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Research Paper, part of a Special Feature on Quantifying Human-related Mortality of Birds in Canada

Estimates of Avian Mortality Attributed to Vehicle Collisions in Canada

Estimation de la mortalité aviaire attribuable aux collisions automobiles au Canada

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ABSTRACT. Although mortality of birds from collisions with vehicles is estimated to be in the millions in the USA, Europe, and the UK, to date, no estimates exist for Canada. To address this, we calculated an estimate of annual avian mortality attributed to vehicular collisions during the breeding and fledging season, in Canadian ecozones, by applying North American literature values for avian mortality to Canadian road networks. Because owls are particularly susceptible to collisions with vehicles, we also estimated the number of roadkilled Barn owls (*Tyto alba*) in its last remaining range within Canada. (This species is on the IUCN red list and is also listed federally as threatened; Committee on the Status of Endangered Wildlife in Canada 2010, International Union for the Conservation of Nature 2012). Through seven Canadian studies in existence, 80 species and 2,834 specimens have been found dead on roads representing species from 14 orders of birds. On Canadian 1 and 2-lane paved roads outside of major urban centers, the unadjusted number of bird mortalities/yr during an estimated 4-mo (122-d) breeding and fledging season for most birds in Canada was 4,650,137 on roads traversing through deciduous, coniferous, cropland, wetlands and nonagricultural landscapes with less than 10% treed area. On average, this represents 1,167 birds killed/100 km in Canada. Adjusted for scavenging, this estimate was 13,810,906 (3,462 dead birds/100 km). For barn owls, the unadjusted number of birds killed annually on 4-lane roads during the breeding and fledging season, within the species geographic range in southern British Columbia, was estimated as 244 owls and, when adjusted for scavenging and observer bias (3.6 factor), the total was 851 owls.

RÉSUMÉ. Bien que l'estimation de la mortalité aviaire attribuable aux collisions automobiles soit de l'ordre des millions aux États-Unis, en Europe et au Royaume-Uni, il n'existe aucune estimation de ce genre au Canada à ce jour. Pour pallier cette lacune, nous avons calculé une estimation de cette mortalité aviaire annuelle durant la saison de nidification et d'envol des jeunes, dans les écozones canadiennes, à partir de données issues de la littérature nord-américaine que nous avons appliquées au réseau de transport canadien. Étant donné que les chouettes et hiboux sont particulièrement susceptibles d'être happés par des véhicules, nous avons aussi estimé le nombre d'Effraies des clochers (*Tyto alba*) happées dans le peu qu'il reste de son aire de répartition au Canada. (Cette espèce figure sur la liste rouge de l'UICN et est aussi listée comme « menacée » au palier fédéral; Comité sur le statut des espèces en péril au Canada 2010; Union internationale pour la conservation de la nature 2012.) À partir de sept études canadiennes sur le sujet, 80 espèces et 2 834 spécimens ont été trouvés morts sur les routes; ces espèces font partie de 14 ordres d'oiseaux. Sur les routes canadiennes pavées à une ou deux voies et situées à l'extérieur des grands centres urbains, le nombre non ajusté de mortalités aviaires par année, pour les 4 mois (122 jours) que dure la saison de nidification et d'envol des jeunes chez la plupart des oiseaux au Canada, s'élève à 4 650 137 en milieux décidus, conifériens, cultivés, humides ou non agricoles comportant moins de 10 % d'arbres. En moyenne, ce résultat se traduit par 1 167 oiseaux happés/100 km au Canada. En ajustant pour tenir compte de la disparition des carcasses par les charognards, cette estimation s'élève à 13 810 906 (soit 3 462 oiseaux happés/100 km). Pour ce qui est de l'Effraie des clochers dans son aire de répartition du sud de la Colombie-Britannique, le nombre non ajusté d'oiseaux happés annuellement sur les routes à quatre voies durant la saison de nidification et d'envol des jeunes s'élève à 244; ce nombre grimpe à 851 lorsqu'il est ajusté pour prendre en compte les biais associés aux observateurs (facteur de 3,6) et à la disparition des carcasses par les charognards.

Key Words: *birds; Canada; casualty estimates; conservation; mitigation; roadkill; roads*

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INTRODUCTION

Avian mortality (roadkill) from vehicular collisions has been raised as a concern for almost a century (Stoner 1925, Dill 1926, Sutton 1927, Scott 1938). The presence of roads also causes fragmentation of habitat (Jacobson 2005); impedes dispersal of wildlife (Bager and Rosa 2011); and generates air, light, and sound pollution (Reijnen et al. 1995, De Molenaar et al. 2006) with traffic noise reducing breeding bird densities, especially of passerines, in habitats adjacent to roads (Slabbekoorn and Peet 2003, Slabbekoorn and den Boer-Visser 2006, Reijnen and Foppen 2006, Habib et al. 2007, Slabberkoorn and Ripmeester 2008). Vehicle collisions, unlike predators, remove many healthy and mature breeding birds from populations (Sutton 1927, Jennings 1961, Massemin and Zorn 1998, Bujoczek et al. 2011). Higher mortality of adults and fledged birds from roadside habitats can create sink populations that can only persist through immigration (Mumme et al. 2000). Migratory species may be even more at risk because they travel long distances and are presumably exposed to more road crossing events than nonmigratory species (Harris and Scheck 1991).

It is estimated that "avian roadkill" totals are in the millions in the United Kingdom, Europe, Scandanavia, and the USA (Hodson 1960, Hodson and Snow 1965, Banks 1979, Jonkers and deVries 1977, as cited in Erritzoe et al. 2003, Erritzoe et al. 2003). Many species are affected, with passerines and owls being among the most commonly reported (Erritzoe et al. 2003, Boves and Belthoff 2012). The numbers of avian fatalities attributed to vehicular collisions are widely considered to be underestimates because a number of factors including rates of crippling by vehicles, scavenging, observer error, and the disappearance of carcasses as vehicles pass over them are rarely taken into account within the estimates (Austin 1971, Slater 2002, Santos et al. 2011, Longcore et al. 2012, Teixiera et al. 2013). Scavenging rates of dead birds on roads are high (Slater 2002) and disappearance rates are rapid (Santos et al. 2011). Scavengers remove animals at a continuous but variable rate, and road surveys will always underestimate roadkill occurrences to some extent, often >50% (Kline and Swann 1998, Santos et al. 2011, Boves and Belthoff 2012, Teixeira et al. 2013). A further challenge to estimating the impact of vehicular collisions on bird populations is that roadkill aggregations of birds are often nonrandomly distributed in time (Smith and Dodd 2003, Bager and Rosa 2012) and space (Clevenger et al. 2003). Estimates are thought to vary, given variations in traffic speed and volume; mode of observer transportation along road transects, that is, vehicle, bicycle, and walking; and survey frequency (Illner 1992, Reijnen et al. 1995, Bager and Rosa 2011).

In the USA, reports of avian mortality from vehicle collisions span 85 yrs (Stoner 1925, Dill 1926, Robertson 1930, Sargeant 1973, Case 1978, Decker 1987, Seibert and Conover 1991, Loos and Kerlinger 1993, Smith et al. 1994, Mumme et al. 2000, Bard et al. 2001, Fahrig et al. 2001, Smith and Dodd 2003, Boves and Belthoff 2012, Glista et al. 2008). In Canada, only seven studies exist with the earliest occurring in 1974. These studies include roads through Banff National Park, Alberta (Clevenger et al. 2003), Big Creek National Wildlife Area, near Port Rowan, Ontario (Ashley and Robinson 1996), southeastern Ontario, and Gatineau, Quebec (Oxley et al. 1974), the south Okanagan Valley, British Columbia (Potvin and Bishop 2010) and the Fraser Valley, British Columbia (Preston and Powers 2006) and on roads near owl aggregations in Alberta (Kerlinger and Lein 1988) and Manitoba (Nero and Copland 1981). No national estimates are available. Therefore, we calculated an estimate of annual avian mortality during the breeding and fledging season attributed to vehicular collisions in Canadian ecozones by applying North American literature values for avian mortality to Canadian road networks. Because owls are particularly susceptible to collisions with vehicles, we also estimated the occurrence of roadkill of a federally threatened species, the Barn owl (*Tyto alba*), in its last remaining range within Canada.

METHODS

We refined the approach used in previous studies attempting to estimate the annual mortality of birds attributed to vehicle collisions in a given country. For example, Banks (1979) summarized the past methods as follows: "if one knows the number of miles of road in an area, and the average annual avian mortality per mile, he can easily calculate the annual toll of birds in any given area." In 1972, there were 3,786,713 miles (6,094,123 km) of road in the U.S. (Federal Highway Administration 1973). The use of a minimum (2.7) and maximum (96.25) annual avian deaths per mile in U.S. studies yields a range of from 10.2–374.5 m birds killed/yr. They used this approach because "the variables related to kinds of habitat, and other factors are too complex for analysis with the meager information on hand" (Banks 1979).

We took this approach and refined it by accounting for the number of birds killed/km/d across variable road types, volumes, and ecozones, and adjusting for scavenging and other biasing factors that affect the number of birds seen dead on the road during surveys. The annual estimate of avian collisions with vehicles in Canada was then conservatively based on mortality occurrences during the breeding and juvenile dispersal season. We also utilized literature values for estimates of Barn owls killed by vehicles in habitats in southern Idaho and California and applied these to southern British Columbia, the last major population center for this species in Canada.

Casualty estimates

To estimate an average number of birds killed/km/d in Canada, our first step was to calculate these values from as many North American literature sources as possible. The literature was searched to find all studies which reported road-killed birds in North America and to identify bird species reported. Search engines and methods used included Scopus, Google Scholar, multiple bibliographies such as Nietvelt 2002, and internet sites posting bibliographies such as Erritzoe 2002, and our own cross-referencing of citations within publications.

From the existing studies, we selected those that represent relatively modern road traffic conditions, volumes, and design; temperate climate; and species diversity conditions in Canada. Therefore, we included only studies that were conducted in temperate zone climatic conditions and were completed since 1970. To calculate the number of birds killed/km/d, it was essential that the studies reported the total number of birds killed, the total number of surveys conducted, the frequency of surveys, and the length of each survey route. We did not account for density of all Canadian species per ecozone so we assumed the number of birds killed/km/d, as represented in the literature, was a product of avian density and other factors that influence rates of death in a particular road type, ecozone, and traffic volume. We applied those estimates to the Canadian road network in specific ecozones. Considering all of these parameters, only six studies met our criteria. These were: Seibert and Conover 1991, Ashley and Robinson 1996, Moore and Mangel 1996, Clevenger et al. 2003, Glista et al. 2008, and Boves and Belthoff 2012. Two are exclusively surveys of owls (Moore and Mangel 1996, Boves and Belthoff 2012) and these were used only in the Barn owl case study (Table 1).

In the selected studies from the literature, roadkill surveys for total birds were based on low traffic volume 2-lane paved roads outside major metropolitan areas (Seibert and Conover 1991, Ashley and Robinson 1996, Glista et al. 2008), except for one survey that was partially conducted on a 4-lane road (Clevenger et al. 2003; Table 2). Surveyed 2-lane roads had average traffic volumes of 6,500 vehicles/d or fewer, which is classified as low traffic volume (Reijnen et al. 1995, Ontario Ministry of Transportation 2009) except for the 4-lane highway surveyed near Banff National Park, Alberta, Canada which had seasonal traffic volumes of up to 35,000 vehicles / d (Clevenger et al. 2003; Table 2). All surveys were done daily and conducted by observers in vehicles.

Surveys in the selected studies were performed on roads traversing a variety of habitats, which we classified based on Canadian ecozone types: (1) cropland, (2) rangeland (<10% treed), (3) mixed forest, (4) broadleaf, (5) coniferous (Natural Resources Canada 2012*a*; Table 2), and (5) wetlands (Natural Resources Canada 2012*b*; Table 2). One survey was conducted on roads in an agricultural area which we classified as cropland (Table 2; Glista et al. 2008) and three were conducted in mixed or broadleaf forests (Table 2; Seibert and Connover 1991, Glista et al. 2008). Two surveys were performed in the coniferous forest ecozone (Clevenger et al. 2003). Two surveys were conducted in roads bisecting wetlands (Table 2; Ashley and Robinson 1996, Glista et al. 2008). The number of birds killed/km/d was calculated for each survey and habitat type (Table 2). These values were then applied to road networks in these ecozone types across Canada (Fig. 1).

In areas designated as rangeland (Fig. 1), we did not have an estimate for number of birds killed/km/d from the literature for this ecozone type. Therefore, we estimated by applying the number of dead birds/km/d found in cropland (Glista et al. 2008; Table 2) for 90% of the road network in this zone. For treed areas within rangeland areas, the number of dead birds/km/d was calculated as an average of the values from mixed forest and broadleaf forest taken from the literature (Seibert and Connover 1991, Glista et al. 2008; Tables 2, 3).

For the coniferous ecozone, we accounted for potential differences in mortality rates on roads with different volumes of traffic because data was available from the literature (Tables 2, 3). For the estimated length of 1- and 2-lane roads in coniferous ecozones that were >14,000 daily vehicle maximum (see also below), we applied 0.0041 total dead birds/km/d (calculated from Clevenger et al. 2003; Table 2). For all 1- and 2-lane roads in coniferous zones with maximum daily vehicle <14,000 vehicles, the value of 0.00093 total birds killed /km/d was applied (calculated from Clevenger et al. 2003; Table 2).

Road networks

To apply the number of birds killed /km/d estimated in the literature to the Canadian road network, we determined the length of the roads in Canadian ecozones that were similar to those reported in the literature (Table 2). That is, we determined the length of paved 1- and 2-lane roads occurring outside of major urban population centers, excluding exit-ramp lengths. Using ArcGIS 10 (ESRI, Redlands, California, USA), road-segment shape files from the National Road Database (Geobase 2011) were overlaid by census subdivisions (Statistics Canada 2010) that were considered urban. We defined urban as a population within the census subdivision less than or equal to 1,000 persons where the density is > or equal to 400 persons/km^2 (Statistics Canada 2008). The road segments within those census subdivisions were erased and the remaining km of paved road that were 1- or2-lane were calculated for each ecozone (Natural Resources Canada 2012*a*, *b*). Because land-cover layers did not include wetlands, a separate layer of Canada's wetlands was used (Natural Resources Canada 2012*b*). The road lengths in each ecozone were overlain by wetland occurrence, and the length of roads in each ecozone that traversed through wetlands were subtracted from the total road estimate for that ecozone to avoid double counting.

The lengths of roads were then spatially joined with Canadian provincial (British Columbia, Alberta, Saskatchewan, Manitoba, Ontario, Quebec, New Brunswick, and Prince Edward Island) traffic-volume data, acquired from individual

Table 1. Results of surveys of roads for avian casualties attributed to collisions with vehicles in North America.

Study	Location and date Common name	Scientific name	Total
Canadian Studies			
Oxley et al. 1974	Frontenac, Lanark, Leeds, and Russell Counties, ON, and Gatineau County, QC, Canada (1972)		
	Birds	†n/a	217
Nero and Copland 1981	Provincial Trunk Hwy. 1 between Hadashville and Falcon Lake, MB, Canada (1 Jan–19 Apr, 1980)		
	Great gray owl	*Strix nebulosa*	50
Kerlinger and Lein 1988	AB, Canada (1973–1983)		
	Snowy owl	*Bubo scandiacus*	10
Ashley and Robinson 1996	Big Creek National Wildlife Area, Lake Erie, ON, Canada (1979–1993)		
	Tree swallow	*Tachycineta bicolor*	60
	Barn swallow	*Hirundo rustica*	65
	Rough-winged swallow	*Stelgidopteryx serripennis*	2
	Cliff swallow	*Petrochelidon pyrrhonota*	13
	Bank swallow	*Riparia riparia*	112
	Purple martin	*Progne subis*	36
	House sparrow	*Passer domesticus*	34
	White-throated sparrow	*Zonotrichia albicollis*	9
	Song sparrow	*Melospiza melodia*	7
	Swamp sparrow	*Melospiza georgiana*	72
	Savannah sparrow	*Passerculus sandwichensis*	2
	Chipping sparrow	*Spizella passerina*	1
	House finch	*Haemorhous mexicanus*	2
	Long-billed marsh wren	*Cistothorus palustris*	58
	Cedar waxwing	*Bombycilla cedrorum*	4
	Hermit thrush	*Catharus guttatus*	1
	Swainson’s thrush	*Catharus ustulatus*	1
	American robin	*Turdus migratoruis*	25
	Brown thrasher	*Toxostama rufum*	6
	Gray catbird	*Dumetella carolinensis*	3
	European starling	*Sturnus vulgaris*	132
	Common grackle	*Quiscalus quiscula*	36
	Brewer’s blackbird	*Euphagus cyanocephalus*	1
	Red-winged blackbird	*Agelaius phoeniceus*	228
	Common yellowthroat	*Geothlypis trichas*	13
	Northern oriole	*Icterus galbula*	1
	Brown-headed cowbird	*Molothrus ater*	1
	Yellow-shafted flicker	*Colaptes auratus auratus*	3
	Mourning dove	*Zenaida macroura*	1
	Rock dove	*Columba livia*	1
	Yellow-billed cuckoo	*Coccyzus americanus*	1
	Black-billed cuckoo	*Coccyzus erythropthalmus*	3
	Eastern kingbird	*Tyrannus tyrannus*	10
	Willow flycatcher	*Empidonax traillii*	1
	Slate-colored junco	*Junco hyemalis*	1
	Eastern wood-pewee	*Contopus virens*	2
	Common nighthawk	*Chordeiles minor*	1
	Common gallinule	*Gallinula galeata*	3
	American coot	*Fulica americana*	1
	Killdeer	*Charadrius vociferous*	10
	Semi-palmated sandpiper	*Calidris pusilla*	2
	Mallard	*Anas platyrhynchos*	9
	Wood duck	*Aix sponsa*	1
	Canada goose	*Branta Canadensis*	7
	Common merganser	*Mergus merganser*	0
	Common snipe	*Gallinago sp.*	2
	Sora	*Porzana carolina*	5
	Clapper rail	*Rallus longirostris*	1
	Virginia rail	*Rallus limicola*	4

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		Short-billed dowitcher	*Limnodromus griseus*	1
		Ring-billed gull	*Larus delawarensis*	2
		Belted kingfisher	*Megaceryle alcyon*	1
		Palm warbler	*Setophaga palmarum*	1
		Myrtle warbler	*Setophaga coronata*	1
		Yellow warbler	*Setophaga petechia*	19
		Northern waterthrush	*Parkesia noveboracensis*	1
		American goldfinch	*Spinus tristis*	5
		Golden-crowned kinglet	*Regulus satrapa*	4
		Least bittern	*Ixobrychus exilis*	5
		American bittern	*Botaurus lentiginosus*	1
		Saw-whet owl	*Aegolius acadicus*	2
		Domestic chicken	*Gallus sp.*	1
		Unidentified birds	n/a	248
Clevenger et al. 2003	Trans-Canada Hwy. 1 (Seebe, Kicking Horse Pass, Bow Valley Parkway), AB, Canada (1997–2003)			
		Common raven	*Corvus corax*	60
		American robin	*Turdus migratorius*	50
		American crow	*Corvus brachyrhynchos*	33
		Black-billed magpie	*Pica hudsonia*	32
		Gray jay	*Perisoreus canadensis*	19
		Chipping sparrow	*Spizella passerina*	16
		Ruffed grouse	*Bonasa umbellus*	9
		White-crowned sparrow	*Zonotrichia leucophrys*	7
		Yellow-rumped warbler	*Setophaga coronata*	7
		Pine siskin	*Spinus pinus*	6
		Hermit thrush	*Catharus guttatus*	5
		Dark-eyed junco	*Junco hyemalis*	5
		Great horned owl	*Bubo virginianus*	4
		Lincoln sparrow	*Melospiza lincolnii*	3
		Mallard	*Anas platyrhynchos*	3
		Northern saw-whet owl	*Aegolius acadicus*	3
		Spruce grouse	*Falcipennis canadensis*	3
		Clark’s nutcracker	*Nucifraga columbiana*	2
		Belted kingfisher	*Megaceryle alcyon*	2
		Merlin	*Falco columbarius*	2
		Swainson’s thrush	*Catharus ustulatus*	2
		Species with 1 roadkill	n/a	15
		Unidentified passerine	n/a	10
		Unidentified sparrow	n/a	4
		Unidentified bird	n/a	5
		Unidentified raptor	n/a	2
		Unidentified swallow	n/a	2
		Unidentified duck	n/a	2
		Unidentified gull	n/a	2
		Unidentified owl	n/a	1
Preston and Powers 2006	Lower Mainland and Central Fraser Valley, BC, Canada (Hwys 1, 1A, 9, 10, 11, 15, 99 and 99A, and secondary roads; 1987, 1995–2005)			
		Northern saw-whet owl	*Aegolius acadicus*	278
		Barn owl	*Tyto alba*	542
		Barred owl	*Strix varia*	45
		Great horned owl	*Bubo virginianus*	30
		Long-eared owl	*Asio otus*	17
		Western screech owl	*Megascops kennicottii*	16
		Short-eared owl	*Asio flammeus*	13
		Northern pygmy owl	*Glaucidium gnoma*	9
		Great gray owl	*Strix nebulosa*	1
		Boreal owl	*Aegolius funereus*	1
Potvin and Bishop 2010	South Okanagan Valley, BC, Canada (2001–2008)			
		Yellow-breasted chat	*Icteria virens*	3
American Studies				
Stoner 1925	Iowa City, Johnson County, to Okoboji, Dickinson County, IA, USA (June–July 1924)			

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		Unidentified fowl	n/a	26
		Mourning dove	*Zenaida macroura*	3
		Yellow-billed cuckoo	*Coccyzus americanus*	1
		Hairy woodpecker	*Picoides villosus*	1
		Red-headed woodpecker	*Melanerpes erythrocephalus*	53
		Red-bellied woodpecker	*Melanerpes carolinus*	2
		Northern flicker	*Colaptesauratus luteus*	19
		Meadowlark	*Sturnella sp.*	1
		Bronzed grackle	*Quiscalus quiscula versicolor*	5
		English sparrow	*Passer domesticus*	20
		Shrike	*Lanius ludovicianus*	1
		Catbird	*Dumetella carolinensis*	1
		Brown thrasher	*Toxostoma rufum*	5
		Robin	*Turdus migratorius*	4
Dill 1926	Iowa City, Johnson County, IA, USA (August 1925)			
		Catbird	n/a	1
		Sparrow hawk	*Falco sparverius*	1
		Cow bird	*Molothrus sp.*	1
		Red-headed woodpecker	*Melanerpes erythrocephalus*	21
Robertson 1930	Buena Park, Orange County, CA, USA (1927–1928)			
		English sparrow	*Passer domesticus*	28
		Coot	*Fulica americana*	16
		Western meadowlark	*Sturnella neglecta*	15
		California shrike	*Lanius ludovicianus*	10
		Brewer’s Blackbird	*Euphagus cyanocephalus*	9
		Linnet	*Haemorhous mexicanus*	8
		Gambel sparrow	*Zonotrichia leucophrys gambelii*	8
		Killdeer	*Charadrius vociferus*	7
		Mourning dove	*Zenaida macroura*	4
		Western mockingbird	*Mimus polyglottos leucopterus*	4
		Barn owl	*Tyto alba*	3
		Western kingbird	*Tyrannus verticalis*	3
		Brown towhee	*Melozone fuscus*	3
		California horned lark	*Eremophila alpestris actia*	2
		Arizona hooded oriole	*Icterus cucullatus nelsoni*	2
		California gull	*Larus californicus*	1
		Western red-tailed hawk	*Buteo jamaicensis calurus*	1
		Burrowing owl	*Athene cunicularia*	1
		Texas nighthawk	*Chordeiles acutipennis*	1
		Red-shafted flicker	*Colaptes auratus cafer*	1
		Golden-crowned sparrow	*Zonotrichia atricapilla*	1
		Western lark sparrow	*Chondestes grammacus strigatus*	1
		Green-backed goldfinch	*Spinus psaltria hesperophila*	1
		Savannah sparrow	*Passerculus sandwichensis*	1
		Black-headed grosbeak	*Pheucticus melanocephalus*	1
		Cliff swallow	*Petrochelidon pyrrhonota*	1
		Pipit	*Anthus rubescens*	1
		Unidentified sparrow	*n/a*	2
Cottam 1931	SD, USA (1931)			
		Red-winged blackbird	*Agelaius phoeniceus*	n/a
		Grasshopper sparrow	*Ammodramus savannarum*	n/a
		Burrowing owl	*Athene cunicularia*	n/a
		Upland plover	*Bartramia longicauda*	n/a
		Lark bunting	*Calamospiza melanocorys*	n/a
		Chestnut-collared longspur	*Calcarius ornatus*	n/a
		Lark sparrow	*Chondestes grammacus*	n/a
		Northern flicker	*Colaptes auratus*	n/a
		Prairie horned lark	*Eremophila alpestris praticola*	n/a
		Domestic chicken	*Gallus sp.*	n/a
		Birds unidentified	*n/a*	n/a
		English sparrow	*Passer domesticus*	n/a
		Pheasant	*Phasianus colchicus*	n/a

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		Bronzed grackle	*Quiscalus quiscula versicolor*	n/a
		Virginia rail	*Rallus limicola*	n/a
		Western meadowlark	*Sturnella neglecta*	n/a
		Robin	*Turdus migratorius*	n/a
		Kingbird	*Tyrannus tyrannus*	n/a
		Arkansas kingbird	*Tyrannus verticalis*	n/a
		Mourning dove	*Zenaida macroura*	n/a
Scott 1938	43 counties in IA, USA (1936–1937)			
		European sparrowhawk	*Accipiter nisus*	1
		European partridge	*Perdix perdix*	1
		Eastern bobwhite	*Colinus virginianus*	1
		Ring-necked pheasant	*Phasianus colchicus*	44
		Sora	*Porzana carolina*	1
		Mourning dove	*Zenaida macroura*	27
		Yellow-billed cuckoo	*Coccyzus americanus*	2
		Eastern screech owl	*Megascops asio*	23
		Long-eared owl	*Asio otus*	1
		Northern flicker	*Colaptes auratus*	21
		Red-headed woodpecker	*Melanerpes erythrocephalus*	115
		Hoyt's horned lark	*Eremophila alpestris hoyti*	1
		Prairie horned lark	*Eremophila alpestris praticola*	1
		Barn swallow	*Hirundo rustica*	2
		Black-capped chickadee	*Poecile atricapillus*	1
		Western house wren	*Troglodytes aedon parkmanii*	1
		Catbird	*n/a*	1
		Brown thrasher	*Toxostoma rufum*	11
		Eastern robin	*Turdus migratorius*	17
		Eastern bluebird	*Sialia sialis*	1
		Migrant shrike	*Lanius ludovicianus migrans*	2
		English sparrow	*Passer domesticus*	432
		Eastern meadowlark	*Sturnella magna*	6
		Western meadowlark	*Sturnella neglecta*	23
		Eastern red-winged blackbird	*Agelaius phoeniceus*	2
		Baltimore oriole	*Icterus galbula*	1
		Bronzed grackle	*Quiscalus quiscula versicolor*	75
		Dickcissel	*Spiza americana*	1
		Lapland longspur	*Calcarius lapponicus*	3
		Snow bunting	*Plectrophenax nivalis*	1
Sargeant 1973	Anoka County, MN, USA (1964–1965)			
		Mallard	*Anas platyrhynchos*	1
		Green-winged teal	*Anas crecca*	1
		Ring-necked duck	*Aythya collaris*	1
		Broad-winged hawk	*Buteo platypterus*	2
		Ruffed grouse	*Bonasa umbellus*	3
		Ring-necked pheasant	*Phasianus colchicus*	11
		Sora	*Porzana carolina*	4
		American woodcock	*Scolopax minor*	1
		Ring-billed gull	*Larus delawarensis*	1
		Rock dove	*Columba livia*	2
		Mourning dove	*Zenaida macroura*	6
		Black-billed cuckoo	*Coccyzus erythropthalmus*	4
		Common nighthawk	*Chordeiles minor*	6
		Yellow shafted flicker	*Colaptes auratus auratus*	6
		Red-headed woodpecker	*Melanerpes erythrocephalus*	3
		Eastern Kingbird	*Tyrannus tyrannus*	6
		Tree swallow	*Tachycineta bicolor*	13
		Barn swallow	*Hirundo rustica*	8
		Cliff swallow	*Petrochelidon pyrrhonota*	1
		Purple martin	*Progne subis*	3
		Blue jay	*Cyanocitta cristata*	4
		Black-capped chickadee	*Poecile atricapillus*	1
		House wren	*Troglodytes aedon*	1
		Brown thrasher	*Toxostoma rufum*	2

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		Robin	*Turdus migratorius*	23
		Veery	*Catharus fuscescens*	2
		Eastern bluebird	*Sialia sialis*	3
		Tennessee warbler	*Oreothlypis peregrina*	1
		Yellowthroat	*Geothlypis trichas*	1
		House sparrow	*Passer domesticus*	18
		Bobolink	*Dolichonyx oryzivorus*	1
		Red-winged blackbird	*Agelaius phoeniceus*	2
		Brewer's blackbird	*Euphagus cyanocephalus*	1
		Brown-headed cowbird	*Molothrus ater*	2
		Rose-breasted grosbeak	*Pheucticus ludovicianus*	1
		American goldfinch	*Spinus tristis*	5
		Unidentified crossbill	*Loxia sp.*	5
		Vesper sparrow	*Pooecetes gramineus*	11
		Lark sparrow	*Chondestes grammacus*	1
		Slate-coloured junco	*Junco hyemalis*	2
		Song sparrow	*Melospiza melodia*	1
		Unidentified sparrow	n/a	13
		Unidentified bird	n/a	8
Case 1978	Interstate-80, NE, USA (1969–1975)			
		Ring-necked pheasant	*Phasianus colchicus*	7195
Decker 1987	Warsaw to Hamilton, Hancock County, IL, USA (1986–1987)			
		Unidentified bird	n/a	69
		Yellow-billed cuckoo	*Coccyzus americanus*	8
		Blue jay	*Cyanocitta cristata*	7
		Red-winged blackbird	*Agelaius phoeniceus*	7
		Indigo bunting	*Passerina cyanea*	6
		Bank swallow	*Riparia riparia*	5
		Gray catbird	*Dumetella carolinensis*	5
		Nortern oriole	*Icterus galbula*	5
		Northern cardinal	*Cardinalis cardinalis*	4
		Eastern screech owl	*Megascops asio*	3
		American robin	*Turdus migratorius*	3
		Rose-breasted Grosbeak	*Pheucticus ludovicianus*	3
		Downy woodpecker	*Picoides pubescens*	2
		Northern flicker	*Colaptes auratus*	2
		American goldfinch	*Spinus tristis*	2
		House sparrow	*Passer domesticus*	2
		Red-shouldered hawk	*Buteo lineatus*	1
		Ring-billed gull	*Larus delawarensis*	1
		Mourning dove	*Zenaida macroura*	1
		Barred owl	*Strix varia*	1
		Red-headed woodpecker	*Melanerpes erythrocephalus*	1
		Yellow-bellied sapsucker	*Sphyrapicus varius*	1
		Hairy woodpecker	*Picoides villosus*	1
		Purple martin	*Progne subis*	1
		Barn swallow	*Hirundo rustica*	1
		Black capped chickadee	*Poecile atricapillus*	1
		Brown thrasher	*Toxostoma rufum*	1
		Song sparrow	*Melospiza melodia*	1
		Common grackle	*Quiscalus quiscula*	1
Seibert and Conover 1991	Hwy. 33, NW of Athens, Athens County, OH, USA (1987–1988)			
		Yellow-billed cuckoo	*Coccyzus americanus*	1
		Eastern screech owl	*Megascops asio*	2
		Mourning dove	*Zenaida macroura*	1
		Rock dove	*Columba livia*	1
		European starling	*Sturnus vulgaris*	4
		Red-eyed vireo	*Vireo olivaceus*	1
		Gray catbird	*Dumetella carolinensis*	2
		Kentucky warbler	*Geothlypis formosus*	1
		Indigo bunting	*Passerina cyanea*	1
		American goldfinch	*Spinus tristis*	1

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	Northern cardinal	*Cardinalis cardinalis*	1
	American crow	*Corvus brachyrhynchos*	2
	Unidentified bird	n/a	3
Loos and Kerlinger 1993	North Cape May Ferry Terminal, Cape May County to Atlantic City, Atlantic County, NJ, USA (1980–1990)		
	Sharp-shinned hawk	*Accipiter striatus*	7
	Cooper’s hawk	*Accipiter cooperii*	1
	Red-shouldered hawk	*Buteo lineatus*	1
	Broad-winged hawk	*Buteo platypterus*	6
	Red-tailed hawk	*Buteo jamaicensis*	7
	American kestrel	*Falco sparverius*	9
	Common barn owl	*Tyto alba*	1
	Eastern screech owl	*Megascops asio*	91
	Great horned owl	*Bubo virginianus*	9
	Barred owl	*Strix varia*	3
	Long-eared owl	*Asio otus*	1
	Northern saw-whet owl	*Aegolius acadicus*	114
Smith et al. 1994	Sebastian Inlet State Park, Brevard County and Indian River County, FL, USA (1989–1994)		
	Royal tern	*Thalasseus maximus*	84
	Brown pelican	*Pelecanus occidentalis*	11
	Sandwich tern	*Thalasseus sandivicensis*	2
	Black skimmer	*Rynchops niger*	1
Codoner 1995	Conneticut, USA (1960–1993)		
	Unidentified birds	n/a	187
Sutton 1996	Garden State Parkway, Cape May County, and Atlantic, Burlington, Ocean, Cumberland, Gloucester Counties, NJ, USA (Winter 1988–1989, 1995–1996)		
	Northern saw-whet owl	*Aegolius acadicus*	129
Bard et al. 2001	Sebastian Inlet State Park, Brevard County and Indian River County, Florida, USA (1989–2001)		
	Royal tern	*Thalasseus maximus*	148
Fahrig et al. 2001	Route 905, Key Largo, Monroe County, FL, USA (1995–1999)		
	Warblers	n/a	132
	Chuck Will’s widow	*Antrostomus carolinensis*	109
	Catbird	n/a	87
	Cardinal	*Cardinalis cardinalis*	50
	Screech owl	*Megascops asio*	34
Mumme et al. 2001	Archbold Biological Stn., Highlands County, FL, USA (1986–1995)		
	Florida scrub-jay	*Aphelocoma coerulescens*	11
Moore and Mangel 1996	I-5 and Hwy. 113, Sacramento County, CA, USA (May–Nov 1995)		
	American wigeon	*Anas americana*	1
	Mallard	*Anas platyrhynchos*	12
	Short-eared owl	*Asio flammeus*	1
	Burrowing owl	*Athene cunicularia*	1
	Great horned owl	*Bubo virginianus*	6
	Red-tailed hawk	*Buteo jamaicensis*	12
	Red-shouldered hawk	*Buteo lineatus*	1
	Northern harrier	*Circus cyaneus*	2
	White-tailed kite	*Elanus sp.*	1
	Black-crowned Night-heron	*Nycticorax nycticorax*	1
	Cliff swallow	*Petrochelidon pyrrhonota*	1
	Ring-necked pheasant	*Phasianus colchicus*	17
	Barn owl	*Tyto alba*	227
Smith and Dodd 2003	Hwy. 441 Paynes Prairie, Alucha County, FL, USA (1998–1999)		
	Red-winged blackbird	*Agelaius phoeniceus*	1
	Cattle egret	*Bubulcus ibis*	4
	Belted kingfisher	*Megaceryle alcyon*	1
	Yellow-billed cuckoo	*Coccyzus americanus*	1
	Turkey vulture	*Cathartes aura*	1

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	Yellow-rumped warbler	*Setophaga coronata*	27
	Palm warbler	*Setophaga palmarum*	1
	Gray catbird	*Dumetella carolinensis*	1
	American coot	*Fulica americana*	2
	Snipe	*Gallinago sp.*	1
	Common moorhen	*Gallinula galeata*	10
	Common yellowthroat	*Geothlypis trichas*	11
	Least bittern	*Ixobrychus exilis*	9
	Swamp sparrow	*Melospiza georgiana*	10
	Northern mockingbird	*Mimus polyglottos*	1
	Eastern screech owl	*Megascops asio*	1
	Sora	*Porzana carolina*	2
	Boat-tailed grackle	*Quiscalus major*	2
	Virginia rail	*Rallus limicola*	1
	Eastern bluebird	*Sialia sialis*	1
	Chipping sparrow	*Spizella passerina*	3
	Eastern phoebe	*Sayornis phoebe*	1
	Tree swallow	*Tachycineta bicolor*	4
	Carolina wren	*Thryothorus ludovicianus*	3
	Mourning dove	*Zenaida macroura*	1
	Unidentified bird	n/a	39
Boves 2007	Interstate 48, Boise, Ada County to Burley, Cassia County, ID, USA (July 2004–June 2006)		
	Barn owl	*Tyto alba*	812
Glista et al. 2008	Lindberg Road, SR 26, US 231, and South River Rd, Tippecanoe County, IN, USA (2005–2006)		
	Red-winged blackbird	*Agelaius phoeniceus*	8
	Canada goose	*Branta canadensis*	2
	Green heron	*Butorides viriscens*	1
	American goldfinch	*Spinus tristis*	1
	Northern cardinal	*Cardinalis cardinalis*	9
	Chimney swift	*Chaetura pelagica*	36
	Northern flicker	*Colaptes auratus*	1
	Gray catbird	*Dumetella carolinensis*	1
	Horned lark	*Eremophila alpestris*	1
	Barn swallow	*Hirundo rustica*	5
	Red-headed woodpecker	*Melanerpes erythrocephalus*	2
	Song sparrow	*Melospiza melodia*	9
	Brown-headed cowbird	*Molothrus ater*	2
	Eastern screech owl	*Megascops asio*	6
	House sparrow	*Passer domesticus*	15
	Indigo bunting	*Passerina cyanea*	3
	Ring-necked pheasant	*Phasianus colchicus*	2
	Sora	*Porzana carolina*	1
	Common grackle	*Quiscalus quiscula*	6
	Chipping sparrow	*Spizella passerina*	1
	Eastern meadowlark	*Sturnella magna*	2
	European starling	*Sturnus vulgaris*	11
	Tree swallow	*Tachycineta bicolor*	1
	House wren	*Troglodytes aedon*	1
	American robin	*Turdus migratorius*	18
	Mourning dove	*Zenaida macroura*	4
	Unknown bird	n/a	56
Brown and Brown 2013	Paxton to Oshkosh, NE, Keith and Garden Counties, USA (1983–2011)		
	Cliff swallow	*Petrochelidon pyrrhonota*	104

†n/a: genus, species, or number of mortalities was not identified in a given study.

provincial transportation departments or ministries. We obtained an estimate of road lengths with traffic volume attributed to them (New Brunswick Department of Transportation and Infrastructure 2009, Ontario Ministry of Transportation 2009, Prince Edward Island Department of Transportation and Infrastructure Renewal 2010, Saskatchewan Ministry of Highways and Infrastructure 2010, Alberta Ministry of Transportation 2011, Manitoba Infrastructure and Transportation 2011, Transports Québec 2011, British Columbia Ministry of Transportation and Infrastructure 2012). The provincial databases on annual average daily traffic (AADT) report on only a portion of the roads (17%-28% of 1- and 2-lane roads for ecozones we studied). Therefore, it was assumed that the AADT of the subsample of 1- and 2-lane paved roads for which data was available was representative of AADT throughout the complete national road network for this road type.

Table 2. Surveys of avian mortality attributed to collisions with vehicles utilized in calculations of total birds killed/km/d on Canadian road networks.

Locality	Source	Survey yr	Total # of dead birds/km/d [Total # of dead birds/100 km/d]	Km road surveyed [Habitat type surrounding survey route]	Survey frequency [Total # of surveys]	Traffic volume as # vehicles/24 h	Total # of dead birds	Total # of dead passerines	Total # of dead owls	Total # of species
Athens, OH, USA	Seibert and Connover 1991	1987–1988	0.26 [26]	1.6 [broadleaf]	daily [50]	low w/o estimate	21	16	2	12
Big Creek National Wildlife Area, ON, Canada	Ashley and Robinson 1996	1979, 1980, 1992, 1993	0.51 [51]	3.6 [wetland]	daily [716]	3,050–2,800	1,301	973	2	62
vicinity of Banff National Park, AB, Canada	Clevenger et al. 2003	1997–2000	0.0041 [0.41]	105.6 (mainly 2-lane, partial 4-lane) [coniferous]	daily [554]	14,000–35,000 seasonal (TransCanada Hwy)	242	...†	...	...
vicinity of Banff National Park, AB, Canada	Clevenger et al. 2003	1997–2000	0.00093 [0.093]	142.5 (2-lane) [coniferous]	daily [554]	1,068–3,231 (parkway)	74	...	...	...
IN, USA	Glista et al. 2008	2005–2006	0.39 [39]	1.8 [wetland]	daily [124]	6,287	88	...	...	...
IN, USA	Glista et al. 2008	2005–2006	0.091 [9.1]	2.9 [mixed forest]	daily [124]	1,900	33	...	...	...
IN, USA	Glista et al. 2008	2005–2006	0.068 [6.8]	3.9 [cropland]	daily [124]	3,404	33	...	...	...
IN, USA	Glista et al. 2008	2005–2006	0.12 [12]	3.4 [broadleaf]	daily [124]	1,930	51	...	...	...

†... = not recorded

Traffic volume is considered an important factor in the occurrence of avian roadkill (e.g., Illner 1992). Therefore, we accounted for traffic volumes among road types by estimating avian roadkill on roads in Canada which were similar in volume to those reported in the literature. The provincial AADT databases show that 1- and 2-laned paved roads in Canada outside major population centers have low to intermediate AADT of <11,000 on average, and these conditions were comparable to those in studies used in avian casualty estimates per ecozone (Table 2). We accounted for differences in avian mortality for the high- and low-volume roads in coniferous ecozones because data were available for these (Clevenger et al. 2003). The length of roads that were considered high volume in the coniferous ecozone was calculated by determining the length of roads that had maximum AADT above 14,000 relative to the total length of roads for which AADT is available, that is, about 27% of all 1- and 2-lane paved roads in coniferous forests. This relative

Fig. 1. Canada’s land cover including wetlands†, geographic range for Barn owls (*Tyto alba*) in British Columbia, Canada, and locations of sites where studies of avian mortality attributed to vehicle collisions have been conducted in Canada. † Natural Resources Canada 2012*a*, *b*

Notes:

1 = Lower Mainland and Central Fraser Valley (Highways 1, 1A, 9, 10, 11, 15, 99 and 99A, and secondary roads; 1987, 1995–2005; Preston and Powers 2006)

2 = South Okanagan valley, British Columbia, Canada (2001–2008; Potvin and Bishop 2010)

3 = Trans-Canada Highway (Seebe, Kicking Horse Pass, Bow Valley Parkway), Alberta, Canada (1997–2000; Clevenger et al. 2003)

4 = Alberta, Canada (1973–1983; Kerlinger and Lein 1988)

5 = Provincial Trunk Highway 1 between Hadashville and Falcon Lake, Manitoba, Canada (1 Jan–19 Apr, 1980; Nero and Copland 1981)

6 = Big Creek National Wildlife Area, Lake Erie, Ontario, Canada (1979–1993; Ashley and Robinson 1996)

7 = Frontenac, Lanark, Leeds, and Russell Counties in south-eastern Ontario, and Gatineau County, Quebec, Canada (1972; Oxley et al. 1974)

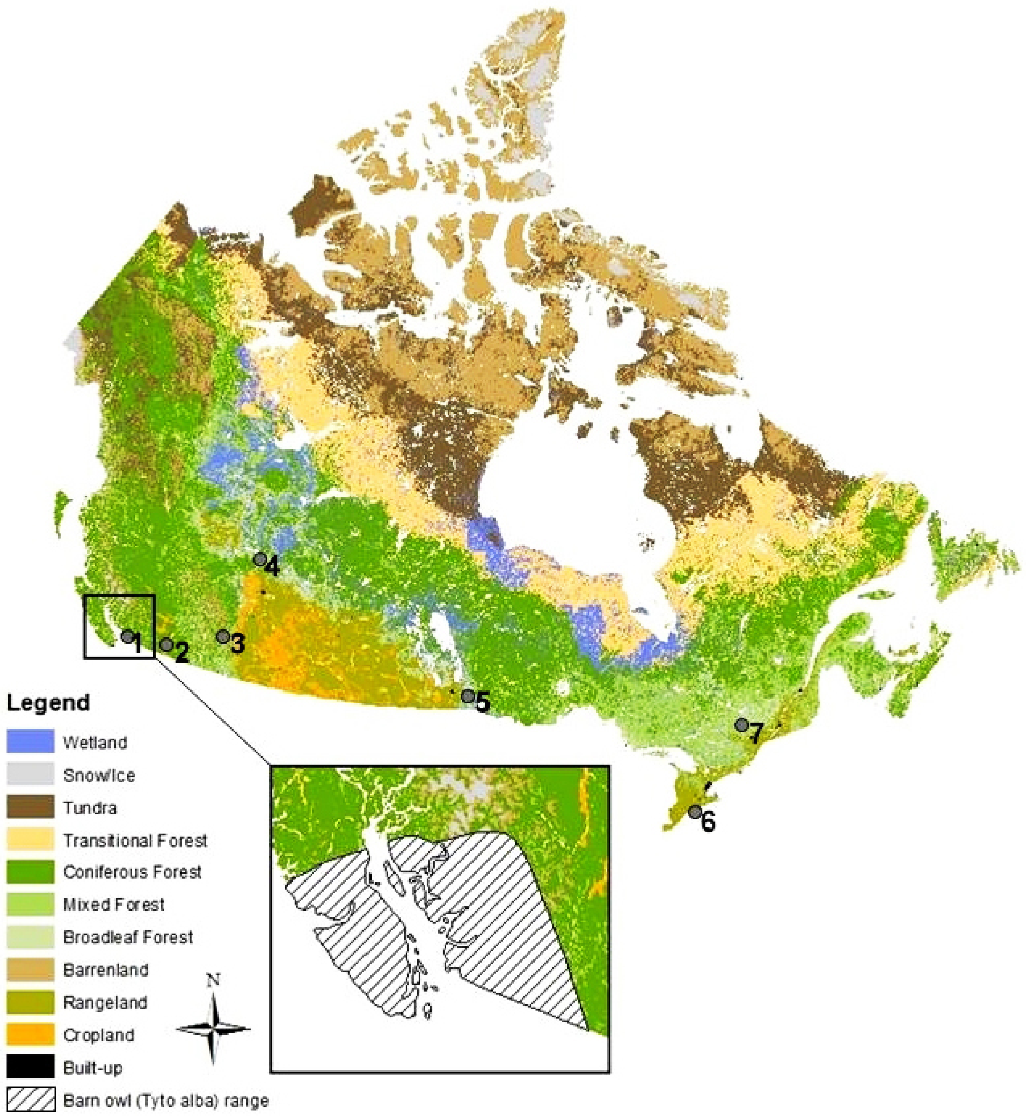

Table 3. Total birds estimated to be killed annually by collisions with vehicles on 1- and 2-laned paved roads in Canada, outside major metropolitan areas.

Total birds killed/yr (i.e., 122 d) (unadjusted)	Total birds killed/yr (i.e., 122 d) (adjusted for scavenging, etc. bias w/ factor 2.97)	Literature values (total birds killed/km/d)	Road length (km)‡	Ecozone†	Average value	References
2,064,667	6,132,060	0.157	107,792.9	broadleaf and mixed forest	0.26	Seibert and Connover 1991 Glista et al. 2008
					0.1209, 0.091	
235	697	0.0041	468.9	coniferous high-volume roads§	...	Clevenger et al. 2003
4,784	14,209	0.00093	42,167.3	coniferous low-volume roads|	...	Clevenger et al. 2003
350,886	1,042,132	0.068	42,295.8	cropland	...	Glista et al. 2008
1,664,144	4,942,507	0.068	200,595.9	90% of rangeland area¶	...	Glista et al. 2008
380,687	1,130,639	0.14	22,288.43	10% of rangeland area¶	...	Seibert and Connover 1991 Glista et al. 2008
184,735	548,662	0.45	3,364.9	wetland	0.51	Ashley and Robinson 1996 Glista et al. 2008
					0.39	
4,650,137 (total, all ecozones)	13,810,907 (total, all ecozones)					
841,161 (standard deviation)	2,498,247 (standard deviation)					

†All ecozones, except wetlands, based on Natural Resources Canada 2012*a*. Table 4). Wetlands based on Natural Resources Canada 2012*b*.

‡Total length of 1- and 2-lane road network per ecozone, excluding major metropolitan areas and exit ramps.

§Coniferous ecozone containing 4-lane roads had >14,000 daily vehicle maximum.

|Coniferous ecozone containing all 1- and 2-lane roads with daily vehicle maximum <14,000 vehicles.

¶In areas designated as < 10% treed areas (“rangeland”), we estimated the # of dead birds/km/d found in cropland (Glista et al. 2008; Table 4) for 90% of the road network in this zone. For the 10% treed areas within “rangeland,” the # of dead birds/km/d was calculated as an average of the values for mixed forest and broadleaf forest found in the literature.

value was 1.1%. We assumed this percentage was constant and applied it to the total length of 1 and 2-lane roads in coniferous forests (Table 3) to calculate an estimate of deaths on high-volume paved roads in the coniferous ecozone. The remaining road length (98.9%) of the total was assumed to be lower volume roads in the coniferous forest zone (Table 3).

Seasonal avian collisions with vehicles

Many studies report seasonal differences in collision rates between birds and vehicles (Erritzoe et al. 2003, Kociolek and Clevenger 2011), and for most birds the peak collision period appears to be during the breeding and fledgling period. For many species in Canada, this occurs over a 4-mo period, but the timing of breeding and fledgling varies among species (Ottawa Field Naturalists’ Club 2005). To account for seasonal collision rates, the number of bird mortalities/km/d was calculated for a 4-mo period representing a courtship, breeding, and fledging period in Canada—which equals 122 d (30 d + 30 d + 31 d + 31 d). The number of birds dead/km/d was multiplied by the length of roads and 122 d, for estimates of the number of birds killed/yr during the breeding season.

Table 4. Proportions of avian orders and total sample size of birds reported, as compiled from North American reports of avian casualties attributed to collisions with vehicles.

	North America†		USA‡		Canada§	
Order	Total	%	Total	%	Total	%
Accipitriformes	9	0.1	9	0.2	0	0
Anseriformes	38	0.6	18	0.4	20	1.06
Apodiformes	36	0.6	36	0.8	0	0
Caprimulgiformes	117	1.9	116	2.7	1	0.05
Charadriiformes	264	4.3	247	5.8	17	0.9
Ciconiiformes	4	0.1	4	0.1	0	0
Columbiformes	52	0.8	50	1.2	2	0.11
Coraciiformes	4	0.1	1	0	3	0.16
Cuculiformes	21	0.3	17	0.4	4	0.21
Falconiformes	47	0.8	45	1.1	2	0.11
Galliformes	92	1.5	79	1.9	13	0.69
Gruiformes	51	0.8	37	0.9	14	0.74
Passeriformes	2,465	40	1,240	29	1,225	65.1
Pelecaniformes	14	0.2	13	0.3	1	0.05
Piciformes	255	4.2	252	5.9	3	0.16
Strigiformes	1,539	25	1,470	35	69	3.67
Not identifiable	1,132	18	624	15	508	27
Total:	6,140	100	4,258	100	1,882	100

†Based on a compilation of the following studies: Stoner 1925, Dill 1926, Robertson 1930, Cottam 1931, Scott 1938, Sargeant 1973, Oxley et al. 1974, Nero and Copland 1981, Decker 1987, Kerlinger and Lein 1988, Seibert and Conover 1991, Loos and Kerlinger 1993, Smith et al. 1994, Codoner 1995, Ashley and Robinson 1996, Moore and Mangel 1996, Sutton 1996, Bard et al. 2001, Fahrig et al. 2001, Mumme et al. 2000, Clevenger et al. 2003, Smith and Dodd 2003, Glista et al. 2008, Potvin and Bishop 2010, Boves and Belthoff 2012, Brown and Brown 2013. (Note: To provide a more representative sample, this compilation excludes Case (1978), in which 7,195 *P. colchicus* were reported as casualties.)

‡Based on a compilation of the following studies: Stoner 1925, Dill 1926, Robertson 1930, Cottam 1931, Scott 1938, Sargeant 1973, Decker 1987, Seibert and Conover 1991, Loos and Kerlinger 1993, Smith et al. 1994, Codoner 1995, Moore and Mangel 1996, Sutton 1996, Bard et al. 2001, Fahrig et al. 2001, Mumme et al. 2000, Smith and Dodd 2003, Glista et al. 2008, Boves and Belthoff 2012, Brown and Brown 2013. (Note: To provide a more representative sample, this compilation excludes Case (1978) in which 7,195 *P. colchicus* were reported as casualties.)

§Based on a compilation of the following studies: Oxley et al. 1974, Nero and Copland 1981, Kerlinger and Lein 1988, Ashley and Robinson 1996, Clevenger et al. 2003, Potvin and Bishop 2010.

Bias estimates for small birds

Where birds are placed on roads and surveyed thereafter, the range in scavenging occurrence is 50%–93% for small birds disappearing from roads after 24 h, by scavenging, or by being crushed beyond recognition (Korhonen and Nurminen 1987, Slater 2002, Erritzoe et al. 2003, Antworth et al. 2005). Using those ground-truthed findings, a mean scavenging rate of 66.4% for small birds, which translates to a factor of 2.97 in our calculations, was determined using rates of 50% (Korhonen and Nurminen 1987), 50% (Erritzoe et al. 2003), 93% (Slater 2002), and 72.6% (Antworth et al. 2005).

Comparisons to other countries

To compare avian casualty estimates from vehicles for Canada to those in other countries, the highest available estimates reported in the literature for all countries (total birds killed annually, unadjusted for scavenging) were calculated (on a 100 km casualty-rate basis) using current national road-length estimates for each country for all paved roads excluding expressways (United Nations Statistics Division 2011, Central Intelligence Agency 2013).

Barn owl case study

For Barn owls, two studies conducted on this species in western North America were available and reported detailed counts of birds found dead on 4-lane roads in rural areas and the outskirts of metropolitan areas (Moore and Mangel 1996, Boves and Belthoff 2012). Scavenging and observer biases were also evaluated and the total of birds killed/km/d was adjusted for these factors (Boves and Belthoff 2012). For southern Idaho, the rate reported was 1.64 dead Barn owls/km/yr (i.e., 0.0044/km/d) and the adjusted rate (5.99 owls/km/

yr; 0.0164/km/d) was 3.6 times higher than the initial estimate (Boves and Belthoff 2012). For the Sacramento area of California, the estimate was 1.85 dead owls/km/yr (i.e., 0.005/km/d; Moore and Mangel 1996).

We applied those estimates to road networks in southern British Columbia for the geographic range where Barn-owl populations still persist in Canada (Ridgely et al. 2007, Hindmarch et al. 2012). Given that Barn owls utilize foraging habitats both within and outside metropolitan areas in British Columbia (Hindmarch et al. 2012) but the available studies (Moore and Mangel 1996, Boves and Belthoff 2012) only report barn-owl roadkill rates on 4-lane paved roads, we estimated the total number of Barn owls killed with and without adjustment (factor = 3.6) for scavenging and other biases (Boves and Belthoff 2012) for the 426 km estimated for the 4-lane paved road network (Geobase 2011), excluding ramps, but including metropolitan areas, in southern British Columbia, Canada. We averaged the unadjusted values for birds/km/d dead estimated by Boves and Belthoff (2012) and Moore and Mangel (1996), and multiplied this value (0.0047/km/d) by 426 km to generate an estimate of the number of Barn owls killed by vehicular collisions over 122 d, representing the annual breeding season.

RESULTS

Most birds reported as roadkill in North America are passerines and owls (Table 1), but our casualty estimates for birds in Canada could represent up to 17 orders of birds (Tables 1, 4). Of 28 studies conducted in North America from 1924–2013, 157 species and 17 orders of birds and a minimum of 14,287 specimens have been found dead on roads (Table 1). Among the seven Canadian studies in existence, 80 species and 2,834 specimens have been found dead on roads, representing species from 14 orders of birds (Table 1, 4). In all instances, the most commonly birds found were Passeriformes (27%–65%). Strigiformes were the second most commonly found bird taxa, but at a much lower proportion of the total (3%–35%; Tables 1, 4).

Among surveys of road-killed birds, the estimate for the number of birds/km/d killed ranged from 0.093–51/100 km/d (Table 2). The highest rates (51/100 km/d and 39/100 km/d) were found on roads through wetlands, followed by rates on roads through mixed and broadleaf forests (9.1–26/100 km/d), and cropland (6.8/100 km/d) (Table 2). The lowest rates were on roads in coniferous habitats in Banff National Park, Alberta. On 2-lane roads with low traffic volume, the rate was 0.093/100 km/d, which was an order of magnitude lower than rates on 2-lane and 4-lane roads with high seasonal traffic volume (0.41/100 km/d) (Table 2).

Estimates of Canadian losses

On Canadian 1- and 2-lane paved roads found outside of major urban centers, the unadjusted number of bird mortalities/yr during the 122-d breeding season was 4,650,137 +/- 841,161 on roads traversing through deciduous, coniferous, cropland, wetlands, and nonagricultural landscapes with <10% treed area (Table 3). On average, this represents 1,167 birds/100 km killed during the 122 d of the breeding season in Canada. Adjusted for scavenging, this estimate was 13,810,906 +/- 2,498,247 (3462 dead birds/100 km; Table 3).

The unadjusted estimates for birds killed on roads on a national basis for all countries for which data has been reported ranges from 350,000–60 m (Table 5). Our unadjusted estimate of 4.6 m birds killed/yr by vehicle collisions (during the 122 d of the breeding season) in Canada is comparable to the annual estimate for Denmark but lower than annual raw estimates in most other countries with large and dense road networks. Our estimate of 1,167 dead birds/100 km is similar to Denmark, Sweden, Germany, and the USA, although the estimates for these countries are somewhat dated (Table 5).

For Barn owls, the unadjusted number of birds killed annually on 4-lane roads during the breeding and fledging season, within the species geographic range in southern British Columbia, Canada, was estimated as 244 owls and, when adjusted for scavenging and observer bias (3.6 factor), the total was 851 owls.

DISCUSSION

Birds are attracted to roads as a location of concentrated resources, especially food (Erritzoe et al. 2003, Rytwinski and Fahrig 2012). The road and road allowances attract prey populations, in particular small mammals and carrion, but also insects and worms that are washed out of the soil onto roads, and snakes that are attracted to the heat, as are some birds (Lindsdale 1929, Tabor 1974, Erritzoe et al. 2003, Kociolek and Clevenger 2011). Other resources found near or on roads include grit and salt (Bennett 1991, Mead 1997, Erritzoe et al. 2003), puddles that serve as a water source (Hodson 1962), and telephone and power lines that serve as perches (Robertson 1930). Road hedgerows offer breeding sites and shelter (Mead 1997). Roads even serve as migration routes (Forman and Alexander 1998). It is no surprise, then, that many birds succumb to the sudden impact of automobiles while they focus on these resources along roads.

Some scholars argue that it is impossible to make comparisons among locations, or combine roadkill survey results for birds, as we have done here. In discussing their roadkill survey data, Seibert and Conover (1991) stated there was

> "*no attempt to extrapolate or quantify the data in terms of numbers per km of highway or to compare our results with other published information. The methodologies employed by others are too disparate to make comparisons with our material useful. Variables such as weather, traffic volume, scavenging pressure, not to mention the efficiency of the collectors, are not possible of replication.*"

Table 5. Highest reported national estimates of total number of birds killed annually by vehicle collisions

Country	Range in national estimates of birds killed annually by vehicle collisions	Number†/100 km	Reference
Netherlands	653,000 (1973–1976)	487	Jonkers and de Vries 1977, as cited in Erritzoe et al. 2003
Denmark	350,000 (1979–1981)– 1.1 m (1964–1965)	1,526	Thomsen 1992, as cited in Erritzoe et al. 2003, Bruun-Schmidt 1994, as cited in Erritzoe et al. 2003
Sweden	500,000 (1977)– 8.5 m (1989–1998)	1,488	Göransson et al. 1978, as cited in Erritzoe et al. 2003, Svensson 1998, as cited in Erritzoe et al. 2003
Bulgaria	7 m (1979–1980)	37,280	Nankinov and Todorov 1983, as cited in Erritzoe et al. 2003
Germany	9.4 m (1987–1988)	1,488	Fuellhaas et al. 1989, as cited in Erritzoe et al. 2003
England	10–60 m (1990s)	15,349	Mead 1997
USA	57.2 m (1973)	1,330	Banks 1979
Canada	4.6 m (2013)	1,167	This study

†The average number of birds killed/100km using current road length estimates for all paved roads, excluding expressways (United Nations Statistics Division 2011, Central Intelligence Agency 2013), and the highest estimates of total birds killed annually, unadjusted for scavenging.

We have attempted to account for many of those factors in our work, whereas past reports of avian roadkill occurrence on a national basis for other countries have not. Even so, our estimates are not complete and do not account for all possible biases. The annual Canadian estimates assumed avian roadkills were occurring on every km of 418,974 km of 1- and 2-lane roads (Statistics Canada 2010, Geobase 2011), which may be an overestimate of the rate of occurrence of roadkill; this estimate applies only to about a quarter of the total length of roads in Canada (Statistics Canada 2010, Geobase 2011). Because we lacked literature values for roadkill on unpaved roads for temperate climates, we did not account for roadkill on unpaved roads. Although one estimate of the incidence of roadkill on unpaved roads indicates it is 13 times lower than on paved roads (Kline and Swann 1998), it still occurs. The estimated length of 2-lane unpaved roads in Canada is about 626,600 km (Statistics Canada 2009). We attempted to account for traffic volume, but did not account for traffic speed, which is considered a relevant factor in the occurrence of avian roadkill (Illner 1992). Furthermore, our estimates are necessarily based on very few studies extrapolated to a large network of roads over a broad area. Even with all of these variables, and differences in calculations among countries, the number of birds per 100 km estimated to be killed by vehicles was surprisingly similar among most countries.

Clustering of avian roadkill events certainly occurs (Slater 2002, Clevenger et al. 2003) and is probably an important source of error in these estimates. Many factors can influence the occurrence of roadkill “hotspots,” especially the type of habitat found beside the road (Orlowski 2005, Crispim de Oliveira Ramos et al. 2011, Kociolek and Clevenger 2011, Rosa and Bager 2012). For studies that we included in this analysis, those reporting the highest road mortality rates for birds (Ashley and Robinson 1996, Glista et al. 2008) were conducted on roads with a relatively low volume of traffic but occurring within or adjacent to wildlife preserves potentially containing a high density of wildlife.

Our estimate of a 2.97 scavenging factor for small birds was close to the estimate of 3.6 for larger birds such as Barn owls (Boves and Belthoff 2012). Those scavenging factors are also consistent with meta-analyses for persistence of carcasses of small birds on or near roads (Santos et al. 2011) and ground-truthed studies of birds killed on roads (Teixeira et al. 2013) and in scavenger removal trials (Smallwood et al. 2010). They are also similar to scavenging rates of birds in agricultural fields (Balcombe 1986, Kostecke et al. 2001) and communication towers (Longcore et al. 2012). Other factors were still not incorporated into those estimates. Groundtruthing surveys comparing results on the same stretches of roads surveyed on foot compared to surveyors in vehicles find that a large portion of animals killed by cars remain undetected by drivers (Kline and Swann 1998). Variation in observers can also affect detection rates of dead animals (Kline and Swann 1998). In Brazil, the biweekly samples for roadkill birds resulted in samples that were similar to those done weekly, but it was concluded that the effects of highways on the avifauna must be evaluated with caution and can require intensive monitoring for at least a yr if the objective is to identify the largest number of species impacted (Bager and Rosa 2011). Birds can even get caught in the grills of vehicles and be carried away from the survey site (Mumme et al. 2000).

The impact on populations of the loss of birds attributed to vehicular collisions is difficult to assess (Kline and Swann 1998). There are approximately 5.2 b land birds in southern Canada, based on an average density of 450 breeding pairs/ km^2 derived from the Canadian Breeding Bird Census database (Kennedy et al. 1999, stratifying bird densities by ecoregion, and assuming a juvenile to adult bird ratio of 3–1 as in Calvert et al. 2013. The loss of 13.8 m birds represents an approximate loss of just under 0.26% of all land birds in southern Canada each yr. Although this proportion is low, it is only one of multiple anthropogenic factors that reduce bird populations in Canada (Calvert et al. 2013).

Estimates of mortality for individual species are needed to assess the biological significance of anthropogenic stressors on bird populations (Longcore et al. 2012). For example, to assess the impact of communication towers, the bird-mortality rates attributed to communication towers were compared with the estimated populations of a range of species in North America (Longcore et al. 2013). Although this research was an extension of current knowledge, they noted that, ideally, they would have compared mortality to individual populations of species within a Bird Conservation Region (Longcore et al. 2012). This was not possible because tower mortality occurs mostly during migration and, therefore, mortality could not be connected to local populations. Our analysis was equally hindered by such constraints, but primarily by a lack of studies within Canada upon which to base our estimates. We did find Canadian and American studies reporting passerines and owls as the most common orders dead on roads, which is consistent with studies in Europe, the UK, and Scandanavia (Erritzoe et al. 2003).

Although young passerines and owls are found in higher numbers than adults in most roadkill surveys (Erritzoe et al. 2003), there are exceptions. Banding data of Bullfinches (*Pyrrhula pyrrhula*) found that adults are more likely to die as roadkill (14.2%) than are young (7.1%; Mead 1997). The specimens of owls killed on roads are biased to adult females, or fledged birds, depending on the time of yr (Moore and Mangel 1996, Boves and Belthoff 2012). As adults die, the remaining nest is deprived of food, which reduces the potential for fledging. Such factors create further losses of birds and impacts on bird populations that are not quantified in our analysis.

It appears that birds collide with vehicles regardless of their typical habitat preferences, and despite the fact that migration movement usually occurs at higher altitudes than roadsides. Even species that often perch high in forests such as the Red-eyed Vireo (*Vireo olivaceus*) or those that restrict foraging to the forest understory such as the Kentucky Warbler (*Oporornis formosus*) and Yellow-breasted Chat (*Icteria virens auricollis*) apparently cross roads at low altitudes and are reported as roadkill (Siebert and Conover 1991, Potvin and Bishop 2010).

As reported for other avian collision scenarios such as communication towers (Longcore et al. 2012), losses of birds to roadkill may be considerably higher in certain localities and the impact could be more significant for species at risk that have extremely small populations located in limited geographic pockets (van der Zande et al. 1980, Forman and Alexander 1998, Potvin and Bishop 2010, Rosa and Bager 2012). For Florida Scrub Jays (*Aphelocoma coerulescens*), a threatened species in the USA, roadside territories are population sinks specifically because of the rates of roadkill among breeding adults and fledged birds. Territories adjacent to roads can maintain populations only through immigration (Mumme et al. 2000).

The loss of healthy, long-lived, top predators in any ecosystem is cause for concern. During a 10-yr survey (1992–2001) of highways in northeastern France, 1,731 Barn owls, 811 Long-eared owls (*Asio otus*), and 123 Tawny owls (*Strix aluco*) were found as roadkill (Baudvin 2004). These findings have been repeated throughout the USA (Loos and Kerlinger 1993, Sutton 1996), Europe (Hernandez 1988, Bairlein and Sonntag 1994) and the UK (Hickling 1983, Harding 1986, Mead 1997). Road mortality is a major factor in the decline in Barn-owl populations in the UK (Ramsden 2003) and Germany (Bairlein and Sonntag 1994). In southern British Columbia, Canada, the population size for Barn owls is estimated to be only 250–1,000 breeding pairs (Committee on the Status of Endangered Wildlife in Canada 2010). The loss of as few as 244 (unadjusted estimate) to as much as 851 (adjusted) individual Barn owls/yr from that population could be a substantial threat to the population even if 75% of them were juveniles, as reported in USA studies (Boves and Belthoff 2012). In Idaho, female Barn owls were more commonly killed by vehicles than males and this appeared to be driven by female mortality during the nonbreeding season (Boves and Belthoff 2012).

Many variations in road characteristics determine the occurrence of birds killed on roads. Effective mitigation is often species- or taxa-specific; sometimes expensive, as in the case of retrofitting roads or changes in design, for example; and politically unpopular, as in the case of road closures or speed bumps, for example (Kline and Swann 1998). The volume of traffic, speed of vehicles, individual configuration of roads, and road density are the most frequently mentioned factors affecting bird mortality on roads (Clevenger et al. 2003, Erritzoe et al. 2003, Holm and Laursen 2011, Kociolek and Clevenger 2011). For example, in hedgerows near roads with fast (60–80 km/h) and frequent traffic (1,500–2,000 vehicles/d), the mortality of Great tit (*Parus major*) broods was higher than in hedgerows beside roads with slower speeds (10–30 km/h), less traffic (30–50 vehicles/d), and hedgerows with no disturbance (Holm and Laursen 2011).

Provision of features such as berms, vegetation, tunnels, and drift fencing may encourage or prevent nonwinged animals from crossing roads (Pons 2000). The mobility of birds and the variation in flying styles used by birds as they forage creates a more complex problem. Creating obstacles that force birds to fly higher, reducing the availability of small mammals on road verges, and/or creating prey-rich foraging areas away from roads are mitigation measures that have been recommended in the UK for Barn owls (Ramsden 2003) and other birds (Huijser et al. 2008). However, road configuration is also an important factor, as is the species examined. Barn owls in France were found to have been killed more often crossing elevated sections of roads beside forests (Massemin and Zorn 1998). In the environs of Banff National Park, Alberta, Canada, it was found that the higher the road elevation, the lower the incidence of road-killed birds (Clevenger et al. 2003). Like hedgerows, the presence of a center median can also increase collisions of birds with vehicles, and the type of vegetation in the median can attract or repel birds (Clevenger et al. 2003). Forested medians may attract birds because they offer a natural habitat in the unnatural gap in the forested habitat on either side of the road (Clevenger et al. 2003).

Where possible, keeping vehicles off roads altogether, or at least in parks at certain times of the day, can make a difference in mitigating this problem on a local scale. In a national park in the USA, loop roads closed at night had fewer animals killed compared with through roads (Kline and Swann 1998), suggesting that the complete closure of some roads in parks at night would be a valuable mitigation method. Road lighting appears to blind owls and precipitate collisions with vehicles (Mead 1997), suggesting that in parks, light pollution could be addressed as part of a strategy to create an overall benefit for wildlife and a more natural atmosphere within the park setting.

In 1994, in response to high numbers of birds (mainly Royal terns, *Sterna maxima*) killed on roads, structures were placed on a 2-lane bridge on the main roadway bisecting the Sebastian Inlet State Park, Florida, USA. The mitigation consisted of 3-m high poles attached vertically 3.7 m apart on both sides of a 2-lane bridge (Egensteiner et al. 1998, Bard et al. 2001). The problem being addressed was that birds were hitting the bridge structure; therefore, the purpose of the poles was to direct birds up and away from traffic. These bridge poles reduced vehicle collisions with Royal terns and Brown pelicans (*Pelecanus occidentalis*) by 64% (Huijser et al 2008).

Bird mortalities caused by vehicular collisions are recognized as a conservation concern at both local and national scales, but are more challenging to address than with other vertebrates (Bennett 1991, Mead 1997, Forman and Alexander 1998, Lode 2000, Harden 2002, Seiler and Helldin 2006, Watts et al. 2007, Leu et al. 2008, Kociolek and Clevenger 2011). Although millions of birds, and a large portion of the Barn-owl population may be lost each year, there have been no mitigative measures for birds incorporated into road construction in Canada. Long-term decisions about road access, closure, engineering, and signage should be influenced by awareness that collisions with vehicles are a growing conservation issue for all wildlife, including birds (Huijser et al. 2008).

Responses to this article can be read online at:
http://www.ace-eco.org/issues/responses.php/604

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