Road systems are extensive in length and area, and are present throughout most terrestrial landscapes (Forman 1995; Forman & Alexander 1998). Despite their pervasiveness the ecology of roads has been understudied compared to other habitats (Erritzoe 2003; Forman et al. 2003). Road ecology can be viewed locally at the road and its immediate surroundings or through broad ecological effects over the landscape (Forman & Alexander 1998).

In Australia, approximately 90 percent of woodland has been cleared and up to 97 percent has been
cleared in the wheatbelt of south-western Australia (Saunders & Curry 1990; Bennett 1991; Saunders & Ingram 1995). In agricultural areas many road-sides provide a critical refuge for plants and animals, in many cases road-side remnants are the only native vegetation that remains (Arnold & Weeldenburg 1990; Saunders & Curry 1990; Bennett 1991; Saunders & Ingram 1995).

Most surveys of birds that frequent Australian roads have been undertaken in agricultural areas, which have narrow road-side strips of vegetation (e.g. Carrick 1963; Vestjens 1973; Lepschi 1992). Yet there are still large remnants of native forests and woodland, in Australia, which remain comparatively unstudied despite harbouring a wealth of Australia’s flora and fauna in complete ecosystems. The make-up of bird assemblages along roads that traverse these large reserves is poorly reported, although studies of roads passing through such ecosystems can provide baseline data on how these roads are used by birds and have implications for conservation management.

Aspects of forest management with regard to the avifauna have been hotly discussed since the 1970s (for review see Recher 2004). The impacts on Australian birds for approximately 200 years since European settlement have also been reported for south-western Australia (Abbott 1999) and the long-term impact of forestry on birds has been reported (e.g. Williams et al. 2001; Abbott et al. 2003). However, I have found no literature that discusses the immediate affects of clearing beside roads (cf. Fulton & Majer 2006).

Community-wide studies of road mortalities generally list birds as the most frequently killed group of animals (Forman et al. 2003 and references therein). Birds may be drawn to roads by increased resources such as carrion (including road-killed invertebrates), spilt grain, pooled water and green regrowth (Forman et al. 2003). Brought into the proximity of fast moving motor vehicles road casualties are likely to occur, although this may not adversely affect the size of populations (Linsdale 1929; Forman et al. 2003). In Australia, most road studies to date have generally focused on identifying and counting avian road fatalities without any analysis of why they might be killed. However, correlating the abundance of each species and the availability of food with their mortality may better identify those species most adversely affected by motor vehicles.

This study focused on easily detected bird species that foraged on the road and its immediate verges in a continuous forest habitat. The aims of this study were to: describe the bird assemblage that used the highway habitat; detect if clearing forest from directly beside the road affected the abundance and species richness of birds that came to the road; detect if road casualties correlated with abundance at roads; and examine why these species came to the road, for example to feed on carrion, invertebrates or grain.

METHODS

1) Bird censuses

Birds were recorded along a 58 km road transect between Armidale and North Bannister on the Albany Highway in south-western Australia (Fig. 1). Albany Highway is a two lane bitumen highway (one lane in either direction), without fences or barriers between the road and the forest. Verges were approximately 4 m wide and consisted of either gravel or short grass and gravel. The transects were undertaken twice each month from June 2003 to May 2005 (48 transects) from a car travelling at 80 km/hr. Only birds on the road or its immediate verges were counted. Birds were recorded from the beginning of continuous Jarrah *Eucalyptus marginata* forest east of Perth to the first agricultural clearing at North Bannister. Forests along the transect were predominately Jarrah with occasional pine *Pinus radiatus* plantations grading eastwards into mixtures of Jarrah and Wandoo *E. wandoo* at the eastern end of the transect. The area immediately to the west of the western (Perth) end of the transect was semi-rural and suburban. The area after the eastern (wheatbelt) end of the transect was predominantly agricultural.

Transects were surveyed from mid-afternoon to late afternoon but before the sun began to set and travelling in an easterly direction to avoid glare from the afternoon sun in the observers’ eyes. Other vehicles were not closely followed because they blocked the observers’ view and larger vehicles such as trucks and buses caused birds to move away from the roads and into the forest. All transects took approximately 45 minutes to complete. Observations were recorded on a hand-held micro-cassette-recorder to minimise the chance of missing a bird while tallying. From one to three observers were used at different times. All observers monitored both sides of the road. We found that each observer, including the driver, detected all of the target species from both sides of the road simultaneously.

This survey only intended to count medium to
large sized birds, because they are easily detected and
identified from a moving car. These birds ranged in
size from 28 cm to more than 2 m, although the most
commonly detected birds ranged from 36 cm to
52 cm. Birds smaller than this, such as fairy wrens
(Maluridae), warblers (Pardalotidae), honeyeaters
(Meliphagidae), robins (Petroicidae), fantails and fly-
catchers (Dicruridae) were considered too small to be
reliably identified from a moving car and were omit-
ted from the study. Small birds were only recorded
when they were detected as road casualties. Bird
lengths are measured from the tip of its beak to the
end of its tail and were taken from Pizzey & Knight
(1997). All birds simply flying over the road were not
recorded. The common and scientific names of birds
follow the official checklist of Australian birds
(Christidis & Boles 1994) and for mammals follow
Strahan (2002).

2) Forest clearings
The length of each forest clearing was measured
by odometer to the nearest one tenth of a kilometre.
The depth of each forest clearing (perpendicular to
the road) was estimated after a 50 m and 100 m sam-
ple had been measured establishing what each of
these distances would look like from the road. In
each cleared block all vegetation had been cut or
knocked down and after the timber was removed the
remaining vegetation was bulldozed into the centre
and burnt. In most cases no buffer of forest was left
between the clearing and the road. Birds were
recorded as present at either the forested areas or the
clearings, or if only one side of the road was cleared
they were recorded either present on the cleared side
or on the forested side of the road. Surveys continued
for 13 months after clearing began.

Clearing beside the road was undertaken approxi-
mately halfway through this two year study, which
gave us the opportunity to report on the immediate
responses by birds. Forest clearing took place for ap-
proximately two months from 12 May to 21 June
2004 along the first 33 percent of the transect. The
first clearing was situated near the western end of the
transect 7.8 km after the start and the last clearing fin-
ished at 27.1 km. The summed length of clearings
taken from both sides of the road equalled 16.3 km:
9.6 km on the north side of the road and 6.7 on the
south. Thus, 14.05 percent of the transect was cleared
(the transect is 116 km when both sides of the road
are added together). In all 1.3 km
2
were estimated to
have been cleared. The mean depth of clearing per-
pendicular from the road was 80 m, SD 20 m, range
150 to 50 m and mode 70 m.
3) Avian road casualties and carrion feeding

Avian road casualties were recorded separately from living birds. Identifications of the carcasses were made to species and age (for birds) from June 2004 to May 2005 only. If a carcass was difficult to identify from the moving car we stopped and identified it. Mammalian carcasses were recorded when birds were seen feeding on them, but road-killed insects were not considered as carrion. The identity of the species and numbers of individuals feeding from carrion were recorded during all transects.

4) Grain transport and seed-fall

Grain was transported through the transect from three regional storage locations to the Metropolitan Grain Centre, in Perth. A single transport company, Co-operative Bulk Handling Ltd. (CBH), were responsible for approximately 99% of grain transport through the transect (CBH in litt.) and their grain-transportation data is used in this study. Grain was unlikely to have been transported, through the transect, from the paddocks where it was harvested to the regional storage centres, because both the wheat paddocks and regional storage centres lie to the eastern (wheatbelt) end of the transect. Trucks moving through the transect were sealed to prevent the loss of grain, although some grain may occasionally spill from these trucks (CBH in litt.). Seed-fall from Jarrah trees was taken from data published in (Abbott & Loneragan 1986; Whitford et al. 2004).

RESULTS

1) Census results

A total of 2319 observations of living birds from 11 species were recorded (Table 1). The Australian Raven Corvus coronoides (38% of observations) and Grey Currawong Strepera versicolor (25% of observations) were detected more frequently than all other species combined (37% of observations). The number of Grey Currawongs dropped markedly each year, during their breeding season, from October to December (Fig. 2a). Australian Ravens and Australian Magpies Gymnorhina tibicen (Figs. 2b and c) showed no marked seasonal changes. The Australian Magpie and Little Crow C. bennetti were observed less frequently, because they are not common forest birds in this study area. The Little Crow’s range is typically further inland in more arid areas (Barrett et al. 2003). The observations of Australian Magpies were generally made at either end of the transect in association with suburban areas and pastures; this species is not considered endemic to Jarrah forest (Abbott 1999), although a small number occurred in Jarrah forest. Other birds detected in larger quantities (>100 observations each) were the granivorous species Common Bronzewing Phaps chalcoptera (Fig. 2d), Australian Ringneck Barnardius zonarius (Fig. 2e) and Short-billed Black-Cockatoo Calyptorhynchus latirostris (Fig. 2f). The Laughing Kookaburra Dacelo novaeguineae was not detected alive during any transect.

2) Forest Clearings

Only five Australian Ravens and two Pacific Black Ducks Anas superciliosa were detected on road-sides adjoining clearings (Fig. 3). The comparative abundance of birds was much greater at forested road-sides with 1052 birds along 100% of the transect during the first 11 months and 1260 birds at the 84% of forested road-sides during the 13 months after clearing began. Equivalent numbers of ravens were detected along the transect both before (422 birds in 11 months) and after (445 birds in 13 months) clearing. The two Pacific Black Ducks detected were taking advantage of water that had pooled due to gouging of the road verge by heavy machinery associated with the clearing, presumably this provided little food for them and they were not encountered during any other count. All other species were detected on road-sides that adjoined forest and none were detected on roads-side which adjoined clearings.

3) Avian road casualties

There were 50 birds from eight species detected as road casualties, during the second 12 months of the study period. For the same period the abundance of bird species showed a strong positive correlation with the road casualties (r=0.91, Pearson’s product moment correlation co-efficient, one-tailed test, N=12, df=10, P<0.0001) (Fig. 4). The two most commonly detected species made up the bulk of the road casualties: Australian Raven (44%) and Grey Currawong (28%)—other species collectively accounted for 28%. Most casualties occurred in spring and early summer (88%) September through January and were predominately juveniles—63% of all casualties (Table 2). There were no bird carcasses detected at the highway adjacent to clearings.

4) Carrion feeding

Australian Ravens (57) and Wedge-tailed Eagles
Table 1. Mean number of each species detected in two transects per month, over two years; standard errors are given in parentheses. Percentages are rounded to one decimal place.

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Fig. 2. Abundance of (a) Grey Currawong, (b) Australian Raven, (c) Australian Magpie, (d) Common Bronzewing, (e) Australian Ringneck, (f) Short-billed Black-Cockatoo.

Fig. 3. The abundances of birds detected adjacent to forests and clearings. No bird carcasses were detected alongside clearings. Note clearings were present along 14% of the length of the transect for 13 of the 24 months surveyed while forest present at the same time accounted 86% of the transect; number of birds adjacent to forests before clearing (100% of the transect) were surveyed for 11 months—this is given as a control. The units for each category are given as the number of birds per kilometre times month to allow direct comparison.
Aquila audax (8) were the only birds observed feeding from carrion during the study. Carcasses from which these birds fed included: Western Grey Kangaroo *Macropus fuliginosus* (35), Common Brushtail Possum *Trichosurus vulpecula* (5), Emu *Dromaius novaehollandiae* (1) and Common Bronzewing (1).

5) Taking road-killed invertebrates from the road

We observed more ravens and Grey Currawongs on the paved section of the road than granivorous species, although we did not keep tallies. During 2006 there was a locust *Chortoicetes terminifera* plague throughout the region and at this time we commonly observed Grey Currawongs and Australian Ravens catching these insects. We also noted that they had quickly learnt that dead locust collect on the front of vehicles, which they picked off when the vehicles were parked. From a moving car it is difficult to discern what a bird is picking from the road, but logic suggests that road-killed invertebrates would be favoured because they are nutritious and more easily procured compared to live invertebrates.

6) Seasonal abundances in granivorous birds

All correlation tests reported below are Pearson’s product moment correlation co-efficient, non-directional tests following (Lowry 2007). The abundances of Common Bronzewing and Australian Ringneck were both poorly correlated to the amount of grain freighted through the transect ($r=0.23$, $N=24$, $df=22$, $P=0.27$ and $r=0.37$, $N=24$, $df=22$, $P=0.07$) respectively (Fig. 5). However, they were strongly and positively correlated to the seed-fall from Jarrah trees ($r=0.93$, $N=12$, $df=10$, $P<0.0001$ and $r=0.84$, $N=12$, $df=10$, $P<0.001$) respectively (van Noorts unpublished seed-fall data from Abbott & Loneragan 1986). Then again the Common Bronzewing was
strongly and positively correlated with Jarrah seed-fall, \((r=0.89, N=12, df=10, P<0.0002)\) while the Australian Ringneck showed a moderate positive correlation \((r=0.43, N=12, df=10, P=0.16)\) (seed-fall data from Whitford et al. 2004) (Table 3). The Common Bronzewing exhibited markedly higher abundances through the warmer months (October–February) compared to the cooler months (March–September). The Australian Ringneck exhibited only marginally lower abundances in winter (July–August) (Figs. 2d and c). Jarrah seed-fall followed a cyclic trend through the seasons with the greatest falls in the summer (December–March) and showed a constant minima in June.

**DISCUSSION**

1) **Forest clearings**

The type of patchwork clearing (gap release) employed here is not thought to significantly affect the long-term avifaunal species richness in Jarrah forests, because few species are locally endemic and most will return as the disturbed area recovers (Abbott et al. 2003). However, clearing has immediate impacts on birds that use the forest with some species declining locally and others increasing (Fulton & Majer 2006). We highlighted that birds using the road-habitat disappeared where clearing took place adjacent to the road—with less than one percent of birds detected adjacent to the clearings. Ravens that frequented the road-habitat apparently shifted to other areas where forest still adjoined the road presumably in response to the availability of invertebrate prey and carrion. The abundance and species richness of road-killed invertebrates where all the vegetation cover was removed would be markedly less compared to those parts of the highway that abutted forests (Fulton & Majer 2006). In addition, granivorous birds were not detected adjacent to clearings highlighting that the removal of vegetation decreased the seed available to them.

Australian Ravens were the first species detected returning to the road-habitat adjacent to cleared blocks, which suggests that they may be early colonisers of cleared areas. Two recent studies found that Australian Ravens were not affected either positively or negatively by clear-felling in either the short or long term (Williams et al. 2001; Kavanagh & Stanton 2003). Australian Ravens occur throughout Jarrah forest although their distribution before European settlement was thought to be patchy and they may have used roads to extend their pre-European range (Rowley & Vestjens 1973; Abbott 1999).

Clearing beside roads hugely reduced the abundance and species richness of birds in the road-habitat. In continuous Jarrah forest this seems unlikely to affect long-term abundances of birds such as ravens, although the immediate local effects to other birds can include death and displacement: during clearing, through habitat loss and the subsequent loss of food (Fulton & Majer 2006).

2) **Road casualties and the proximity of food**

Previous Australian studies have reported that Australian Magpies are frequently detected as road casualties (Carrick 1963; Vestjens 1973; Disney & Fullagar 1978; Thomas 1988; Bennett 1991; Lepschi 1992; Taylor & Goldingay 2004). These studies were primarily undertaken in agricultural areas where magpies are numerous. However, they lacked clear quantitative comparisons between the numbers of casualties and the abundances of species. In contrast, we detected greater numbers of Australian Ravens and Grey Currawongs as road casualties and we found that abundance positively correlated with road death.

Invertebrates are killed in vast numbers on roads as windscreens counts could attest (Forman & Alexander 1998). The presence of abundant and easily procured road-killed invertebrates could explain why Australian Ravens and Grey Currawongs were frequently observed on the road and consequently as frequent road casualties. We found fewer carcasses of granivorous species as road casualties, perhaps because they forage on road verges and within the forest, for native seed, rather than on the road. Thus, abundance and

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Table 3. Jarrah seed fall data from: van Noort’s unpublished data (Abbott & Loneragan 1986) \([\text{seeds} \ 0.81 \ \text{m}^{-2}]\), the dash indicates no data; and from (Whitford et al. 2004) \([\text{millions} \ \text{ha}^{-1}]\). All numbers have been rounded to one decimal place.
road casualties most likely co-correlate with food availability on roads.

In other studies undertaken in agricultural areas, granivorous species have been reported as frequent road casualties (e.g. Vestjens 1973; Anon 1980; Brown et al. 1986; Bennett 1991). We found comparatively fewer carcasses of granivorous species along our study transect through native forest. However, numerous road casualties of one common granivorous species, the Australian Ringneck, were opportunistically observed on secondary roads in adjacent agricultural areas (personal observation). Often groups of this species were killed at the same place. These birds appeared to have gathered at grain spillages where grain had been transported, in open and inadequately covered trucks, from the paddocks where it is harvested to regional storage sites. In contrast, trucks carrying grain through our study transect were sealed to avoid spillage. This suggests that efforts to mitigate future road casualties, of granivorous birds, might be directed at how grain is carted from the paddock to regional storage sites and what efforts are made to secure these loads.

3) Road casualties: age and seasonal trends

In Australia, surveys that recorded avian road casualties found a disproportionately high number of juvenile birds in their counts (e.g. Vestjens 1973 (37%); Brown et al. 1986 (57%); Thomas 1988 (unquantified); Bennett 1991 (28%); Lepschi 1992 (unquantified)). In this study, we detected that approximately two thirds (63%) of all casualties were juveniles. The majority of casualties were the young of Australian Ravens and Grey Currawongs. All the young birds were killed in spring and summer, and accounted for most of the elevated number of casualties at this time. Vestjens (1973) and Brown et al. (1980) attributed the higher losses of young birds to their inexperience with moving vehicles. It is not explicitly known if the same mortality rate among young birds holds for birds nesting away from the road. Though high mortality of younger birds, at roads, may shift the age structure of populations to older age classes. Future studies could investigate the rate and consequences of change in age structure, particularly within isolated populations such as those in fragmented landscapes. In our study factors including: food availability and the inexperience of young birds appeared to be the most important variables in relation to road death.

4) Carrion feeding

In Australia corvids and raptors are predominately found at carcasses of road casualties (Read & Wilson 2004). In this study, Wedge-tailed Eagles and Australian Ravens fed from carcasses, both species are well documented carrion feeders (e.g. Marchant & Higgins 1993; Higgins et al. 2006). Grey Currawongs and Australian Magpies were not detected in any transect taking carrion. Higgins et al. (2006) refer to a small number of occasions where Australian Magpies fed from carrion, although the Grey Currawong was not reported taking carrion. The Grey Currawong is omnivorous and will depredate birds, nestlings and small mammals (Van Buel & Pruett-Jones 2000; Higgins et al. 2006; Fulton 2006a). Unlike Australian Ravens they apparently have no interest in feeding from carrion even if they are aware that the carrion is fresh (Fulton 2006b).

5) Grey Currawong range shift during breeding

The numbers of Grey Currawong declined sharply through spring and early summer indicating they undertook a shift away from the road-habitat, during their breeding season (Fig. 2). In a concurrent study, the Grey Currawong moved away from a small woodland village, during their breeding season, even though tourists regularly fed them there (Fulton 2006a). It is not known why they might undertake these territorial shifts. Its congener the Pied Currawong Strepera graculina is an important nest predator in eastern Australia where it undertakes dietary and territorial shifts switching from mostly invertebrate prey to the nests and eggs of other birds, during its breeding season (Bass 1989; Prawiradilaga 1994; Bass 1995; Wood 2000; Fulton & Ford 2001). Closer examination of the Grey Currawong may detect if it undergoes a similar shift for similar reasons.

6) Granivorous birds respond to native Jarrah seed-fall

Grain was transported in large quantities through the transect most months of the year (116 510 tonnes over two years). Variations in the quantity of grain transported did not correlate with the observed abundances in granivorous species. Grain was transported under protocols that required trucks to be sealed to avoid either contamination or spillage of the grain (CBH in litt.). The more likely explanation for the patterns of abundances observed in the granivorous species is the availability of dehisced native seed. Seed-fall from the dominant native tree (Jarrah) was
positively correlated to the abundances of Common Bronzewings and Australian Ringnecks, although more strongly with the former. The weaker yet still positive response shown by the Australian Ringneck may reflect its broader diet, in which it takes a variety of seeds—from introduced weeds to native Eucalyptus spp (Long 1984). Common Bronzewings have been identified taking large quantities Jarrah seeds from the soil surface (Stoneman 1992; Stoneman & Dell 1994).

Stoneman (1992) found that Jarrah seed was consumed at a faster rate when understorey vegetation and litter are removed, because the seed is more visible on the soil-surface. In our study, the lack of vegetative cover on road verges that are maintained by mowing and grading combined with a Jarrah canopy that overhung the verge undoubtedly interacted to bring granivorous birds into the road-habitat. Our results highlight that in the absence of spilt grain native granivores respond to seed-fall from native vegetation. These birds may be more numerous in the road-habitat, because seeds are easier to find and access.

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REFERENCES


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