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ORIGINAL ARTICLE

Roadkill mortality decreases after road inauguration

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Abstract

The main factors affecting specific road casualty rates are related to life-history traits, road features, and landscape variables. After road inauguration, roadkill rate and spatial and temporal patterns can change substantially due to changes in traffic intensity, avoidance behaviour or local population decline. Despite the Canary Islands constituting a biodiversity hotspot, Canarian ecosystems are highly threatened because of the high human density, and studies on anthropogenic sources of mortality of wildlife are scarce. Here, we counted roadkills during two annual cycles after the inauguration of an 8.8-km-road section on Tenerife, the largest and most densely populated island of the Canaries. We counted 694 roadkills belonging to a minimum of 19 species of birds and six species of introduced mammals. Seasonal variation was apparent during both annual cycles, particularly for birds, being the majority of victims concentrated in May and June. Although traffic intensity increased since road inauguration, the number of roadkills decreased significantly in the second annual cycle. The reduction in road mortality in the second cycle could be related to some non-mutually exclusive factors such as population decline, road avoidance, or weather conditions. As road networks of the Canary Islands are still increasing, further studies quantifying road mortality impacts on Canarian ecosystems and threatened species are urgently needed to guarantee the management and conservation of its fragile wildlife.

Keywords Canary Islands · Road ecology · Road mortality · Traffic mortality · Wildlife-vehicle collision

Introduction

The indirect or direct ecological effects of roads on wildlife have been widely studied worldwide (Coffin, 2007). Indirect effects include habitat loss or fragmentation; the discharge of toxic gases and substances, such as oils and waste, acoustic and light pollution; facilitation for invasive exotic species or barrier effects (Forman and Alexander 1998; Parris and Schneider 2009; Wiącek et al. 2015). Direct effects involve wildlife mortality caused by vehicle collisions, which have been identified as a major threat. Roadkills affect healthy individuals in a non-selective manner (Bujoczek et al. 2011), and then cause population declines and even extirpations (Fahrig and Rytwinski 2009; Benítez-López et al. 2010; Kociolek et al. 2010; Jack et al. 2015).

The main factors affecting specific road casualty rates are related to life-history traits, road features, and landscape (Erritzoe et al. 2003; Lin 2016; Santos et al. 2016; Canal et al. 2019; Duffett et al. 2020). From a spatial perspective, clusters of roadkills, or hot spots, are frequently associated with particular landscape features (Grilo et al. 2011; Roger et al. 2012; Nguyen et al. 2019). Temporally, patterns of wildlife road casualties usually show seasonal peaks related to life-history processes such as juvenile dispersal and migration (Erritzoe et al. 2003; Smith-Patten and Patten 2008; Garrah et al. 2015) or, at a shorter time scale, to factors such as temperature and precipitation (Mazerolle 2004). Also, mortality changes annually due to weather

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conditions or traffic intensity (Carvalho and Mira 2011; Grilo et al. 2015). In general, casualties increase with traffic intensity, but when a threshold is surpassed, the road avoidance response for some species is so intense that the number of victims might be reduced (Grilo et al. 2015).

After inauguration or after long periods of functioning, roads could change substantially its mortality rate patterns due to associated variations in traffic intensity, specific avoidance behaviour or local population decline (Eberhardt et al. 2013; Grilo et al. 2015; Jacobson et al. 2016; Rendall et al. 2021). Therefore, sites with high traffic volume in locations where wildlife habitat is near the road, and particularly where it straddles the road, will often correspond with roadkill hotspots. However, the lack of roadkills in road sections surrounded by good habitats might indicate local extinction and then particularly important locations for restoration (Eberhardt et al. 2013; Ascensão et al. 2019).

Animal populations living on islands are often more susceptible to human impacts than their mainland relatives (Biber 2002) being smaller, isolated and showing life-history traits of the so-called insular syndrome, such as low reproductive rates or high adult survival (Blondel 2000; Whittaker and Fernández-Palacios 2007). Hence, gathering local information of roadkill hotspots could contribute to improving our knowledge in species distributions, population dynamics and behaviour, as well as informing us about the health of the species and the environment (Schwartz et al. 2020). Such information is crucial to plan or develop effective conservation measures, particularly for threatened species (Trombulak and Frissell 2001; García-Carrasco et al. 2020).

The Canary Islands constitute a biodiversity hotspot due to the high degree of endemism of its biota (Myers et al. 2000). However, its ecosystems are highly threatened as some islands (especially the central islands) are densely human-populated by locals, but also more than ten million tourists visit the archipelago each year (ISTAC 2021). Moreover, the local economy has changed from being based on agriculture and fishing to being dependent on the tourism industry (Ledesma-Rodriguez et al. 2001). In this scenario, almost 50% of the land is protected under the framework of Natura 2000, but the fragile insular ecosystems continue suffering the massive development of urban areas and road networks (Fernández-Palacios and Martín-Esquivel 2001; Bianchi 2004; Dickinson and Robbins 2007; Otto et al. 2007). Both unprotected and protected areas are receiving many visitors, which in turn may increase wildlife road casualties as a result of the construction of new roads or greater traffic density (Garriga et al. 2012).

Studies on sources of non-natural direct mortality to the Canary Islands birds are scarce and mainly related to contaminants (e.g. Luzardo et al. 2014; Ruiz-Suárez et al. 2014), collisions with human utilities (Rodríguez et al. 2010; Gómez-Catasús et al. 2021) or fatal attraction to artificial lights (Rodríguez et al. 2022). To our best knowledge, just one study estimated the vertebrate (including birds and mammals) roadkills and assessed the main factors affecting them on Lanzarote, a volcanic and almost flat island of the Canary Islands (Tejera et al. 2018). In light of this information gap, we studied roadkills during two annual cycles taking advantage of the inauguration of an 8.8-km road section on Tenerife, Canary Islands. We identified the road-killed species and described the temporal patterns of road casualties. We assessed if the roadkills declined since the road inauguration.

Materials and methods

Study site

The Canary Islands are a volcanic archipelago located 100 km off the Atlantic coast of northwest Africa. The study was conducted in the northwest sector of Tenerife Island, which is the largest island (2034 km^2 and up to 3,718 m a.s.l.) and is situated in the central part of the archipelago (Fig. 1). Island vegetation is greatly influenced by north-easterly humid trade winds, altitude and orientation (Del Arco et al. 2006).

The human population of the island is composed of a total of 966,354 in 2020 (ISTAC 2021), and it is concentrated in the coastal sectors and is mainly employed in the agriculture and tourism industry. The fast urban development has brought the development of an important road network on the island (currently 1,197 km of paved roads) that is still increasing (http://atlastenerife.es/portalweb/es/isla-de-infraestructuras/carreteras-2). We studied a road section of 8.8 km long (excluding tunnels; $n = 15$, ranging from 20 to 1200 m) with a speed limit (80 km) and an equal width (~16 m) throughout its length. The road was inaugurated on 24 July 2014, and traffic intensity increased during the following 24 months (mean 5970 cars/month: Fig. 2). The number of vehicles was counted at two points of the road by the regional Government, Cabildo de Tenerife (Pedregales y Amparo; available at http://www.tenerife.es/AforoNetWeb/Web/IMDs/listarIMD.aspx; see Fig. 1 for location). The road section crosses human transformed land (farmlands and small towns) and also remnants of thermophilous woodlands, laurel forest, and pine woodlands (including stands of native *Pinus canariensis* but also of exotic *Pinus radiata* and *P. halepensis*) at the highest elevations (Del Arco et al. 2006).

Road surveys

The surveys ran from 4 August 2014 to 11 July 2016 both included, covering two annual cycles (August 2014–July 2015 and August 2015–July 2016, thereafter

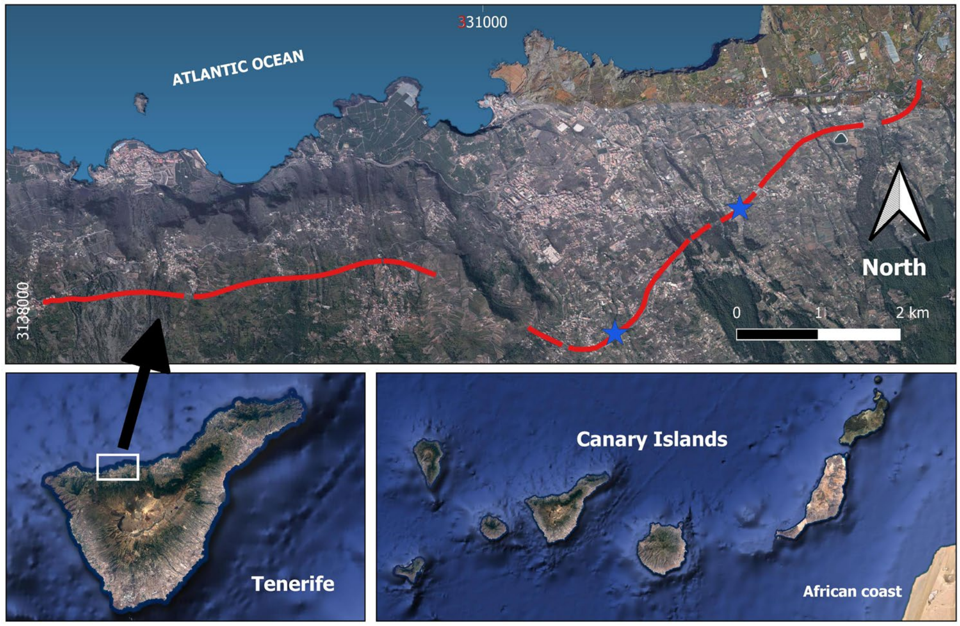

Fig. 1 Location of the study road (red line) and vehicle counting points (blue stars) in Tenerife, Canary Islands

first annual cycle and second annual cycle, respectively). Data on road mortality were collected during 154 surveys made from a vehicle at the minimum speed of the road (~ 50 km/h) on 5 to 6 days each month (both directions). Whenever possible, all victims were precisely georeferenced (at secure locations using a handheld GPS or a GIS in the rest), identified to species level, and aged into two categories (juvenile and adult). When species identification was not possible due to corpses' disintegration, they were pooled into higher taxa. Due to safety reasons, carcasses were not removed by the observer (ES), but we paid special attention to avoid double counting on the subsequent surveys.

Data analysis

To assess if roadkill numbers were similar between both annual cycles, we grouped roadkills by month and calculated a roadkill rate (roadkills/1000 vehicles). We ran three generalised linear mixed models, using as response variables the total, the avian and the mammal roadkill rates. As an explanatory variable, we included the two-level factor annual cycle (first or second cycle). Month identity was included as a random factor to take into account the repeated measures design.

Geographical analyses were conducted in *QGIS* version 3.4.15 (Open Source Geospatial Foundation Project, http://qgis.osgeo.org). All statistical analyses were conducted in *R* version 4.0.3 (R Foundation for Statistical Computing, Vienna, Austria).

Results

We counted a total of 694 roadkills belonging to a minimum of 19 species of birds (all native except one domestic chicken *Gallus gallus domesticus*) and six species of introduced mammals (Table 1). The majority of victims were birds ($n = 530$; 76.4%), with passerines being the most frequently killed ($n = 417$). The most common species were the Canarian chiffchaff *Phylloscopus canariensis* (16.4% of total roadkills), the Blackcap *Sylvia atricapilla* (9.1%), the Sardinian warbler *Sylvia melanocephala* (8.9%), the Atlantic canary *Serinus canaria* (8.6%), the Blackbird *Turdus merula* (6.6%) and the long-eared owl *Asio otus* (5.9%) (Table 1). The most frequent mammal species found were the Algerian hedgehog *Atelerix algirus* (8.5% of total roadkills), the rabbit *Oryctolagus cuniculus* (5.2%) and the cat *Felis catus* (3.7%) (Table 1). No reptiles were detected.

Seasonal variation was apparent during both annual cycles and especially for birds, being the majority of victims concentrated in May and June (Fig. 2). Although traffic intensity increased during the study period (Fig. 2), it was not correlated with the monthly number of victims (Pearson correlation coefficient = −0.03, $p = 0.516$, 95% CI −0.51 to 0.28). Indeed, the number of roadkills decreased significantly in the second annual cycle for all roadkills (second cycle = −3.48 ± 0.60, $p < 0.001$, 95% CI −4.69 to −2.26: Fig. 3), for birds (second cycle = −2.36 ± 0.52, $p < 0.001$, 95% CI −3.42 to −1.29) and for mammals (second cycle = −1.01 ± 0.26, $p < 0.001$, 95% CI −1.52 to −0.50).

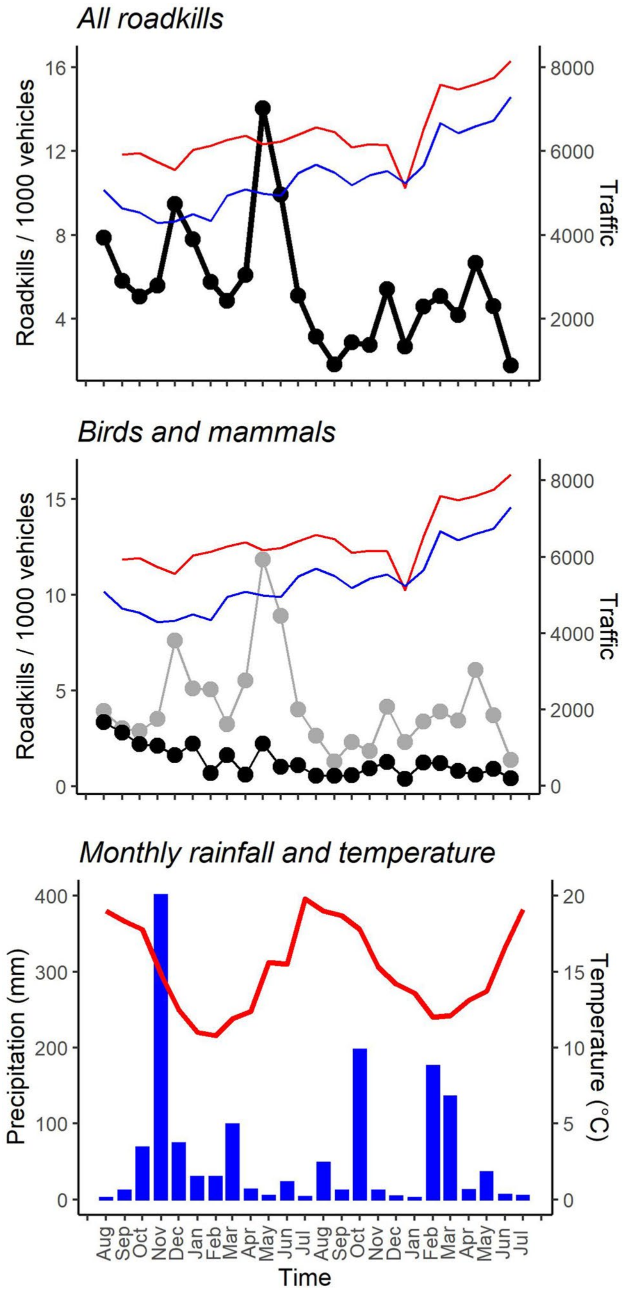

Fig. 2 Monthly roadkill rates, precipitation and temperature in the northwest of Tenerife, Canary Islands, from August 2014 to July 2016. The top panel shows all roadkills including birds and mammals and traffic measured in two points of the road: Amparo and Pedregal (blue and red lines respectively; see Fig. 1 for locations on the road). The middle panel shows the birds (grey) and mammal (black) roadkills and traffic as above. The bottom panel shows averaged monthly precipitation (blue bars) and temperature (red line). Climatic data from the insular government (Cabildo de Tenerife, available at http://www.agrocabildo.org/)

Excepting two birds (Sardinian Warbler *S. melanocephala* and Blackbird *T. merula*) and one mammal (Domestic Dog *Canis familiaris*), all species were registered in higher numbers (> 1) during the first annual cycle than during the second annual cycle (Table 1).

Table 1 The number and percentage (%) of carcasses (roadkills) found in the northwest of Tenerife (Canary Islands) during two annual cycles (AC1 and AC2) since road inauguration (AC1 = August 2014-July 2015; AC2 = August 2015–July 2016)

Species	AC1	AC2	Total	Percentage	AC2-AC1
Birds					
Phylloscopus canariensis	68	46	114	16.4	−22
Sylvia atricapilla	41	22	63	9.1	−19
Sylvia melanocephala	25	37	62	8.9	12
Serinus canaria	43	17	60	8.6	−26
Turdus merula	19	27	46	6.6	8
Asio otus	21	20	41	5.9	−1
Cyanistes teneriffae	15	14	29	4.2	−1
Erithacus rubecula	13	14	27	3.9	1
Columba livia	9	9	18	2.6	0
Sylvia sp.	5	3	8	1.2	−2
Fringilla coelebs	2	3	5	0.7	1
Alectoris barbara	3	1	4	0.6	−2
Falco tinnunculus	1	–	1	0.1	−1
Apus unicolor	–	1	1	0.1	1
Caprimulgus europaeus	1	–	1	0.1	−1
Fulica atra	–	1	1	0.1	1
Gallus gallus domesticus	–	1	1	0.1	1
Motacilla cinerea	1	–	1	0.1	−1
Regulus teneriffae	1	–	1	0.1	−1
Phoenicurus phoenicurus	1	–	1	0.1	−1
Unidentified birds	40	5	45	6.5	−35
Number of individuals	309	221	530	76.4	−88
Number of species	16	14	19		−2
Mammals					
Atelerix algirus	43	16	59	8.5	−27
Oryctolagus cuniculus	20	16	36	5.2	−4
Felis catus	18	8	26	3.7	−10
Rattus rattus	17	8	25	3.6	−9
Canis familiaris	2	5	7	1	3
Mus musculus	2	3	5	0.7	1
Number of individuals	102	56	158	22.8	−46
Number of species	6	6	6		0
Unidentified	6	–	6	0.8	−6
Total	417	277	694	100	−140

Discussion

Our study provides information on road mortality of wildlife in one of the most important biodiversity hotspots in Europe, the Canary Islands. Most victims were birds, and seasonal variation in roadkill rates was observed, with maximum values during the breeding season (May). Excepting

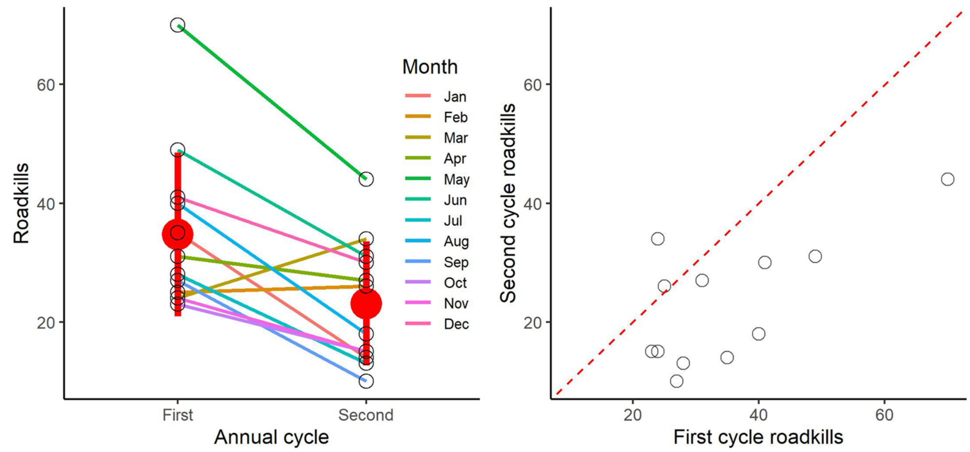

Fig. 3 Variation in the number of roadkills during the first and the second annual cycle. Left panel: Number of roadkills per month (open circles) during the first and the second annual cycle. Lines link months. Red circles indicate the annual mean and SD. Right panel: Number of roadkills per month (open circles) and $y = x$ line (dashed line)

two bird species and one mammal species, the domestic dog, our results indicate that the total number of victims (both birds and mammals) was lower during the second annual cycle than during the first annual cycle. Our roadkill rates must be considered as minimum numbers as several factors, including the ability of fieldworkers, animal size, survey method, weather conditions and traffic volume, affect the detectability of carcasses (Santos et al. 2011; Guinard et al. 2012; Teixeira et al. 2013). Furthermore, some animals undoubtedly moved off the road after being run over and injured by vehicles, were disintegrated after being repeatedly run over by vehicles or were removed by scavengers, and were thus not observed on surveys. In this sense, lizards and small mammals usually exhibit low detection rates and short permanence times (Ruiz-Capillas et al. 2015). So, the real roadkill rate is higher than that observed by simply counting corpses from a moving vehicle (Santos et al. 2011; Guinard et al. 2012; Teixeira et al. 2013).

Seasonal pattern of roadkills

Road mortality is usually linked to species' seasonal abundance (Erritzoe et al. 2003; Garrah et al. 2015; Seo et al. 2015; Pinto et al. 2020). In our study, mammal victims showed little seasonal variation, maybe related to climate stability on our study area that does not produce great oscillation in species abundance through the year. However, bird victims concentrated mainly in May (around 22.3% of total birds counted: Fig. 2) coinciding with the local post-fledging dependence and dispersal periods of the majority of passerine species (Martín and Lorenzo 2001). Although we tried to sex and age passerine carcasses, it is a very challenging task since they disintegrate easily (Erritzoe et al. 2003). We only got a very small sample size to pinpoint any clear pattern, but we are confident that the many bird victims registered in May were inexperienced juveniles. Supporting our reasoning, admissions to the unique wildlife rehabilitation centre on Tenerife correlate with the phenology of species, increasing after the breeding season (Rodríguez et al. 2010).

Roadkill reduction after road inauguration

The decrease in road mortality in the second cycle could be related to non-mutually exclusive factors such as population decline, road avoidance, traffic intensity or weather conditions. An experience-dependent relationship in road mortality could be caused either by surviving individuals learning to avoid roads or by selective mortality operating through time (Mumme et al. 2000; Brown and Brown 2013). In our study, roadkill reductions in species such as *Atelerix algirus* could be related to a true local population decline, as suggested for other related species in mainland areas (Brockie et al. 2009; Canova and Balestrieri 2019). In birds, direct traffic mortality may cause a negative relationship between bird species richness/abundance and proximity to roads (Summers et al. 2011), but other explanations are plausible. Traffic intensity is often perceived as one of the most important factors regulating roadkill rates, as they are positively related (Erritzoe et al. 2003; Fahrig and Rytwinski, 2009; Trombulak and Frissell, 2001). However, we did not observe a positive correlation between traffic intensity and roadkill rate. A threshold traffic intensity above which the road avoidance response is so intense that roadkills are reduced has been proposed (Forman and Alexander, 1998; Brockie et al. 2009; Grilo et al. 2015). The traffic intensity increase (as in our study) can affect the road cross behaviour or the foraging on the verge roads due to exposure to high levels of traffic noise or visual disturbance from passing vehicles (Parris and Schneider 2009; Grilo et al. 2015). So, we cannot rule out that, at least for some elusive, shy or adaptable species (e.g. *Phylloscopus canariensis*, *Sylvia atricapilla*, and *Serinus canaria*), traffic intensity exceeds the threshold maintaining birds far away from the road. In this regard, abundance, richness and diversity of bird communities from laurel forest from Tenerife were higher on the proximities of unpaved (with presumed lower traffic intensity) than on asphalt road edges (Delgado et al. 2008).

Be that as it may, large roads can act also as barriers to the movement of some animals, especially some mammals (Rondinini and Doncaster 2002). In this sense, specific traits could be predictors of vulnerability or avoidance towards road and traffic (Johnson et al. 2017; González-Suárez et al. 2018; Duffett et al. 2020). For example, the vulnerability of passerines to road mortality could be related to foraging behaviour and in the least extent to its body size and wing load; accordingly, the species could be significantly more (or less) road-killed than expected from their abundance (Santos et al. 2016; Cooke et al. 2020). In Tenerife, the most affected bird species were the passerines probably related to their high abundance in the habitats of our study area (Carrascal and Palomino 2005). By contrast, the relatively high number of Long-eared Owl *Asio otus* victims must be related to its nocturnal and hunting behaviour, which lead owl species to be severely affected by road mortality (Gomes et al. 2009; Grilo et al. 2014).

Local climatic conditions influence survival and reproduction in animals (Salewski et al. 2013; Bensouilah and Barrientos 2021), and then modulating both the offspring abundance and the probability of roadkills (Mazerolle 2004; Pinto et al. 2020). In our study, important differences in autumn rains were detected among the two annual cycles, being the first annual cycle wetter than the second (Fig. 2). In the Canary Islands, studies are scarce, but at least for the endemic Canary Islands stonechat *Saxicola dacotiae*, reproduction is greatly influenced by rains (Illera and Díaz 2006), so this fact might explain in some degree the reduction in the numbers of several common and widespread species during the second cycle (e.g. *Phylloscopus canariensis*, *Sylvia atricapilla*, and *Serinus canaria*). Studies linking demographic parameters (e.g. breeding success or survival) and weather conditions will be crucial to fully understand our results.

In this framework, explanations for the only two avian species that increased the number of roadkills during the second annual cycle are intriguing. In the case of *S. melanocephala*, a shrubland-dwelling specialist, vegetation restoration in roadsides after its inauguration could play a role. In this sense, wind farm construction can have greater impacts upon birds than the direct mortality by collision, and such effects may result from vegetation disturbance during construction works (Pearce-Higgins et al. 2012).

Conservation implications

Although the 8.8-km-long section of road studied here is not representative of the island road network, our study lets us calculate minimum number of roadkills. If we roughly extrapolate the raw number of our roadkill counts (417 and 277 in the first and the second annual cycle in a road of 8.8 km) to the insular high-speed road network (197 km), we get a coarse estimation of more than 7768 individuals dying each year. Applying this simple procedure for species such as the long-eared owl *Asio otus*, the figure reaches more than 450 individuals annually killed by vehicle collisions. These figures are clear underestimates given that the real mortality rate is higher than the observed using our methodology, particularly for small animals (see above). In addition, road mortality is not occurring only on high-speed roads. Apart from mortality, roads produce other ecological impacts on Canarian biodiversity. Roads can facilitate the dispersion of invasive species or alter the natural distribution of endemic lizards and birds (Arévalo et al. 2005; Delgado García et al. 2005, 2007).

Traffic intensity has increased in Tenerife, e.g. passenger cars increased from 403,085 to 496,662 during 2007–2017, and also tourism affluence in fragile and protected areas (ISTAC 2021). Consequently, the insular road network is also increasing and more motorways are planned, even crossing areas protected by Natura 2000 Network. Under this scenario, there is a need to consistently, systematically, and extensively monitor wildlife roadkill to reduce both the direct and indirect effects of roads on populations together with expanding knowledge across a wide range of ecological research areas (Schwartz et al. 2020). Hence, further studies covering other habitats and areas of high ecological value in the Canary Islands are urgently needed to assess the road mortality impact on its fragile biodiversity.

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