# Bird roadkill occurences in Aragon, Spain

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**Abstract**
*Bird roadkill occurences in Aragon, Spain*. The increase in road networks and vehicular traffic has posed a major threat to vertebrates over the last century. Although it is difficult to determine the annual number of avian–vehicle collisions, 2 to 9 million roadkills have been estimated for Europe, with numbers varying from country to country. Few studies have been conducted at a national or regional level in Spain. In this study we used data from La Alfranca Wildlife Rehabilitation Centre database to determine location, season and incidence of avian–vehicle collisions in the autonomous county of Aragon (Spain). A total of 643 wild birds representing 71 species were killed on roads between 2012 and 2014. Nine of these species have a high incidence of avian–vehicle collisions, four a moderate incidence, and 57 a low incidence. The species with the highest incidence was the griffon vulture (120 individuals). Spatial distribution of avian–vehicle collisions was heterogeneous, and the incidence was highest in July, August and September. We identified 41 reas of high roadkill occurrence, using a number of roadkills per km index (RI): 28 in the province of Zaragoza, nine in Huesca and four in Teruel. Management strategies are proposed to reduce this threat on wild birds.

Key words: Areas of high roadkill occurrence, Mitigation, Necrophagous, Number of roadkills per km index, Raptor, Road ecology

**Resumen**
*Atropellos mortales de aves en Aragón, España.* La expansión de la red viaria y el aumento del tráfico de vehículos se han convertido en una amenaza importante para los vertebrados en el último siglo. Algunas estimaciones sitúan entre 2 y 9 millones los individuos afectados anualmente en Europa, con variaciones entre países. En España existen pocos estudios a escala nacional y autonómica. En este estudio se ha utilizado la base de datos del Centro de Recuperación de Fauna Silvestre de La Alfranca para determinar la localización, temporalidad e incidencia de los atropellos de avifauna que se producen en la comunidad autónoma de Aragón. Se han detectado 643 atropellos mortales de aves silvestres (71 especies) entre los años 2012 y 2014. Nueve de estas especies presentan una incidencia de atropellos alta; cuatro, una incidencia moderada, y 57, una incidencia baja. La especie con la mayor incidencia fue el buitre leonado (120 individuos). La distribución espacial de los atropellos fue heterogénea y julio, agosto y septiembre fueron los meses con mayor incidencia. Se identificaron 41 áreas de incidencia alta de atropellos, usando el índice de atropellos mortales por kilómetro (RI): 28 en la provincia de Zaragoza, nueve en la de Huesca y cuatro en la de Teruel. Se proponen una serie de estrategias de gestión con el fin de reducir esta amenaza para las aves silvestres.

Palabras clave: Áreas de incidencia alta de atropellos, Mitigación, Necrófago, Índice de atropellos mortales por kilómetro, Rapaz, Ecología de carreteras

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## Introduction

Road networks can generate major impacts on wildlife, the two most important being habitat fragmentation and direct mortality. Habitat fragmentation creates barriers that prevent wildlife movements, thereby increasing the rate of local extinction (Fahrig, 2003; Martínez–Freiría and Brito, 2012; Loss et al., 2014), while direct mortality involves death of individuals due to vehicle collisions (Loss et al., 2014; Sáenz–de–Santa–María and Tellería, 2015). Although precise global estimates of the number of collisions are lacking, the number of vertebrate roadkills per year could exceed 1,000 million individuals (PMVC, 2003). Among vertebrates, small mammals are those most likely to be killed on roads because their size allows them to get through highway containment barriers (Haigh, 2012; Saranholi et al., 2016). Scavengers or species with opportunistic feeding habits –such as badgers and martens or vultures and kites– may also have increased possibility of becoming roadkill when they are attracted to corpses on the road.

Although it is complex to estimate the real number of individuals hit on a road network, studies from various countries have shown that the number of bird roadkills is high and a serious problem for conservation. Recent studies indicate an annual average of 199 million birds in the United States (Loss et al., 2014), 9.4 million in Germany (Fuellhaas et al., 1989), 7 million in Bulgaria (Nankinov and Todorov, 1983), 4.6 million in Canada (Bishop and Brogan, 2013), and 2 million in the Netherlands (Schrijver, 1993). In Spain, few estimates are available at a national level. However, 74,600 wildlife collisions were estimated between 2006 and 2012 (Sáenz–de–Santa–María and Tellería, 2015). For birds, the most relevant data may be the 16,036 roadkilled individuals, corresponding to 193 species, during 1990–1992 (PMVC, 2003). Recent studies have been conducted in entire Autonomous Communities (Catalonia: Garriga et al., 2012; Aragón: Vidal–Vallés and Pérez–Collazos, 2016) and large natural areas (Rico–Guzmán et al., 2011; Espinosa et al., 2012; Martínez–Freiría and Brito, 2012).

This study aimed to identify the non–hunted wild bird species with the highest incidence of vehicle collisions in Aragón, Spain, and to determine the locations and the temporality with the greatest incidence.

## Material and methods

### Roadkill maps

Our study area included the entire road network of the Autonomous Community of Aragon, in northeastern Spain. Aragon comprises three provinces (from North to South: Huesca, Zaragoza and Teruel) and covers an area of 47,710 km$^2$. It has a population of around 1,300,000 people. We obtained information on wild bird collisions from the database of the Wildlife Recovery Center (WRC) of La Alfranca (Zaragoza, Spain), which is the only WRC in Aragon. Injured birds were kept at the WRC until death or release. In the case of animals that arrived dead, the cause of the death was determined by the WRC veterinarians through necropsies. WRC database holds information on terrestrial vertebrates collected in the field, injured or dead, from any part of Aragon and admitted for any cause. Given that it is a database from a WRC, it does not include game species, especially large ungulates, which are managed by the *SEPRONA, Servicio de Protección de la Naturaleza* of the *Guardia Civil* (Nature Protection Service of the National Police). We selected only records referring to vehicle collisions of birds in the WRC database and we assumed that all admitted birds (deceased or recovered and released into the wild) would have died without admission to the WRC. When available, UTM coordinates and place–names of the locations helped us to georeference collisions. By using geoprocesses of ArcMap 10.1, we created a layer of points in *shapefile* format that represents the bird collisions recorded in the road network from 2012–2014.

For each record, we manually added the following information: bird species, month and year of collision detection, and category of threat according to regional Aragón law (EN, Endangered; VU, Vulnerable; SAH, Sensitive to the alteration of its habitat; Decree 181/2005). We intersected the road network of Aragon, downloaded from the *Instituto Geográfico de Aragón* (Spatial Data Infrastructure of Aragon: available online at http://idearagon.aragon.es/portal/), to the point layer representing bird collisions. To determine the species with the highest incidence of roadkills, we adapted the incidence categories proposed by Tenés et al. (2007): low (0–3 roadkills per year), moderate (4–6 roadkills per year), high (7–23 roadkills per year) and very high (more than 24 roadkills per year, i.e. two or more roadkills every month).

### Data analyses

To determine roadkill temporality, we classified each roadkill record within seasons (spring: April–June; summer: July–September; autumn: October–December; winter: January–March). We then conducted a Kruskal–Wallis test to assess potential roadkill mean differences between seasons and Nemenyi post–hoc tests to test which levels (seasons) differed from each other. To study the spatial distribution of roadkills in Aragon, we created a grid of 10 x 10 km cells. We inserted the point layer of collisions with the grid to identify the grids with the highest incidences of roadkills (black squares). We calculated the number of roadkills per kilometre Index (RI), taking into account the kilometres of road in each 10 x 10 km cell. We conducted a Pearson correlation test to assess the relationship between number of roadkills and RI (number of roadkills per kilometre index). The areas of high roadkill occurrence were identified by the RI in each of them. We assigned four incidence ranges (very low, low, moderate and high) according to the number of roadkills: very low incidence (RI = 0–0.09, results not shown), low incidence (RI = 0.1–0.19), moderate incidence (RI = 0.2–0.29) and high incidence (RI > 0.3). This information was turned onto the GIS, generating an Aragon map of areas of high roadkill occurrence ordered by wild bird roadkills. In addition, a heat map was created with the Heatmap tool in QGIS (version 2.18.12) with a radius of 10,000 m.

## Results

### Involved species

A total of 643 records of bird collisions (64 % of the total database) were detected, involving 71 species (table 1). The griffon vulture (*Gyps fulvus*) was the species with the highest incidence (120 cases), with a mean of 3.3 vehicle collisions per month during 2012–2014, and it was classified in the Very High category (mean of 40 roadkills per year). In addition, nine species showed a high incidence: common buzzard, black kite, white stork, common kestrel, eagle owl, short–eared owl, little owl, marsh harrier and barn owl (table 1). Four species reached a moderate incidence: tawny owl, red kite, sparrow hawk and scops owl. The remaining species showed a low incidence (table 1). Eleven species affected by road casualties are catalogued in the maximum category of protection according to the Aragón law (Decree 181/2005; table 1).

### Spatial distribution and temporality

The spatial distribution of bird collisions was heterogeneous but associated with the main roads of the Aragon road network, 88.3 % of the bird collisions were reported in the provinces of Zaragoza and Huesca (302 and 266 roadkills, respectively) (fig. 1). The highest incidence of roadkill occurred in September (83 cases), followed by July and August with 80 and 69 roadkills, respectively. Lowest values were recorded in October, November and December (34, 30 and 31, respectively) (fig. 2). The number of roadkills varied among seasons (K–W = 16.127; d.f. = 3; $P < 0.001$), although pairwise comparisons only detected significant differences between summer and autumn ($P < 0.001$; fig. 2). The remaining pairwise comparisons reached *P*–values higher than 0.097. In case of the griffon vulture, the species with the highest incidence, the highest mortalities were reached in September and March (19 and 17 roadkills, respectively) and the minimum in May (5).

### Identification of areas of high roadkill occurrence

We identified 41 areas of high roadkill occurrence, with a total of 238 roadkills. Two cells had a high incidence, while the rest were classified as moderate (5) or low (34) incidence (fig. 3). We found a positive correlation between the number of roadkills and RI (r = 0.734, $P < 0.001$). The number of roadkills also correlated positively with the length of roads in each cell in kilometres (r = 0.533; $P < 0.001$). The number of areas of high roadkill occurrence (28) was highest in the province of Zaragoza, followed by Huesca (9) and Teruel provinces (4) (fig. 3). The species with the highest incidence at areas of high roadkill occurrence were the white stork (5 roadkills) and the black kite (3 roadkills).

## Discussion

### Methodological aspects

Conducting a sampling of wildlife collisions in large areas such as Aragon is a difficult task due to multiple factors, such as detectability (detection of roadkills and injured birds) and carcass persistence times (removal of carcasses by scavenger species or disappearance by multiple vehicle run over) (Bishop and Brogan, 2013; Beckmann and Shine, 2015; Santos et al., 2015; Vidal–Vallés and Pérez–Collazos, 2016). La Alfranca WRC database has relevant data missing due to: (i) lack of game species records, (ii) bias related to areas with a lower/greater presence of Nature Protection Agents, (iii) data deletion of non–informative records (i.e. records without date or location), and iv) lack of citizen awareness to inform the WRC about run over species. Despite these limitations, this database allowed us to determine a list of bird species affected by vehicle collisions in Aragon (table 1), the spatial and temporal distribution of the roadkills (figs. 1, 2), and to identify the areas of high roadkill occurrence where incidence is higher in the region (fig. 3). Furthermore, we suggest management recommendations (see below), linked to more detailed studies confirming the magnitude of bird mortality in the detected black squares.

### Involved species

The griffon vulture was the species with the highest incidence (120 vehicle collisions, table 1), and given its body mass (around 6–11 kg), it poses a serious threat to road safety. Its large population in Aragon (the autonomous community with the second largest population in Spain, the largest being Castilla–León (Hernández, 2009), its high capacity of movement to explore large areas, its heavy weight, making it difficult to take off from the ground, and its strict scavenger feeding habits could explain the high number of collisions. The number of individuals run over annually (34 in 2012, 42 in 2013 and 44 in 2014) may affect the population dynamics of the species (Oschadleus and Harebottle, 2002; Fahrig and Rytwinski, 2009).

The fact that a species with strict necrophagous feeding is the most vulnerable to vehicle collision suggests the accidents occur while the birds are feeding on corpses of other run over vertebrates. This is similar to findings for other species of opportunistic feeding habits, such as black kite, red kite, booted eagle, and common buzzard, which, in some cases, feed on dead animals (Planillo et al., 2015). These predatory opportunistic species can prey 73 % of the animals run over in a few hours (Beckmann and Shine, 2015). Black kite, red kite and common buzzard can become accustomed to travelling and exploiting roads as a source of food (Blanco and Viñuela, 2004; Planillo et al., 2015). This effect might be enforced by high densities of keystone prey species of the Mediterranean ecosystem near roads, according to a study on small mammals (*Apodemus sylvaticus*, *Crocidura russula*, *Mus spretus*; Ruiz–Capillas et

Table 1. List of avian–vehicle collisions in Aragon (2012–2014) with number (N) and incidence (I). Species included in the Aragon Red List: * Endangered; ** Vulnerable; and *** Sensitive to habitat alteration.

*Tabla 1. Listado de las especies de aves silvestres atropelladas en Aragón (2012–2014). Se indica el número de atropellos (N) y su incidencia (I). Especies incluidas en el Catálogo de Especies Amenazadas de Aragón: * en peligro de extinción; ** vulnerable; *** sensible a la alteración de su hábitat.*

| Family | Common name | Scientific name | N | I |
|---|---|---|---|---|
| Accipitridae | Griffon vulture | *Gyps fulvus* | 120 | Very High |
| | Common buzzard | *Buteo buteo* | 53 | High |
| | Black kite | *Milvus migrans* | 46 | High |
| | Western marsh harrier | *Circus aeruginosus* | 26 | High |
| | Red kite *** | *Milvus milvus* | 17 | Moderate |
| | Eurasian sparrowhawk | *Accipiter nisus* | 17 | Moderate |
| | Short–toed snake eagle | *Circaetus gallicus* | 8 | Low |
| | Booted eagle | *Aquila pennata* | 6 | Low |
| | European honey buzzard | *Pernis apivorus* | 4 | Low |
| | Northern goshawk | *Accipiter gentilis* | 5 | Low |
| | Bearded vulture * | *Gypaetus barbatus* | 2 | Low |
| | Egyptian vulture ** | *Neophron percnopterus* | 2 | Low |
| | Hen harrier *** | *Circus cyaneus* | 1 | Low |
| | Montagu's harrier ** | *Circus pygargus* | 1 | Low |
| | Golden eagle | *Aquila chrysaetos* | 1 | Low |
| | Cinereous vulture | *Aegypius monachus* | 1 | Low |
| Alaudidae | Crested lark | *Galerida cristata* | 1 | Low |
| Alcedinidae | Common kingfisher | *Alcedo atthis* | 3 | Low |
| Apodidae | Common swift | *Apus apus* | 2 | Low |
| Ardeidae | Grey heron | *Ardea cinerea* | 8 | Low |
| | Western cattle egret | *Bubulcus ibis* | 2 | Low |
| | Eurasian bittern * | *Botaurus stellaris* | 1 | Low |
| | Purple heron ** | *Ardea purpurea* | 1 | Low |
| Burhinidae | Eurasian stone–curlew | *Burhinus oedicnemus* | 4 | Low |
| Caprimulgidae | European nightjar | *Caprimulgus europaeus* | 11 | Low |
| | Red–necked nightjar | *Caprimulgus ruficollis* | 2 | Low |
| Ciconiidae | White stork | *Ciconia ciconia* | 42 | High |
| Corvidae | Common raven | *Corvux corax* | 3 | Low |
| | Red–billed chough ** | *Pyrrhocorax pyrrhocorax* | 2 | Low |
| Cuculidae | Great spotted cuckoo | *Clamator glandarius* | 2 | Low |
| | Common cuckoo | *Cuculus canorus* | 2 | Low |
| Falconidae | Common kestrel | *Falco tinnunculus* | 39 | High |
| | Lesser kestrel *** | *Falco naumanni* | 4 | Low |
| | Peregrine falcon | *Falco peregrinus* | 4 | Low |
| | Merlin | *Falco columbarius* | 2 | Low |
| | Red–footed falcon | *Falco vespertinus* | 1 | Low |
| | Eurasian hobby | *Falco subbuteo* | 1 | Low |

Table 1. (Cont.)

| Family | Common name | Scientific name | N | I |
|---|---|---|---|---|
| Fringillidae | European greenfinch | *Chloris chloris* | 1 | Low |
| Gruidae | Common crane *** | *Grus grus* | 3 | Low |
| Hirundinidae | Barn swallow | *Hirundo rustica* | 3 | Low |
| | Common house martin | *Delichom urbicum* | 1 | Low |
| Laniidae | Woodchat shrike | *Lanius senator* | 1 | Low |
| Meropidae | European bee–eater | *Merops apiaster* | 3 | Low |
| Motacillidae | White wagtail | *Motacilla alba* | 1 | Low |
| Muscicapidae | European pied flycatcher | *Ficedula hypoleuca* | 2 | Low |
| Oriolidae | Eurasian golden oriole | *Oriolus oriolus* | 2 | Low |
| Otidae | Great bustard * | *Otis tarda* | 1 | Low |
| Paridae | Great tit | *Parus major* | 2 | Low |
| Passeridae | Rock sparrow | *Petronia petronia* | 1 | Low |
| Phalacriciracidae | Great cormorant | *Phalacrocorax carbo* | 2 | Low |
| Picidae | European green woodpecker | *Picus viridis* | 2 | Low |
| | Great spotted woodpecker | *Dendrocopos major* | 1 | Low |
| Podicipedidae | Great crested grebe | *Podiceps cristatus* | 1 | Low |
| Rallidae | Common moorhen | *Gallinula chloropus* | 3 | Low |
| Strigidae | Eurasian eagle–owl | *Bubo bubo* | 36 | High |
| | Long–eared owl | *Asio otus* | 35 | High |
| | Little owl | *Athene noctua* | 27 | High |
| | Tawny owl | *Strix aluco* | 19 | Moderate |
| | Eurasian scops owl | *Otus scops* | 12 | Moderate |
| | Short–eared owl | *Asio flammeus* | 2 | Low |
| Sylviidae | Sardinian warbler | *Sylvia melanocephala* | 1 | Low |
| | Common whitethroat | *Sylvia communis* | 1 | Low |
| Turdidae | Common blackbird | *Turdus merula* | 2 | Low |
| | Black redstart | *Phoenicurus ochruros* | 1 | Low |
| | Common redstart | *Phoenicurus phoenicurus* | 1 | Low |
| | Whinchat | *Saxicola rubetra* | 1 | Low |
| | European stonechat | *Saxicola rubicola* | 1 | Low |
| | Northern wheatear | *Oenanthe oenanthe* | 1 | Low |
| | European robin | *Erithacus rubecula* | 1 | Low |
| Tytonidae | Western barn owl | *Tyto alba* | 23 | High |
| Upupidae | Hoopoe | *Upupa epops* | 2 | Low |
| Total roadkill number | | | 643 | |
| Total number of species | | | 71 | |

al., 2013) and another on European rabbits (Planillo and Malo, 2013; and references therein). Roadside verges have shown to be an important refuge for abundant populations of small mammals, attracting avian and mammal predators (Ruiz–Capillas et al., 2013). Abundant records on actively hunter species, such as the marsh harrier, the short–toed eagle and the lesser kestrel, suggest that they can also be killed while overflying roads and ditches in search of rodents and run–over vertebrates (PMVC, 2003).

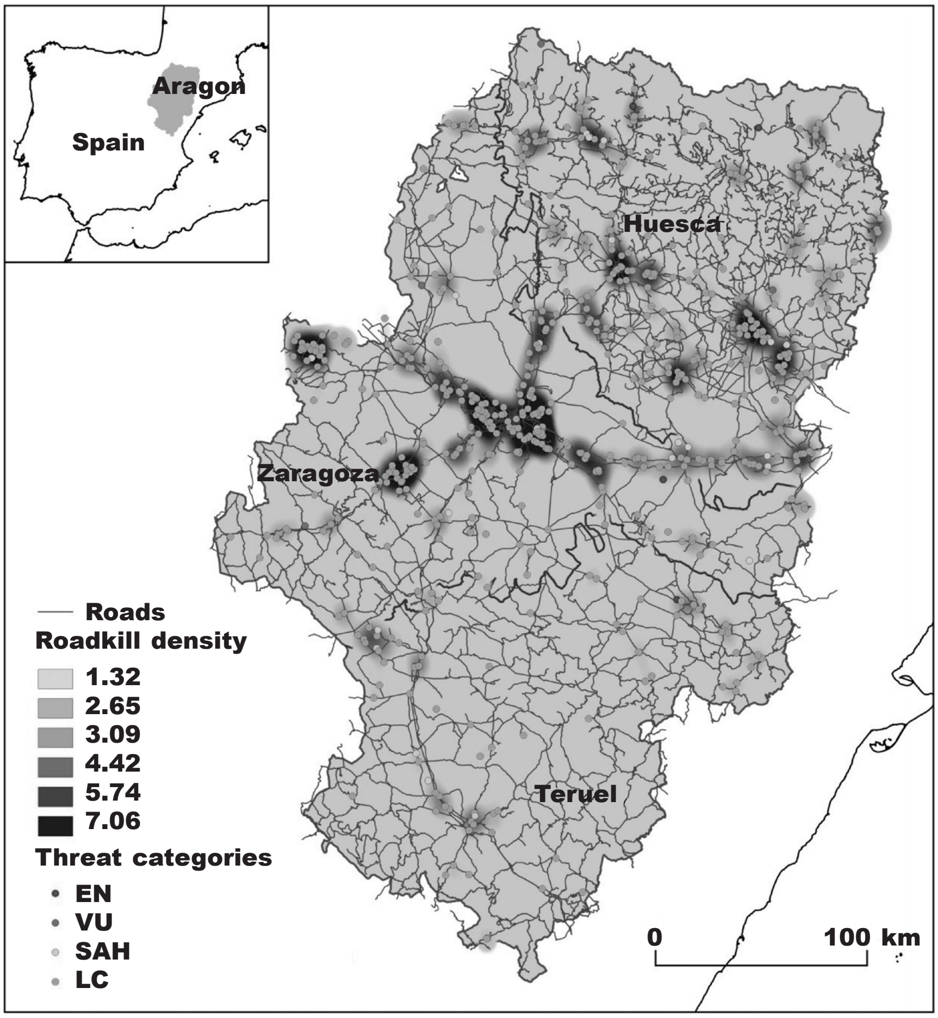


Fig. 1. Spatial distribution of avian–vehicle collisions (n = 643) detected in the Aragon autonomous county road network (2012–2014). Threat categories: EN, Endangered; VU, Vulnerable; SAH, Sensitive to the habitat alteration; LC, Least concern.

*Fig. 1. Distribución espacial de los atropellos de aves (n = 643) detectados en la red viaria de la comunidad autónoma de Aragón (2012–2014). Categorías de amenazas: EN, en peligro de extinción; VU, vulnerable; SAH, sensible a la alteración de su hábitat; LC, preocupación menor.*

Although some species, such as the Spanish imperial eagle and vultures, avoid roads with high intensity traffic, other species such as the common kestrel, the Eurasian buzzard, the booted eagle, red and black kites, and goshawks exploit roads independently of traffic intensity (Bautista et al., 2004). Therefore, the probability of these opportunistic and necrophagous species being hit seems to be higher than for other bird species.

Another factor that may increase the incidence is migration (Pérez–Tris and Santos, 2004; Santos et al., 2015). For example, although some individuals are resident, a large part of the black kite population migrates to the Iberian peninsula in spring to breed and returns to Africa in September–November (Scholerl et al., 2016), favouring the formation of roosts often located in groves near landfills and urban centres (Viñuela, 1997), and increasing roadkills during spring and summer (38 cases) rather than autumn and winter (8 cases). This species shows a high incidence of roadkills, especially if we take into account the number of months that the species occurs in Aragon. Thus, road mortality could constitute an even more relevant threat for the species during the breeding period. The red kite (7 roadkills in winter, 5 in spring, 1 in summer and 4 in autumn), classified as EN and SAH by the Spanish and Aragón laws, respectively, migrates in winter from its Central European breeding areas to

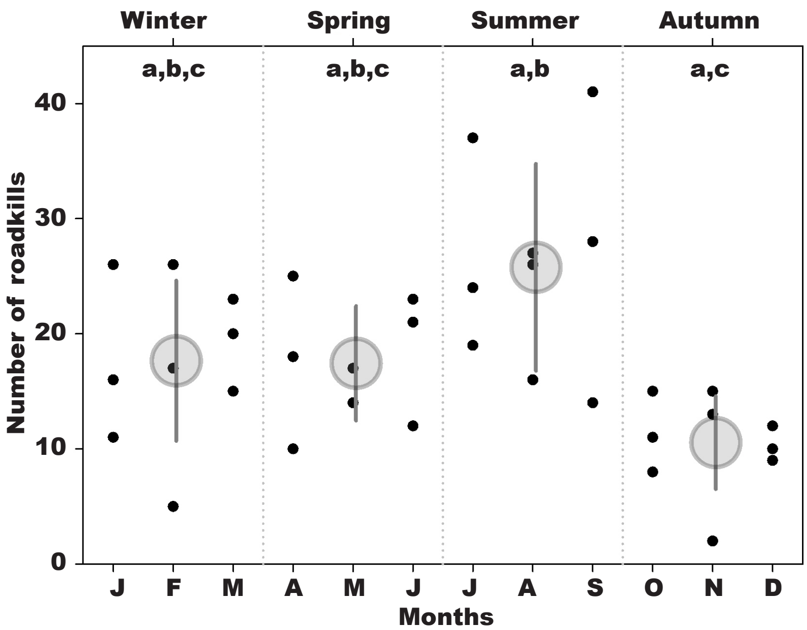


Fig. 2. Temporality of avian–vehicle collisions in Aragon over three years (2012–2014). Black dots indicate the number of avian roadkills per month. The large grey dots indicate the mean and standard deviation (vertical grey lines) of the number of avian roadkills per season. Letters indicate significant differences between seasonal roadkill means (Nemenyi post–hoc test). Differences were detected between summer and autumn, but no differences were reached between winter–spring and summer–autumn.

*Fig. 2. Estacionalidad de los atropellos de aves en la comunidad autónoma de Aragón durante tres años (2012–2014). Los puntos negros indican el número de atropellos mortales registrados por mes. Los círculos grandes grises y las líneas verticales grises indican la media y la desviación estándar de los atropellos mortales por estación, respectivamente. Las letras indican las diferencias significativas observadas entre las medias de los atropellos mortales de las cuatro estaciones (prueba* a posteriori *de Nemenyi). Se observaron diferencias entre las estaciones de verano y otoño, pero no entre los períodos invierno–primavera y verano–otoño.*

the Iberian Peninsula (Viñuela, 1997), although many couples are resident in Aragon (400–600 pairs; Viñuela, 2004). The incidence of road mortality in this species is not as serious as that of the black kite, but 50 % of the records occurred within in a small area of highway A–23 between Sabiñánigo and Jaca, in the province of Huesca.

Temporality

The months with the highest incidence of road mortality were July, August and September, the latter being the most critical month (fig. 2). This period is linked to the first flights of inexperienced young (note that most species breed in spring, and in summer juveniles are dispersing), which might be affected to a greater extent by collisions, as well as the postnuptial migration of species, such as black kite, white stork, European bee–eater or Egyptian vulture, which occurs in August and September (Pérez–Tris and Santos, 2004).

Spatial distribution and areas of high roadkill occurrence

As previously mentioned, determining the magnitude of the road mortality and identifying the areas of high roadkill occurrence is complex and depends on the methodology and the scale of the study (Santos et al., 2015). Our study is a first approach to map the areas with a high incidence in Aragon. Subsequent studies should evaluate each of the areas of high roadkill occurrence in greater depth, combining different models, such as traffic flow, road crossing models depending on the species' ethology and geometric models, which allows to calculate a probability of collision for each grid (Lin, 2016). Our results indicate a distribution of heterogeneous bird–vehicle collisions in space, although it is associated with the main axes of the Aragon road network, especially to the highways AP–2, A–2, AP–68, A–68 and A–23 (figs. 1, 3).

The areas of high roadkill occurrence with a high incidence are located in the Tarazona area and Pastriz–La Alfranca (7 and 19 roadkills, respectively; fig. 3).

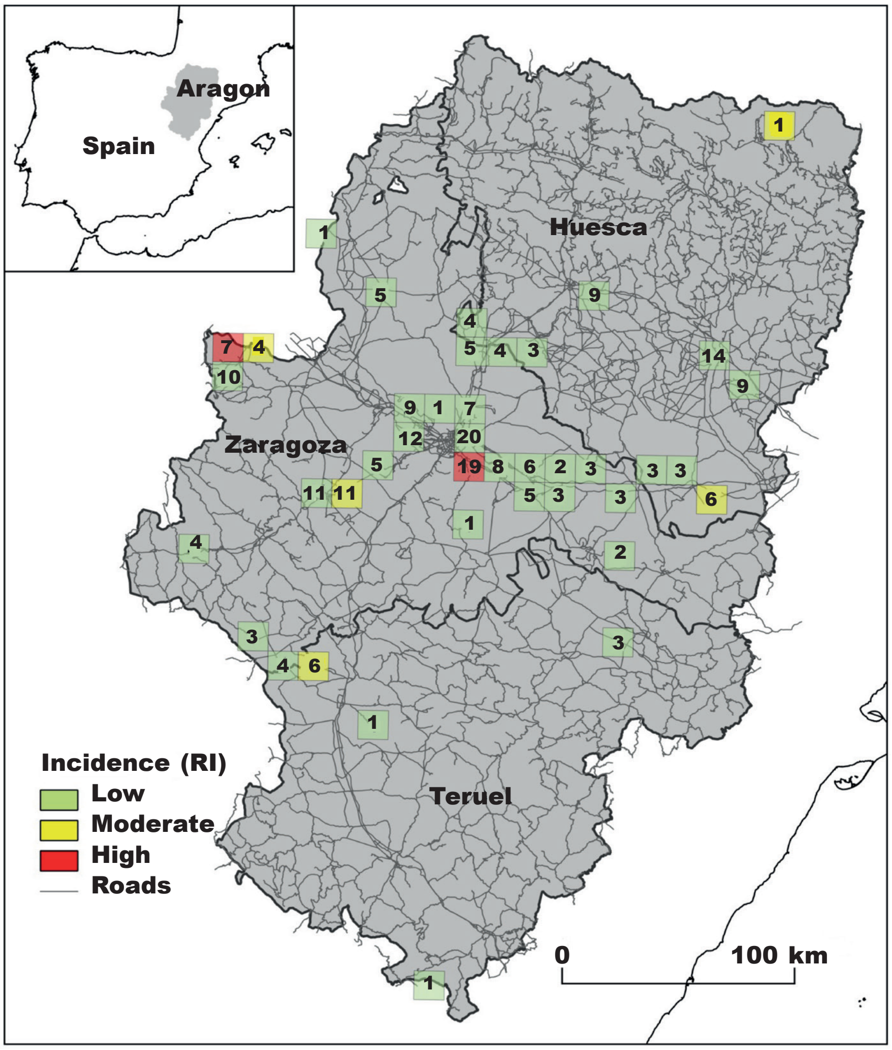


Fig. 3. Location of avian–vehicle collisions in Aragon in areas of high roadkill occurrence; the numbers therein are the number of roadkills per km index (RI) (2012–2014). Low, moderate and high incidence spots are indicated. The number of roadkills detected in each cell is also shown ('very low' incidence cells are not shown).

*Fig. 3. Localización de los atropellos de aves en las áreas* de incidencia alta de atropellos*; los números indican el índice de atropellos por kilómetro (RI) (2012–2014). Se señalan los puntos con incidencia de atropellos baja, moderada y alta. También se muestra el número de atropellos detectado en cada celda (la categoría de atropellos "muy baja" no se muestra en el mapa).*

No particular high traffic density is present in either areas of high roadkill occurrence. The high number of roadkills in the area of high roadkill occurrence Pastriz–La Alfranca is probably influenced by the special attention given by wildlife police due to the proximity of two protected areas and the WRC of La Alfranca (fig. 3). Two areas of high roadkill occurrence with a moderate incidence of roadkill are located in Zaragoza province, one next to Tarazona and the other on highway A–2, close to the town of La Almunia de Doña Godina town, this latter having a high number of roadkills (11; fig. 3). Another two areas of high roadkill occurrencewith a moderate incidence are located in the province of Huesca, one in the Monegros area (6 cases) and the second on the Pyrenean road of Benasque, with only one case in very few kilometres in that area of high roadkill occurrence, but many in that road (figs. 1, 3). Only one moderate area of high roadkill occurrence was detected in Teruel province, close to the Natural Reserve of Gallocanta (6 cases), which is an important resting and reproductive bird area (fig. 3). Elevated numbers of roads and high traffic intensity explain the presence of areas of high roadkill occurrence (Fahrig and Rytwinski, 2009; Beckman and Shine, 2015). Nevertheless, our areas of high roadkill occurrence do not match the roads with a significant increase in traffic in these specific areas, suggesting that a high density of birds might be the cause of the elevated number of vehicle collisions detected. Detailed field prospection in high and moderate areas of high roadkill occurrence should be carried out to confirm this hypothesis or to test other possible causes, such as closeness of areas of high roadkill occurrence to lagoons, bird resting or reproduction areas, or presence of bird corridors. Low incidence cells appear to be associated with the Ebro Valley, demonstrating a significant presence of birds in the valley and its functionality as a biological corridor for this taxonomic group. However, these road networks are also the roads with most traffic in Aragon.

Determining the points of the road network where road mortality is highest is essential to implement management measures that reduce the main effects of roads on wildlife (mortality due to collisions and habitat fragmentation). We therefore propose following management measures for the 41 areas of high roadkill occurrence detected, especially in the moderate (5) and high incidence (2) areas of high roadkill occurrence (fig. 3).

### Management recommendations

Given that our results are extracted from a database and not from on–site sampling, we recommend monitoring roadkills in the areas of high roadkill occurrence to confirm the magnitude of vehicle collision and develop management actions.

Given that scavengers are killed when they feed or look for food on the roads, we suggest roadkill carcasses be removed from roads, verges and gutters as soon as possible to minimise the likelihood of collisions.

The finding of two species (great bittern and great bustard) catalogued as in danger of extinction by Spanish law (the maximum threat category) emphasises the need to monitor the locations where these roadkills were found (N–232, PK.138–141, and N–II, Bujaraloz–Pina de Ebro) to determine whether these road sections constitute a serious threat to the populations.

Road signs for drivers should be reinforced in the areas of high roadkill occurrence.

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