Title

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Modeling the Effect of Roads and Other Disturbances on Wildlife Populations in the Peri-Urban Environment to Facilitate Long-Term Viability

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Abstract: Roads and traffic exhibit a multitude of impacts on wildlife populations. Most road ecology research seeks to assess the quantity and diversity of fatalities from collisions with vehicles, while studies documenting the impact of roads on the structure and sustainability of wildlife populations adjacent to roads have been lacking.

Populations of wildlife existing within the confines of fragmented reserves are particularly susceptible to fatalities on roads, especially those situated within peri-urban and semi-rural matrices.

We chose to examine the effects of disturbances, including fatalities on roads, using four case studies from Australia. These studies included a range of fauna, including the long-nosed bandicoot, the koala, and two studies of the swamp wallaby. To explore the impact of the various threats to wildlife living in peri-urban reserves, each case study utilized a population modeling approach. A combination of PVA modeling and sensitivity analysis was used to assess the impact of disturbances on the populations and identify appropriate management options to target disturbances. We discuss the utility of this approach in enabling conservation managers to assess the long-term viability of wildlife in these environments and in establishing management targets for improving viability in populations predicted to decline.

In all four cases road fatalities were a major disturbance, but the different landscape characteristics of each reserve and other threat levels altered the relative impact of roads. The findings suggest that the combination of a range of management options, such as road fatality prevention, control of predation, and improvements in immigration and fertility, are often necessary although the exact combination will be location specific.

Road management in the peri-urban environment can play a substantial role in ensuring the persistence of isolated populations in protected reserves that are surrounded by, and traversed by, roads. Given the broad geographic scale of roads, their effect on wildlife populations may be best understood from a landscape perspective, taking into account other disturbances that may be influencing population viability. We recommend the integration of PVA, sensitivity analysis, and GIS-based dispersion models as a suitable means for addressing both the temporal and spatial impacts of roads in order to successfully manage wildlife populations.

Introduction

Urban and peri-urban ecosystems include a multiplicity of anthropogenic disturbances, such as disruption by pets and habitat fragmentation and loss that impinge on the persistence of urban wildlife populations. Many of these disturbances are managed or planned for in management plans for peri-urban reserves (NSW NPWS 2000). Yet the impacts of roads on wildlife in these reserves are often given only cursory management consideration if any. This is a cause for concern as many studies indicate that roads can be a debilitating source of disturbance (Jones 2000; Lopez et al. 2003; Ng *et al*. 2004), particularly when road-impacts combine with other human-induced impacts to be the final blow to native wildlife living in semi-rural matrices of remnant bush land, agricultural lands, and urbanized areas.

Roads and the vehicles that traverse them have a multitude of effects on both the surrounding environment and the wildlife that persist there. A growing awareness of this problem has prompted a wide range of research that seeks to document the effects and develop programs to mitigate negative impacts (Forman et al. 2003; Sherwood et al. 2002). There have been numerous studies describing the pattern of road-based fatalities in different parts of the world, and yet relatively few studies have examined the impact of these fatalities on the conservation of roadside populations (Hels and Buchwald 2001; Lopez 2004). Frameworks for addressing the viability of roadside populations have to date received little attention, and exploration of this concept will provide conservation and road managers with the necessary tools for designing conservation strategies that best facilitate sustainable wildlife populations. Mitigation of road impacts will not always be the most beneficial conservation strategy, as it will depend on the impacts of other disturbances on the populations in question.

As a first step in this process, we use examples taken from Australia to indicate how currently available population models can be used to provide this framework. We examine the impact of roads relative to other disturbances, such as residential development, predation and fire, and discuss the potential benefits of managing roads in four different peri-urban reserves and how target-based conservation strategies can be developed. Four cases are explored, including two swamp wallaby populations on the outskirts of Sydney (Ben-Ami 2005; Ramp and Ben-Ami in press), a bandicoot population confined within Sydney (Banks 2004), and a koala population in northern New South Wales (Lunney et al. 2002). In all four cases road fatalities were a major disturbance, but the different landscape characteristics of each reserve and other threat levels altered the relative impact of roads. In all four cases population viability assessment (PVA) was used to model various management strategies aimed at improving the viability of the populations. These models were used to ascribe target-based objectives for conservation managers.

Case Summaries

Koalas at Iluka (NSW, Australia) – Lunney *et al*. (2002)

The Iluka Peninsula is situated at the mouth of the Clarence River in northern New South Wales. The peninsula contains two core natural areas: the World Heritage Iluka Nature Reserve, which is 136 ha, and the adjacent Bundjalung

National Park. The township of Iluka which lies directly adjacent to the reserve was settled in the 1870s. Early clearing, sand mining, urban subdivision, and population growth have reduced available koala habitat. The only road out of the township runs along one edge of the reserve and effectively bisects the peninsula along its length. The human population of Iluka is approximately 2,000, although there are an estimated 20,000 visitors per annum to Bundjalung National Park.

A two-year study of the koala population identified 17 individuals (D. Lunney, unpublished data), while it was estimated that the reserve had enough room for a population size of 50, much higher than was present. The major threats to the Iluka koala population were identified as habitat loss due to urban development, wildfire, fatalities on the road, predation by dogs, and low fertility due to disease (Ingersoll 1998; Lunney et al. 1996b; Lunney et al. 2000). Habitat loss and fatalities on roads were considered the most significant and immediate factors in the decline of the koala population, although low fertility was of concern. Movement of animals was known to connect the Iluka koala population to a larger population in Bundjalung National Park (Lunney et al. 1996a), forming part of a regional metapopulation (Haila et al. 1996). Two extensive bushfires in Bundjalung National Park in 1989 and 1994 were considered to have affected the mortality and fertility of the Bundjalung National Park koala population (NSW National Parks and Wildlife Service 1995). These fires also would have impacted the Iluka population through the drop in immigration from the national park.

Simulations conducted using PVA indicated that the population of koalas was heading for extinction. Investigation of the potential benefit of different management strategies aimed at preventing this decline indicated that a substantial reduction in fatalities on roads, either as a single mitigation strategy or even when considered with an improvement in fertility through disease control, was not sufficient to prevent the population from declining toward extinction (table 1). In contrast, the impact of even a low level of regular immigration was shown to dramatically improve the viability of the population in the long term, as the modeled population was particularly sensitive to immigration of females. A considerable improvement in fertility combined with regular immigration was predicted to provide the most effective population improvement, achieving both high probability of survival and an increased population size for this modeled population.

Table 1. Management scenarios explored for koalas within Iluka Nature Reserve. See Lunney et al. (2002) for more details.

Scenario	Initial Population	Fertility (%)	Probability of Survival	
			20 Years	50 Years
Basic model	20	20	0.25	0.01
Decrease fatalities 40%	20	20	0.58	0.06
Increase fertility 100%	20	40	0.69	0.12
Immigration 1M/1F per year	20	20	1	1
Immigration 2F per year	20	20	0.73	0.52
Fertility +20%, Fatalities -20%, Add 20 animals	40	24	0.71	0.05
As above, Immigration 1M/1F per 2 years	40	24	0.99	0.99
Fertility +35%, Immigration 1M/1F per 4 years	20	27	0.99	0.99

This outcome suggests that while fatalities of koalas on the road and predation by domestic dogs are of major concern and should remain as targets for mitigation, the viability of the population in the long term will be dependent upon improving immigration and fertility.

Bandicoots at North Head (NSW, Australia) – Banks (2004)

North Head is a 360-ha isolated pocket of remnant bushland at the opening to Sydney Harbor. A population of the threatened long-nosed bandicoot (*Perameles nasuta*) present on the headland is a small isolate of a once Sydney-wide population that has eroded, and now shows all the hallmarks of a fragmented population in danger from predation, road-based fatalities, and disease. Research into the ecology of the population over five years suggested that it was small and potentially declining (Chambers and Dickman 2002). The headland includes just over 40 percent of protected reserve and a mixture of residential, council, and private land holdings, none of which is free from potential development.

Major land use changes are already under way, and the primary reason for the modeling undertaken was the potential for a proposed development project on the headland. The PVA simulation considered a population size of 100 animals with a mean total carrying capacity of 120 individuals, allowing some scope for disease and natural mortality to hold the population below carrying capacity. It was assumed that the population had an even sex ratio (Scott et al. 1999), a stable age distribution, and also that all males were able to breed in a polygynous breeding system (Banks 2004). Bandicoot populations are typically variable, having evolved to exploit highly unpredictable conditions. Juvenile mortality in bandicoots is typically high, regardless of annual conditions, while adult mortality is relatively low, with 10 percent mortality every 10 months. Causes of mortality include predation by cats, dogs, native predators (birds of prey), and starvation (lack of resources), although the most common source of death is from collisions with vehicles. Predation by red foxes (*Vulpes vulpes*) is sporadic but devastating, with two recordings of their presence on the headland in the past seven years, killing four radio-collared animals in one instance and 15 adult animals in another year.

The simulation indicated that under current conditions, the population had a good chance of survival (table 2). The prevention of predation was predicted to have a positive effect on the population, indicating the need for a rapid response to fox arrival on the headland.

Table 2. Management scenarios explored for bandicoots at North Head. See Banks (2004) for more details.

Scenario	Carrying Capacity	Adult Mortality (%)	Probability of Survival	
			20 Years	50 Years
Basic model	120	10	0.90	?
Remove predation	120	9	0.97	0.94
Increase fatalities	120	16	0.68	0.20
Increase habitat and fatalities	200	16	0.85	0.35
Decrease habitat and increase fatalities	75	16	0.69	0.28

If the proposed development went ahead it was anticipated that fatalities on roads might increase, and this increase was predicted to have a dramatic impact on the probability of the population surviving. The likelihood of extinction after 50 years was 0.8 under this scenario. As a potential means of offsetting this increase in fatalities, the possibility of increasing the amount of habitat was examined (i.e., increasing the carrying capacity from 120 to 200 individuals). The modeling indicated that even with this adjustment the population would still be at risk of extinction. On this basis the proposed development was suspended.

Swamp wallabies at Muogamarra Nature Reserve (NSW, Australia) – Ben-Ami (2005)
Muogamarra Nature Reserve is a 2,274-ha peri-urban reserve located 50 km north of Sydney. A population of swamp wallabies (*Wallabia bicolor*) exists within the reserve but is isolated as the reserve is bounded by Berowra Creek, the Hawkesbury River, the six-lane F3 Freeway, and the townships of Berowra and Cowan. Although swamp wallabies have an extensive range, running from Cape York to southeastern Australia, an estimate of their numbers is purely guess-work. In addition, the genus *Wallabia* is distinct from all other wallabies and represents a monophyletic clade. The swamp wallaby population in Muogamarra Nature Reserve ranges from 300 to 800 individuals. The public are prohibited from entering the reserve, and it is, therefore, reasonably pristine.

Threats to the swamp wallabies within the reserve include wildfire, road-kill, and predation. Detailed fire records for the past 25 years show that two large-scale fires occurred within the last 10 years, although there were none in the previous 15 years (NSW NPWS 2000). Radio-tracking of mature individuals during fire events in the reserve indicated that all wallabies survived load-reduction burns by management and that where the fuel load was decreased in this way all wallabies survived the subsequent wildfire (N. Garvey, University of New South Wales, unpublished data). As there are no roads within the park, only along its border, road-based fatalities are not high, although estimates indicate that roughly five percent of the population is killed on the F3 Freeway and Pacific Highway each year. Predation by domestic dogs, entering the park from townships, appears to be a larger problem, with 10 percent of juveniles and 5 percent of adults taken annually (Ben-Ami 2005). The swamp wallaby is the preferred dietary wildlife item of free-roaming domestic dogs and a component of the red fox diet in the reserve.

As the population was currently predicted to be in decline, a range of management strategies was explored to investigate how the population could be prevented from this decline (Ben-Ami 2005). If predation was to be removed from the system, the annual mortality of young (< one year old) and adult females would decrease by about half from the current best estimates of 25 and 20 percent, respectively (table 3). Under this scenario, the population is projected to experience a positive growth trend of 14 percent per year. If only one major fire were to occur every 50 years, rather than two, no other management actions would be necessary. Under this scenario, over the next 50 and 100 years, the population would only be limited by the carrying capacity of the reserve, and the risk of extinction would be minimal. This possibility is unlikely to occur given that in the last 10 years two major wildfires occurred in the area. As such, prescribed-burn management action is critical. This action increases the chance of swamp wallabies surviving wildfires, and even a slight increase in swamp wallaby survival of large-scale wildfires, from 85 to 90 percent, can ensure the population's survival. The elimination of road-kill along the Pacific Highway and the F3 Freeway adjacent to Muogamarra would also decrease annual mortality and, therefore, greatly increase the probability of survival. However, even if road-kill was completely eliminated from the system, the risk of population extinction would not be completely removed. From this it is apparent that while the prevention of road-fatalities in this system is important, on its own it would not stabilize the population.

Table 3. Management scenarios explored for swamp wallabies within Muogamarra Nature Reserve. See Ben-Ami (2005) for more details.

Scenario	Female Mortality		Probability of Survival	
	Juvenile	Adult	50 Years	100 Years
Basic model	25	20	0.88	0.29
Prevention of second wildlife in 50 years	25	20	1	1
Predator control	15	15	1	1
Eliminate road-kill	20	15	0.99	0.87

Swamp wallabies at the Royal National Park (NSW, Australia) – Ramp and Ben-Ami (In Press)
A population of swamp wallabies also exists to the south of Sydney in the Royal National Park, the second oldest national park in the world behind Yellowstone. The park covers 16,000 ha and has a wide diversity of vegetation communities, including heathland, woodland, eucalypt forest, rainforest, and wetland. The park contains 90 km of single-lane paved roads with various speed zones of 50, 60, and 80 kmh^{-1}, although recommended speeds are often 25 kmh-1 on bends. Traffic volume comprises mostly local residents of the two townships within the parks boundary, visitors and tourists, and NSW National Parks and Wildlife Service staff. Again, as is common in peri-urban reserves, the park is effectively isolated. On its western and southern limits the park is bounded by a major highway, partially fenced train tracks, and contiguous urban communities. The Pacific Ocean and a series of bays and inlets mark the eastern and northern boundaries of the park. Population assessments using fecal pellet counts and known defecation rates estimated the population in the Royal National Park to be 402 in 1999, 328 in 2000, and 381 in 2001 (Moriarty 2004). As pellet-based population surveys tend to be inaccurate as pellet degradation can lead to an underestimation of population size (Johnson and Jarman 1987), we set the initial population size at an optimistic 1,000 individuals.

Threats to the swamp wallabies within the reserve include wildfire, road-kill, and predation. Fires occur regularly in the park, but wallaby survivorship is thought to be high as these fires are of low intensity. There are few if any dogs within the park, although there are red foxes and these may predate on juvenile swamp wallabies (Banks 2004; Higginbottom 2000). There is currently no published information on how predation affects breeding success but it is highly likely that it does so. Road-based fatalities are thought to be the primary cause of mortality within the park, killing up to 15 percent of the population annually (Morrissey 2003).

Given the estimated levels of the threats identified, the population was predicted to be in a slow decline. A range of management strategies was explored to investigate how the population could be prevented from this decline (Ramp and Ben-Ami In Press). The high survival rate associated with wildfires and the negligible impact of increased carrying capacity on the model suggest that wildfire would not, on its own, be an effective management strategy (table 4).

Table 4. Management scenarios explored for swamp wallabies within Muogamarra Nature Reserve. See Ramp and Ben-Ami (In Press) for more details.

Scenario	Female Mortality			Reproduction	Population after 100 years
	Pouch Young	Juvenile	Adult		
Basic model	25	30	20	0.70	100 ± 129
Decrease road-kill by 20%	23	27	18	0.70	876 ± 143
Decrease road-kill by 40%	21	24	16	0.70	973 ± 49
Decrease road-kill by 60%	19	21	14	0.70	989 ± 24
Decrease foxes by 20%	24	29	20	0.71	385 ± 209
Decrease foxes by 60%	22	27	20	0.73	831 ± 187

Management of the red fox population was shown to be beneficial; however, the growth rate of the swamp wallaby population changed from negative to positive only after 60 to 80 percent of fox-related fatalities was prevented. On the other hand, reducing fatalities of female swamp wallabies on roads by only 20 percent had a dramatic impact on the viability of the population, and any reduction greater than this resulted in the population reaching carrying capacity and becoming stable. Road management, as a means of reducing fatalities and increasing reproduction, is clearly the most beneficial approach to reversing the current trend of population decline. In addition, managers have a tangible goal of fatality reduction on roads to achieve, although on-going monitoring should be encouraged to investigate the success of the program. The only remaining factor park managers need to consider is just how they will achieve this reduction.

Conclusion

Vehicles on roads caused fatalities of wildlife in all four reserves and presented a direct threat to the persistence of the populations investigated. In the Royal National Park where the population of swamp wallabies is in decline, roads were the primary threat, yet in the other systems roads were not the major contributor to decline. However, in the case of North Head, if the proposed development was to proceed, the likely increase in road-kill was predicted to be the primary cause of decline. In the Muogamarra Nature Reserve, predation by free-roaming domestic dogs and wildfires were the primary disturbances, yet these disturbances are difficult and expensive to manage. Easier to manage disturbances, such as road mortality in conjunction with the restriction of free-roaming domestic dogs, would also ensure the persistence of the population, yet these factors are not addressed by park managers. At Iluka, the small koala population was identified as requiring increased immigration and fertility, yet before this could be successfully addressed, road-kill and predation made the population virtually extinct. In part, this outcome reveals a collective inability to address local threats, such as road deaths, clearing of koala habitat, and a high frequency of fires (Lunney *et al.* 2002).

The take-home message is that conservation strategies that seek to address the impact of roads must include an assessment of other threats to wildlife and must be situation specific.

Management of peri-urban and urban reserves in Australia is focused on maintaining biodiversity, cultural heritage, and ensuring public access. Contrary to the objectives of conservation management plans, roads are normally listed as an asset to be developed further to support fire management programs and public access of the peri-urban parks. Fire management is a well recognized threat in the Australian landscape whose management, unfortunately, requires the mobilization of heavy equipment. Nonetheless, as evidenced by the case summaries and the stated objectives of management plans for national parks and reserves, a road management program should accompany roads that intrude on such conservation areas, and these plans should include models to estimate the effectiveness of various conservation strategies that could be employed to ensure the viability of wildlife populations. Little effort has so far been made to utilize the improvement in population modeling over the last 10 years, and there is great opportunity to develop robust frameworks for managing our wildlife and transportation networks sustainably.

Biographical Sketch: Dror Ben-Ami received his B.A. in biology from the University of California-Santa Cruz in 1997, then his master's qualifying at the University of New South Wales in 1998, and he was recently awarded his doctorate in animal ecology at the University of New South Wales in 2005. He has been working with the Road Ecology Research Group since 2004 as a research associate. Daniel Ramp received his B.S. (with honors) from the University of Melbourne in 1994, and his doctorate in botany/zoology at the University of Melbourne in 2001. He has worked at the University of New South Wales since 2001, and in 2003 he established the Road Ecology Research Group with Dr. David Croft.

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