammals for movement through the easement after release, these structures do not create conditions suitable for foraging, as recorded from animals in familiar habitat.

### 7.2.5 Response to Translocation

The main findings of Chapter 6, in which I explored the response of *R. fuscipes* to translocation across the powerline easement, were as follows:

- The majority of animals returned to their side of origin within a few days of translocation. This required movement back across the powerline easement.
- Translocated *R. fuscipes* individuals showed few significant associations with any habitat feature, with the exception of one measure of logs.
- Compared to animals in familiar habitat, translocated *R. fuscipes* individuals showed less selective use of habitat features.
- The turning frequency (tortuosity) of translocated animals was significantly greater than for animals in familiar habitat. The movement paths of translocated animals featured significantly more 45° and 180° turns. The exception to this was the portion of the path where the individual entered the powerline easement to return back home, this tended to be straighter, with few turns.
- Compared to movement paths in the linkage, there were significantly more large turns in the paths of translocated animals (in unfamiliar habitat). The same pattern emerged when paths of translocated animals were compared with paths recorded in the open easement.
- No evidence of flight response in the first 12m after release of an animal was detected in the habitat utilisation records.

The ability of small mammals to return to their site of origin following translocation has been previously documented (Schreiber & Graves, 1977; Klee *et al.*, 2004; Hodara & Busch, 2006). The incidence of return to origin that I discovered was particularly interesting, given the strong reluctance to cross the easement revealed earlier in the

course of this study. Existing research has documented the rate of return of translocated animals (cited above), as well as their survival (Mosillo *et al.*, 2002; Arrendal *et al.*, 2004; Dullum *et al.*, 2005) in new habitat after translocation. However, few studies have described the movement characteristics or the nature of the return journey of translocated individuals.

The willingness of animals in this study to travel back to their home range across an exposed powerline easement may be explained by very strong sense of philopatry, or site attachment, as described by Schreiber & Graves (1977) and Wood (1970). Intra- or interspecific competition with resident small mammals in the area to which they were translocated is also likely to play a role in motivating the animals to return home.

Movement path tortuosity can be indicative of searching behaviour (Anderson *et al.*, 1988). I believe this may explain the tortuous nature of the paths of translocated *R. fuscipes*. However, based on the evidence of prompt return journeys back across the easement in this study, I would suggest that the searching behaviour I observed is more likely to be indicative of a search for familiar habitat rather than for food. As mentioned above, the ability of small mammals to perceive habitat from a distance is poor (Zollner & Lima, 1999a; Schooley & Branch, 2005), and in unfamiliar habitat, navigational aids such as landmarks are absent. The translocated animals in my study must therefore rely on other biotic and abiotic cues such as scent, light conditions and wind direction, along with more complex ethological homing instincts, to navigate back to their familiar habitat.

The lack of a detectable flight response in the paths of animals released at the point of capture was a useful discovery. This suggests that responses of individuals later released on the linkage and in unfamiliar habitat, may be more attributable to factors related to their immediate environment, rather than the handling process. However, modifications to this investigation, such as use of a remote release mechanism or variations to the handling procedure or release location, are required to confidently eliminate the effects of handling and transportation from the reported results.

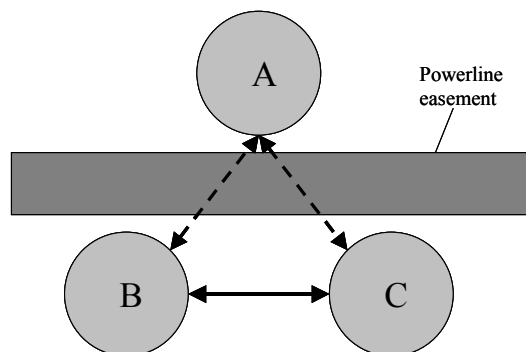
#### 7.4 Future Research and Associated Management Implications

My studies have identified some key areas of research that would contribute to our understanding of the effects of habitat fragmentation on native species and associated mitigation strategies. Additionally, based on the findings presented in this thesis, new questions have emerged. Below I summarise those areas that I suggest to be most important.

##### *(1) Impacts of powerline easements on the genetic structure of populations.*

In support of the findings of Goosem & Marsh (1997), based in the wet tropics of north-east Queensland I have shown that powerline easements also represent a considerable barrier to the movement of small mammals in eucalypt forest areas of south-eastern New South Wales. Given the great importance of dispersal and exploratory movements maintaining and regulating populations (Kozakiewicz, 1993; Peakall *et al.*, 2003), the impacts of movement inhibition resulting from powerline easements deserves further attention. Having explored this issue at the fine-scale (Chapter 3), research attention could now be focused on the broader implications of my findings at the landscape scale. Genetic techniques could be employed to compare the effect of powerline easements on levels of gene flow among neighbouring populations with those of populations that become fragmented as a result of powerline easement construction. If powerline easements do indeed disrupt the movement of small mammals, this may result in small effective population sizes, which may lead to increased levels of inbreeding, potentially resulting in loss of genetic diversity. For example, for populations in a given landscape (see A, B and C in Fig. 7.1), there should be little genetic differentiation among populations if a powerline easement had no effect on gene flow, i.e. populations would be genetically similar. However, if the powerline easement did restrict gene flow between population A and the other two populations, the genetic composition of population B would be expected to more closely resemble C than A, i.e. population A becomes genetically distinct from either populations B or C (see Kozakiewicz & Konopka (1991)). Additionally, reduced gene flow to population A may result in increased inbreeding, especially if population A consists of a small number of closely related individuals. Banks *et al.* (2005) conducted a similar study to that proposed here. In their research, the impacts of habitat fragmentation resulting from establishment of an exotic pine plantation on dispersal of *Antechinus agilis* were

studied. The results of analysis of gene flow suggested a behavioural barrier to crossing habitat interfaces. It is likely, based on the evidence of movement inhibition detected in my study, that the investigations I propose would return similar results.



**Figure 7.1 Schematic presentation of proposed investigation into the effects of powerline easements on gene flow.**

Measures such as microsatellite genotypes recorded from individuals in each of the hypothetical populations A, B and C may reveal patterns reflecting the rate of gene flow between these populations.

*(2) Comparison of gene flow between populations isolated by linear landscape features.*

It would be useful to compare results from the investigations outlined above in regions with powerline easements, with results of similar studies regarding roads of various kinds. Comparisons of the impacts of powerline easements that vary in terms of location, width, and vegetation management policy could be made in a similar fashion. Studies of this kind would facilitate a quantitative assessment of the impact of linear habitat fragmentation on native small mammals, as well as assist in the prioritisation of impact mitigation strategies. They could, in addition, assist reserve selection and design.

*(3) Impact of flight response on movement paths.*

The question of flight response was addressed using habitat utilisation data gathered early in this study. Investigations of path tortuosity (angle analysis) began subsequently, when I was exploring the response of animals to release on artificial habitat linkages, and later to translocation experiments on movement patterns of small mammals.

Therefore, records of path tortuosity could not be used in flight response analysis, as results would potentially have been confounded by the effect of unfamiliar environment (linkage, open easement or opposite side of easement) as well as the transportation to

the release site. There were significant differences in the movement patterns of translocated versus untranslocated animals (Section 6.3.3). A potential extension of the flight analysis investigations that I carried out would be to compare the composition of the angles in the initial and later portions of spools when animals are released in familiar surroundings.

*(4) Edge effects at powerline easements.*

Above, I proposed further investigations of the barrier effect, one of the key ecological impacts associated with linear landscape features such as powerline easements. As explained in Chapter 2, another result of such disturbance is the generation of various edge effects where there is natural habitat adjacent to a mowed easement. Edge effects are neither simple nor static, a point stressed by Gascon *et al.* (2000). Murcia (1995) also noted that too often the dynamic, interacting nature of edges is over-looked, and also that this science would benefit from a more mechanistic approach to associations between cause and observed patterns. Similarly, Fagan *et al.* (1999) called for greater research focus to be placed upon mechanisms that may alter ecological processes rather than the simple edge patterns *per se*. This approach would involve manipulative experiments in the edge zones adjacent to powerline easements, in which edge conditions were altered in order to test both biotic responses as well as the impacts on abiotic factors. For example Yahner & Hutnik (2005) have promoted the concept of a ‘wire-border zone’ (Section 2.4.5), which would result in a more gradual change from forest to mowed conditions in the powerline easement. How does this affect habitat use by small mammals at the edge? Would this design increase the presence of forest species in the easement and/or reduce the barrier effect? The simulations presented in Chapter 2 were generated using estimates of edge effect zone from edge studies in other contexts and geographical locations. While my simulations provide a valuable guide to the maximum and minimum extent of edge effects, the accuracy of these simulations would be greatly improved if there were a larger database of research describing easement-specific edge effects from which to draw.

*(5) Use of GIS in powerline easement design and location.*

As described above, simulations such as mine can make valuable predictions about the magnitude and extent of the environmental impacts of anthropogenic activities. As

urban areas expand, and the need for power increases, existing powerline networks may require upgrading and extension. With the increasing sophistication of vegetation and species distribution databases the opportunity now exists to employ technologies such as GIS for the purpose of optimising easement location in terms of cost and accessibility while minimising their environmental impacts. For example, Treweek and Veitch (1996) advocate the use of GIS and remotely sensed data for the ecological assessment necessary prior to the sanctioning of new road-building projects. Research has shown how remote sensing imagery (Coops & Catling, 2002) and airborne videography (Catling & Coops, 1999) can be used to predict the relative abundance and distribution of ground dwelling mammals. The development of powerline networks would benefit from the incorporation of this data into the decisions regarding easement design and location, as Treweek & Veitch (1996) described for roads.

*(6) Improvements to vegetation management in powerline easements.*

The results of my simulations of powerline easement impact magnitude revealed that a surprisingly large area of habitat in my study area is affected, either directly or indirectly. Prompted by this result, in Section 2.4.5 I described the potential economic and conservation benefits of a more selective approach to vegetation removal. In addition to this, post-management comparative studies of herbicide techniques have found differences in persisting tree growth. For example, Dreyer and Niering (1986) showed that basal herbicide application (as opposed to stem foliar herbicide application) yielded a mean of 100% greater shrub and 50% less herbaceous cover. Overall tree seedling establishment on basally treated rights of way (easements) was less than on stem-foliar treated lines. Findings such as this not only show that the creation of stable shrublands can potentially limit the invasion of seedlings, such as resprouting eucalypt seedlings in Australia, but can also, therefore, reduce the amount of herbicide usage. Johnstone (1990) also found that a shift from traditional, regular mechanical mowing of powerline easements (termed in the United States) resulted not only in improved wildlife habitat but also enhanced aesthetics, accessibility and environmental protection. While Integrated Vegetation Management is an established area of study in the United States and Canada (Johnstone, 1990; Wagner, 1994; Wells *et al.*, 2002), similar research into contrasting chemical and physical vegetation management techniques, and their impacts for wildlife, have not yet been undertaken in Australia. Given the prevalence of

powerline easements in the landscape, I advocate the implementation of a wider range of management techniques, based on those described above, on a trial basis initially for comparative purposes. Results from Australia may be expected to be quite different to those reported in the US and Canada, given the different ecological contexts and plant species present. Furthermore, within Australia there is great variation in the composition of plant communities (Specht, 1970). Therefore a broader, more comprehensive assessment of the efficacy of different management techniques would involve trials in a range of the more widespread plant communities.

Increasing easement use by small mammals may involve reducing the contrast between habitat and powerline easement conditions. Stamps *et al.* (1987) explained that the penetrability of a habitat boundary can vary. They distinguish ‘hard edges’, which individuals can virtually never cross, and ‘soft edges’ that are permeable to emigrating individuals. Perhaps a more natural vegetation gradient from habitat to easement would ‘soften’ the boundary as they describe it, thereby presenting less of a movement-deterrent to small mammals?

Captures made within the easement in my study, while not entirely absent, were mostly very infrequent, a result which is thought to be related to the sparse vegetation in the easements in my study region, amongst other factors (Section 3.4). However, numerous captures were made in Sussex easement (Section 3.3.3), which featured abundant easement vegetation. Monitoring of easement entry by small mammals over a longer period of time, as vegetation re-establishes, may provide support for the view that more easement vegetation provides better foraging conditions for small mammal fauna. A second reason for the investigation of a range of alternative management techniques would be to monitor the rate of regrowth of taller plant species likely to interfere with powerline conductors. Results of these parallel investigations would guide future vegetation policies with a more meaningful conservation and economic basis than at present.

*(7) Use of powerline easements by exotic predators*

The experiments proposed above involving the alteration of vegetation cover in powerline easements would provide an opportunity to assess the presence of exotic species in powerline easements. The feral predator, the red fox, has been associated with the decline of Australian mammal fauna (Christensen, 1980; Jarman, 1986; Dickman, 1996). Some research has indicated that the fox favours established pathways for movement (Mahon *et al.*, 1998), while others have confirmed the sighting of foxes in powerline easements (Goldingay & Whelan, 1997). This evidence builds a strong case for a more quantitative evaluation of the use of powerline easements by exotic predators such as the red fox, but perhaps also wild dogs and cats. Possible techniques that could be employed in this investigation would be spotlighting and the use of sandplots, both of which could be used to generate indices of predator presence. Based on the suggestion that greater habitat complexity can hinder the pursuit efficiency of predators (Lima & Dill, 1990), confirmation of a negative correlation between vegetation presence and the occurrence of predators in the easement may prove valuable to conservation biologists and reserve managers alike.

*(8) Further experimentation with habitat linkages*

While the presence of habitat linkages did not increase the rate of easement crossing in this study, this was not a strong test of the hypothesis (being just a comparison of before-and-after installation of linkages with not ‘treatment-control’ comparison) and there was evidence that animals released on linkages did use the structures either partially or entirely for return to the adjacent habitat from the easement. In Section 5.4.2.1 I discuss possible explanations for the observed patterns of linkage use. For example, I suggest that a longer period of time with the linkages established in the easement may result in increased usage of linkages by small mammals. This may provide the animals with an exploratory period to become familiar with the linkages. Perhaps also the linkages were of insufficient height or width to encourage more use by the small mammals in this study. Because the construction of linkages was not costly in terms of time or resources, in order to eliminate these possibilities, I suggest further experimentation with linkages in powerline easements.

The evidence from Bennett (2006), that a translocated *A. stuartii* individual returned to its side of origin via a linkage, is an exciting finding because it suggests that animals will voluntarily move along linkages. Although this was an isolated record, further testing may reveal evidence of more frequent use of linkages. This crossing event occurred in June 2006, nine months after the easements were established and two months after the completion of my own similar investigations at the same site. This may provide evidence of the need for an extended period of time before linkages are utilised by small mammals in the area. Together with the pieces of evidence indicating linkage use discussed in this study, the crossing event observed by Bennett (2006) supports the case for establishment of linkages in powerline easements. However, I would stress that because linkages did not guarantee linkage utilisation by these animals in my study, other measures such as experimentation with alternative vegetation management, control of exotic predators and continued tolerance of gully vegetation are of vital importance in reducing the barrier effect of powerline easements. In general, greater research attention on the processes of habitat selection and animal movement, in combination with new analytical tools describing landscape features such as those described by Chetkiewicz *et al.* (2006), will lead to more integrated, holistic approach to corridor design and implementation. Moreover, the question of corridor design is only relevant where habitat patches are fragmented and isolated. As discussed in Chapter 2, ideally, and where possible, powerline easements should not be located in regions with extensive reserves of natural habitat, but rather in areas where disturbance and existing linear fragmentation are already a feature in the landscape.

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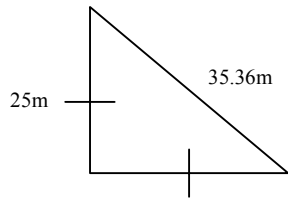
**Appendix 1 Examples of reported road-generated edge effect distances.**

Distance	Focus	Location	Road type	Reference
50m	Small mammals	NW Sydney	All roads	(Ryan, 1999)
500-600m	Birds: Lapwing, oystercatcher and redshanks	Netherlands	Quiet, rural	(Veen, 1973) cited in Reijnen <i>et al.</i> (1995)
1600-1800m	Birds: Lapwing, oystercatcher and redshanks	Netherlands	Busy highway	(Veen, 1973) cited in Reijnen <i>et al.</i> (1995)
480-2000m	Birds: Lapwing, oystercatcher and redshanks	Netherlands	Busy highway	(van der Zande <i>et al.</i> , 1980)
100-200m	Roadside vegetation species	Britain	Highway	(Angold, 1997)
305m	Birds in woodland	Netherlands	10,000 vehicles per day	(Reijnen <i>et al.</i> , 1995)
810m	Birds in woodland	Netherlands	50,000 vehicles per day	(Reijnen <i>et al.</i> , 1995)
365m	Birds in grassland	Netherlands	10, 000 vehicles per day	(Reijnen <i>et al.</i> , 1995)
930m	Birds in grassland	Netherlands	50,000 vehicles per day	(Reijnen <i>et al.</i> , 1995)
>100m	Altered drainage, road salt intrusion, exotic species, mammal and amphibian movement patterns, forest, grassland birds	Massachusetts, USA	Busy 4-lane highway	(Forman & Deblinger, 2000)
650m	Sensitive forest interior bird species	Massachusetts, USA	Busy 4-lane highway	(Forman & Deblinger, 2000)
200-1500m	Road salt effects on aquatic communities	Massachusetts, USA	Busy 4-lane highway	(Forman & Deblinger, 2000)
>100m	All effects	Massachusetts, USA	Busy 4-lane highway	(Forman, 2000)
100m	Increase in edge-species in bird community	Maine, USA	Interstate highway	(Ferris, 1979)

## Appendix 2 Summary of fieldwork activities carried out at the four sites involved in this study.

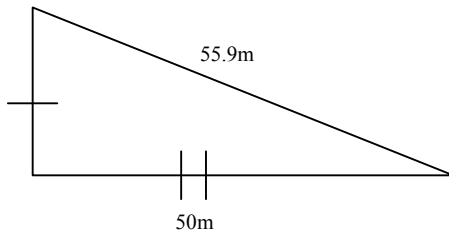
Month specified indicates when the two week trapping session was conducted e.g. eight fieldwork sessions involving mark recapture were conducted for both *R. fuscipes* and *A. stuartii*

Study Site				
Study	Currambene State Forest	Conjola National Park	Parnell (Jervis Bay National Park)	Jerrawangala National Park
<b>Mark recapture</b> (Chapter 3)	<i>R. fuscipes</i> & <i>A. stuartii</i>			
	Sep & Nov-04, Feb, Apr, Sep & Nov 05, Feb & Apr-06	Sep & Nov-04, Feb, Apr, Sep & Nov 05, Feb & Apr-06	Sep & Nov-04, Feb, Apr, Sep & Nov 05, Feb & Apr-06	Sep & Nov-04, Feb, Apr, Sep & Nov 05, Feb & Apr-06
<b>Habitat use</b> Spooling - Release in-situ (Chapter 4)	<i>R. fuscipes</i>			
	Sep & Nov-04, Feb & Apr-05	Sep & Nov-04, Feb & Apr-05	Sep & Nov-04, Feb & Apr-05	Sep & Nov-04, Feb & Apr-05
	<i>A. stuartii</i>			
	Feb-06	Feb-06 & Apr-06	Feb-06	Feb-06 & Apr-06
<b>Linkage use</b> Spooling - Release on the linkages and in the open easement (Chapter 5)	<i>R. fuscipes</i>			
	Sep & Nov-05 & Feb-06	Sep & Nov-05 & Feb-06	Sep & Nov-05 & Feb-06	Sep & Nov-05, Feb & Apr-06
	<i>A. stuartii</i>			
	Apr-06	Apr-06	n/a	Apr-06
<b>Translocation experiments</b> Release on opposite side of easement (Chapter 6)	<i>R. fuscipes</i>			
	Apr-06	Feb & Apr-06	n/a	Apr-06



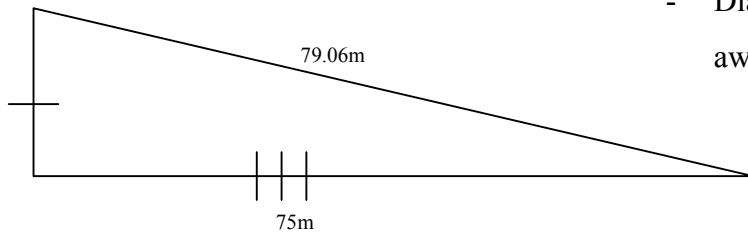
**Category 1 Movements:**

- Directly to the next trap = 25m
- Diagonally to the next trap = 25m



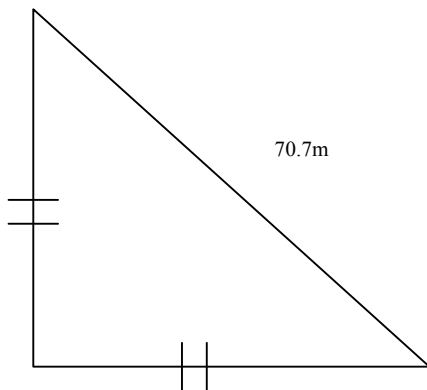
**Category 2 Movements:**

- Two trap intervals away = 50m
- Diagonally two trap intervals away = 55.95m



**Category 3 Movements:**

- Three trap intervals away = 75m
- Diagonally three trap intervals away = 79.06m



**Category 4 Movements:**

- Diagonally, 2\*2 trap intervals away = 70.7m

**Appendix 3 Explanation of movement distance categories, as used in  $\chi^2$  goodness of fit test for the analysis of easement crossings in Chapter 3.**

Pythagoras' theorem ( $a^2 + b^2 = c^2$ ) was used to calculate the diagonal distance between traps on a grid. The distance between traps opposite each other, or in the same row, was determined by the trap spacing. Trap spacing at each site was 25m, except for at Jerrawangala, where it was 40m owing to the wider easement at that site.

**Appendix 4 Explanation of  $\chi^2$  goodness of fit test used in analysis of easement crossing events.**

The number of potential easement crossings and same side movements were calculated for each trapping station. These values were then used to generate a ratio of expected crossings. The ratio was applied to the actual number of movements recorded and compared with the observed numbers of same side movements and easement crossings. This was done for Category 1, 2 and 3 movements, as well as all movements categories combined.

**Category 1 movements**

Trap no.	Potential easement crossings	Potential same side movements	Total potential movements
1	2	3	5
12	3	5	8
11	3	5	8
10	3	5	8
9	3	5	8
8	2	3	5
<b>Total</b>	<b>16</b>	<b>26</b>	<b>42</b>

**Contingency table for  $\chi^2$  goodness of fit test for investigation of easement crossing events; Category 1 movements**

Movement	Observed	Expected
Cross easement	2	155.4
Same side	406	252.6
Total	408	408.0

	Ratio
Expected crossing ratio = 16/42	<b>0.3810</b>
Expected same side ratio = 26/42	<b>0.6190</b>

$$\chi^2 = \sum \frac{(o-e)^2}{e} = 243.12 \text{ df} = 1 \quad P < 0.001$$

**Appendix 4 (ctd.) Explanation of  $\chi^2$  goodness of fit test used in analysis of easement crossing events.**

**Category 2 movements**

Trap no.	Potential easement crossings	Potential same side movements	Total potential movements
1	3	2	5
2	2	2	4
3	3	2	5
4	3	4	7
5	3	4	7
6	3	2	5
7	2	2	4
8	3	2	5
9	4	2	6
10	5	4	9
11	5	4	9
12	4	2	6
<b>Total</b>	<b>40</b>	<b>32</b>	<b>72</b>

**Contingency table for  $\chi^2$  goodness of fit test for investigation of easement crossing events;**

**Category 2 movements**

Movement	Observed	Expected
Cross easement	8	61.7
Same side	103	49.3
Total	111	111

Expected crossing ratio = 40/72      **Ratio**  
 Expected same ratio = 32/72      **0.5556**  
    **0.4444**

$$\chi^2 = \sum \frac{(o-e)^2}{e} = 103.15 \quad df = 1 \quad P < 0.0001$$

**Appendix 4 (ctd.) Explanation of  $\chi^2$  goodness of fit test used in analysis of easement crossing events.**

**Category 3 movements**

Trap no.	Potential easement crossings	Potential same side movements	Total potential movements
1	2	2	4
2	2	2	5
3	3	2	5
4	3	2	5
5	3	2	5
6	3	2	5
7	3	2	5
8	2	2	4
9	2	2	4
10	3	2	5
11	3	2	5
12	2	2	4
<b>Total</b>	<b>32</b>	<b>24</b>	<b>56</b>

**Contingency table for  $\chi^2$  goodness of fit test  
for investigation of easement crossing events;  
Category 3 movements**

Movement	Observed	Expected
Cross easement	6	18.9
Same side	27	14.1
Total	33	33.0

	<b>Ratio</b>
Expected crossing ratio = 32/56	<b>0.5714</b>
Expected same ratio = 24/56	<b>0.4286</b>

$$\chi^2 = \sum \frac{(o-e)^2}{e} = 18.89 \quad df = 1 \quad P < 0.0001$$

**Appendix 4 (ctd.) Explanation of  $\chi^2$  goodness of fit test used in analysis of easement crossing events.**

**All Category Movements**

Trap No.	Potential easement crossings	Potential same side movements	Total potential movements
1	7	7	14
2	5	4	9
3	6	4	10
4	6	6	12
5	6	6	12
6	6	4	10
7	5	4	9
8	7	7	14
9	9	9	18
10	11	11	22
11	11	11	22
12	9	9	18
<b>Total</b>	<b>88</b>	<b>82</b>	<b>170</b>

Movement	Observed	Expected
Cross easement	17	170.8
Same side	313	159.2
Total	330	330.0

	<b>Ratio</b>
Expected crossing ratio = 44/85	<b>0.5176</b>
Expected same ratio = 41/85	<b>0.4824</b>

$$\chi^2 = \sum \frac{(o-e)^2}{e} = 285.24 \text{ df} = 1 \quad P < 0.0001$$

**Appendix 5 Captures made within powerline easements at five trapping locations on the South Coast of New South Wales, Australia**

Shrub and ground vegetation in the easement was described as low, medium or high, or a combination of these measures if borderline. Species abbreviations are as follows; A.s. = *Antechinus stuartii*, R.f. = *Rattus fuscipes*, S.m. = *Sminthopsis murina*

#	Date	Location	Trap no.	Species	Sex	Ground vegetation density	Shrub vegetation density
1	February 16, 2006	Currambene	12b	A.s.	M	Low-Medium	Medium-High
2	February 17, 2006	Conjola	10a	S.m.	F	Low-Medium	Low-Medium
3	February 25, 2006	Parnell	12a	R.f.	F	Thick	Low-Medium
4	April 19, 2006	Currambene	11a	A.s.	F	Low-Medium	Medium-High
5	April 19, 2006	Conjola	1a	S.m.	M	Low	Low-Medium
6	April 19, 2006	Currambene	12b	A.s.	M	Low-Medium	Medium-High
7	April 22, 2006	Currambene	1a	A.s.	M	Low-Medium	Medium-High
8	April 22, 2006	Conjola	10a	S.m.	F	Low	Low-Medium
9	April 25, 2006	Jerrawangala	8a	A.s.	F	Low-Medium	None
10	April 26, 2006	Sussex	1d	R.f.	F	Medium	Medium-High
11	April 28, 2006	Sussex	1f	R.f.*	F	Medium	Medium-High
12	April 29, 2006	Sussex	1d	R.f.*	F	Medium	Medium-High
13	April 26, 2006	Sussex	2d	R.f.	F	Medium	Medium-High
14	April 28, 2006	Sussex	2e	R.f.*	F	Medium	Medium-High
15	April 29, 2006	Sussex	2e	R.f.*	F	Medium	Medium-High
16	April 26, 2006	Sussex	3c	R.f.	M	Medium	Medium-High
17	April 28, 2006	Sussex	1b	R.f.*	M	Medium	Medium-High
18	April 29, 2006	Sussex	2c	R.f.*	M	Medium	Medium-High
19	April 28, 2006	Sussex	1d	A.s.	M	Medium	Medium-High
20	April 29, 2006	Sussex	3e	A.s.*	M	Medium	Medium-High
21	April 28, 2006	Sussex	1e	A.s.	F	Medium	Medium-High
22	April 29, 2006	Sussex	1b	A.s.	M	Medium	Medium-High
23	April 29, 2006	Sussex	1e	Rf	M	Medium	Medium-High
24	April 29, 2006	Sussex	2a	A.s.	M	Medium	Medium-High
25	April 29, 2006	Sussex	3d	R.f.	M	Medium	Medium-High

\*Indicates a recapture of the animal listed immediately above

### Appendix 6 Comparison of two years of habitat features within the trapping grid.

Five habitat features were assessed [logs, leaf litter, branches, ground vegetation (GrVeg) and shrub vegetation (ShVeg) see Table 4.2] at 396 points on each grid for two consecutive years. Residual is the difference between observed values and the values that would be expected if there were no differences between the two years. A positive residual indicates that Year Two had more records of that feature than Year One.

Significance values were attained through  $\chi^2$  analysis of data and refer to significance of the difference of proportions from one year to the next. Significant results are shown in bold.

Site		Currumbene			Conjola			Parnell			Jerrawangala		
Habitat feature	Measure	$\chi^2$	Residual	<i>P</i>	$\chi^2$	Residual	<i>P</i>	$\chi^2$	Residual	<i>P</i>	$\chi^2$	Residual	<i>P</i>
Logs	No Logs		0.7			10.2			4.6			10.4	
	Logs10		3.7			2.7			0			8.1	
	Logs20	5.8	0.6	0.217	15.7	-5.3	<b>0.003</b>	2.2	-4.9	0.690	24.4	-3.6	<b>&lt;0.001</b>
	Logs>20		-4.9			-8			-0.8			-4.1	
	Trunk		-0.2			0.4			1.2			-10.7	
Leaf	Leaf0-20%		-5.3			-7.5			-30.6			-16.2	
	Leaf20-40%		6.6			-2.7			13.7			6.4	
	Leaf40-60%	6.5	-0.5	0.167	23.9	-19.7	<b>&lt;0.001</b>	29.8	4.6	<b>&lt;0.001</b>	16	10.1	<b>0.003</b>
	Leaf60-80%		6.7			13.8			9.8			0	
	Leaf80-100%		-7.5			16.2			2.5			-0.3	
Branches	BranchL		41.1			-33.1			-40.1			12.8	
	BranchM	39.2	-28.3	<b>&lt;0.001</b>	28.2	30.9	<b>&lt;0.001</b>	44.5	19.1	<b>&lt;0.001</b>	8.13	-13	<b>0.020</b>
	BranchH		-12.7			2.2			21			0.2	
GrVeg	GrVeg0-20%		14			-49.7			3.9			3	
	GrVeg20-40%		6.8			29			-0.7			8.5	
	GrVeg40-60%	40.9	18	<b>&lt;0.001</b>	58.2	16.9	<b>&lt;0.001</b>	12.7	7.8	<b>0.010</b>	17.46	-17.3	<b>0.002</b>
	GrVeg60-80%		-9			2.3			7			1.7	
	GrVeg80-100%		-29.7			1.5			-18			4.2	
ShVeg	ShVeg0-20%		13.2			-7.3			-16			-1.9	
	ShVeg20-40%		25.6			2.9			-2.5			4	
	ShVeg40-60%	68	10.8	<b>&lt;0.001</b>	2.1	4.2	0.7	9.6	-12.5	0.050	2.49	-0.5	0.653
	ShVeg60-80%		-25.9			2.6			-0.9			-2.9	
	ShVeg80-100%		-23.6			-2.4			1.9			1.3	

**Appendix 7(a) Explanation for calculations of ratios of habitat utilisation and habitat feature availability, used in the construction of boxplots (Fig. 4.2 – 4.10).**

**Example of spool data proportion calculations**

<b>Spool Ref.</b>	FW3Cur4	
<b>Number of record Points</b>	28	
	<b>Score</b>	<b>Proportion in spool</b>
NoLogs	14	14/28=0.5
Logs10	1	1/28=0.036
Logs20	5	5/28=0.179
Logs>20	2	2/28=0.071
Trunk	6	6/28=0.214

*1 Subtract background proportions from spool proportions to find ratio.  
e.g. for No Logs:  
 $0.5 - 0.356 = 0.144$*

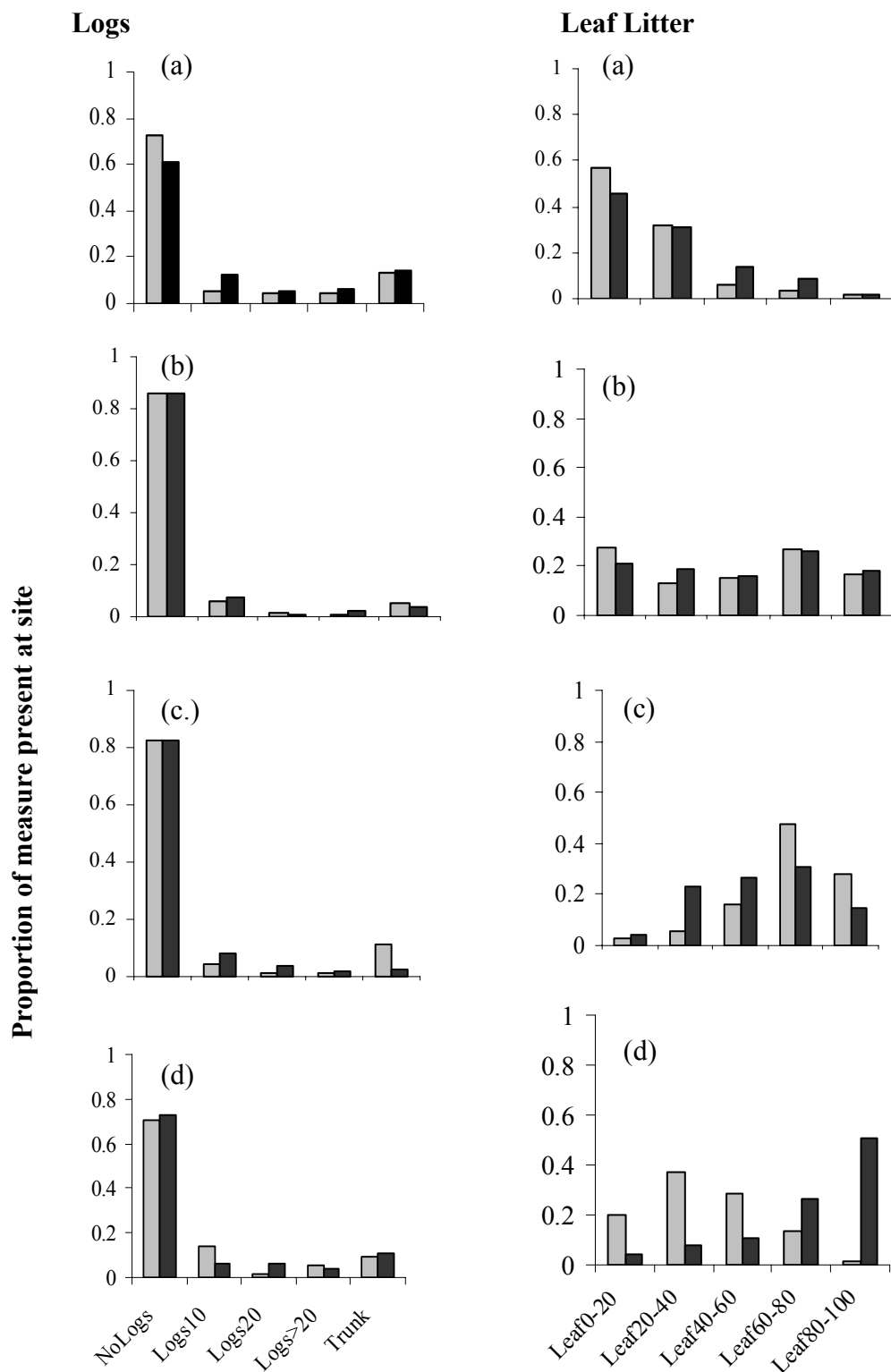
**Example of background data proportion calculations**

<b>Background Site</b>	Currambene	
<b>Number of record Points</b>	180	
	<b>Score</b>	<b>Proportion in background</b>
NoLogs	128	128/180 = 0.356
Logs10	8	8/180 = 0.022
Logs20	5	5/180 = 0.013
Logs>20	15	15/180 = 0.042
Trunk	24	24/180 = 0.067

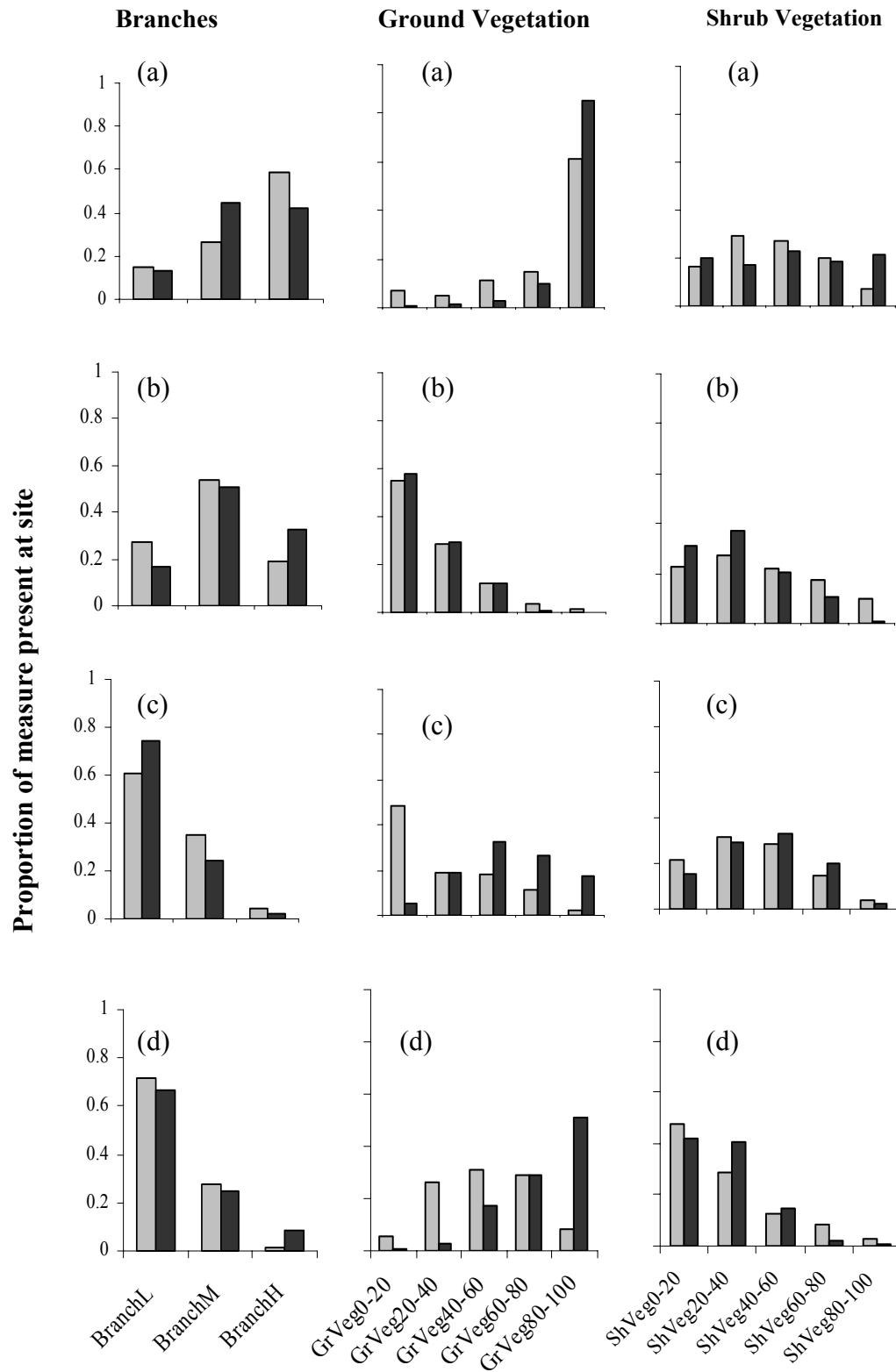
*2 Graph ratios (e.g. 0.144) using boxplots*

**Appendix 7(b) Sample layout of data for logistic regression in which all points recorded from spools (Source = 1), are compared with all points from the background habitat (Source = 0).**

Spool Ref	Point Ref	Source	GrVeg0-20	GrVeg20-40	GrVeg40-60	GrVeg60-80	GrVeg80-100
FW1Jer18	FW1Jer18.1	1	0	0	0	1	0
FW1Jer18	FW1Jer18.2	1	0	0	0	1	0
FW1Jer18	FW1Jer18.3	1	0	1	0	0	0
FW1Jer18	FW1Jer18.4	1	0	1	0	0	0
FW2Jer16	FW2Jer16.1	1	0	1	0	0	0
FW2Jer16	FW2Jer16.2	1	0	1	0	0	0
FW2Jer16	FW2Jer16.3	1	1	0	0	0	0
FW2Jer16	FW2Jer16.4	1	0	1	0	0	0
FW2Jer16	FW2Jer16.5	1	0	0	1	0	0
Nil	1A	0	0	0	1	0	0
Nil	2A	0	0	1	0	0	0
Nil	3A	0	0	0	1	0	0
Nil	4A	0	0	0	1	0	0
Nil	5A	0	0	0	1	0	0
Nil	6A	0	0	0	1	0	0
Nil	7A	0	0	0	0	1	0
Nil	8A	0	0	0	1	0	0
Nil	9A	0	0	0	1	0	0
Nil	10A	0	0	1	0	0	0



**Appendix 8 Comparison of vegetation composition on opposite sides of the easement at four sites. Pale grey/dark grey = opposite sides of the easement. (a) = Parnell, (b) = Conjola, (c) = Currambene, (d) Jerrawangala**



**Appendix 8 (cld.) Comparison of vegetation composition on opposite sides of the easement at four sites. Pale grey/dark grey = opposite sides of the easement. (a) = Parnell, (b) = Conjola, (c) = Currambene, (d) Jerrawangala**

**Appendix 9 Associations between habitat features for study species as revealed by robust logistic regression\*.**

The x-axis refers to the measure of the habitat feature i.e. Leaf 1 = Leaf0-20% (see Table 4.2). (a) Logs and ShrubVeg – *R. fuscipes*. If there were no interaction, the 5 lines would all be parallel. The interaction does not have an obvious interpretation. Animal preference is clearly increasing with logs for shrub vegetation, though this increase is not consistent. I conclude that animals are more attracted to logs when there is a complete absence of shrub vegetation.

(b) Leaf and Ground Vegetation – *A. stuartii*: Animals preferred high levels of leaves, regardless of the ground vegetation, as all 5 lines are generally increasing. Animals preferred a

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\* These figures were produced and interpreted by Dr. Robert Clark of the Statistical Consulting Service, School of Mathematics and Applied Statistics at The University of Wollongong.

high level of ground vegetation when there was no leaf cover, but apparently preferred less ground vegetation when there was heavy leaf cover.

**Appendix 9 (ctd.) Associations between habitat features for study species as revealed by robust logistic regression.**

The x-axis refers to the measure of the habitat feature i.e. Leaf 1 = Leaf0-20% (see Table 4.2).

(c) Shrub and Ground Vegetation – *A. stuartii*: The points on the far bottom right of the plot are probably due to small or empty cells and should be ignored. The remainder of the plot shows that animals prefer high levels of shrub vegetation and ground vegetation. The attraction to higher levels of ground vegetation seems to increase when there is a high level of shrub vegetation. (d) Leaf and Branches – *A. stuartii*. Animals tend to select points with more leaf or branch cover. Points with none of either type of cover are particularly unattractive.

### Appendix 10 Summary of tree-climbing activity (arboreality) by *Antechinus stuartii*

Data derived from 36 spools recorded as part of the investigation of habitat associations for *A. stuartii*, during which habitat features (logs, leaf litter, branches, ground vegetation (GrVeg) and shrub vegetation (ShVeg) see Table 4.2) along the course of the spool were simultaneously recorded at three sites; Currumbene (Cur), Conjola (Cnj) and Jerrawangala (Jer).

Spool Ref.	Site	Date	# of tree climbs	Total (m) in a tree	Distance (m) in each climb (Average)	Distances (m) between climbs (Average)	Total length of spool (m)	% of spool in a tree
FWVIICur2	Currumbene	Feb-06	2	24	12, 12 (12)	6	47	51.1
FWVIICur3	Currumbene	Feb-06	1	18	18 (18)	n/a	40	45.0
FWVIICur4	Currumbene	Feb-06	0	n/a	n/a	n/a	52	0.0
FWVIICur5	Currumbene	Feb-06	0	n/a	n/a	n/a	16	0.0
FWVIICur6	Currumbene	Feb-06	5	30	3, 6, 15, 3, 3 (7.8)	6, 12, 24, 18 (15)	111	27.0
FWVIICur9	Currumbene	Feb-06	1	6	6	n/a	106	5.7
FWVIICur10	Currumbene	Feb-06	3	36	12, 6, 18 (9)	18, 69 (43.5)	168	21.4
FWVIICur11	Currumbene	Feb-06	2	12	6, 6 (6)	3	85	14.1
FWVIICur12	Currumbene	Feb-06	3	9	3, 3, 3 (3)	18, 21 (19.5)	63	14.3
FWVIICur18	Currumbene	Feb-06	3	45	12, 9, 24 (45)	3, 15 (9)	149	30.2
FWVIICur19	Currumbene	Feb-06	2	18	12, 6 (9)	18	81	22.2
FWVIICur20	Currumbene	Feb-06	2	18	3, 15 (9)	84	116	15.5
FWVIICur23	Currumbene	Feb-06	4	20	21, 6, 30, 3 (15)	54, 9, 3 (22)	168	11.9
FWVIICur24	Currumbene	Feb-06	0	0	n/a	n/a	12	0.0
FWVIICur25	Currumbene	Feb-06	4	15	3, 3, 3, 6 (3.75)	15, 6, 24 (15)	78	19.2
FWVIICur29	Currumbene	Feb-06	6	39	6, 3, 3, 12, 12, 3 (6.5)	3, 9, 3, 12, 6 (6.6)	129	30.2
FWVIICnj14	Conjola	Feb-06	3	18	6, 6, 6 (6)	48, 6 (27)	81	22.2
FWVIICnj15	Conjola	Feb-06	5	48	12, 12, 3, 6, 15 (9.6)	12, 3, 3, 21 (9.8)	94	51.1
FWVIICnj1	Conjola	Apr-06	3	21	3, 12, 6 (7)	15, 18 (16.5)	50	42.0
FWVIICnj7	Conjola	Apr-06	3	33	9, 18, 6 (11)	6, 15 (10.5)	54	61.1
FWVIICnj8	Conjola	Apr-06	0	0	n/a	n/a	77	0.0

# Appendix 10 (ctd.) Summary of tree-climbing activity by *Antechinus stuartii*

Data derived from 36 spools recorded as part of the investigation of habitat associations for *A. stuartii*, during which habitat features (logs, leaf litter, branches, ground vegetation (GrVeg) and shrub vegetation (ShVeg) see Table 4.2) along the course of the spool were simultaneously recorded; Currumbene (Cur), Conjola (Cnj) and Jerrawangala (Jer).

Spool Ref.	Site	Date	# of tree climbs	Total (m) in a tree	Distance (m) in each climb (Average)	Distances (m) between climbs (Average)	Total length of spool (m)	% of spool in a tree
FWVIII Cnj11	Conjola	Apr-06	2	12	9, 3 (6)	114	129	9.3
FWVIII Cnj12	Conjola	Apr-06	1	12	12	n/a	119	10.1
FWVIII Cnj19	Conjola	Apr-06	2	6	3, 3 (3)	54	114	5.3
FWVII Jer39	Jerrawangala	Feb-06	1	15	15	n/a	47	31.9
FWVIII Jer40	Jerrawangala	Feb-06	0	0	n/a	n/a	7	0.0
FWVII Jer41	Jerrawangala	Feb-06	2	6	3, 3	3 (3)	33	18.2
FWVII Jer42	Jerrawangala	Feb-06	1	3	3	n/a	60	5.0
FWVII Jer43	Jerrawangala	Feb-06	2	18	3, 15 (9)	18	75	24.0
FWVII Jer44	Jerrawangala	Feb-06	1	24	24	n/a	44	54.5
FWVIII Jer24	Jerrawangala	Apr-06	0	0	n/a	n/a	39	0.0
FWVIII Jer25	Jerrawangala	Apr-06	0	0	n/a	n/a	16	0.0
FWVIII Jer26	Jerrawangala	Apr-06	0	0	n/a	n/a	9	0.0
FWVIII Jer27	Jerrawangala	Apr-06	4	12	3, 3, 3, 3 (3)	15, 48, 33 (32)	143	8.4
FWVIII Jer35	Jerrawangala	Apr-06	0	0	n/a	n/a	137	0.0
FWVIII Jer39	Jerrawangala	Apr-06	1	9	9	n/a	36	25.0
<b>Total</b>			<b>69</b>	<b>567</b>	<b>567</b>	<b>891</b>	<b>2785</b>	<b>-</b>
<i>Average</i>			<i>1.92</i>	<i>15.75</i>	<i>8.22</i>	<i>21.21</i>	<i>77.36</i>	<i>19.4</i>
<i>Standard Deviation</i>			<i>1.65</i>	<i>15.37</i>	<i>6.21</i>	<i>23.9</i>	<i>46.30</i>	<i>17.97</i>

### Appendix 11 Summary of log use by *Antechinus stuartii*

Data derived from 36 spools recorded as part of the investigation of habitat associations for *A. stuartii*, during which habitat features (logs, leaf litter, branches, ground vegetation (GrVeg) and shrub vegetation (ShVeg) see Table 4.2) along the course of the spool were simultaneously recorded at three sites, Currumbene (Cur), Conjola (Cnj) Jerrawangala (Jer).

Spool Ref.	Site	Date	Total spool length (m)	Following log at ground level		On log/trunk off the ground		On branch off the ground		Total log/branch use	
				(m)	% Total spool length	(m)	% Total spool length	(m)	% Total spool length	(m)	% Total spool length
FWVIICur2	Cur	Feb-06	47	0	0	0	0	0	0	0	0.0
FWVIICur3	Cur	Feb-06	40	0	0	0	0	0	0	0	0.0
FWVIICur4	Cur	Feb-06	52	3	5.8	0	0	0	0	3	5.8
FWVIICur5	Cur	Feb-06	16	0	0.0	0	0	0	0	0	0.0
FWVIICur6	Cur	Feb-06	111	0	0.0	0	0	0	0	0	0.0
FWVIICur9	Cur	Feb-06	106	0	0.0	18	17.0	3	2.8	21	19.8
FWVIICur10	Cur	Feb-06	168	0	0.0	18	10.7	0	0.0	18	10.7
FWVIICur11	Cur	Feb-06	85	0	0.0	0	0.0	0	0.0	0	0.0
FWVIICur12	Cur	Feb-06	63	0	0.0	0	0.0	12	19.0	12	19.0
FWVIICur18	Cur	Feb-06	149	0	0.0	15	10.1	6	4.0	21	14.1
FWVIICur19	Cur	Feb-06	81	3	3.7	12	14.8	0	0.0	15	18.5
FWVIICur20	Cur	Feb-06	116	3	2.6	0	0.0	0	0.0	3	2.6
FWVIICur23	Cur	Feb-06	168	18	10.7	0	0.0	15	8.9	33	19.6
FWVIICur24	Cur	Feb-06	12	0	0.0	0	0.0	0	0.0	0	0.0
FWVIICur25	Cur	Feb-06	78	9	11.5	6	7.7	3	3.8	18	23.1
FWVIICur29	Cur	Feb-06	129	0	0.0	15	11.6	0	0.0	15	11.6
FWVIICnj14	Cnj	Feb-06	81	0	0.0	0	0.0	9	11.1	9	11.1
FWVIICnj15	Cnj	Feb-06	94	0	0.0	0	0.0	0	0.0	0	0.0
FWVIICnj1	Cnj	Apr-06	50	0	0.0	0	0.0	6	12.0	6	12.0
FWVIICnj7	Cnj	Apr-06	54	3	5.6	0	0.0	3	5.6	6	11.1
FWVIICnj8	Cnj	Apr-06	77	12	15.6	21	27.3	0	0.0	33	42.9

# Appendix 11 (ctd.) Summary of log use by *Antechinus stuartii*

Data derived from 36 spools recorded as part of the investigation of habitat associations for *A. stuartii*, during which habitat features (logs, leaf litter, branches, ground vegetation (GrVeg) and shrub vegetation (ShVeg) see Table 4.2) along the course of the spool were simultaneously recorded at three sites; Currumbene (Cur), Conjola (Cnj) and Jerrawangala (Jer).

Spool Ref.	Site	Date	Total spool length (m)		Following log at ground level		On log/trunk off the ground		On branch off the ground		Total log/branch Use	
			(m)	% Total spool length	(m)	% Total spool length	(m)	% Total spool length	(m)	% Total spool length	(m)	% Total spool length
FWVIII Cnj11	Cnj	Apr-06	129	15	11.6		0	0.0	4	3.1	19	14.7
FWVIII Cnj12	Cnj	Apr-06	119	6	5.0		39	32.8	15	12.6	60	50.4
FWVIII Cnj19	Cnj	Apr-06	114	0	0.0		0	0.0	0	0.0	0	0.0
FWVII Jer39	Jer	Feb-06	47	0	0.0		0	0.0	3	6.4	3	6.4
FWVIII Jer40	Jer	Feb-06	7	0	0.0		0	0.0	0	0.0	0	0.0
FWVII Jer41	Jer	Feb-06	33	0	0.0		9	27.3	0	0.0	9	27.3
FWVII Jer42	Jer	Feb-06	60	0	0.0		0	0.0	0	0.0	0	0.0
FWVII Jer43	Jer	Feb-06	75	0	0.0		0	0.0	0	0.0	0	0.0
FWVII Jer44	Jer	Feb-06	44	0	0.0		0	0.0	0	0.0	0	0.0
FWVIII Jer24	Jer	Apr-06	39	12	30.8		6	15.4	0	0.0	18	46.2
FWVIII Jer25	Jer	Apr-06	16	3	18.8		3	18.8	3	18.8	9	56.3
FWVIII Jer26	Jer	Apr-06	9	3	33.3		0	0.0	0	0.0	3	33.3
FWVIII Jer27	Jer	Apr-06	143	15	10.5		30	21.0	15	10.5	60	42.0
FWVIII Jer35	Jer	Apr-06	137	12	8.8		54	39.4	9	6.6	75	54.7
FWVIII Jer39	Jer	Apr-06	36	3	8.3		6	16.7	3	8.3	12	33.3
<b>Total</b>			<b>2785</b>	<b>120</b>			<b>252</b>		<b>109</b>		<b>481</b>	
<i>Spool Average</i>					3.3		7.0		3.0		13.4	
<i>Standard Deviation</i>					8.4		11.1		5.5		17.7	

**Appendix 12 Results of multivariate analysis to determine patterns of distribution of habitat features (Logs, Shrub Vegetation, Branches, Leaf Litter and Ground Vegetation at edge and interior regions of bushland adjacent to powerline easements at four sites; Currumbene, Conjola and Jerrawangala. ('Location = Edge or Interior)).**

Habitat feature	Source	df	Significant effect tests		
			Sum of Squares	F Ratio	Prob > F
<b>Logs</b>	Site	3	20.304	4.553	0.004
	Location	1	28.823	19.392	<0.0001
	Site*Location	3	20.254	4.542	0.004
	Source	Level	Least sq mean	Std error	Mean
	Site	Conjola	0.440	0.089	0.447
		Currumbene	0.487	0.093	0.483
		Jerrawangala	0.480	0.099	0.480
		Parnell	0.856	0.091	0.856
	Location	Edge	0.771	0.066	0.786
		Interior	0.361	0.066	0.353
	Site*Location	Conjola,Edge	0.707	0.126	
		Conjola,Interior	0.172	0.126	
		Currumbene,Edge	0.576	0.132	
		Currumbene,Interior	0.397	0.132	
		Jerrawangala,Edge	0.487	0.140	
		Jerrawangala,Interior	0.474	0.140	
		Parnell,Edge	1.312	0.129	
		Parnell,Interior	0.400	0.129	
Habitat feature	Source	df	Significant Effect Tests		
			Sum of squares	F Ratio	Prob > F
<b>Shrub vegetation</b>	Site	3	131.302	34.7309	<.0001
	Side	1	14.601	11.5861	0.0007
	Location	1	19.816	15.7248	<.0001
	Site*Location	3	30.761	8.1365	<.0001
	Source	Level	Least sq Mean	Std error	Mean
	Site	Conjola	1.392	0.082	1.410
		Currumbene	1.649	0.086	1.651
		Jerrawangala	0.967	0.091	0.967
		Parnell	2.189	0.084	2.194
	Side	North	1.695	0.060	1.728
		South	1.404	0.061	1.417
	Location	Edge	1.719	0.061	1.766
		Interior	1.379	0.061	1.387
	Site*Location	Conjola,Edge	1.706	0.116	
		Conjola,Interior	1.077	0.116	
		Currumbene,Edge	1.753	0.121	
		Currumbene,Interior	1.545	0.121	
		Jerrawangala,Edge	0.816	0.129	
		Jerrawangala,Interior	1.118	0.129	
		Parnell,Edge	2.602	0.118	
		Parnell,Interior	1.777	0.118	

**Appendix 12 (ctd.) Results of multivariate analysis to determine patterns of distribution of habitat features (Logs, Shrub Vegetation, Branches, Leaf Litter and Ground Vegetation at edge and interior regions of bushland adjacent to powerline easements at four sites; Currumbene, Conjola and Jerrawangala. ('Location' = Edge or Interior).**

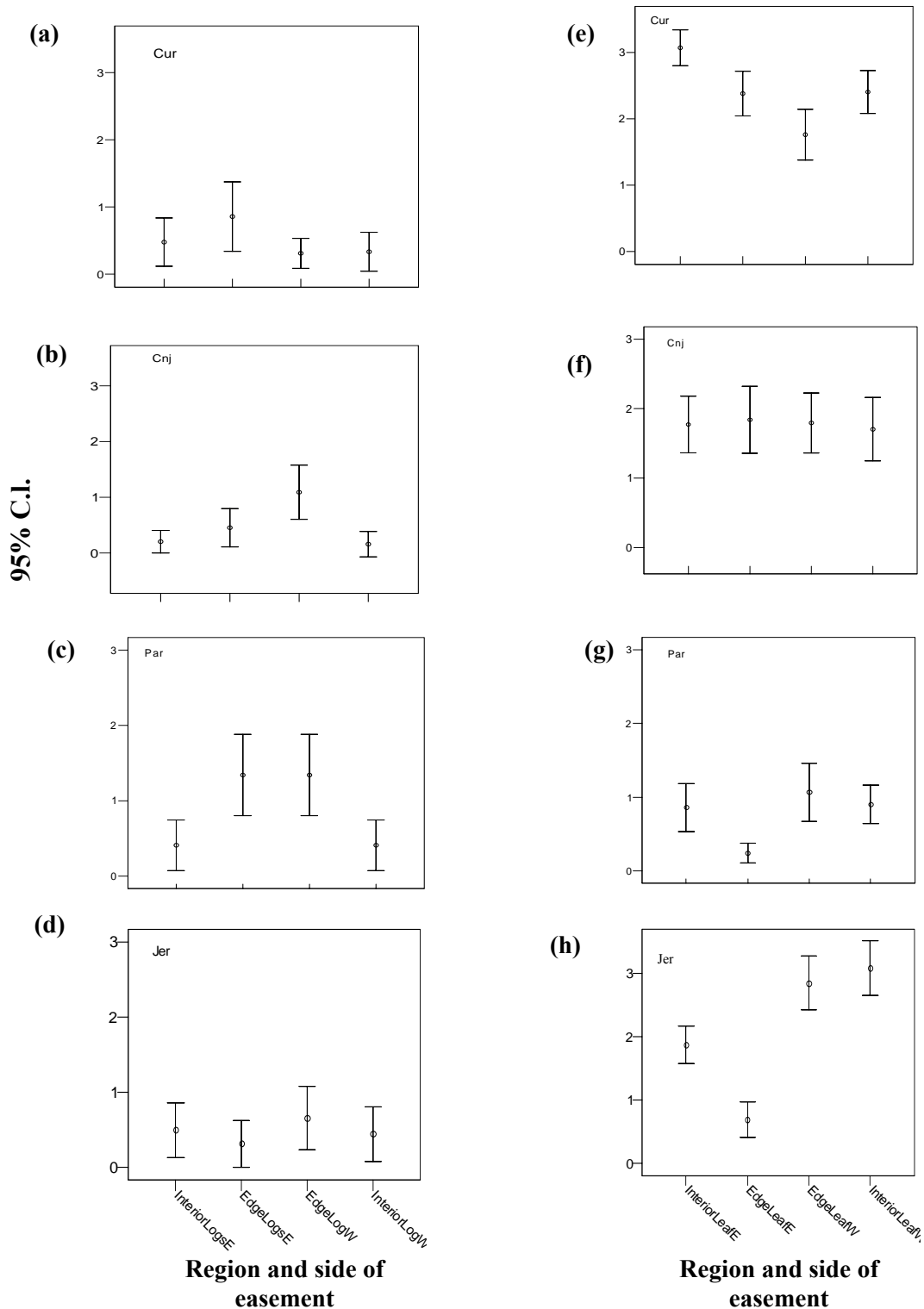
Habitat feature	Source	df	Significant effect tests		
			Sum of squares	F Ratio	Prob > F
Branches	Site	3	157.224	83.383	<.0001
	Side*Site	3	5.190	2.753	0.042
	Site*Location	3	6.042	3.205	0.023
	Site*Side*Location	3	9.525	5.051	0.002
	Source	Level	Least sq mean	Std error	Mean
	Site	Conjola	1.388	0.058	1.378
		Currumbene	0.380	0.060	0.378
		Jerrawangala	0.336	0.064	0.336
		Parnell	1.222	0.059	1.222
	Side*Site	Conjola,North	1.220	0.079	
		Conjola,South	1.557	0.085	
		Currumbene,North	0.284	0.085	
		Currumbene,South	0.476	0.087	
		Jerrawangala,North	0.382	0.091	
		Jerrawangala,South	0.289	0.091	
		Parnell,North	1.239	0.083	
		Parnell,South	1.205	0.085	
	Site*Location	North,Edge	0.786	0.060	
		North,Interior	0.776	0.060	
		South,Edge	0.877	0.061	
		South,Interior	0.887	0.061	
	Site*Side*Location	Conjola,North,Edge	1.100	0.112	
		Conjola,North,Interior	1.340	0.112	
		Conjola,South,Edge	1.568	0.120	
		Conjola,South,Interior	1.545	0.120	
		Currumbene,North,Edge	0.205	0.120	
		Currumbene,North,Interior	0.364	0.120	
		Currumbene,South,Edge	0.690	0.122	
		Currumbene,South,Interior	0.262	0.122	
		Jerrawangala,North,Edge	0.579	0.129	
		Jerrawangala,North,Interior	0.184	0.129	
		Jerrawangala,South,Edge	0.316	0.129	
		Jerrawangala,South,Interior	0.263	0.129	
		Parnell,North,Edge	1.261	0.117	
		Parnell,North,Interior	1.217	0.117	
		Parnell,South,Edge	0.932	0.120	
		Parnell,South,Interior	1.477	0.120	

**Appendix 12 (ctd) Results of multivariate analysis to determine patterns of distribution of habitat features (Logs, Shrub Vegetation, Branches, Leaf Litter and Ground Vegetation at edge and interior regions of bushland adjacent to powerline easements at four sites, Currumbene, Conjola and Jerrawangala. ('Location' = Edge or Interior).**

Habitat feature	Source	df	Significant effect tests		
			Sum of squares	F Ratio	Prob > F
Leaf	Site	3	275.572	67.043	<.0001
	Side	1	27.439	20.027	<.0001
	Location	1	25.716	18.769	<.0001
	Side*Site	3	109.161	26.557	<.0001
	Side*Location	1	8.163	5.958	0.015
	Site*Location	3	16.703	4.064	0.007
	Source	Level	Least sq mean	Std error	Mean
	Site	Conjola	1.848	0.086	1.851
		Currumbene	2.431	0.089	2.424
		Jerrawangala	2.118	0.095	2.118
		Parnell	0.768	0.087	0.772
	Side	North	1.991	0.062	1.944
		South	1.592	0.064	1.589
	Location	Edge	1.598	0.063	1.590
		Interior	1.985	0.063	1.954
	Side*Site	Conjola,North	1.890	0.117	
		Conjola,South	1.807	0.125	
		Currumbene,North	2.136	0.125	
		Currumbene,South	2.726	0.128	
		Jerrawangala,North	2.961	0.134	
		Jerrawangala,South	1.276	0.134	
		Parnell,North	0.978	0.122	
		Parnell,South	0.557	0.125	
	Side*Location	North,Edge	1.907	0.088	
		North,Interior	2.076	0.088	
		South,Edge	1.289	0.090	
		South,Interior	1.894	0.090	
	Site*Location	Conjola,Edge	1.860	0.121	
		Conjola,Interior	1.836	0.121	
		Currumbene,Edge	2.100	0.126	
		Currumbene,Interior	2.763	0.126	
		Jerrawangala,Edge	1.763	0.134	
		Jerrawangala,Interior	2.474	0.134	
		Parnell,Edge	0.668	0.123	
		Parnell,Interior	0.867	0.123	

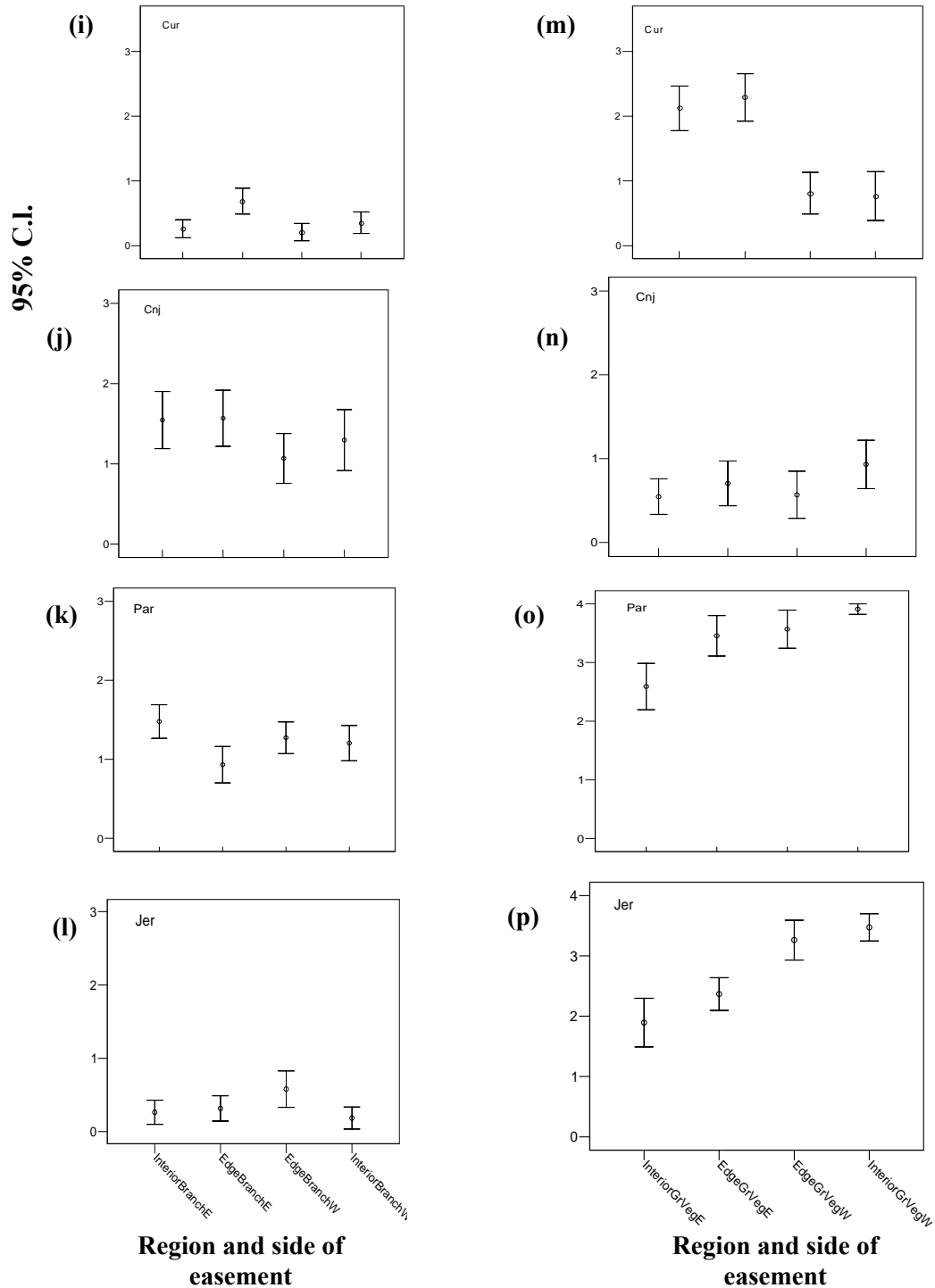
**Appendix 12 (ctd.) Results of multivariate analysis to determine patterns of distribution of habitat features (Logs, Shrub Vegetation, Branches, Leaf Litter and Ground Vegetation at edge and interior regions of bushland adjacent to powerline easements at four sites, Currumbene, Conjola and Jerrawangala. ('Location = Edge/Interior).**

Habitat feature	Source	df	Significant Effect Tests		
			Sum of squares	F Ratio	Prob > F
Ground vegetation	Site	3	798.738	272.560	<.0001
	Side	1	129.748	132.825	<.0001
	Side*Site	3	46.358	15.819	<.0001
	Site*Location	3	15.422	5.263	0.001
	Site*Side*Location	3	9.946	3.394	0.018
	Source	Level	Least sq mean	Std error	Mean
	Site	Conjola	0.678	0.072	0.681
		Currumbene	1.495	0.075	1.512
		Jerrawangala	2.750	0.080	2.750
		Parnell	3.381	0.074	3.389
	Side	North	2.511	0.053	2.435
		South	1.641	0.054	1.634
	Side*Site	Conjola,North	0.730	0.099	
		Conjola,South	0.625	0.105	
		Currumbene,North	2.205	0.105	
		Currumbene,South	0.786	0.108	
		Jerrawangala,North	3.368	0.113	
		Jerrawangala,South	2.132	0.113	
		Parnell,North	3.739	0.103	
		Parnell,South	3.023	0.105	
	Site*Location	North,Edge	2.421	0.074	
		North,Interior	2.600	0.074	
		South,Edge	1.618	0.076	
		South,Interior	1.664	0.076	
	Side*Site*Location	Conjola,North,Edge	0.560	0.140	
		Conjola,North,Interior	0.900	0.140	
		Conjola,South,Edge	0.705	0.149	
		Conjola,South,Interior	0.545	0.149	
		Currumbene,North,Edge	2.295	0.149	
		Currumbene,North,Interior	2.114	0.149	
		Currumbene,South,Edge	0.810	0.153	
		Currumbene,South,Interior	0.762	0.153	
		Jerrawangala,North,Edge	3.263	0.160	
		Jerrawangala,North,Interior	3.474	0.160	
		Jerrawangala,South,Edge	2.368	0.160	
		Jerrawangala,South,Interior	1.895	0.160	
		Parnell,North,Edge	3.565	0.146	
		Parnell,North,Interior	3.913	0.146	
		Parnell,South,Edge	2.591	0.149	
		Parnell,South,Interior	3.455	0.149	



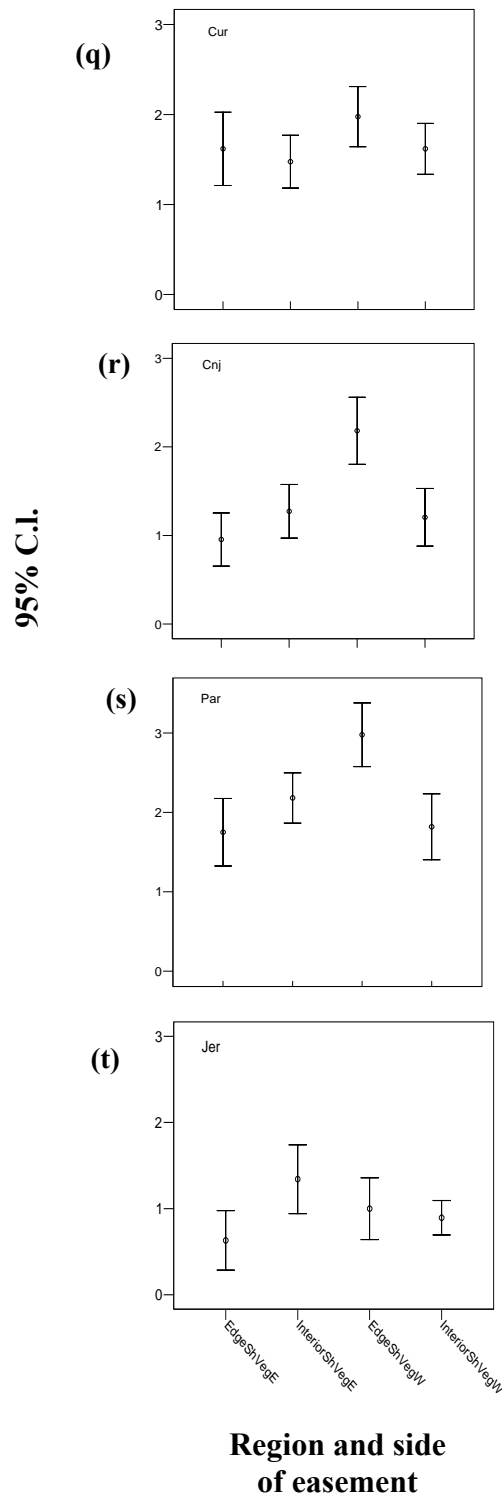
**Appendix 13 Comparison of 95% confidence intervals for edge and interior habitat features at four sites. Cur = Currambene, Cnj = Conjola, Par = Parnell, Jer = Jerrawangala**

Figures (a)-(d) show tests using data relating to logs, figures (e)-(h) refer to leaf litter abundance. On the x-axis, interior or edge refer to the region of the habitat with edge next to the easement. E and W (or N and S) refer to the East or West (or North and South) side of the powerline easement.



**Appendix 13 (ctd.) Comparison of 95% confidence intervals for edge and interior habitat features at four sites. (i) – (l) = Branch, (m) – (p) = Ground Vegetation. Cur = Currambene, Cnj = Conjola, Par = Parnell, Jer = Jerrawangala**

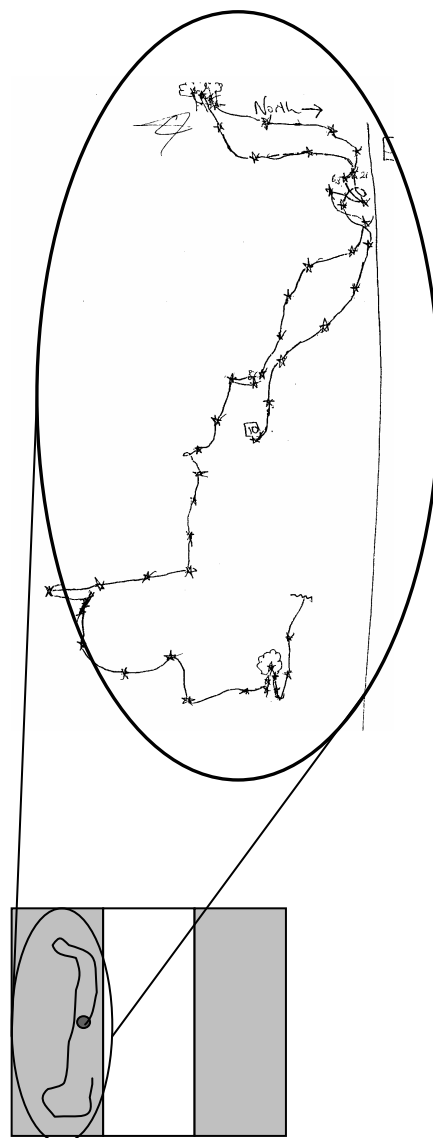
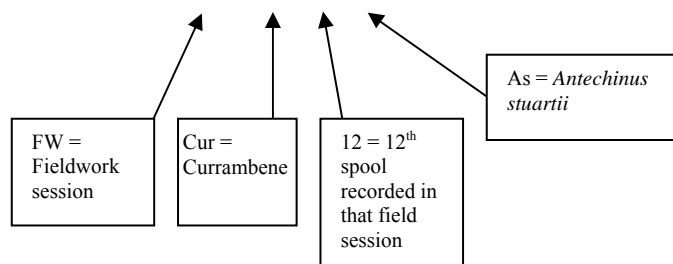
Figures (i)-(l) show tests examining branch abundance and figures (m)-(p) relate to Ground vegetation. On the x-axis, interior or edge refer to the region of the habitat with edge next to the easement. E and W (or N and S) refer to the East or West (or North and South) side of the powerline easement.



**Appendix 13 (ctd.) Comparison of 95% confidence intervals for edge and interior habitat features at four sites. (q) – (t) = Shrub Vegetation. Cur = Currambene, Cnj = Conjola, Par = Parnell, Jer = Jerrawangala**

Figures (q)-(t) describe the density of shrub vegetation at edge and interior regions of the habitat grid.

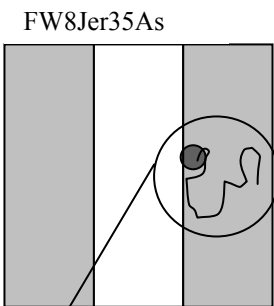
Code: e.g. FW4Cur12As



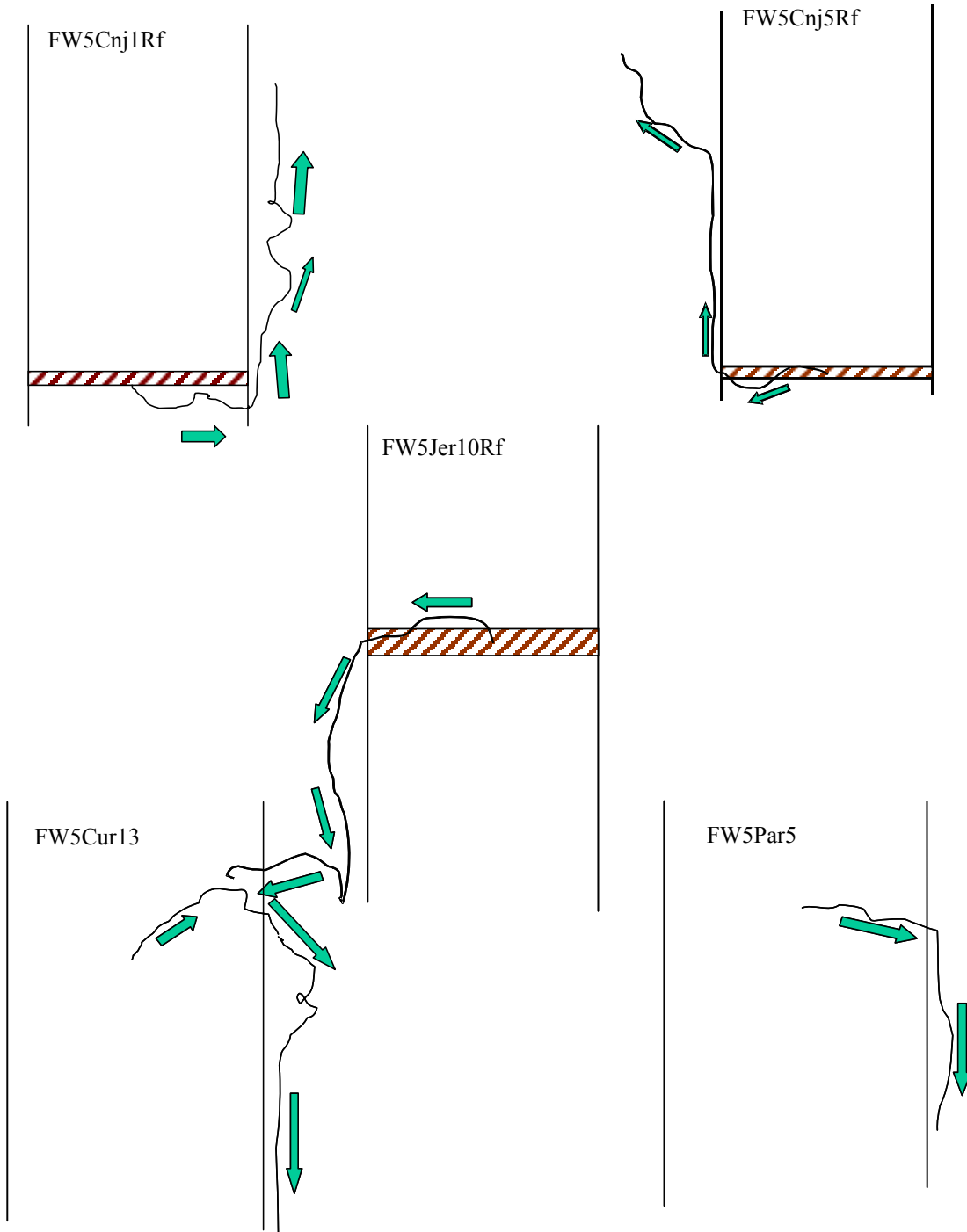
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#### Appendix 14(a) Examples of Type 1 spools: Animals released at a point of capture exhibiting a tortuous path when released at point of capture

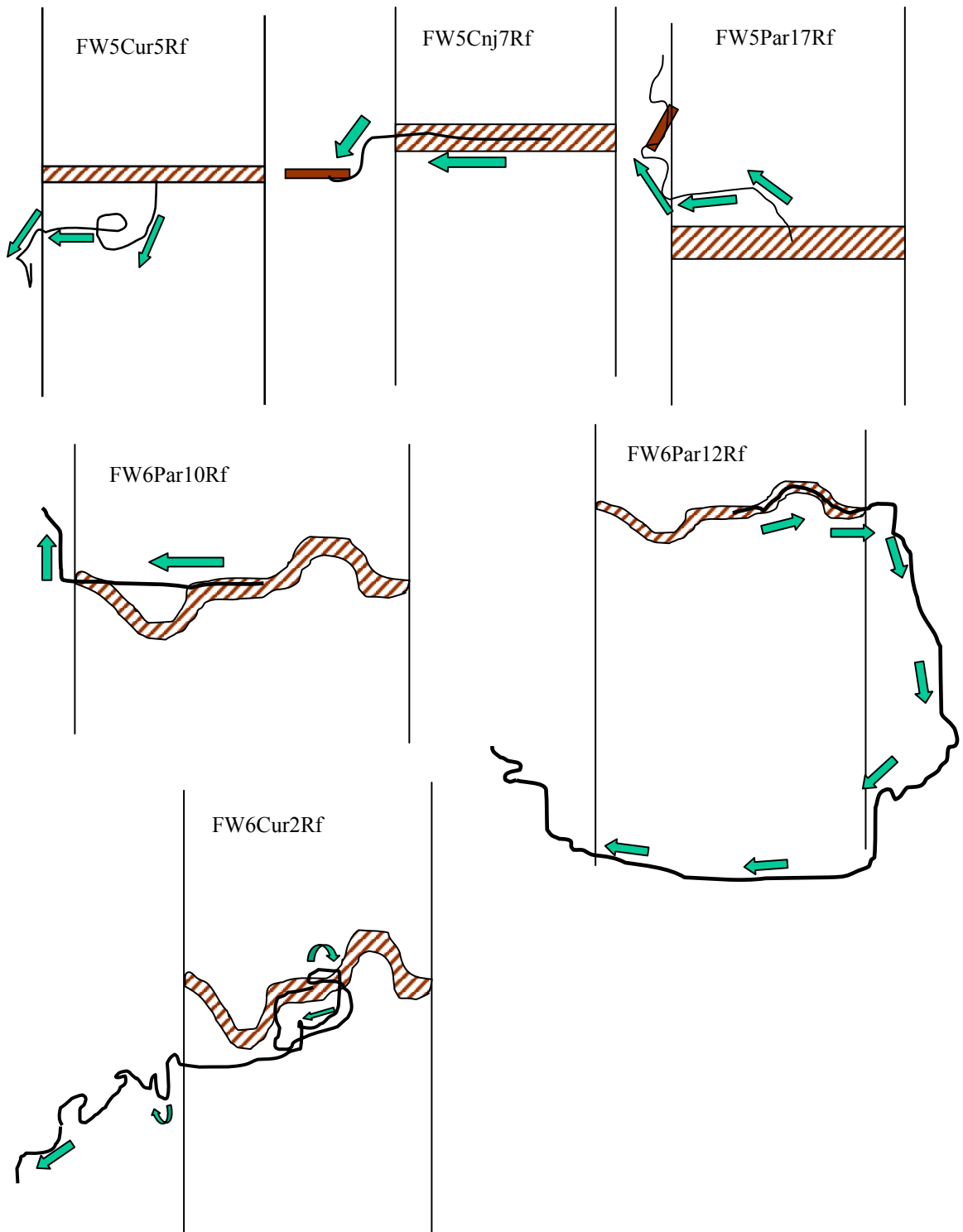
Stars along the length of the spools represent the 3m intervals at which habitat features were recorded. Some of these sketches were converted into computer-generated pictures for clarity. The area within the parallel lines represents the easements. The hatched strip represents the linkage. Arrows show direction of movement after release. Other sketches were taken directly from field notebooks. Insert shows location of spool relative to powerline easement. White strip between two grey strips represents the easement. Cnj = Conjola, Jer = Jerrawangala, Par = Parnell, Rf = *Rattus fuscipes*, As = *Antechinus stuartii* (No kinks were present in fieldwork session 5, FW%). They were added subsequently). Black dots signify point of release of animal.



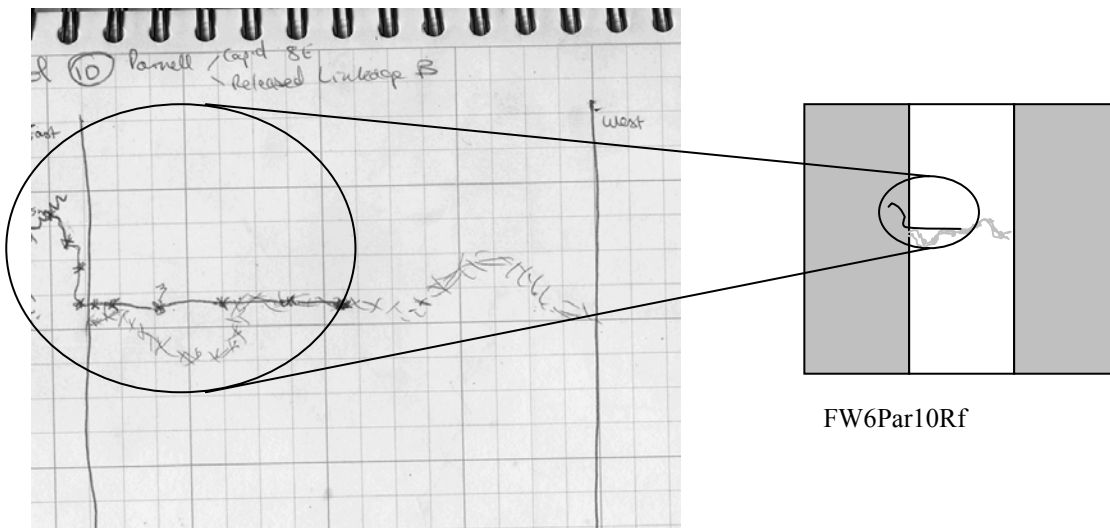
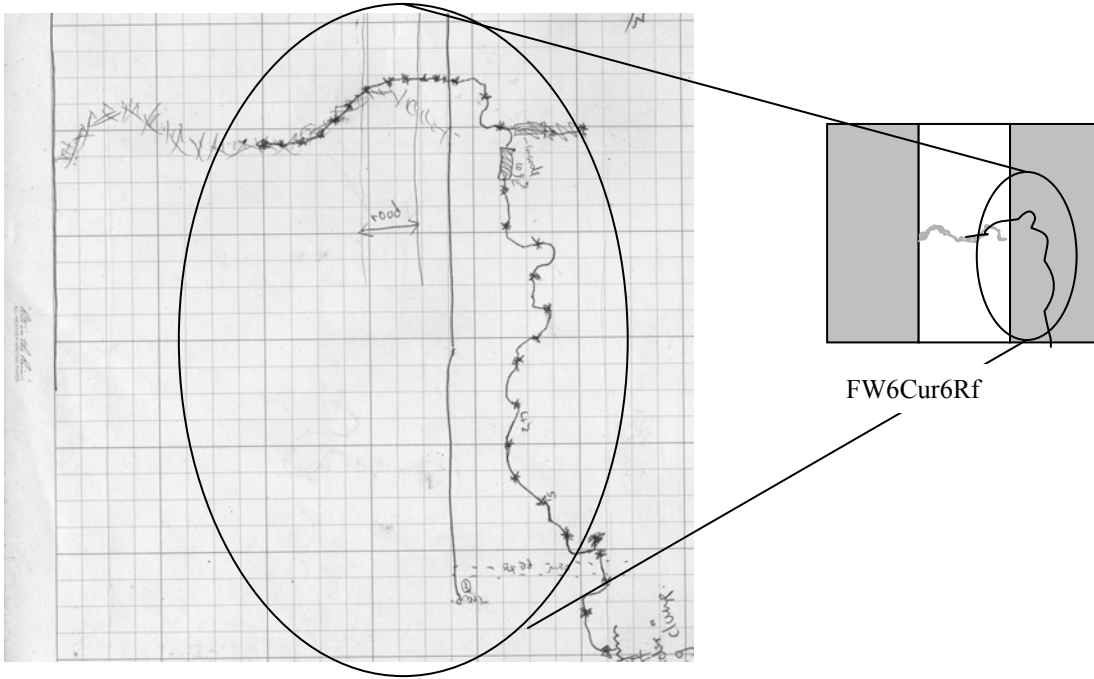
**Appendix 14.1(a) (ctd.) Type 1 spools: Animals released at a point of capture exhibiting a tortuous path when released at point of capture**



**Appendix 14(b) Examples of Type 2 spools showing tendency for animals to skirt the edge after re-entry into the habitat following release in the easement.**

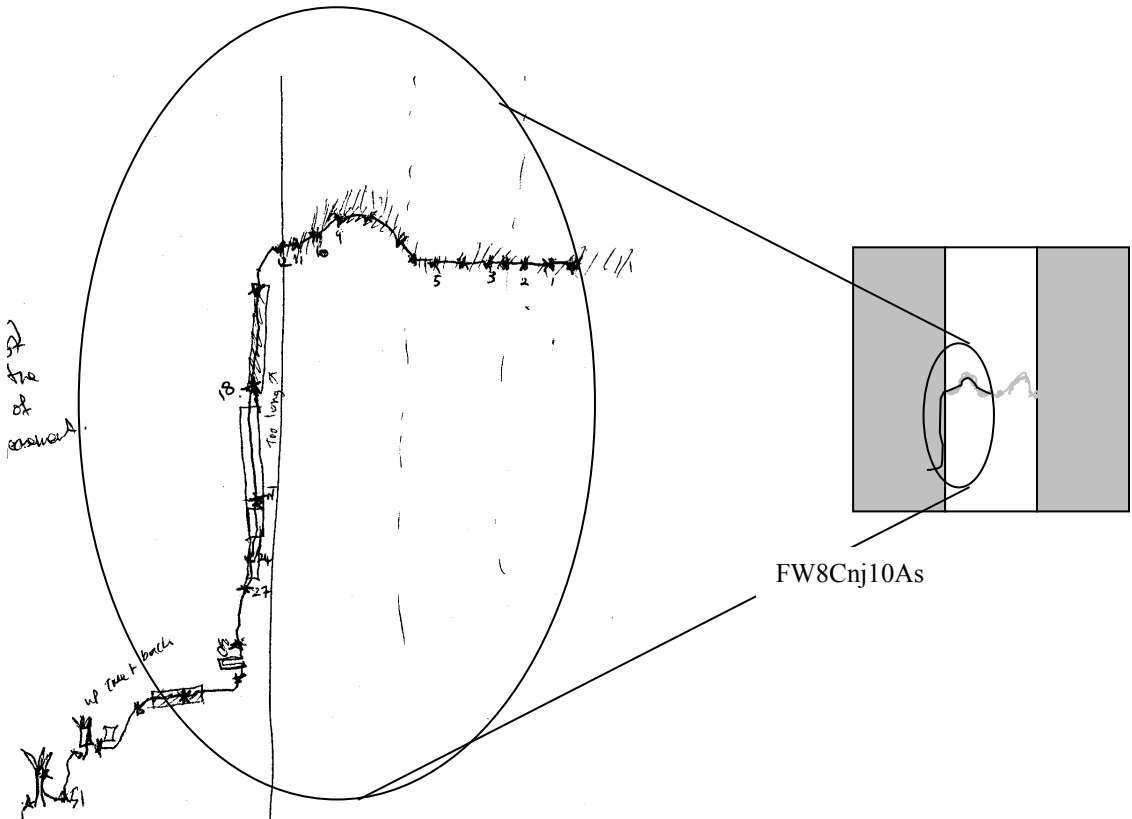
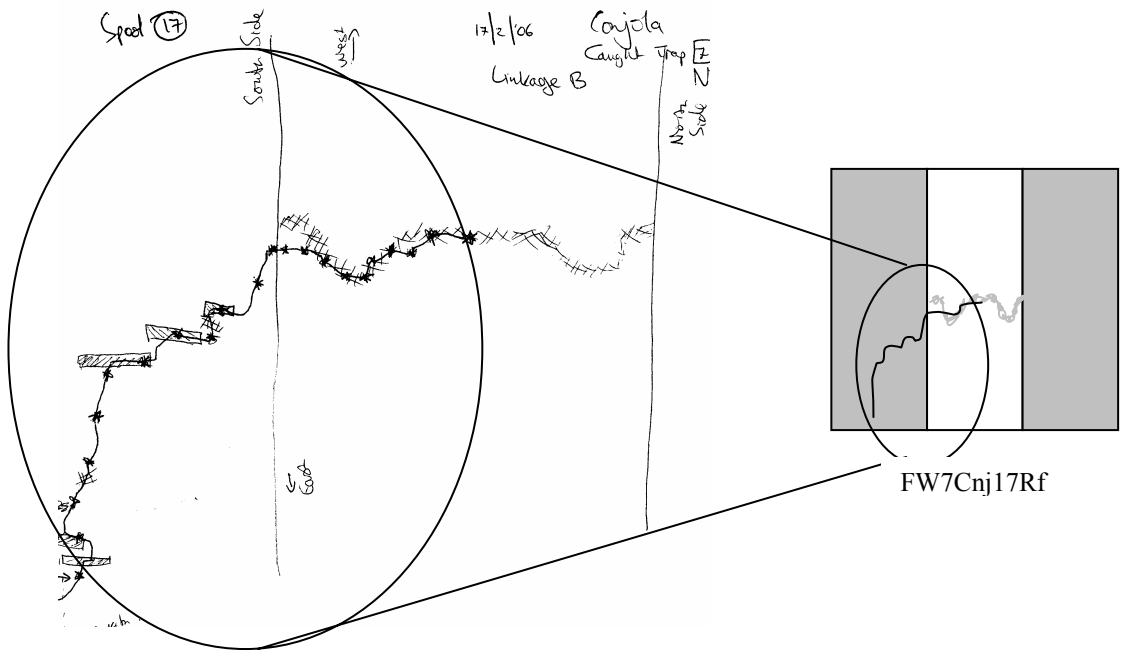


**Appendix 14(c) Examples of Type 3 spools: Animals' varying responses to release on the linkage.**



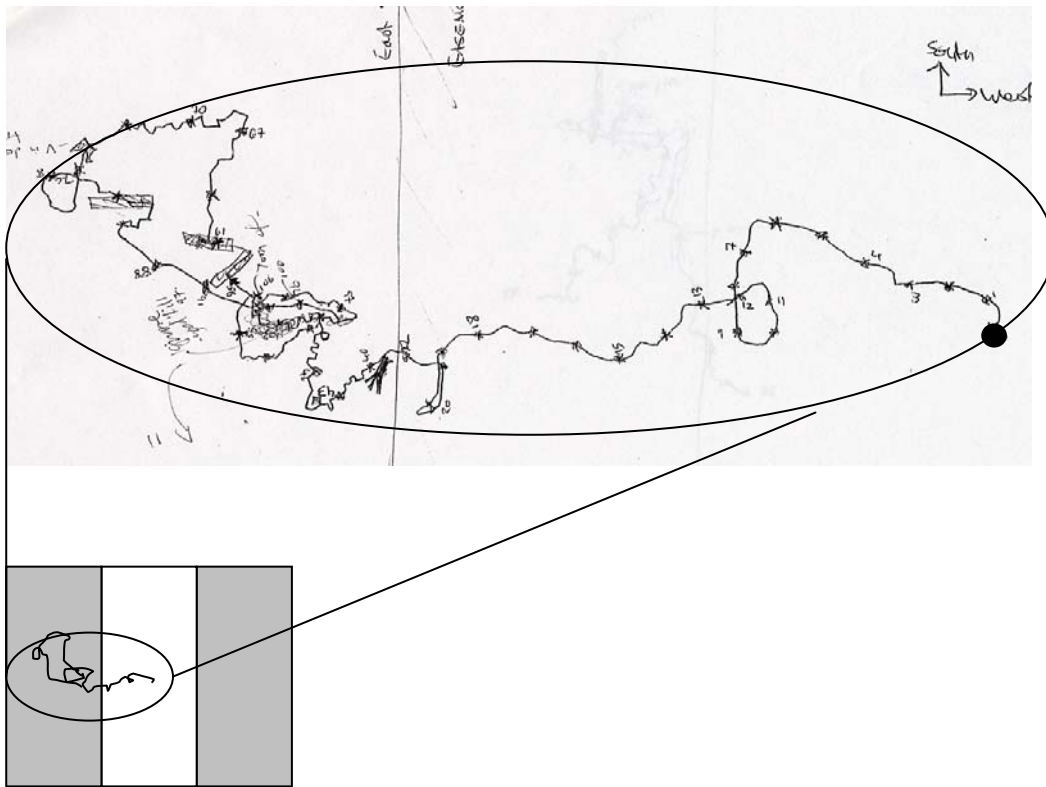
**Appendix 14.(c) (ctd.) Examples of Type 3 spools: Animals' varying responses to release on the linkage.**

Sketches are taken directly from field notebook. Inset shows location of spool relative to easement–habitat boundary. White strip between two strips of grey represents the easement located within the habitat. Linkage in easement shown in pale grey

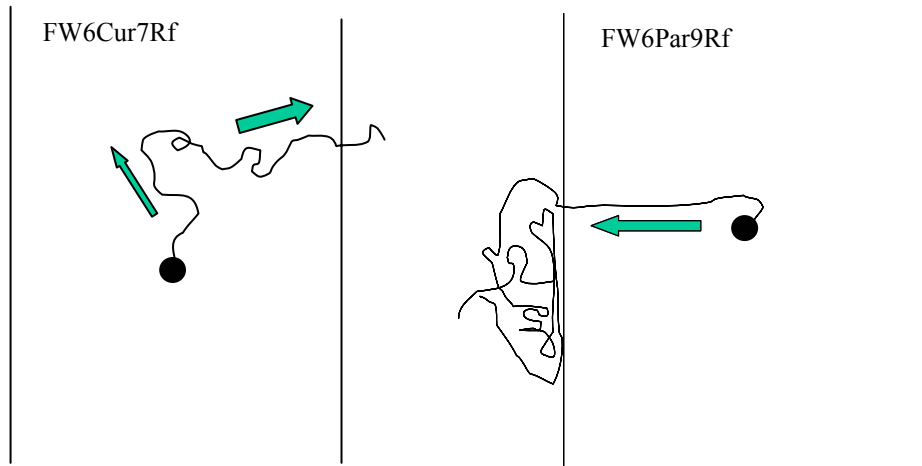


**Appendix 14(c) (ctd.) Examples of Type 3 spools: Animals' varying responses to release on the linkage.**

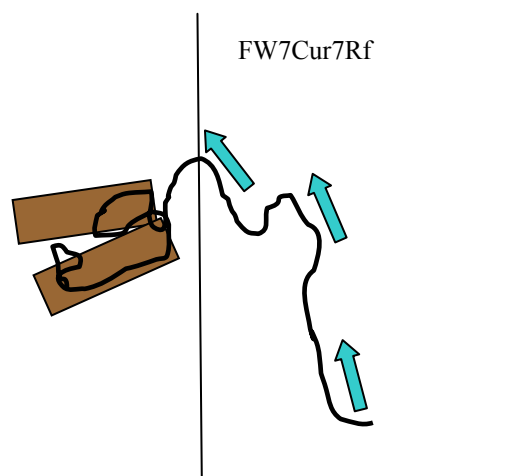
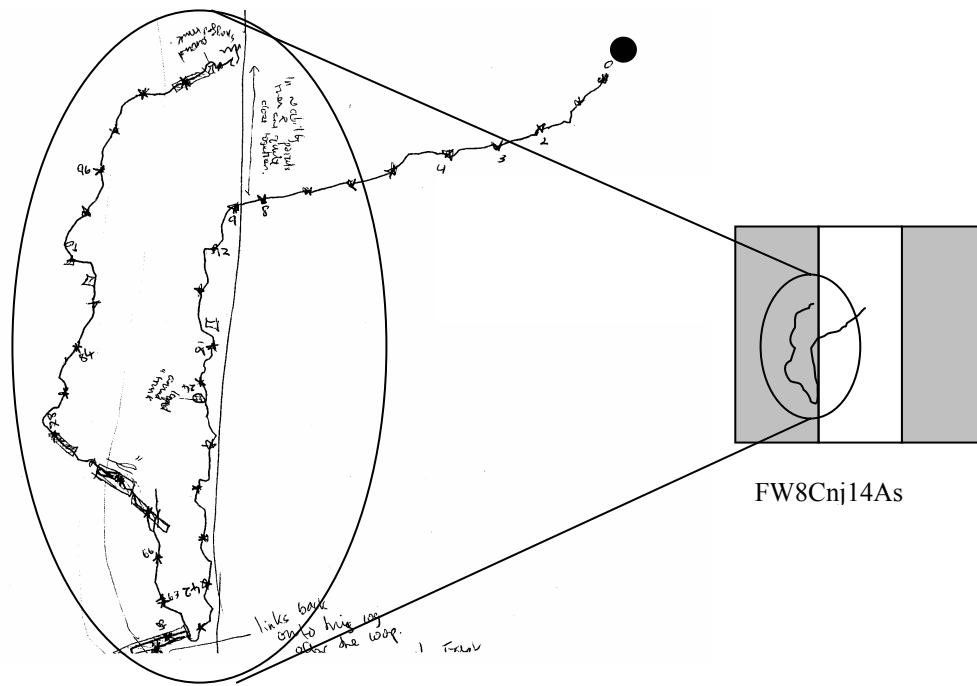
Sketches taken directly from field notebook. Inset shows location of spool relative to easement-habitat boundary. White strip between two strips of grey represents the easement located within the habitat. Linkage in easement shown in pale grey.



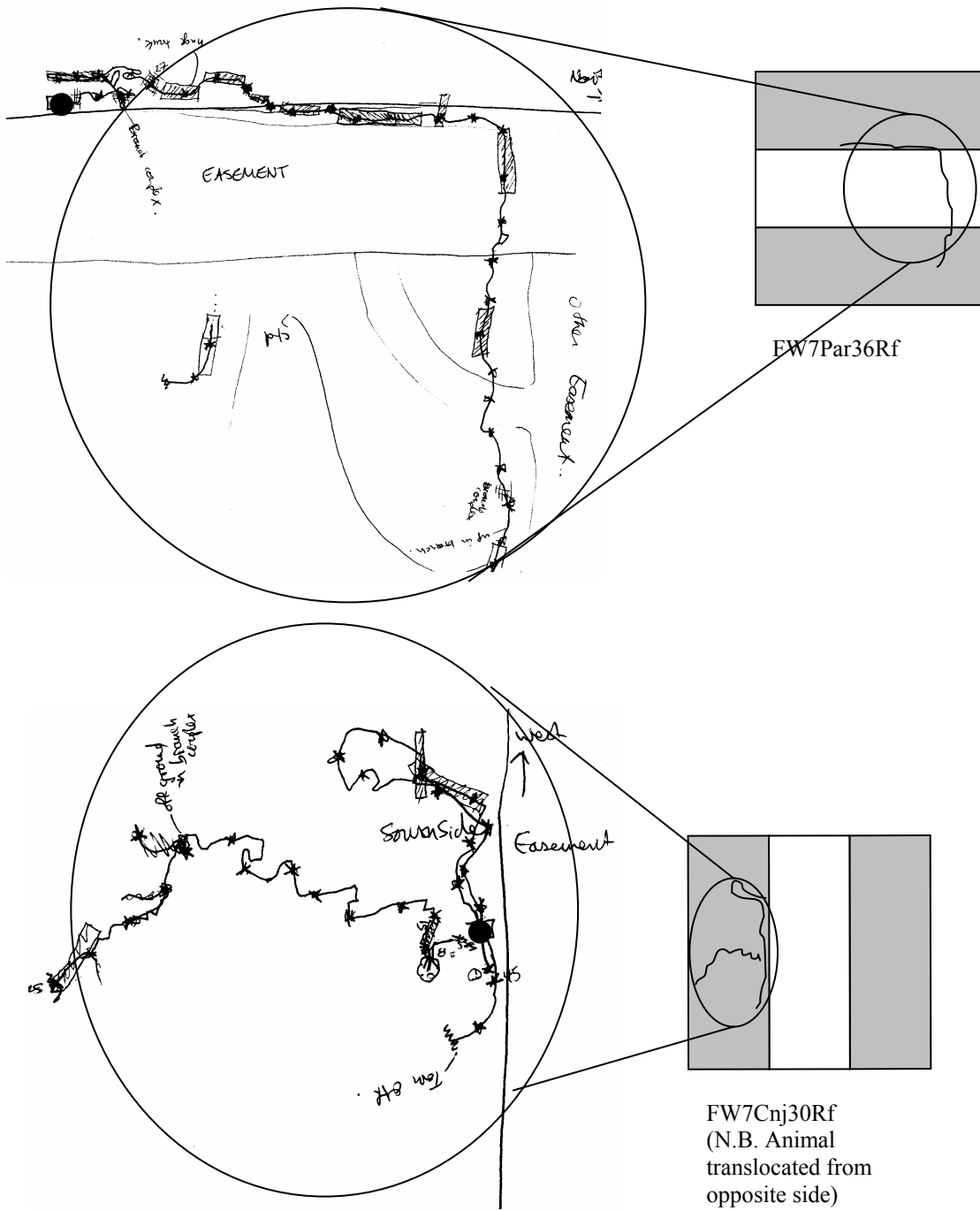
FW8Jer46As



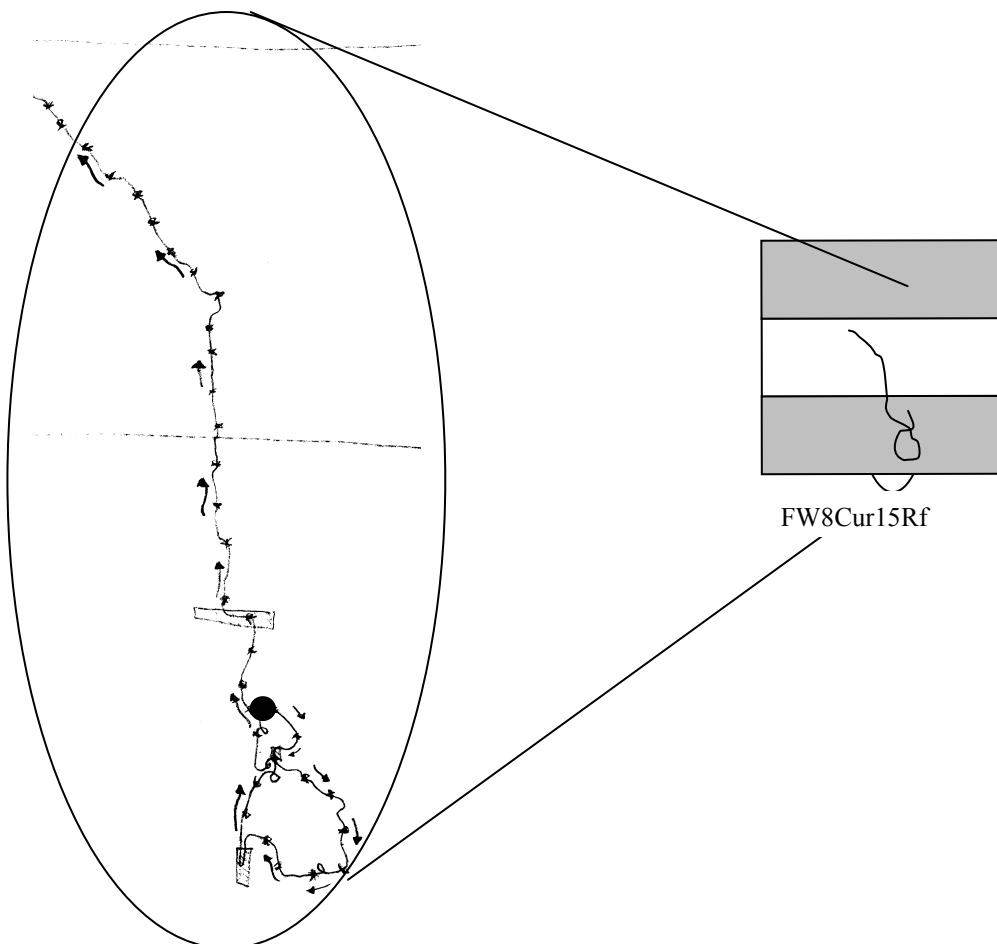
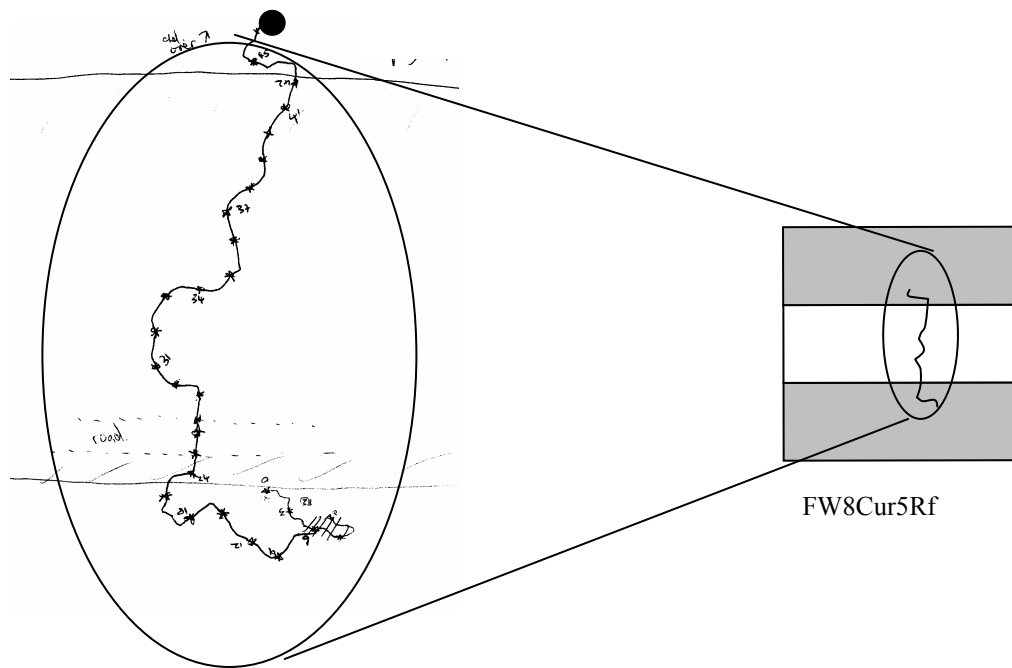
**Appendix 14(d) Examples of Type 4 spools: Varying responses of *Rattus fuscipes* and *Antechinus stuartii* to release on the open.**



Appendix 14(d) (ctd.) Examples of Type 4 spools: Varying responses of *Rattus fuscipes* and *Antechinus stuartii* to release on the open.



Appendix 14(d) Examples of Type 5 spools: Responses of *Rattus fuscipes* to translocation.



Appendix 14.5 (ctd.) Examples of Type 4 spools: Responses of *R. fuscipes* to translocation.