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HOW FAR INTO A FOREST DOES THE EFFECT OF A ROAD EXTEND?

Defining Road Edge Effect in Eucalypt Forests of South-Eastern Australia

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Abstract: The concept of the road-effect zone has been developed and researched predominantly in the Northern Hemisphere. This study measures the extent of road impacts into a temperate eucalypt forest ecosystem in south-eastern Australia. The Epsom-Barnadown Road is a two-lane arterial road connecting regional centres in northern Victoria to the City of Greater Bendigo. Passing through the Bendigo Regional Park, the Epsom-Barnadown Road carries more than 1,600 vehicles per day. Transects of 1 km in length cited perpendicular to the road were established to measure road impacts on the flora and fauna of box-ironbark forest. Exotic vegetation was found to extend about 50 m from the road. Traffic noise and light penetration varied according to topography and vegetation cover, but averaged of 350 m and 380 m, respectively, from the road. Mammal surveys indicated there was an increase in species richness once traffic noise reached ambient levels (40 dB) and traffic light penetration ceased. Bird surveys resulted in the identification of four species (9%) that only occurred within 150 m of the road (edge species) and 21 species (58%) that only occurred at distances of 150 m or more from the Epsom-Barnadown Road (interior species). A core habitat area for bird species was identified at about 900 m from the road. It was found that the average width of forest in the Bendigo Regional Park impacted by the Epsom-Barnadown Road was 1800 m, which translates to an area of 1.8 km² per kilometre of road.

The Road-Effect Zone

In recent years, Forman and Deblinger (2000), Forman (2000), and Forman et al. (2003) have developed the concept of a road-effect zone. The road-effect zone is defined as the area over which significant ecological effects related to species, soil, and water extend outward from a road into the surrounding landscape (Forman & Deblinger 2000). Over 20 ecological effects of roads have been identified, including alteration to the physical and chemical environment, dispersal of exotic species, noise and pollutants, increased mortality and the alteration to wildlife behaviour (Forman and Deblinger 2000). The road effect zone is usually many times wider than the road surface and associated verge habitat, which is traditionally considered within transportation planning. It is a useful tool to address the ecological effects of roads and to provide a basis for sustainable road management strategies.

The outer boundary or effect distances on either side of the road is usually dictated by a combination of topography, the quality of adjacent vegetation, animal behavior and wind direction (Forman et al. 2003). Wind carries sediments, dust, pollutants, and traffic noise farther distances downwind than upwind. Similarly, sediment and dissolved chemicals carried by water, or noise carried by wind, affect greater distances down slope opposed to upslope. The behavioral attraction to suitable habitat by animals to forage, breed, or live, and by non-native species looking for habitat to invade, all occur for varying distances in one direction more than another (Forman et al. 2003). As a result, the outer boundaries of the road-effect zone are highly asymmetric, convoluted, and generally extend farther down slope and down wind of the road and in areas of higher quality vegetation or habitat (Forman and Alexander 1998, Forman and Deblinger 2000, Forman et al. 2003).

Comprehensive reviews of the ecological effects of roads have been written by Andrews (1990), Bennett (1993), Forman and Alexander (1998), Spellerberg (1998), Trombulak and Frissell (2000), and Forman et al. (2003). Road effects to be considered here are the spread of exotic weeds via roads, habitat fragmentation produced by roads, and road avoidance behavioral traits adapted by some fauna species. Habitat fragmentation relates to the size of the fragment after roads have subdivided habitat into smaller isolated blocks. Removal of forest habitat results in a greater proportion of edge habitat or forest edge. Species can be grouped according to their response to an edge. "Edge" species are those whose abundance increases near habitat edges and are typically habitat generalists. By contrast, "interior" species are those that decrease or are absent from edge habitat, and are habitat specialists, having large home ranges and inhabiting large-sized habitat remnants (Berry 2001). Generalist species are usually able to tolerate disturbed edge habitat, as substantial areas are still available for colonisation. However, for those species restricted to forest interiors, habitat loss due to the construction of a road is several times that of actual forest removal (Andrews 1990, Bennett 1993, Forman et al. 2003).

Roads provide a conduit for the dispersal of exotic species via three mechanisms: providing habitat for exotic species by altering natural conditions, making invasion more likely by stressing or removing native species, and allowing easier movement of wild or human vectors (Trombulak and Frissell 2000). Where weeds replace indigenous vegetation, animals are left without food, breeding sites or shelter from predators (Csurhes and Edwards 1998). In sclerophyll forests of Dartmouth, Australia, Amor and Stevens (1976) recorded the frequency of alien plants and diffuse light both decreased with distance from a road, with an abundant growth of weeds within moisture pockets of water runoff formed in the road shoulder. Morgan (1998) found a similar pattern in south-eastern Australian grassland habitat, and attributed exotic species richness in roadsides to higher nutrient concentrations, such as phosphorous and ammonium, emitted from vehicle exhausts. Vehicle emissions, which extend short distances from a road, fertilized the growth of exotic species, which, in turn, prevented the growth of native vegetation (Morgan 1998).

Road disturbance arises from vehicular noise, headlights, vibrations, and human presence. Species that are sensitive to such disturbance may modify their movement patterns and/or home range to avoid favored habitat near a road

(Trombulak and Frissell 2000, Forman et al. 2003). In both woodland and pastureland adjacent to a road in the Netherlands, 26 of the 43 (60%) grassland bird species encountered showed evidence of reduced abundance and richness near the road, exhibiting avoidance zones up to 3,530 m where the traffic volume was 50,000 vehicles per day (Reijnen et al. 1996). Likewise, on highly trafficked two-lane roads in Boston, MA, USA, supporting 15,000-30,000 vehicles/day, both bird presence and regular bird breeding were reduced to a distance of 700 m away from the road (Forman et al. 2002). Interestingly no distance effect could be determined on adjacent roads supporting 3,000-8,000 vehicles/day in Boston.

In all studies to date, avoidance zones have been shown to widen with an increase in traffic volume. Traffic noise has postulated to be the independent variable causing birds to stop breeding and/or move away from the road. It is believed traffic noise causes both hearing loss and increased stress levels leading to illness, premature death, and population decline (Bowles 1997). A study investigating a disturbance effect zone from vehicle headlights by Jones (2000) reported Tasmanian Devils *Sarcophilus laniarius* becoming dazzled by car headlights when trying to cross a tourist road in Tasmania, Australia. Bright light temporarily destroys an animal's night adaptation vision, and it has been suggested that it can take a half hour for the night vision of fauna to be fully restored once light has been removed (Wilson 1999).

The Box-Ironbark Forest of the Bendigo Regional Park

This study was undertaken in the Bendigo Regional Park, 10 km north-west of the central Victorian city of Bendigo in south-eastern Australia (figure 1). The area is characterized by undulating rises and low hills, comprising Ordovician sandstones and mudstones. The soils are typically shallow, low in nutrients, and have poor water-holding capacity. The vegetation comprises Box-Ironbark eucalypt forest (Muir et al. 1995). The Box-Ironbark ecosystem exists as forests and woodlands between the inland slopes of the Great Dividing Range and the adjacent Riverina Plains of south-east Australia (Environment Conservation Council 1997). The dominant tree species consist of Grey Box *Eucalyptus microcarpa*, Red Ironbark *Eucalyptus tricarpa*, with Yellow Gum *Eucalyptus leucoxylon* growing at lower moister sites, and Red Box *Eucalyptus polyanthemus* on drier upper slopes of the forest. The understorey is dominated by sclerophyllous Acacias *Mimosaceae*, Heaths *Epacridaceae*, and Bush-peas *Fabaceae* (figure 2). Local composition of the forest is dependent on variables of aspect, elevation, and drainage (Campi and Mac Nally 2001).

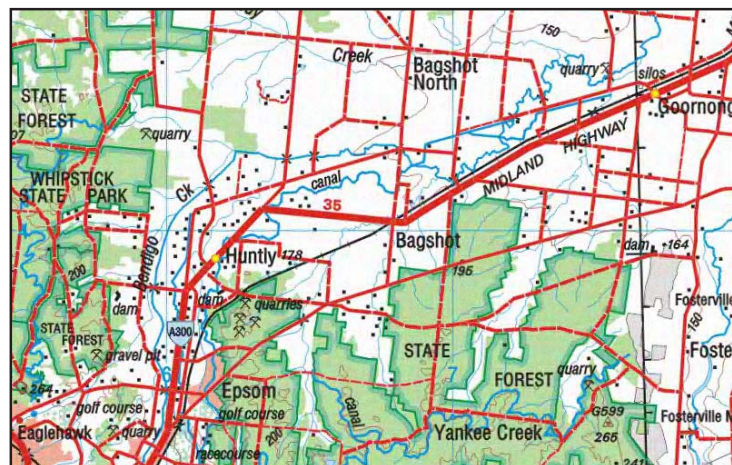


Figure 1. Location of the Epsom-Barnadown Road relative to the Bendigo Regional Park.



Figure 2. The Epsom-Barnadown Road bisecting the box-ironbark eucalypt forests of the Bendigo Regional Park.

Several issues relating to road-edge effect identified in the literature are applicable to box-ironbark forests. For example, fragmentation is one of the most problematic challenges to species conservation in box-ironbark forests. Once existing as three million hectares of large continuous forest and woodland, European settlement and its associated activities of mining, agriculture, and timber harvesting have reduced the ecosystem to a meagre 15 percent of its original extent. Remaining habitat is highly modified and fragmented, and exists as linear remnants along roadsides and streams, or as patches that range from small fragments to large bushland reserves. Furthermore, bushland reserves are internally fragmented by an expanding road network. The structure, width, and present management of this road system is far from uniform, varying from single-lane mining, recreational and forestry roads to multilane paved highways and freeways that carry large volumes of high speed traffic. Yet, as this prevalent network carves its way through almost every corner of the Box-Ironbark ecosystem, the ecological effects of roads, traffic disturbance, and their associated edge effects have not been examined.

The Bendigo Regional Park covers an area of 8,745 ha (Parks Victoria 2002), with the Epsom-Barnadown Road bisecting it from east to west. In October 2003, the traffic volume along this road was determined by the City of Greater Bendigo to average 1,617 vehicles per day, an increase from 1,077 vehicles per day in July 1999 (City of Greater Bendigo 2003). The legal speed limit for this section of road is 100 km/hr. Vehicular speeds were recorded from 10-160 km/hr, and 49 percent of vehicles travelled between 90-100 km/hr. The study was conducted between July and September 2004.

Exotic Vegetation

To measure the extent of exotic vegetation spread into the forest, the flora along three survey lines was determined using the line transect method (Brower et al. 1998). The presence of trees, shrubs, groundcover, herbs, grasses, and weeds, which were found one meter on either side of a 50-m measuring tape, were recorded. Notes were made of the topographical characteristics of the transects (e.g., ridge, gully, etc.). This method was also helpful in identifying major native vegetation zones along the transects.

Transect results indicated the vegetation in the study area was relatively weed free with a few pasture weed species and Large Quaking Grass *Briza maxima* common in the first 50 m, especially where pools of water formed in the road shoulder. Throughout the forest *Oxalis pescaprae* and three species of pasture weed including Cape Weed *Arctotheca* were found under patches of Totem Pole *Melaleuca decussate*. These species are considered to be “naturalised weeds” due to their ubiquitous nature within the box-ironbark bioregion, and were not regarded as indicative of road-edge effect. The mean distance for weed penetration from the Epsom-Barnadown Road into the Bendigo Regional Park was about 50 m, creating an effect zone of 0.1 km² per km of road.

Traffic Noise Penetration

The distance traffic noise extended into the forest was determined along 17 transects running perpendicular to the road marked at 50-m intervals. These transects were strategically placed to encompass gullies, ridge lines, and flat terrain so as to determine the influence of landscape features on noise penetration. A background noise absorber was used to determine the maximum noise each vehicle emitted when it passed the observer. The average noise of 10 cars was recorded each 50-m interval.

Traffic noise could be heard throughout the entire study area. The distance that noise above 40 dB (the ambient level) extended into the forest varied in relation to landscape features (gullies, ridges, flat terrain) 400 m on flat terrain, 325 m down gullies, and 300 m on ridges (figure 3). Past these points, traffic noise remained between 30-40 dB. On average, traffic noise (dB) was recorded slightly higher at each 50-m interval away from the center of the road along gullies compared with flat terrain or ridgelines (figure 3). The mean distance for traffic noise penetration from the Epsom-Barnadown Road into the Bendigo Regional Park was 350 m, creating an effect zone of 0.7 km² per km of road.

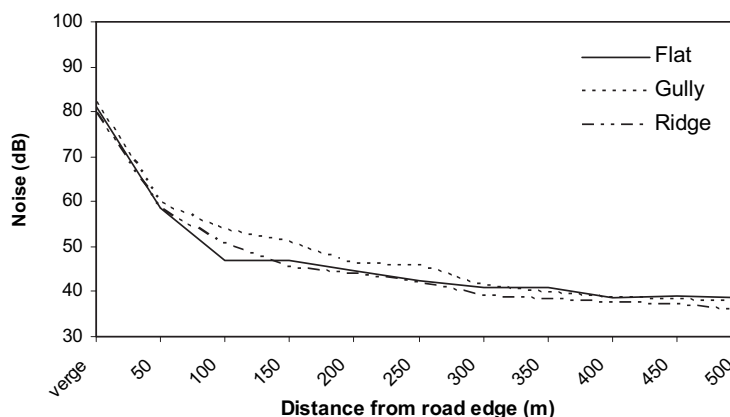


Figure 3. Noise levels in the Bendigo Regional Park at varying distances from the Epsom-Barnadown Road.

It must be noted that traffic noise in the surrounding road network could also be heard within the study area during the peak traffic times of 0800 and 1000, and 1700 and 1900. In the forest block north of the Epsom-Barnadown Road, traffic on the Midland Highway, approximately 2.5 km to the north (figure 1), could be heard between 500 m and 1000 m from the Epsom-Barnadown Road. Where farmland connected the Midland Highway and the Epsom-Barnadown Road, Midland Highway traffic noise could be heard a distance of 100 m into the southern forest block. The Fosterville Road, approximately 2 km south, could also be heard in the southern block at a distance of 1 km away from the Epsom-Barnadown Road.

Traffic Light Penetration

The same 17 transects used to measure traffic noise penetration were also used to determine traffic light penetration. The extent of traffic light illumination into the forest was determined as the distance from the road where traffic lights were no longer visible. The average distance light extended into forest habitat was 360 m for flat terrain, 450 m down gullies, and 260 m across ridges. The mean distance for traffic light penetration from the Epsom-Barnadown Road into the Bendigo Regional Park was 380 m, creating an effect zone of 0.76 km² per km of road.

It should be noted that 55 percent of the time, dense vegetation defined the outer boundary or effect zone for both traffic noise and light. Randomly placed clumps of Whirrakee Wattle *Acacia williamsonii* and Totem Pole *Melaleuca decussate* reduced noise by 5 dB and screened out vehicle light penetration.

Mammal Surveys

The presence and abundance of arboreal and diurnal mammals was surveyed along three transects in the Bendigo Regional Park using a combination of spotlighting and search surveys. Each transect was traversed six times between 1900 and 2300 hours, and entailed walking each 1,000-m transect checking the ground, bole, branches, and canopy of the trees on a 50-m front ahead of the surveyor (Soderquist and MacNally 2000). Eyeshine from species was detected in the spotlight beam, and the substrate used by the species was recorded. Along each transect, 20 1-m² quadrats were searched for presence of fauna. These quadrats were cited every five meters for the first 50 m from the road and then one every 100 m thereafter. Mammal tracks, scats, diggings (eg., Echidna *Tachyglossus aculeatus*), and hair, skull, and bone fragments were sought, and identified with the help of Triggs (2004). Within each 100-m x 50-m cell of the three transects, the bases of three trees were searched for the presence of species. Trees were chosen if they contained hollows or were simply the three largest trees in each cell. Whilst conducting field work, incidental observations involving the occurrence of diurnal fauna were recorded, along with their position in relation to the Epsom-Barnadown Road.

Table 1 details species richness and distribution of mammals in relation to distance from the Epsom-Barnadown Road, synthesized for the three transects. Eighteen hours of spotlighting and incidental observations resulted in a total of 12 individual sightings of four mammal species. Three of the four mammals observed were arboreal: the Sugar Glider *Petaurus breviceps*, Common Ringtail Possum *Pseudocheirus peregrinus*, Common Brushtail Possum *Trichosurus vulpecular*, and the fourth was the introduced Red Fox *Vulpes vulpes* (table 1). Search surveys detected six additional species: the Eastern Grey Kangaroo *Macropus giganteus*, Swamp Wallaby *Wallabia bicolor*, Echidna *Tachyglossus aculeatus*, the introduced European Rabbit *Oryctolagus cuniculus*, the introduced Hare *Lepus capensis*, and an unknown bat species.

Table 1. Mammals present in the Bendigo Regional Park at varying distances from the Epsom – Barnadown Road

| | | 1 | 5 | 10 | 15 | 20 | 25 | 30 | 35 | 40 | 45 | 50 | 100 | 200 | 300 | 400 | 500 | 600 | 700 | 800 | 900 | |
|---------------------------------|-------------------------|---|---|----|----|----|----|----|----|----|----|----|-----------|-----------|-----------|-----------|-----------|-----------|-----------|-----------|------------|--|
| | | | | | | | | | | | | | to 200 | to 300 | to 400 | to 500 | to 600 | to 700 | to 800 | to 900 | to 1000 | |
| <i>Macropus giganteus</i> | Eastern Grey Kangaroo | # | | | | | | | | | | | | | | | | | | | | |
| <i>Wallabia bicolor</i> | Swamp Wallaby | | | | | | | | | | | | | | | | | | | | | |
| <i>Tachyglossus aculeatus</i> | Echidna | | | | | | | | | | | | | | | | | | | | | |
| <i>Oryctolagus cuniculus</i> | *Rabbit | | | | | | | | | | | | | | | | | | | | | |
| <i>Pseudocheirus peregrinus</i> | Common Ringtail Possum | | | | | | | | | | | | | | | | | | | | | |
| <i>Trichosurus vulpecula</i> | Common Brushtail Possum | | | | | | | | | | | | | | | | | | | | | |
| <i>Petaurus breviceps</i> | Sugar Glider | | | | | | | | | | | | | | | | | | | | | |
| <i>Lepus capensis</i> | *Hare | | | | | | | | | | | | | | | | | | | | | |
| <i>Vulpes Vulpes</i> | *Fox | | | | | | | | | | | | | | | | | | | | | |
| Unknown species | Bat | | | | | | | | | | | | | | | | | | | | | |
| | Total number of species | 1 | 4 | 2 | 1 | 2 | 1 | 2 | 3 | 4 | 5 | 8 | 6 | 4 | 4 | 4 | 4 | 4 | 4 | 4 | 8 | |

Notes: * indicates introduced species

The data in table 1 suggest a positive relationship between mammal presence and distance from the Epsom-Barnadown Road. Maximum species richness was attained between 400 and 500 m from the Road. Figure 4 presents mammal species richness (with data for the first 100 m cumulated) plotted in relation to noise and light penetration. There was an increase in species richness after traffic light penetration ceased and traffic noise reached ambient levels of 40dB. That the Common Brushtail Possum *Trichosurus vulpecula* and Common Ringtail Possum *Pseudocheirus peregrinus* were found throughout the transects is not surprising, as these species are commonly found

in disturbed environments (Menkhorst 1995). The distribution of arboreal mammals is strongly associated with the distribution of tree hollows (Trail 1991), with distance from the road being a lesser factor. The Sugar Glider *Petaurus breviceps* and the unknown bat species may be regarded as interior species that avoid the road traffic zone.

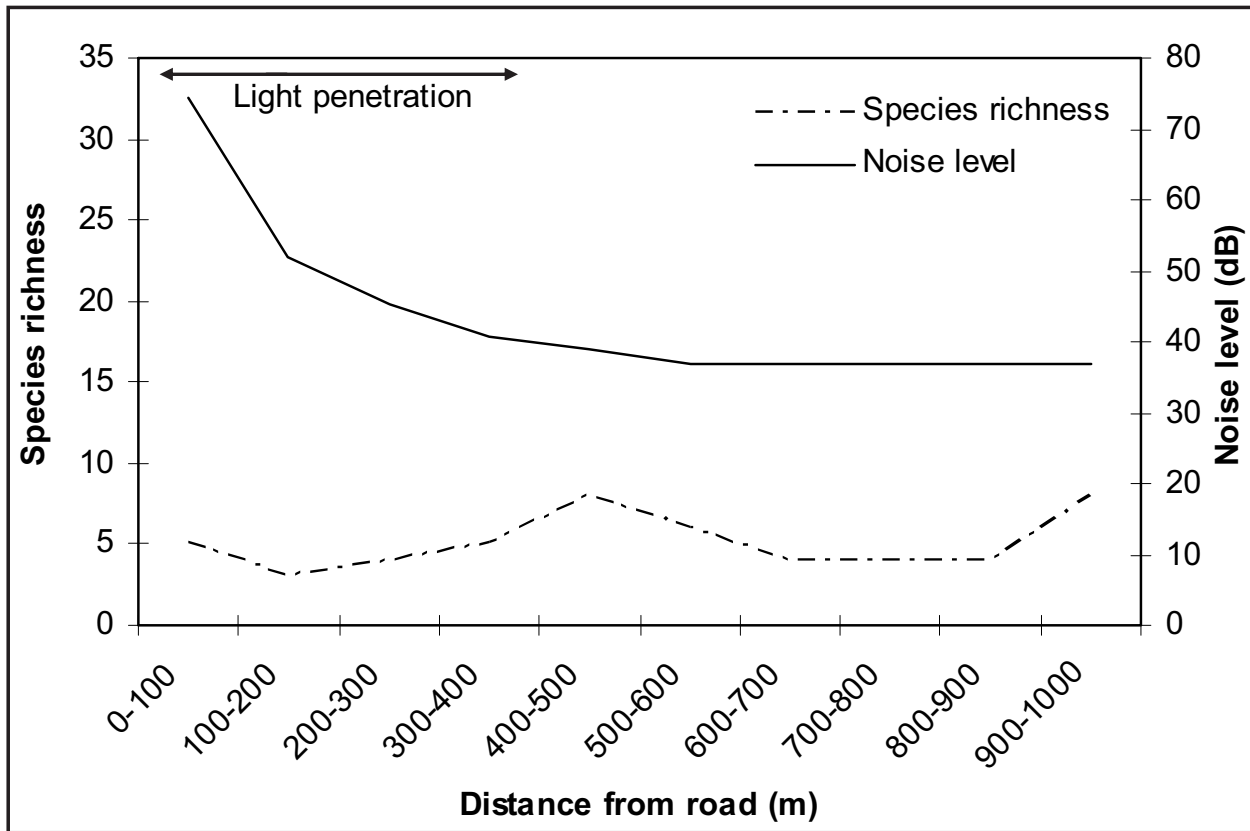


Figure 4. Mammal species richness relative to noise level and light penetration synthesized for three transects in the Bendigo Regional Park

It is noted that two species known to inhabit the research area, the Yellow-footed Antechinus *Antechinus flavipes* and the highly mobile Brush-tailed Phascogale *Phascogale tapoatafa* (Robinson & Rowley 1996) were not recorded in this study. It is possible that such cryptic mammal species may also demonstrate a strong aversion to the road-effect zone, as these species have been found to show a strong preference for large intact forest blocks (Deacon and MacNally 1998).

Bird Surveys

Birds were surveyed along three 1,000-m transects by walking at a pace of 100 m every six minutes and recording species type, relative abundance, and the forest zone used. Only birds seen or heard ahead of the observer and 25 m on either side of the transect line were recorded. Each transect was surveyed six times, equalling a total of 18 person hours of observation. The field guide by Simpson and Day (2000) aided bird identification. Surveys were only conducted during fine weather, between 0800 and 1230, as birds call most frequently in the mornings, and this is when feeding is most obvious (Keast 1984). To avoid bias, the order in which transects were surveyed was randomized. The direction in which the transects were walked was also alternated to avoid the potential problem of continual observer movement pushing birds away from the edge (Luck et al. 1999) or attracting or repulsing different species (Pyke and Recher 1984).

A list of species type and their diversity and abundance synthesized for the three transects is presented in table 2. Species present were typical of those normally inhabiting Box-Ironbark forests. Eighteen hours of surveying resulted in a total of 975 individual sightings of 47 species recorded within the study area. Eleven species were recorded only once.

Table 2. Bird species diversity and abundance in the Bendigo Regional Park at varying distances from the Epsom – Barnadown Road

| | | 0-50 | 50-100 | 100-150 | 150-200 | 200-250 | 250-300 | 300-350 | 350-400 | 400-450 | 450-500 | 500-550 | 550-600 | 600-650 | 650-700 | 700-750 | 750-800 | 800-850 | 850-900 | 900-950 | 950-1000 | |
|-----------------------------------|----------------------------|------|--------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|---------|----------|----|
| <i>Ocyphaps lophotes</i> | Crested Pigeon | † | 1 | | | | | | | | | | | | | | | | | | | |
| <i>Manorina melanocephala</i> | Noisy Miner | | 2 | | | | | | | | | | | | | | | | | | | |
| <i>Corvus coronoides</i> | Australian Raven | | 3 | 2 | | | | | | 1 | | | 1 | 1 | | | | 1 | | | | |
| <i>Anthochaera carunculata</i> | Red Wattle Bird | | 12 | 4 | 4 | 2 | 1 | 2 | 7 | 2 | 4 | 5 | 8 | 4 | | | | 1 | | 3 | | 2 |
| <i>Acanthiza nana</i> | Yellow Thornbill | | 16 | 8 | 14 | 10 | 9 | 1 | 4 | 4 | | | | | | | 3 | | | | 3 | |
| <i>Gymnorhina tibicen</i> | Australian Magpie | † | 1 | | | | | | | | | | | | | | | | | | | |
| <i>Malurus cyaneus</i> | Superb Fairy-wren | | 2 | 8 | 2 | 5 | 17 | 13 | 4 | | 4 | 1 | 3 | 4 | | | | | | | | |
| <i>Eolophus roseicapillus</i> | Galah | | 3 | 2 | | | | | | 3 | 1 | 5 | 4 | 3 | 1 | 6 | 1 | 2 | 3 | 3 | 1 | |
| <i>Smicromis brevirostris</i> | Weebill | | 7 | | 5 | 2 | 3 | 14 | | | 2 | 10 | | | 7 | | 5 | 2 | 6 | | 3 | 3 |
| <i>Psephotus haematonotus</i> | Red-rumped Parrot | | | 5 | | | | | | | | 6 | | | | | | | | | | |
| <i>Corcorax melanorhamphos</i> | White-winged Chough | | | | 9 | | | | | | 5 | 10 | 18 | | | 10 | | | | | | |
| <i>Lichenostomus leucotis</i> | White-eared Honeyeater | | | | 3 | 1 | 4 | 4 | 4 | | | 1 | | 1 | 4 | 10 | 3 | | | | | |
| <i>Melithreptus brevirostris</i> | Brown-headed Honeyeater | § | | | | 1 | | 8 | 10 | 6 | 2 | | | 1 | 2 | 1 | 10 | 4 | | | | 8 |
| <i>Rhipidura fuliginosa</i> | Grey Fantail | § | | | | 1 | | | | | | | | | | | | | | | | 2 |
| <i>Pardalotus punctatus</i> | Spotted Pardalote | § | | | | 1 | 1 | | | | | | | 2 | | | 1 | | | | | 1 |
| <i>Lichenostomus melanops</i> | Yellow-tufted Honeyeater | § | | | | 3 | 7 | | | | | 2 | 2 | 11 | | 7 | 4 | 6 | 6 | 5 | | 8 |
| <i>Pachycephala pectoralis</i> | Golden Whistler | § | | | | 1 | | | 2 | | | | 1 | | | 1 | | | | | | |
| <i>Cacomantis flabelliformis</i> | Fan-tailed Cuckoo | § | | | | 1 | 1 | | | | | | | | | | | | | | | |
| <i>Colluricincla harmonica</i> | Grey Shrike-thrush | | | | | 2 | | | 2 | | | | | 1 | | 3 | | | 1 | | | |
| <i>Glossopsitta concinna</i> | Musk Lorikeet | | | | | 2 | 12 | | | | | | | | | | | | 8 | | | |
| <i>Zosterops lateralis</i> | Silvereye | § | | | | 4 | | | | | | 1 | | | | | | | | | | |
| <i>Lichenostomus fuscus</i> | Fuscous Honeyeater | | | | | 6 | 12 | 22 | 11 | 8 | 3 | | | | | 1 | 4 | 11 | 13 | 6 | | 4 |
| <i>Lichenostomus penicillatus</i> | White-plumed Honeyeater | | | | | 8 | 4 | 10 | | | 3 | | | 11 | | 8 | | 2 | 4 | | | 15 |
| <i>Melithreptus lunatus</i> | White-naped Honeyeater | § | | | | 6 | 6 | | | | | | | 5 | | 2 | | | | | | 2 |
| <i>Microeca leucophaea</i> | Jacky Winter | § | | | | 2 | | 1 | | | | | | | | | | | 2 | | | |
| <i>Pardalotus striatus</i> | Striated Pardalote | | | | | | | 3 | | | | | | | | | 2 | | 1 | | | 15 |
| <i>Pomatostomus superciliosus</i> | White-browed Babbler | § | | | | | | 10 | 4 | | | | 1 | 3 | 1 | | 2 | | | | | |
| <i>Falcunculus frontatus</i> | Crested Shrike-lit | † | | | | | | | 1 | | | | 10 | 6 | | | 20 | 5 | 2 | | | |
| <i>Podargus strigoides</i> | Tawny Frogmouth | † | | | | | | | 1 | | | | | | | | | | | | | |
| <i>Cormobates leucophaeus</i> | White-throated Treecreeper | § | | | | | | | | | 2 | 3 | | | | | 2 | | | | | 1 |
| <i>Daphoenositta chrysoptera</i> | Varied Sittella | § | | | | | | | | | 4 | | | | | | | | 4 | | | |
| <i>Ninox connivens</i> | Barking Owl | † | | | | | | | | | | 1 | | | | | | | | | | |
| <i>Eopsaltria australis</i> | Eastern Yellow Robin | § | | | | | | | | | | 10 | | | | | | | | | | |
| <i>Strepera versicolor</i> | Grey Currawong | † | | | | | | | | | | | 1 | | | | | | | | | |
| <i>Phaps chalcoptera</i> | Common Bronzewing | † | | | | | | | | | | | | | | | | | | | | |
| <i>Petroica multicolour</i> | Scarlet Robin | † | | | | | | | | | | | | 1 | | | | | | | | |
| <i>Platycercus eximius</i> | Eastern Rosella | | | | | | | | | | | | | 2 | 4 | 1 | | | | | | |
| <i>Acanthiza reguloides</i> | Buff-rumped Thornbill | † | | | | | | | | | | | | | 1 | | | | | | | |
| <i>Oreica gutturalis</i> | Crested Bellbird | § | | | | | | | | | | | | | | 1 | | | | | | 4 |
| <i>Climacteris picumnus</i> | Brown Treecreeper | § | | | | | | | | | | | | | | 2 | 2 | | | | | 1 |
| <i>Coracina novaehollandiae</i> | Black-faced Cuckoo Shrike | § | | | | | | | | | | | | | | 3 | | | | | | |
| <i>Artamus cyanopterus</i> | Dusky Woodswallow | § | | | | | | | | | | | | | | 4 | | 1 | 2 | | | |
| <i>Oriolus sagittatus</i> | Olive-backed Oriole | § | | | | | | | | | | | | | | | | | | | | |
| <i>Pachycephala rufiventris</i> | Rufous Whistler | † | | | | | | | | | | | | | | | 1 | | | | | 1 |
| <i>Melithreptus gularis</i> | Black-chinned Honeyeater | § | | | | | | | | | | | | | | | | | | | | |
| <i>Accipiter fasciatus</i> | Brown Goshawk | † | | | | | | | | | | | | | | | | | | | | 1 |
| <i>Lichenostomus chrysops</i> | Yellow-faced Honeyeater | § | | | | | | | | | | | | | | | | | | | | 2 |
| Total number of individuals | | | 34 | 41 | 42 | 22 | 24 | 65 | 90 | 63 | 47 | 27 | 84 | 47 | 59 | 25 | 54 | 59 | 55 | 44 | 20 | 73 |
| Total number of species | | | 5 | 8 | 6 | 5 | 9 | 15 | 13 | 11 | 10 | 8 | 16 | 10 | 17 | 9 | 16 | 14 | 14 | 10 | 6 | 16 |

Notes: § indicates species classified as interior species; † indicates species sighted only once.

Species abundance was not found to change by either increasing or decreasing with distance from the road. However, for select bird species, the Epsom-Barnadown Road either provided desirable habitat or was a feature to be avoided. Four species were only ever encountered within the first 150 m from the road verge, and only one of those was observed on more than one occasion: the Noisy Miner *Manorina melanocephala* and Red-rumped Parrot *Psephotus haematonotus*. These species are known to tolerate open country habitat (Tzaros 2005). The Noisy Miner has been found to greatly benefit from native forest fragmentation and favors isolated tree patches or fragment edge habitats (Grey et al. 1998).

Species diversity was found to increase away from the road (figure 5). Excluding those species sighted only once (which were too infrequent for meaningful comment), 21 species (58%) were only found at distances of 150 m or more from the Epsom-Barnadown Road. These species have been classified as “interior species” as they demonstrate a distinct avoidance of edge habitat (table 2). Some of these species were observed to avoid vegetation communities next to the road, while inhabiting those same vegetation communities at greater distances away from the road. The average distance avoided by interior species varied according to the species studied and ranged from 150-900 m.

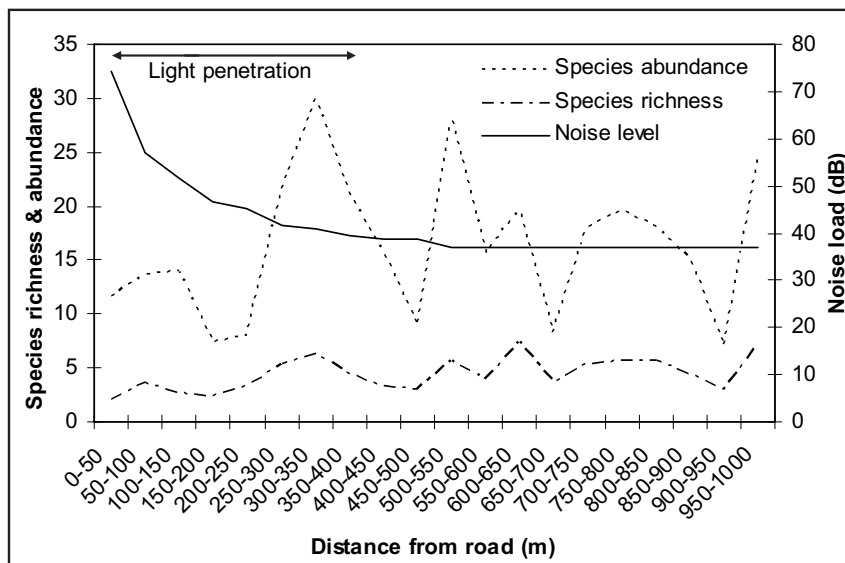


Figure 5. Bird species richness and abundance relative to noise level and light penetration synthesized for three transects in the Bendigo Regional Park

Spatial Patterns of Road Edge Effect

Figure 6 synthesizes the results obtained from this study by mapping the boundaries of the road-effect zone in the Bendigo Regional Park. The area affected by exotic plant invasion associated with the presence of a road is shown to be minimal. The asymmetric nature of traffic noise and light penetration is clearly seen, being dependent primarily on topography and the spatial arrangement of thicket vegetation across the landscape. Specific mammal sightings and zones of habitat are also shown in figure 6. The fact that most mammals were sighted away from the zones of traffic noise and light penetration is evident.

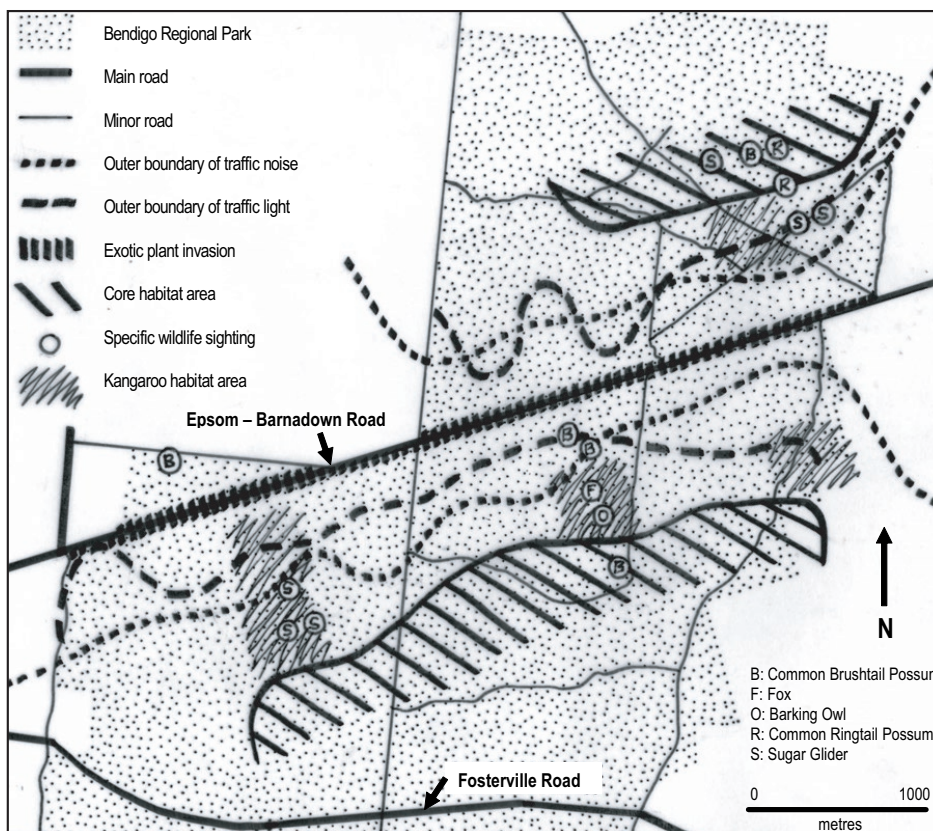


Figure 6. Spatial distribution of parameters contributing to the road effect zone within the Bendigo Regional Park

Also depicted in figure 6 is a zone identified as core habitat area. This zone has been identified as the core area occupied by fauna such as interior bird species. There were 21 species listed in table 2 that demonstrated an aversion to the road-effect zone and were denoted as interior species. The width of the bird aversion zone varied from 150-900 meters. Particularly sensitive species, such as the Crested Bellbird *Oreoica gutturalis*, Dusky Woodswallow *Artamus cyanopterus*, and Brown Treecreeper *Climacteris picumnus*, exhibited a 700-m avoidance zone. Likewise, the avoidance zone for the Olive-Backed Oriole *Oriolus sagittatus* was 750 m, the Black-chinned Honeyeater *Melithreptus gularis* was 850 m, and the Yellow-faced Honeyeater *Lichenostomus chrysops* was 900 m. The maximum distance significant ecological effects extended outward from the Epsom-Barnadown Road coincides with the core habitat area demonstrated in figure 6.

Thus the width of the road-effect zone on Box-Ironbark Forest requiring management for conservation averaged 900 m on either side of the Epsom-Barnadown Road. This amounts to a total width of 1800 m or an area of 1.8 km² per kilometre of highway. The implications of this finding have serious ramifications for road management authorities. Traditionally, road engineers have identified the boundary of the road-effect zone as the sum of the road surface and the adjacent road verge. The findings in this study demonstrate the ecological extent of the road-effect zone to be an order of magnitude greater than traditional reckoning.

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