Review

Effects of Road Networks on Bird Populations

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Abstract: *One potential contributor to the worldwide decline of bird populations is the increasing prevalence of roads, which have several negative effects on birds and other vertebrates. We synthesized the results of studies and reviews that explore the effects of roads on birds with an emphasis on paved roads. The well-known direct effects of roads on birds include habitat loss and fragmentation, vehicle-caused mortality, pollution, and poisoning. Nevertheless, indirect effects may exert a greater influence on bird populations. These effects include noise, artificial light, barriers to movement, and edges associated with roads. Moreover, indirect and direct effects may act synergistically to cause decreases in population density and species richness. Of the many effects of roads, it appears that road mortality and traffic noise may have the most substantial effects on birds relative to other effects and taxonomic groups. Potential measures for mitigating the detrimental effects of roads include noise-reduction strategies and changes to roadway lighting and vegetation and traffic flow. Road networks and traffic volumes are projected to increase in many countries around the world. Increasing habitat loss and fragmentation and predicted species distribution shifts due to climate change are likely to compound the overall effects of roads on birds.*

Keywords: bird populations, roads, road mortality, roadway lighting, surface transportation, traffic noise

Efectos de las Redes de Caminos sobre Poblaciones de Aves

Resumen: *El incremento en la prevalencia de caminos, que han tenido varios efectos negativos sobre aves y otros vertebrados, es un potencial contribuyente a la declinación mundial de poblaciones de aves. Sintetizamos los resultados de estudios y revisiones que exploran los efectos de los caminos sobre las aves, con énfasis en caminos pavimentados. Los bien conocidos efectos directos de los caminos sobre las aves incluyen la pérdida y fragmentación de hábitat, mortalidad causada por vehículos y envenenamiento. Sin embargo, los efectos indirectos pueden ejercer una mayor influencia sobre poblaciones de aves. Estos efectos incluyen ruido, luz artificial, barreras al movimiento y bordes asociados con caminos. Más aun, los efectos indirectos y directos pueden actuar sinérgicamente para causar decrementos en la densidad poblacional y en la riqueza de especies. De los muchos efectos de los caminos, parece que la mortalidad y el ruido del tráfico tienen los efectos más significativos sobre las aves en relación con otros efectos y grupos taxonómicos. Las medidas potenciales para mitigar los efectos perjudiciales de los caminos incluyen estrategias de reducción de ruido y cambios en la iluminación y vegetación de los caminos y en el flujo de tráfico. Se proyecta que las redes de caminos y los volúmenes de tráfico incrementen en muchos países en el mundo. Es probable que el incremento en la pérdida y fragmentación de hábitat y los cambios pronosticados en la distribución de especies debidos al cambio climático compliquen los efectos de los caminos sobre las aves.*

Palabras Clave: caminos, iluminación en caminos, poblaciones de aves, mortalidad en caminos, ruido de tráfico, transportación terrestre

Introduction

Bird populations are declining around the world (BirdLife International 2008*a*). In North America the abundances of at least 20 species previously categorized as common have declined more than 50% in the last 40 years (Butcher & Niven 2007; BirdLife International 2008*b*). Additionally, abundances of over half the species of Neotropical

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migrants have declined substantially. The reasons for these declines are not fully understood (Butcher & Niven 2007; BirdLife International 2008*c*). One likely contributor is the expansion of paved roads, mostly in terms of widening (National Research Council 2005), and corresponding increases in the speed and volume of vehicles on those roads (Ritters & Wickham 2003). We synthesized these effects on birds to balance the much greater attention that has hitherto been paid to the effects of roads on mammals and to examine the potentially negative effects of roads on birds worldwide.

Reduced breeding success is correlated with proximity of birds to roads and road density for species ranging from passerines (Catchpole & Phillips 1992; Reijnen & Foppen 1994) to vultures (Donazar et al. 1993). In some cases, avian communities adjacent to roads differ from nearby avian communities (Glennon & Porter 2005), presumably because of some combination of the direct and indirect effects of roads on animals in general (Forman & Alexander 1998; Trombulak & Frissell 2000; Fahrig & Rytwinski 2009).

There is a little understanding of whether declines in persistence of birds are more affected by direct or indirect effects. If this could be determined in urban areas, it may be possible to increase bird abundance and species richness. It is also important to identify and mitigate any negative road effects in protected areas, which are assumed to buffer populations of wild animals from human activities.

Many of the negative effects of roads on other vertebrates (e.g., mortality, habitat fragmentation, and audiovisual disturbance, chemical pollution) also apply to birds (Forman et al. 2003; Jacobson 2005). There are a few ways roads can benefit birds. For example, roads retain heat that can reduce metabolic costs for birds that rest on road surfaces (Whitford 1985), associated road infrastructure (e.g., poles and bridges) can create nesting sites (Forman 2000), and verges increase availability of food sources (Lambertucci et al. 2009) and link patches of habitat (Meunier et al. 1999; Huijser & Clevenger 2006; Reijnen & Foppen 2006). We reviewed recent reports and peer-reviewed articles focused primarily on direct and indirect negative effects of roads on bird populations and identified some potential forms of mitigation. Much of the literature we reviewed concerns paved roads because they have been the subject of more study and because their ecological effects are assumed to be greater than gravel, dirt, or ice roads (Forman et al. 2003; National Research Council 2005).

Direct Threats Posed to Birds by Roads and Traffic

For bird populations the most visible direct negative effects of roads are habitat loss and mortality due to collisions with vehicles. Because the effects of habitat loss on birds have been comprehensively reviewed elsewhere (Andren 1994), we did not focus on this effect here. Nonetheless, roads have other effects that are related to habitat loss. For example, maintenance activities in the right-of-way can further reduce habitat quality and destroy nests, which may reduce population viability for rare species (e.g., Burrowing Owl [*Athene cunicularia*]) (Catlin & Rosenberg 2006). We focused on the negative effects associated with vehicular traffic.

Vehicle-Caused Mortality

For individual birds and other vertebrate groups, a direct threat of roads is death due to collisions with vehicles (Erritzoe et al. 2003). In the United States, vehicles are estimated to cause approximately 80 million bird fatalities each year (Erickson et al. 2005). Despite the high number of mortalities each year, vehicle-caused mortality has been assumed to have less of an effect on persistence than some indirect effects of roads (Forman & Alexander 1998; Reijnen & Foppen 2006). Only three bird species found in the United States appear to suffer population declines as a result of them: Florida Scrub-Jay (*Aphelocoma coerulescens*) (Mumme et al. 2000; IUCN 2008), Audubon's Crested Caracara (*Polyborus plancus audubonii*), and Hawaiian Goose (*Branta sandvicensis*) (Huijser et al. 2007; IUCN 2008). A greater understanding of what makes some species more susceptible to vehicle collision and population decline as a result of vehicle-caused mortality is needed, but some generalities emerge from the literature.

First, birds are more likely to collide with vehicles if they forage, roost, or nest near roads (Erritzoe et al. 2003; Huijser et al. 2007). Collision frequency can increase near watercourses (Erritzoe et al. 2003; Ascensao & Mira 2006) and houses (Ascensao & Mira 2006). Collisions are also more likely to occur at lower elevations (Clevenger et al. 2003) and in open areas than in forests (e.g., Clevenger et al. 2003; Ascensao & Mira 2006; Ramp et al. 2006).

Several other factors have less consistent effects on vehicle-induced bird mortality. For many species, vehicle-induced mortality increases during breeding and migration (Fulton et al. 2008; Gryz & Krause 2008), but for other species it increases during winter (Loos & Kerlinger 1993; Boves 2007). Collisions can increase (Jackson 2003) or decrease as roadside lighting increases (Hernandez 1988). Roadside trees, hedgerows, and other features that cause birds to fly higher across roads typically decrease collision frequency (Pons 2000; Bard et al. 2002; Clevenger et al. 2003; Erritzoe et al. 2003; Taylor & Goldingay 2004; Orlowski 2005), but they can also increase it (Ramp et al. 2006; Varga et al. 2006). Birds also vary in their responses to roads. Some individuals appear to learn to avoid vehicles (Mumme et al. 2000), whereas others do not (Loos & Kerlinger 1993; Jackson 2002).

It is difficult to measure the true extent of vehicle-induced mortality because estimates are typically far lower than the actual number of birds killed (Erickson et al. 2005). Estimation accuracy is reduced by variation in searcher efficiency, scavenger bias (Erickson et al. 2005; Boves 2007), and incorrect attribution of cause of death (Kerlinger & Lein 1988). Even long-term studies in which 100% of individuals are marked, researchers can fail to detect all instances of vehicle-caused mortality (Mumme et al. 2000). Vehicle collisions may also cause nonfatal injuries that increase the probability birds will die from other causes (Orlowski & Siembieda 2005). In addition, inaccurate estimates of vehicle-induced mortality can result if only carcasses are studied in the absence of data on species abundance (Hernandez 1988; Aebischer et al. 2005). Missing information about population size makes it difficult to compare rates of mortality in different areas, especially on different continents (Erritzoe et al. 2003).

Pollution and Poisoning

Deicing agents, petroleum-based organic compounds, nutrients, sediments, agricultural chemicals, and other substances regularly run off paved roads during construction, maintenance, and use (Buckler & Granato 1999). Road salt is a common deicing agent that attracts birds. Its ingestion can lead to death, which dispels the notion that road salt has a negative effect only because it attracts birds to the road surface, making them subject to collisions with vehicles (Mineau & Brownlee 2005). Dust on unpaved roads can change the composition of vegetation (Walker & Everett 1987), which can affect birds (Kalisz & Powell 2003). Gravel roads are frequently treated with dust suppressants, the environmental and toxicological effects of which are not well understood (Fay & Kociolek 2009). Despite the ubiquity of road contaminants from vehicles and maintenance activities, toxic effects of roads appear to be rare, even in areas with high traffic volumes (Buckler & Granato 1999), and pollution appears to have fewer effects on birds than other road-related effects (Reijnen & Foppen 2006).

Indirect Threats Posed to Birds by Roads and Traffic

Even in the absence of direct deleterious effects, many bird species appear to avoid roads purposely (e.g., Bollinger & Gavin 2004; Balbontin 2005; Gavashelishvili & McGrady 2006). Some species may be present near roads for a time, but they are more likely to abandon nests near roads (Gorog et al. 2005). For birds, road avoidance appears to be associated with the physical barrier to movement roads present, noise, artificial light, and edge effects.

Physical Barriers

Of the indirect threats of roads, the barriers to movement roads present may have the greatest effect on vertebrates (Forman & Alexander 1998). Several forest-dwelling bird species are unlikely to cross gaps in forest cover ≥50 m in areas dominated by agriculture (Desrochers & Hannon 1997), timber harvesting (Awade & Metzger 2008), and urban infrastructure (Tremblay & St. Clair 2009). Some species exhibit reluctance to cross dirt roads that are 10–30 m wide (Develey & Stouffer 2001). Nonetheless, the barriers caused by roads may be a simple function of the width of the gap they create in the surrounding habitat, unless the roads are also noisy (St. Clair 2003; Tremblay & St. Clair 2009) or are associated with tall features such as power lines (Pruett et al. 2009).

Noise

Traffic noise probably has the most widespread and greatest indirect effect on birds (Reijnen et al. 1995 (Table 1). Noise likely causes reductions in population densities that have been reported for several bird species that are present near roads (Reijnen & Foppen 2006; Patricelli & Blickley 2006). In grasslands the effects of noise appear to extend farther from roads than in forests (Forman et al. 2002), perhaps because grasslands have less vegetation to absorb sound. In addition to the effects of traffic volume and its associated noise, there may be synergistic effects of noise, habitat loss and fragmentation (Forman & Deblinger 2000), and edge effects (Habib et al. 2007).

Birds may be affected by anthropogenic noise because they rely extensively on acoustic communication (Table 1). Chronic industrial noise can reduce species richness, alter population age structure, and change avian predator–prey dynamics (Francis et al. 2009). Like industrial noise, chronic traffic noise appears to produce younger age structures and reduces population densities in several bird species (Reijnen & Foppen 2006). These effects may occur because anthropogenic noise masks the frequencies of calls used to attract mates (Rheindt 2003; Pohl et al. 2009), communicate with flock members (Lohr et al. 2003; Slabbekoorn & Ripmeester 2008) or offspring (Leonard & Horn 2005), defend territories (Habib et al. 2007; Mockford & Marshall 2009), and detect predators (Slabbekoorn & Ripmeester 2008; Francis et al. 2009) (Table 1). Effects of noise on both birds and anurans seem to depend on the frequencies and amplitudes of species-specific signals (Lengagne 2008; Slabbekoorn & Ripmeester 2008; Hu & Cardoso 2009). Some species seem unaffected by roads or traffic (Kaseloo 2005; Reijnen & Foppen 2006), and others may not come near roads when traffic volume is high (Bautista et al. 2004). Several urban-dwelling songbird species appear to counteract the masking effects of traffic noise (Table 1) by singing at a higher pitch (Slabbekoorn & Peet 2003), increasing song amplitude (Brumm 2004b), or singing

Table 1. The effects of anthropogenic noise on avian communities and communication.

Category	*Effect*	*References*
Community		
species richness	reduced as noise increases	Stone 2000
density & abundance (all species)	reduced as noise increases	Reijnen et al. 1995, 1996; Kuitunen et al. 1998; Bayne et al. 2008
	no overall reduction	Peris & Pescador 2004
densities & abundance (specific species)	reduced as noise increases	Reijnen & Foppen 1994; Reijnen et al. 1995, 1997
	dependent on species	Kuitunen et al. 1998; Peris & Pescador 2004
	higher abundance of birds with higher song pitch near roads	Rheindt 2003
age structure	younger at noisy sites	Reijnen & Foppen 1994; Habib et al. 2007
physiology	increased stress at higher noise levels	Campo et al. 2005
	no stress difference at higher noise levels	Byers et al., unpublished data
Breeding cycle		
pairing and mate retention	decreased time devoted to courtship behavior	Goudie & Jones 2004
	reduced pairing success	Habib et al. 2007
	reduced mate preference	Swaddle & Page 2007
territory and nest-site selection	farther from noise sources	Francis et al. 2009
nest success	increased as noise increases for some species	Francis et al. 2009
Foraging		
begging calls	reduced parental discrimination in noisy locations	Leonard & Horn 2005
prey location and probability of predation	predator reduction increases nest success in noisy locations	Francis et al. 2009
	potential alterations to interspecies interactions	Slabbekoorn & Halfwerk 2009
	increased vigilance as noise increases	Quinn et al. 2006
Communication		
temporal adjustment	sing more at night in noisy locations	Fuller et al. 2007
amplitude increase	sing louder as noise increases (Lombard effect)	Cynx et al. 1998; Brumm 2004a, 2004b; Brumm et al. 2009; Osmanski & Dooling 2009
	louder begging calls in noisy locations	Leonard & Horn 2005
pitch modification	increased pitch in noisy locations	Slabbekoorn & Peet 2003; Fernandez-Juricic et al. 2005; Slabbekoorn & den Boer-Visser 2006; Wood & Yezerinac 2006; Parris & Schneider 2009; Kirschel et al. 2009; Nemeth & Brumm 2009
redundancy	no correlation between pitch and road noise	Skiba 2000
detection of con- and heterospecific vocal signals	more repetition in noisy locations	Brumm & Slater 2006
	reduced detection probability of signals in noisy locations	Langemann et al. 1998; Lohr et al. 2003
response to signals	strongest response to played-back signals when ambient noise levels are similar to local environment	Mockford & Marshall 2009
reviews	effects of noise and implications	Patricelli & Blickley 2006; Slabbekoorn & Ripmeester 2008; Barber et al. 2010
Brain response		
gene activation	immediate early-gene ZENK expression in the neural pathway of the avian brain not modified by noise playback	Vignal et al. 2004

during periods of low traffic noise (Fuller et al. 2007). Other species may be unable to adapt their songs to accommodate chronic noise (Slabbekoorn & Ripmeester 2008; Barber et al. 2010), and pairing success of birds with relatively high amplitude songs is reduced when they are exposed to high levels of chronic noise (Habib et al. 2007).

Artificial Light

Light from roadways can have negative effects on many animals (Rich & Longcore 2006), including birds (Ogden 1996; Van De Laar 2007). Some lighting structures attract migrating bird species, which increases the probability they will be preyed on or collide with structures and often causes them to redirect flight paths and thus deplete energy stores (van de Laar 2007). Artificial lighting can also affect avian patterns of nestling development, singing, breeding, molting, and migration (De Molenaar et al. 2006). There is some evidence that roadway lighting may reduce habitat quality and change the timing of breeding for the Black-tailed Godwit (*Limosa limosa*), a species associated with grasslands in Africa, Europe, and Asia (De Molenaar et al. 2006). American Robins (*Turdus migratorius*) sing earlier in the morning in areas with more anthropogenic light (Miller 2006), but this response may be difficult to disentangle from the associated effect of road noise, which is more important than light for explaining nocturnal singing by European Robins (*Erithacus rubecula*; Fuller et al. 2007).

Edge Effects

Positive and negative effects of edges on breeding birds have been documented in many studies (Stephens et al. 2003). The edge effects of roads may be particularly acute when introduced species, such as rats (*Rattus rattus*), prey on ground-nesting birds (Delgado et al. 2001) or parasitic species, such as Brown-headed Cowbirds (*Molothrus ater*), target the nests of species of conservation concern (Chace et al. 2003). In some cases, these edge effects are contradictory (Bergin et al. 2000; Lariviere 2003).

Mitigation

Paved roads are a pervasive feature across much of North America, and existing roads are being widened, new roads are being built, and, and traffic volume is increasing (Forman et al. 2003; National Research Council 2005) throughout the world (Urban Land Institute 2007; Bhattacharya 2008). Efforts to mitigate road effects are most likely to increase probabilities of persistence of birds when applied across extensive areas (Stutchbury 2009).

New information about the ubiquity of the effects of noise on birds suggests reducing road noise may be cost-effective because it can benefit both birds and humans (Bluhm et al. 2007; Slabbekoorn & Ripmeester 2008; Barber et al. 2010). Promising measures to reduce road noise include temporal adjustments to traffic flow (Reijnen & Foppen 2006) and increased reliance on mass transit (Barber et al. 2010). The unvegetated area created by light-rail train tracks is more permeable to bird movement than roads of equivalent sizes, perhaps because they are quieter (Tremblay & St. Clair 2009). New tire designs (Carstens 2003) and noise-absorbing porous asphalt (Piepers 2001) can substantially reduce levels of highway noise (Elvik & Greibe 2003). Other noise-reducing strategies include the use of earth berms and vegetation that, unlike walls (Varga et al. 2006), do not create vertical barriers to animal movement, although this may depend on the animal. These features typically also increase quality of life and property values for human residents.

Changing roadway lighting may also benefit both birds and people through reductions in energy consumption and increases in safety (De Molenaar et al. 2006). Replacing red or white lights with green lights greatly reduces the negative effect of artificial lights on oil platforms on birds (van de Laar 2007). Such lighting could be used on highway (Poot et al. 2008).

Edge effects might be partially mitigated with vegetation management and restoration. Poisoning and nonpoint source pollution can be mitigated, in part, by policy aimed at encouraging use of nontoxic agents to maintain safe driving conditions. A practice that would reduce vehicle-induced bird mortality would be to refrain from planting along roadsides fruit-bearing vegetation that attracts birds.

Future Implications

In the United States road area is expected to increase by 27,900 km^2 by 2030, and lanes added to existing roadways to accommodate increased traffic volume is projected to increase road area by an additional 94,100 km^2 (Theobald 2010). Exponential increases in the road network and traffic volume are anticipated to occur in large, densely populated, countries such as China and India (Bhattacharya 2008). Among the factors studied to date, it appears that traffic noise has the greatest potential to reduce population abundance and species richness of birds (Reijnen & Foppen 2006; Barber et al. 2010). Although vehicle-caused mortality does not appear to affect persistence for most populations, it is a problem for some species (Huijser et al. 2007) and may exacerbate other anthropogenic threats to birds (Erickson et al. 2005). Given global traffic projections and in light of losses due to collisions, road-induced mortality of birds should be examined more systematically and comprehensively. Other road-related disturbances such as light and chemical pollution appear to have minor effects at the population level, but their spatial extent may still generate a large collective effect on birds. Finally, increasing habitat loss and fragmentation, in addition to predicted species distribution shifts due to climate change, are likely to compound the overall effect of roads (Heller & Zavaleta 2009).

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