HABITAT FRAGMENTATION is regarded as one of the greatest threats to biodiversity globally. In the last 200 years the Australian landscape has been altered at exponential rates, and in some regions, less than 10% of original native vegetation cover remains and, generally, these remnants are heavily fragmented (Bennett 2003). This situation is ominous, as Andren (1994) identified between 10 and 30% of original vegetation cover as a threshold for native species occupation. Hugget (2005) suggested that once these vegetation thresholds have been exceeded, the effect of habitat fragmentation heavily influences the distribution and abundance of native species. The major processes of fragmentation can be defined as a reduction in total habitat area, changes to the abiotic and biotic ecosystem components, and edge effects (Saunders et al. 1991; Euskirchen et al. 2001).

Edge effects are arguably the most important of these fragmentation processes (Murcia 1995; McDonald & Urban 2006) and have been found to alter the abundance of many taxa (e.g. Laurence et al. 2002). Edges can be classed as either inherent edges, generally represented by the natural ecotones between habitat types, or induced edges, associated with anthropogenic processes (Luck et al. 2001). Human-induced habitat edges have been linked with a number of changes in ecosystem structure, with the most obvious relating to the decline of native species, but often less obvious abiotic changes such as increased daytime temperatures and evaporation rates, increased nutrient loads, greater wind velocities and altered fire regimes (Saunders et al. 1999; Newmark 2005; Siitonen et al. 2005).

Many studies have examined the effects of habitat fragmentation (e.g. Mac Nally & Bennett 1997; Bennett et al. 2004; Watson et al. 2005) and edge effects (e.g. Zheng & Chen 2000; Berry 2001; Cadessano & Pickett 2001; Antos & White 2004) on various avian species. However, there are very few data available on the impact edges have on the distribution of Australian owls in varying forest types. Previous studies have investigated forest owls in relation to disturbance by fire and logging, and fragmentation mosaics (Milledge et al. 1991; Kavanagh & Bamkin 1995; Kavanagh et al. 1995; Kambouris 1998; Loyn et al. 2001; Kavanagh & Stanton 2002).

Forest owls, including the Sooty Owl (*Tyto tenebricosa* Gould, 1845), Barking Owl (*Ninox connivens*...
Latham, 1801), Powerful Owl (Ninox strenua Gould, 1838), Masked Owl (Tyto novaehollandiae Stevens, 1826) and Southern Boobook (Ninox novaceelan- dlae Gmelin, 1788), are all present in Victoria but vary in their distribution. The Southern Boobook is the most common of the five species and is widespread across the State (Higgins 1999). However, the other four species are sporadically distributed throughout Victoria. Of the three large forest owls (Powerful, Sooty and Masked) the Powerful Owl has the most extensive distribution occupying most of Victoria bar the north-west of the State, whereas the Sooty and Masked Owl populations are generally concentrated in south-eastern Victoria (Garnett & Crowley 2000). The Barking Owl is sparsely distributed throughout the State, with the population size in Victoria estimated at 50 pairs (Garnett & Crowley 2000). All of these owls, however, are top-order predators and have specific resource requirements, including the presence of suitable roost and nest trees (e.g. Cooke et al. 2002a), and sufficient prey bases to meet their dietary requirements (e.g. Bilney et al. 2006). The reliance on such resources has meant that these owls often occupy extremely large home-ranges (Soderquist et al. 2002) or are not present in areas where these resources are inadequate.

Previous studies that have investigated the distribution of forest owls have been based largely on sites throughout southern New South Wales, East Gippsland and the greater Melbourne region of south-eastern Australia (e.g. Kavanagh 2002; Bilney et al. 2006; Cooke et al. 2006), and there are very limited data available on the distribution of forest owls and owlet nightjars in south-western Victoria and, more specifically, the Otway Ranges. Conole (1985) did suggest the presence of Powerful Owls, Barking Owls and Masked Owls within the Otways region; however, there are few data describing the factors influencing their distribution.

Therefore, this study aimed to determine the presence of forest owls and owlet nightjars in different habitat types of Cape Otway, in south-western Victoria. More specifically this research aimed to determine:

1. differences in the detection of forest owls and owlet nightjars between wet and dry forests within Cape Otway;
2. differences in the detection of forest owls and owlet nightjars between dry forest interiors and dry forest edges;
3. the frequency of occurrence of arboreal mammals in all three habitat types.

**METHODS**

**Study area**

This study was undertaken within Victoria’s newest national park, the Great Otway National Park, which stretches from Anglesea to Princetown, and encompasses more than 100,000 ha. The rainfall is extremely variable in the Otways, ranging from around 800 mm annually at sea level to regions at the top of the range exceeding an annual rainfall of 1800 mm.

The study site was between the Grey River Reserve and Castle Cove, a stretch of coast approximately 60 km in length. The area has a diverse range of forest types, from wet through to dry coastal forests (Fig. 1). The higher altitudes are predominantly occupied by wet forest, dominated by a canopy of Manna Gum (Eucalyptus viminalis Labill, 1806), Mountain Grey Gum (Eucalyptus cypellocarpa Johnson, 1962), and Mountain Ash (Eucalyptus regnans Muell, 1870). Throughout the wet forests are pockets of Cool Temperate Rainforest which are characterized by a canopy of Myrtle Beech (Nothofagus cunninghamii (Hook.) Oerst, 1871) with a Blackwood (Acacia melanoxylon R.Br, 1813) subcanopy and a dense understorey of Soft Tree-ferns (Dicksonia antarctica Labill, 1807) (Cochraine et al. 1968; Costermans 2002).

As the range drops toward sea level, the vegetation becomes significantly drier. These open forests have a canopy of Messmate Stringybark (Eucalyptus obliqua L'Hér, 1789), Manna Gum and shrubby understorey plants such as the Coast Wattle (Acacia sophorae (Labill.) R.Br, 1813), Coast Banksia (Banksia integrifolia L.f. 1782), Drooping She-oak (Allocasua-rina verticillata) (Lam.) Johnson, 1982) and Bursaria (Bursaria spinosa Cav, 1797) (Costermans 2002).

The Otways were heavily logged during the 1880s and, as a consequence, very little remnant forest remains. Although there is now a system of parks and reserves which protect Otway forests, there are still large areas of cleared land. In the flatter more fertile regions along the coast, farming and agriculture has created a hard edge between the drier coastal forests and cleared land. This boundary provided the majority of edge sites for this study. Wet forest that abutted farmland was not common and, therefore, an edge effect was not investigated for this forest type. As the farmland edges were adjacent to dry forest, the vegetation was very similar to that outlined above for dry forest.

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Site selection

Sites were selected using Geographic Information Systems (GIS). Data layers for the study area were compiled using ArcView 3.3 (Environmental Systems Research Institute (ESRI), Redlands, California 92372, USA). GIS data sets used in this study were supplied under licence by the Department of Sustainability and Environment (DSE). Raw data layers of Ecological Vegetation Classes (EVC) and Tree Density were overlaid to produce a view of the vegetation type and cleared land for the region (Fig. 1). This made it possible to select dry forest, wet forest, and edge sites. A total of 43 sites was selected (Fig. 1). Fifteen sites were situated in the interior of wet forest, fourteen sites within dry forest and a further fourteen sites were located at farmland edges. Edge sites were located at the border of dry forests and farmland, to allow comparison with dry forest interiors. All sites were visited before surveying commenced, to confirm vegetation types. Sites were located at least 1 km apart to minimize the chance of detecting individual birds at more than one site, especially given that large forest owls can have home ranges in excess of 1000 ha (Schodde & Mason 1980; Kavanagh & Murray 1996; Soderquist et al. 2002).

Call playback

Fieldwork was undertaken between February and September 2006. Each site was visited three times during this period, once in each of the three seasons, to undertake call playback. On arrival at each site, a period of five minutes was spent listening for any nocturnal forest birds calling naturally. After this there was a playback period, whereby pre-recorded territorial calls of each target species were broadcast from a megaphone (five minutes for each species). Playback is a common technique used to determine the presence of nocturnal forest birds by eliciting a territorial call response, and has been used in many owl studies (e.g. Milledge et al. 1991; Debus 1995; Kavanagh & Bamkin 1995; Kambouris 1998; Loyn et al. 2001). The target species for this study were the Australian Owlet-nightjar (*Aegotheles cristatus* Shaw, 1790), Southern Boobook, Powerful Owl, Barking Owl, Sooty Owl and Masked Owl. Spotlighting was undertaken for 20 minutes, directly after the playback sequence. Spotlighting was necessary to increase the probability of detecting any non-vocal owls.

Each site was visited three times to maximize the opportunity of detecting birds that remained cryptic during initial visits. On consecutive visits playback
was not carried out for species that had already been detected at that particular site previously. Each site was visited at different times of both the year and night to avoid any bias arising from more responsive seasons or periods of the night (e.g. Kavanagh & Peake 1993; Debus 1995; Olsen et al. 2002).

**Spotlighting**

Spotlighting surveys for arboreal mammals were undertaken at each site. The spotlighting technique involved walking a linear transect of 500 m with a 12 volt spotlight, undertaken twice at each site. The spotlight’s range was approximately 20 m in the forests surveyed, which produced an area of one hectare coverage per visit. A relative density of arboreal mammals observed was generated. For the glider species, which were difficult to detect with a spotlight, an encounter rate was generated. This encounter rate was the number of times each species was detected divided by the possible maximum number of times it could have been recorded (maximum possible is five: three during playback surveys and two during spotlighting surveys). The calls of any arboreal mammal species detected during the listening period and call playback were also recorded, as call playback often caused mammals to give warning calls which made detection easier.

**Vegetation analysis**

A vegetation analysis was undertaken at each site. Six parameters were measured in order to provide an indication of structural complexity: dominant tree species exceeding four metres in height; tall shrubs ranging from two to four metres in height; low shrubs ranging from half to two meters in height; ground herbage flora; litter layer and fallen dead wood. These parameters were chosen as indicators of vegetation complexity and show the layering of strata within a forest. They were collected by estimating the percentage cover of each parameter along the same 500 m linear transects surveyed during spotlighting.

**Statistical analysis**

To assess the compositional difference of vegetation parameters between habitat types, a matrix of similarity among sites was developed using a Bray-Curtis index based on the percentage cover of each vegetation parameter at each site. Gross differences in vegetation parameters of each site were compared by using ANOSIM (analysis of similarity), and SIMPER (similarity percentage) was used to determine which vegetation parameters were contributing most to the similarity between sites. Both ANOSIM and SIMPER were conducted using the PRIMER software package (Clarke & Warwick 1994). Multidimensional scaling was used to generate an ordination of similarity of the vegetation parameters between sites.

A series of Chi-squared tests was conducted to calculate any difference in the detection of nocturnal forest birds across wet forest, dry forest and edge sites. A series of t-tests also was conducted to test for differences in the means of density and encounter rates of arboreal mammals across the three habitat types.

**RESULTS**

Four nocturnal bird and four arboreal mammal species were recorded during the field surveys (Table 1). Of the owls, the Southern Boobook was recorded most frequently, with 39 observations from 43 sites. The Australian Owlet-nightjar was also recorded frequently, with a total of 20 records (Table 1). Of the large forest owls, the Powerful Owl was the most frequently encountered with 10 records. The Masked Owl was recorded at eight sites and was found to overlap with the Powerful Owl at four sites. The Sooty Owl and Barking Owl were not detected at any sites throughout the study.

Of the arboreal mammals, the Yellow-bellied Glider (*Petaurus australis* Shaw, 1791) was the most frequently encountered, being detected at 32 of the 43 sites (Table 1). The Common Ringtail Possum (*Pseudocheirus peregrinus* Boddaert, 1785) was also recorded frequently, with a total of 20 records (Table 1). Of the large forest owls, the Powerful Owl was the most frequently encountered with 10 records. The Masked Owl was recorded at eight sites and was found to overlap with the Powerful Owl at four sites. The Sooty Owl and Barking Owl were not detected at any sites throughout the study.

Based on Bray-Curtis similarity indices, there was a significant difference in the composition of vegetation parameters between wet forest sites, dry forest sites and edge sites (ANOSIM) (Fig. 2), with none of 999 random permutations exceeding the global R sta-
tistic (0.511). Pairwise comparisons of vegetation between wet forest and dry forest showed a significant difference (p < 0.001). Approximately 40% of dissimilarity between these sites was described by the percentage cover of tall understorey plants and ground herbage cover (Table 2). Wet forests had higher cover of tall understorey plants and dry forests had a greater cover of ground herbs. A pairwise comparison of vegetation between dry forest and edge sites showed no significant difference (p > 0.05).

Differences in vegetation composition between wet and dry forests allowed comparisons of nocturnal forest birds and arboreal mammals between two structurally different habitats to be investigated. The broad similarity of vegetation composition between dry forests and edges allowed a true comparison of edge effects on species distribution without the influence of varied vegetation structure.

There was no significant difference in the rate of occurrence of the Australian Owlet-nightjar between dry forests and wet forests ($X^2=0.293$, df=1, p=0.588). There was also no significant difference in the rate of detection of the Southern Boobook ($X^2=0.213$, df=1, p=0.909) and Masked Owl ($X^2=0.333$, df=1, p=0.564) between these forest types (results for the Powerful Owl and Masked Owl should be viewed with caution due to the low rate of detection). Similarly there was no significant difference in the average density of the Common Ringtail Possum between wet and dry forest types ($t=0.368$, df=27, p=0.715). To examine the differences between site types for Sugar Gliders and Yellow-bellied Gliders, we compared the proportion of visits in which the species was encountered at a site. Overall there were no significant differences in the encounter rates of Sugar Gliders ($t=1.651$, df=27, p=0.110) and Yellow-bellied Gliders ($t=1.527$, df=27, p=0.138) between the forest types.

There was no significant difference in the presence of the Australian Owlet-nightjar ($X^2=1.348$, df=1, p=0.246), Southern Boobook ($X^2=0.000$, df=1, p=1.000), Powerful Owl ($X^2=0.848$, df=1, p=0.357), and Masked Owl ($X^2=0.000$, df=1, p=1.000) between dry forest and edge sites. There were also no significant differences between the density of Common Ringtail Possums ($t=-0.177$, df=26, p=0.861) or the encounter rate of Sugar Gilders ($t=-1.894$, df=26, p=0.069) between dry forest and edge sites. There

Table 1. Detection of nocturnal forest birds and arboreal mammals in wet forest interiors (Wet), dry forest interiors (Dry) and dry forest edges (Edge) within Cape Otway, south-western Victoria. Numbers indicate the number of sites at which each species was recorded.

<table>
<thead>
<tr>
<th>Species</th>
<th>Wet (n=15)</th>
<th>Dry (n=14)</th>
<th>Edge (n=14)</th>
<th>Total (n=43)</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Nocturnal Birds</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Southern boobook owl</td>
<td>13</td>
<td>13</td>
<td>13</td>
<td>39</td>
</tr>
<tr>
<td>Aegotheles cristatus</td>
<td>9</td>
<td>7</td>
<td>4</td>
<td>20</td>
</tr>
<tr>
<td>Ninox strenua</td>
<td>4</td>
<td>4</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Tyto novaehollandiae</td>
<td>2</td>
<td>3</td>
<td>3</td>
<td>8</td>
</tr>
<tr>
<td><strong>Arboreal Mammals</strong></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Petaurus australis</td>
<td>13</td>
<td>13</td>
<td>7</td>
<td>32</td>
</tr>
<tr>
<td>Pseudocheirus peregrinus</td>
<td>12</td>
<td>8</td>
<td>9</td>
<td>29</td>
</tr>
<tr>
<td>Petaurus breviceps</td>
<td>9</td>
<td>5</td>
<td>1</td>
<td>15</td>
</tr>
<tr>
<td>Trichosurus vulpecula</td>
<td>0</td>
<td>3</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

Fig. 2. Multi-dimensional scaling ordination of study sites based on Bray-Curtis similarity measures of vegetation composition. □ = wet forest sites, △ = dry forest sites, ○ = edge sites. (Stress = 0.13).
was, however, a significant difference in the encounter rate of Yellow-bellied Gliders between dry forest and edge sites ($t = -4.101, df = 27, p < 0.001$). The encounter rate for Yellow-bellied Gliders was much higher in the dry forest sites than sites within edge habitats (Fig. 3).

For wet forest, dry forest and edge sites an average species richness of the nocturnal forest bird and arboreal mammal community was calculated. There was no significant difference in the species richness between wet forest and dry forest sites ($t = 0.126, df = 27, p = 0.901$). There was, however, a significant difference in the species richness between edge and dry forest sites ($t = 2.066, df = 26, p = 0.049$). Dry forest and wet forest sites contained higher species richness than edges (Fig. 4).

DISCUSSION

This study identified the presence of four species of nocturnal forest birds and four species of arboreal mammals across the 43 sites surveyed throughout Cape Otway in south-western Victoria. Each of the species recorded during this study were detected in all three habitat types, wet forest interiors, dry forest interiors and dry forest edges. The similarity of nocturnal forest bird and arboreal mammal species richness between wet and dry forest types indicates that both habitats are of similar quality and are supporting an equally wide range of species.

The two smallest nocturnal forest birds, the Australian Owlet-nightjar and the Southern Boobook,
showed no significant difference in their presence at dry forest interiors and edge sites. Both of these small nocturnal forest birds are predominantly insectivorous (Hollands 1991). A study in North America detected a positive edge association in an insectivorous species, the Northern Pygmy Owl (*Glaucidium gnoma* Wagler, 1832), due to increased visibility and the subsequent ease of spotting prey (Piorecky & Prescott 2006). This would imply that although the Australian Owlet-nightjar and Southern Boobook owl show no positive association with edge sites, hunting is unlikely to be adversely affected at farmland edges.

The larger forest owls have more demanding resource requirements than the smaller nocturnal forest birds, requiring high prey densities, habitat diversity and large hollow-bearing trees within their home range (e.g. Seebeck 1976; Lown et al. 2001; Soderquist et al. 2002; Cooke et al. 2002b). Neither the Powerful Owl nor the Masked Owl, however, showed any significant edge effect in their occurrence. This result should be viewed with caution as the detection of these species was low and it is possible that the playback technique has drawn the owls to the edge from the forest interiors (see Kavanagh & Stanton 2002).

Very few species actually displayed any edge-related effects in this study, which is consistent with other Australian studies (e.g. Campi & Mac Nally 2001). All nocturnal forest birds and arboreal mammals detected during this study were present in both forest interiors and edges. There was, however, significantly higher average species richness in dry forest interiors when compared with farmland edges. This implies that although edges can support a range of nocturnal forest birds and arboreal mammals, habitat change is reducing species richness at farmland edges. This situation could be derived from compositional changes in plant species along edges. However, this study could not confirm this hypothesis as only vegetation structure was compared. Additionally, many other edge effects could be influencing the nocturnal forest bird and arboreal mammal community by altering ecosystem functions such as interspecific competition, nest predation, competition with edge-favored species and invasion by exotic flora and fauna (Ford 1979; Keyser et al. 1997; Ley et al. 1997; Ford et al. 2001; Berry 2002; King & Buckney 2002; Laurel et al. 2003). It also is important to note that species richness can mask other results, and, therefore, species-specific responses should not be ignored (Miller & Cale 2000). In this study individual nocturnal forest bird and arboreal mammal species did in-

habit forest edges, and therefore, these areas are offering useful habitat.

As top-order predators, the presence of large forest owls reflects an array of environmental parameters and makes them a very useful conservation tool. By conserving forest owl habitat in a top-down approach to management, a suite of other species also can be protected (see Simberloff 1998). As an implication of this use, further research should investigate the ecology and broad response to habitat fragmentation of large forest owls within the Otways, which has proven to support populations of both Masked Owls and Powerful Owls. The survey’s failure to detect Barking Owls and Sooty Owls is not surprising, due to the sporadic distribution and low population densities of the Barking Owl, and to the distribution of the Sooty Owl being heavily concentrated in the south-east of the State. Further research, however, would need to be conducted to identify their presence/absence in different habitat types throughout the Otways. Arboreal mammals are important factors in the distribution of nocturnal forest birds, especially large forest owls, and these mammals are known to respond to habitat fragmentation (Pahl et al. 1988; Laurence & Laurence 1999; Harding & Gomez 2006; Wayne et al. 2006). It is, therefore, important to further the knowledge on the specific effects of edges on these mammals within the Cape Otway.

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OWLS, OWLET NIGHTJARS AND ARBOREAL MAMMALS IN EDGE ENVIRONMENTS OF CAPE OTWAY


