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Effects of Road-traffic Disturbances on the Bird Community of a Subtropical Island

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The rapid expansion of road networks worldwide is one of the most serious threats to biodiversity conservation. Evaluating the effects of various anthropogenic factors on the distribution and abundance of birds in subtropical and tropical ecosystems is extremely important in the context of the dynamic developments that these areas have been subject to in recent years. This study assessed the impact of road traffic on the abundance and species richness of roadside birds on the subtropical island of Tenerife. The effect of road traffic on birds was assessed at 162 observation points located in different places on the island by use the point-count method. During the counts a total of 765 individuals from 35 species were recorded. The number of avian species was lower in the vicinity of roadsides. Seven of the 17 most numerous birds clearly avoided the vicinity of roads, but another seven actually preferred roadside habitats; three species were neutral in this respect. The assemblage of traffic-sensitive birds consisted of specialised and endemic species, mainly inhabiting endangered native habitats such as laurel and pine forests.

Key words: Road ecology, Endemism, Disturbances, Acoustic adaptation

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BACKGROUND

As a result of intensive economic development and the increasing human population, transport networks worldwide are expanding rapidly (Benitez-López et al. 2010; Cooke et al. 2020). In recent years, existing transport routes in many countries have been modernised, and new motorways, highways and railways have been built (Johnson et al. 2022). Components of the associated infrastructure, such as road hubs, bridges, service areas, fences, lighting and other facilities, are being built in their vicinity (Johnson et al. 2017; Forman and Sperling 2003; van der Horst et al. 2019). Recent studies have indicated that the dynamic increase in the density of roads and railways is modifying and significantly affecting the natural environment (Arévalo et al. 2005; Senzaki et al.; 2020; Wiącek et al. 2020; Dharmasiri et al. 2022). Construction of new transport routes, which cut through many environments, is fragmenting habitat patches, making them less attractive for many animal species (Ortega and Capen 1999; Lees and Peres 2009; Šálek et al. 2010; Johnson et al. 2017). Mortality of individuals due to collisions with vehicles and transport infrastructure is becoming an increasingly serious factor, limiting the proper functioning of many avian populations (Orłowski 2008; Sacramento et al. 2022). Increased levels of various types of pollution near roads and railway lines pose direct or indirect threats to the birds living in their vicinity (Summers et al. 2011; Zollinger et al. 2019; Grunst et al. 2020).

A number of recent articles have evaluated the effects of road traffic and the associated noise pollution on avian abundance and species composition (Benitez-López et al. 2010; Canal et al. 2019; Johnson et al. 2022). Most of those studies were carried out in temperate latitudes (Morelli et al. 2014; Grunst et al. 2020; Dharmasiri et al. 2022), but more of the world's bird species occur in tropical and subtropical areas, from where we have little knowledge of how road traffic and noise affect bird assemblages (Avalos and Bermúdez 2016; Collinson et al. 2019; Avalos et al. 2020; Delgado et al. 2021). Many tropical bird species are poorly known, highly specialised in habitat and food, and have restricted ranges (Lees and Peres 2009; Da Silva et al. 2017; Ducrettet et al. 2020). Features of avian communities inhabiting subtropical and tropical regions of the world include low densities and high species diversities (Silva et al. 2019). However, island animal communities are relatively poor in species richness, forming simple assemblages if compared to continental ecosystems (Delgado et al. 2008).

Of particular interest for further research is assessing the impact of vehicle traffic on birds in recreationally attractive areas exposed to mass tourism (Avalos et al. 2020; Konstantopoulos et al. 2020). Coasts and many islands in tropical and subtropical regions are places of rest and recreation for tourists, which can have a number of negative consequences for the animals living in island ecosystems, as in Hawaii and the Canary Islands (Carrascal and Palomino 2002; Seoane et al. 2011; Delgado et al. 2021).

Birds living near busy roads react differently to disturbances created by the traffic and can be divided into three groups. (i) One group consists of sensitive and specialised species that avoid inhabiting areas near roads (Polak et al. 2013; Cooke et al. 2020; Delgado et al. 2021). The birds are overwhelmed by road traffic, the light from vehicles and roadside lamps, noise, and people stopping by roadsides (Wiącek et al. 2015; Johnson et al. 2017). Some bird species may have serious problems emitting and perceiving acoustic signals within a network of co-existing individuals in an environment contaminated by excessive noise (Morelli et al. 2014; Senzaki et al. 2020). Birds avoid such places because within them they have problems finding a mate, defending their territory, and hearing contact and alarm calls (Slabbekoorn and Peet 2007; Halfwerk et al., 2012). (ii) Another group comprises neutral species that occur at similar densities in habitats adjacent to and away from roads (Polak et al. 2013; Da Silva et al. 2017; Ducrettet et al. 2020). Although these individuals do not avoid habitats close to the road, some studies show that a range of indirect impacts can turn such environments into ecological traps for them (Orłowski 2008). For example, levels of breeding success in many populations are reduced in areas of increased noise because feeding parents have difficulty assessing the level of offspring hunger from begging calls (Dharmasiri et al. 2022). (iii) The third group is made up of cosmopolitan and generalist animals, which may even prefer habitats adjacent to transport infrastructure (Polak et al. 2013; Wiącek et al. 2020; Delgado et al. 2021). A number of recent studies have indicated that some avian species are flexible and readily adapt to life near roads (Carrascal and Palomino 2005; Slabbekoorn and Peet 2007; Halfwerk et al. 2012; Hennigar et al. 2019). They make use of a range of adaptations such as: increasing the amplitude of songs (Brumm 2004), adapting the song perch height (Polak 2014), shifting the peak of vocalisations during the day (Fuller et al. 2007), and modifying the frequency spectrum (Dharmasiri et al. 2022).

Roads act as a deterrent to many predator species, so that pressure from terrestrial mammals in such places is reduced (Forman and Sperling 2003; Khamcha et al. 2018; Silva et al. 2019). Moreover, some species have been found to use objects like transmission lines and poles as roosting sites or song perches (Morelli et al. 2014). Such flexible species may find more anthropogenic food near roads. In addition, transport routes may modify the structure of a monotonous habitat (edge effect) and enlarge the ecotone, which may be beneficial for insectivorous birds, for example, as it offers richer food resources (Polak et al. 2013; Wiącek et al. 2015 2020).

The main aim of this research was to assess the impact of road vehicle traffic and the associated disturbances on the species composition and abundance of birds inhabiting the subtropical island of Tenerife. It was tentatively assumed that increasing pressure from tourists and increasing vehicle traffic on the island's roads would adversely affect the occurrence particularly of habitat-specialised and endemic bird species (Sacramento et al. 2022), but would not be a major deterrent to or disrupt the pattern of occurrence of synanthropic, generalist and cosmopolitan species.

MATERIALS AND METHODS

Study area

The fieldwork was carried out on Tenerife, an island with an area of 2,034 km^2 lying off the north-western coast of Africa (Fig. 1). It occupies a central position in the Canary Islands archipelago, which is located in the Atlantic Ocean (Carrascal 1987). Tenerife is the largest and one of the most complex islands in the region in terms of origin, geology, geographical and natural conditions (Carrascal and Palomino 2002). This region lies in the subtropical climate zone (Delgado et al. 2021). The weather conditions of the island are generally mild during the whole of the annual cycle. With its central volcanic massif of Teide, Tenerife has a unique set of flora and fauna, including many endemic species (Arévalo et al. 2005; Carrascal and Palomino 2005). It is of volcanic origin, having been formed in the Atlantic Ocean as a result of a volcanic eruption that gave rise to the land about 12 million years ago. In the central part of the island the volcano Teide reaches an altitude of 3,718 m above sea level. It is also the most densely populated of the all the Spanish islands. The human population of the island is composed of a total of 966,354 in 2020 and the fast urban development has brought the development of an road network on the island (currently 1,197 km of paved roads, Sacramento et al. 2022). Ten million tourists visit Tenerife every year, making it one of the most important tourist destinations in Spain. Passenger cars have increased from 403,085 to 496,662 during 2007-2017 in Tenerife (Sacramento et al. 2022).

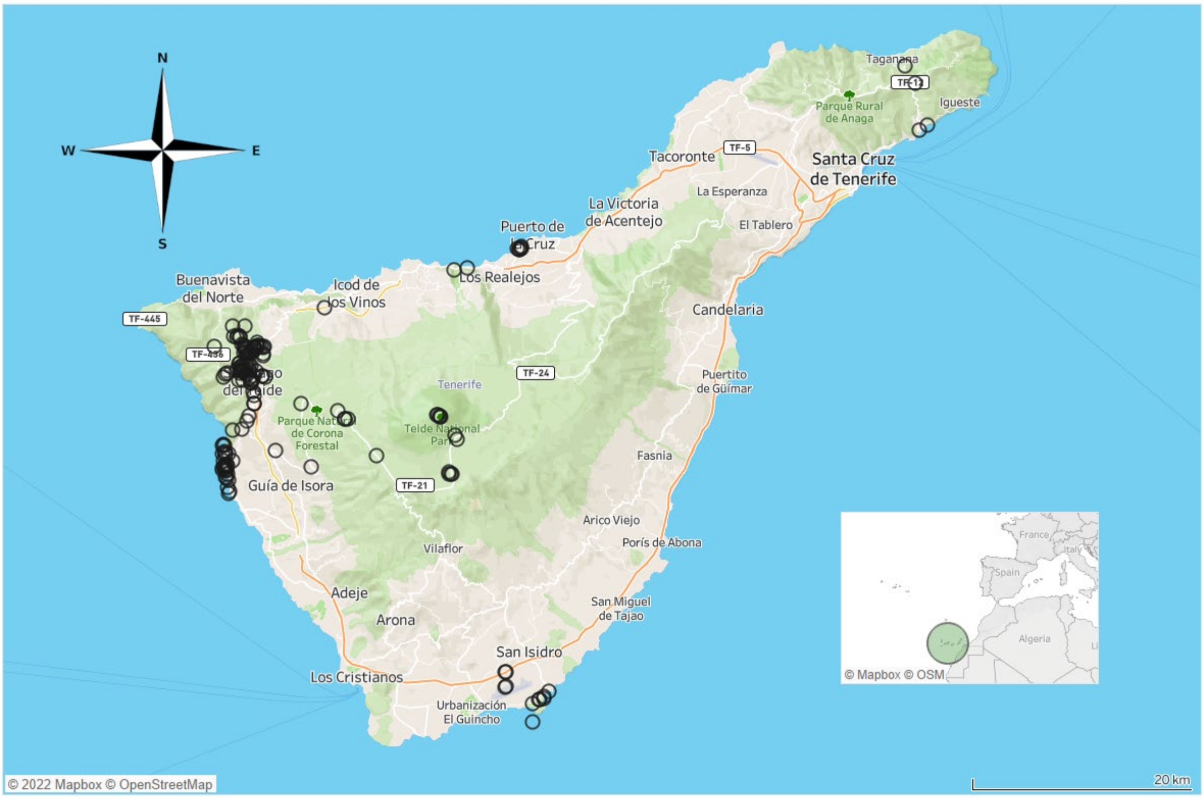

Fig. 1. The study area with the point-count locations (black dots) on Tenerife Island.

Data collection

The effect of road traffic on birds was assessed at 162 observation/listening points located in different places on the island (Fig. 1) by use the point-count method (Bibby et al. 1992). To limit the edge effect, the points were located in the middle of patches of relatively homogeneous habitats, although this was not possible in more heterogeneous habitats in some locations. The study was carried out in all the main habitat types in areas between 3 m and 3,718 m above sea level. The following number of points were located in the island's most important habitats: summit scrub habitats – 40, human settlements – 35, The Canarian laurel forest (laurisilva) – 32, coast scrub habitats – 28, pine forest with *Pinus canariensis* – 23, semi-desert habitats – 4. The counts took place from 11 to 22 January 2020. All the 162 points were established and recorded on GPS receivers. Only one count was carried out at each point. Counting at each point lasted for five minutes. All the stationary birds observed within a radius of 50 m were recorded, but birds flying high over the points were ignored. To minimise the observer effect, all the individuals recorded near points were identified and counted by one person (MP). A limiting factor in this type of survey is that it can sometimes be difficult for a observer to detect all birds due to the omnipresent road noise (Rheindt 2003; Summers et al. 2011). We were aware of this problem during the fieldwork and tried to minimise it. This task was made easier by the fact that vehicle traffic along the roads was not continuous and we were able to detect vocalising birds in the gaps between passing vehicles. Fieldwork took place only during stable weather conditions, i.e. no counts during strong wind and/or rainfall. The counts took place at different times of the day from before sunrise to the afternoon hours. Birds were observed using 10 × 50 binoculars. The species richness was defined as the sum of all species come across during the count, and the abundance of individuals was defined as the sum total of all birds detected during the count. The distance between the observation point and the edge of the road was measured to the nearest 1 m using a Google maps application. At all the points during every count the amplitude of road noise was measured by use a digital sound level meter CHY 650 (IEC 651-1979 Type 2, ANSI S1.4-1983 Type 2, JIS C 1502; Polak 2014). The noise level at the centre of each point was measured for five minutes and the highest level recorded (Polak et al. 2013; Wiącek et al. 2015 2020).

Statistical analysis

To detect effects of road-traffic disturbances on abundance and species richness correlation analysis was used. The results were considered statistically significant if the probability of type I error was equal to or less than 0.05. The average values were presented with a standard deviation (± SD). Analysis of variance (ANOVA) was used to assess the propagation of noise over the study area. We used redundancy analysis (RDA) to determine the association between the numbers of avian species and distance from the road as the environmental predictor in the analysis. This method was carried out to detect the species' preferences for being near the road. Every observation point was assigned to three categories of distance from the road: i) < 50 m, ii) 50-150 m and iii) > 150 m. To determine the significance of canonical axes we used the Monte Carlo test with 500 permutations. Only species with abundances > 10 individuals were included in the RDA analysis (see Table 1). The statistical calculations were performed using the STATISTICA 13.3 packet (StatSoft Inc. 2021) and Canoco 4.0 packet (ter Braak and Smilauer 1998).

Table 1. Bird community composition observed during counts at points on Tenerife island

Species	Number of ind./5 min. (all counts)	Number of ind./5 min. (counts with presence)	Total number of ind.	Dominance (%)
Phylloscopus canariensis	0.7	1.6	118	15.4
Turdus merula cabrerae	0.6	1.7	95	12.4
Serinus canaria	0.6	2.2	92	12
Larus michahellis atlantis	0.4	3	68	8.9
Streptopelia decaocto	0.4	1.9	58	7.6
Cyanistes teneriffae	0.3	1.4	43	5.6
Columba bollii	0.2	1.9	40	5.2
Erithacus superbus	0.2	1.3	34	4.4
Arenaria interpres	0.14	5.7	23	3
Falco tinnunculus	0.13	1.2	21	2.7
Corvus corax	0.12	1.8	20	2.6
Fringilla teydea	0.12	1.3	20	2.6
Anthus berthelotii	0.11	1.3	18	2.3
Curruca melanocephala leucogastra	0.10	1.1	17	2.2
Regulus regulus teneriffae	0.09	2	16	2.0
Buteo buteo	0.09	1.25	15	1.9
Passer hispaniolensis	0.09	2.1	15	1.9
Apus unicolor	0.04	1.7	7	0.9
Motacilla cinerea canariensis	0.04	1.4	7	0.9
Sylvia atricapilla heineken	0.03	1	5	0.5
Charadrius hiaticula	0.02	4	4	0.5
Gallinula chloropus	0.02	2	4	0.5
Numenius phaeopus	0.01	1	3	0.4
Pluvialis squatarola	0.01	3	3	0.4
Alectoris barbara	0.01	2	2	0.3
Ardea cinerea	0.01	1	2	0.3
Chloris chloris	0.01	2	2	0.3
Columba junoniae	0.01	1	2	0.3
Columba livia	0.01	1	2	0.3
Egretta garzetta	0.01	1	2	0.3
Falco peregrinus pelegrinoides	0.01	2	2	0.3
Lanius meridionalis koenigi	0.01	2	2	0.3
Cygnus atratus	0	1	1	0.1
Dendrocopos major canariensis	0	1	1	0.1
Sylvia conspicillata	0	1	1	0.1
Total			765	≈100.0

RESULTS

During the counts at all the points a total of 765 individuals from 35 species were recorded (Table 1). The most common species was Canary Island Chiffchaff *Phylloscopus canariensis* (15.4% of the community), and the group of dominant birds (> 5.0% of the community) also included Canarian Blackbird *Turdus merula cabreare*, Eurasian Collared Dove *Streptopelia decaocto*, Island Canary *Serinus canaria*, Atlantic Yellow-legged Gull *Larus michahellis atlantis*, African Blue Tit *Cyanistes teneriffae* and Bolle's Pigeon *Columba bollii*. These species together constituted 70% of the bird community. The group of subdominant species (2.0–5.0% of the assemblage) included: Tenerife Robin *Erithacus superbus*, Ruddy Turnstone *Arenaria interpres*, Kestrel *Falco tinnunculus*, Raven *Corvus corax*, Tenerife Blue Chaffinch *Fringilla teydea*, Sardinian Warbler *Curruca melanocephala leucogastra*, Berthelot's Pipit *Anthus berthelotii* and Tenerife Goldcrest *Regulus regulus teneriffae*. The species with the highest frequency were Canary Island Chiffchaff (present at 46% of all 162 counts), Canarian Blackbird (35%), and Island Canary (26%, Fig. 2). The average number of species per point was 2.7 ± 1.6 (range 0–7, n = 162) and the mean number of individuals per point was 4.7 ± 3.8 (range 0-21, n = 162). The level of traffic noise during all counts at the points varied from 36.0 to 88.0 dB (mean = 62.0 ± 16.7 dB, n = 162). The noise intensity during the counts at points near roads (< 50 m) was 74.3 ± 11.7 dB (range 42.0-88.0 dB; n = 63), at points a medium distance (50-150 m) was 68.4 ± 12.1 dB (39.0-84.0 dB; n = 20) and at further points (> 150 m) was 50.6 ± 13.0 dB (36.0–88.0; n = 79). Significant differences were demonstrated in noise propagation between the point categories during the counts (Fig. 3; ANOVA; $F_{2, 159}$ = 67.4; P < 0.001). There was a significant negative relationship between the level of traffic noise and species richness (r = - 0.22; P < 0.005; n = 162), but no association between the level of noise and the abundance of birds (r = - 0.03; P = 0.70; n = 162). The abundance of the most numerous birds (>10 individuals) differed in relation to distance from the communication line (Monte Carlo test of the significance of the first axis with 500 permutations; F ratio = 6.444; P = 0.002; Monte Carlo test of the significance of all axes with 500 permutations; F ratio = 5.150; P = 0.002). The group of seven bird species clearly avoided the vicinity of roadsides: Canarian Blackbird, Bolle's Pigeon, Tenerife Robin, Tenerife Blue Chaffinch, Sardinian Warbler, Tenerife Goldcrest and Common Buzzard *Buteo buteo*. The other three common species, *i.e.*, Atlantic Yellow-legged Gull, Kestrel and Ruddy Turnstone, reached their highest numbers at a medium distance (50-150 m) from roads. The following seven species preferred the neighbourhood of the road: Canary Island Chiffchaff, Island Canary, Eurasian Collared Dove, African Blue Tit, Raven, Berthelot's Pipit and Spanish Sparrow (Fig. 4).

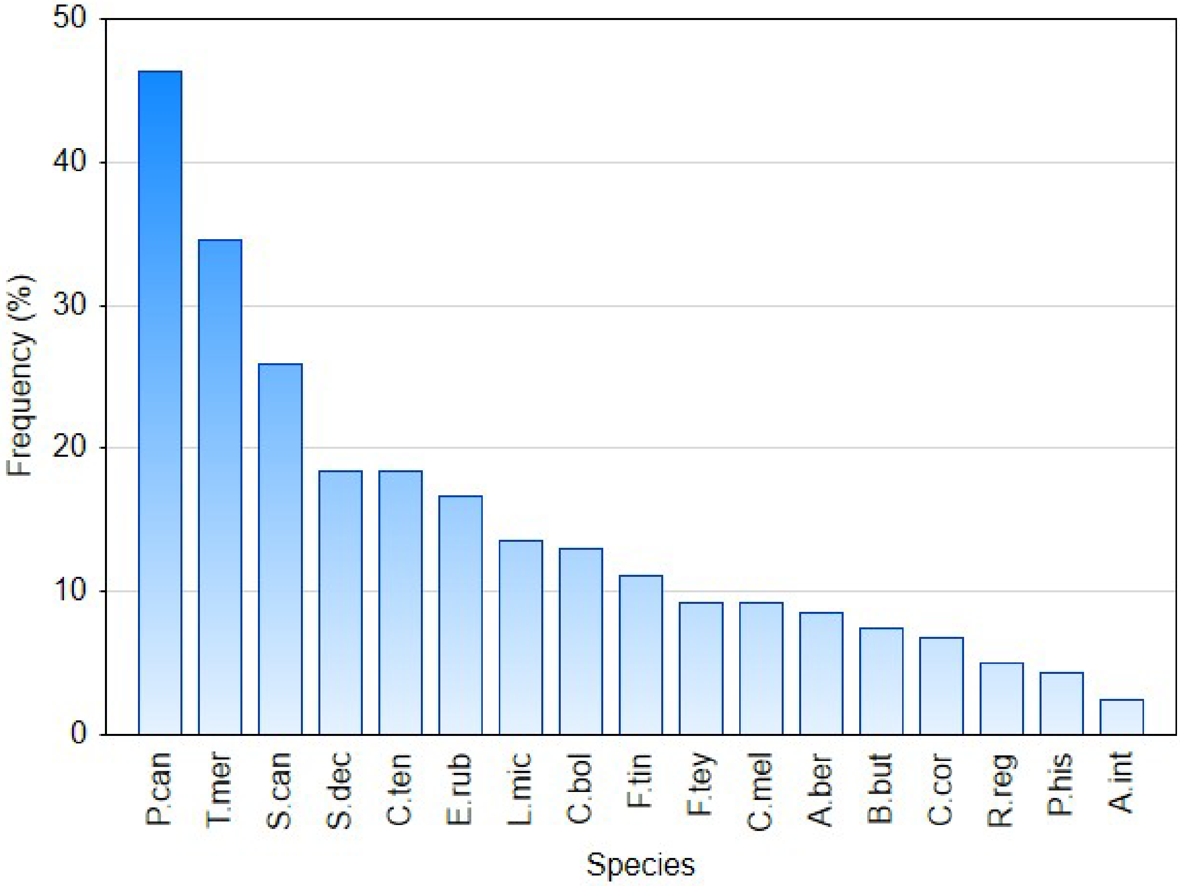

Fig. 2. Composition and frequency of the most common (>10 individuals) birds on the island of Tenerife. Abbreviations of species names include the first one letter of the genus and the first three letters species scientific names.

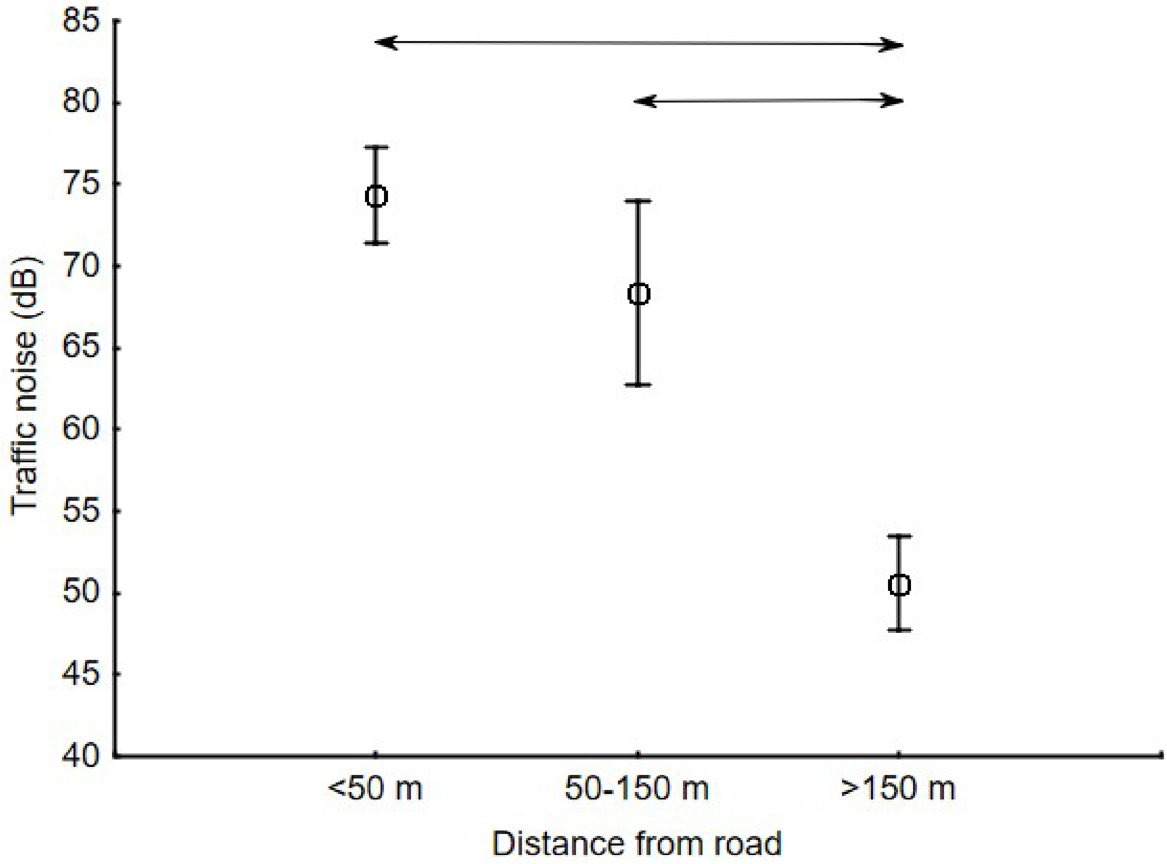

Fig. 3. Relationship between traffic noise (mean ± 95% confidence intervals) at point-count locations and distance from the road. The arrows show significant differences between points (Tukey's test, $P < 0.001$).

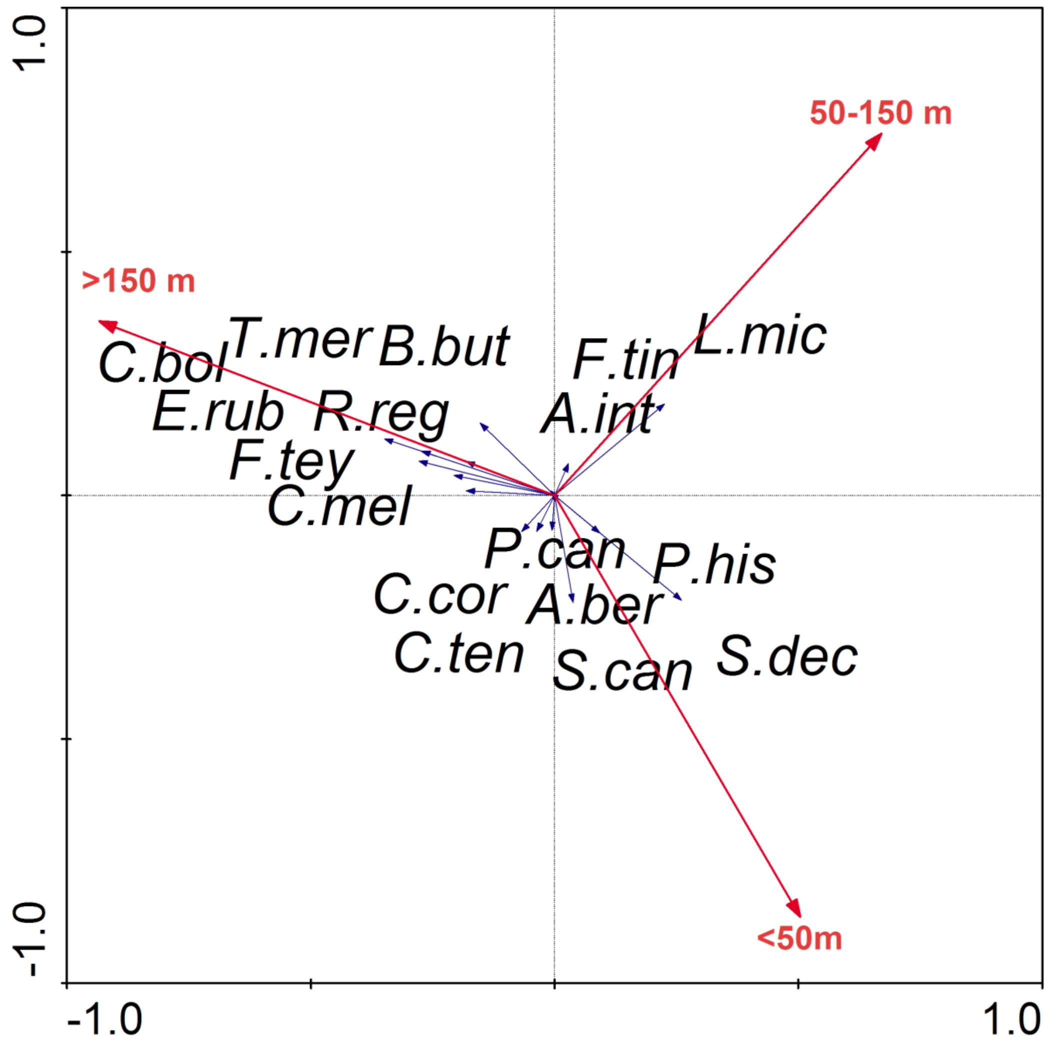

Fig. 4. Ordination diagram of redundancy analysis (RDA) with 17 of the most common bird species recorded on Tenerife Island explained by the point-count locations in relation to distance from the road. Abbreviations of species names include the first one letter of the genus and the first three letters species scientific names.

DISCUSSION

With the increasing pressure of human activities on the natural ecosystems, a number of negative impacts significantly affecting living organisms have become apparent in recent years (Arévalo et al. 2005; Johnson et al. 2017; Dharmasiri et al. 2022; Johnson et al. 2022). One of the most serious threats emerging from the growth of transport infrastructure is posed by the road traffic, noise and other disturbances caused by vehicles (Benitez-López et al. 2010; Collinson et al. 2019; Cooke et al. 2020), which can significantly modify the abundance, distribution, behaviour, physiology and reproductive success of animals living in the vicinity of roadsides (Zollinger et al.

2019; Cooke et al. 2020; Grunst et al. 2020). Owing to the high mobility and specific nature of their vocal communication, birds are one of the most vulnerable groups of animals (Senzaki et al. 2020). The difficulties in voice communications caused by traffic noise appear to be one of the main problems of individuals in a noise-contaminated environment (Morelli et al. 2014). Recent studies have indicated that road noise can affect different bird species, reducing breeding success (Halfwerk et al. 2012), making it more difficult to find a suitable mate (Fuller et al. 2007), increasing stress levels (Benitez-López et al. 2010; Johnson et al. 2022) and forcing changes in the bioacoustic parameters of the songs and vocalisations produced during the reproductive season (Bruum 2004).

We have poor knowledge of how the new and existing transport routes affect avian communities in tropics and sub-tropics and numerous studies from temperate latitudes showed that higher densities of common and eurytopic species can be observed in transformed, simplified and urbanised roadside habitats (Carrascal and Palomino 2005; Šálek et al. 2010; Polak et al. 2013; Wiącek et al. 2015). The previous research and the present study highlights the differential impact of road vehicle traffic on the assemblage of birds inhabiting the subtropical island of Tenerife (Carrascal and Palomino 2005; Delgado et al. 2021; Sacramento et al. 2022). Some of the species found within the study area actually preferred the vicinity of roads, for example, common and widespread ones like Canary Island Chiffchaff, Island Canary, Eurasian Collared Dove and African Blue Tit. This study confirmed that they are well adapted to high noise levels and disturbance from vehicle traffic (see also Carrascal and Palomino 2005). Most of these species are cosmopolitan ones inhabiting a wide range of diverse habitats, readily inhabiting transition zones between different habitat types and often reaching higher densities in ecotones (Carrascal and Palomino 2002; Delgado et al. 2008). Road construction in patches of homogeneous habitat creates new or expands existing ecotones – this is known as the edge effect (Šálek et al. 2010; Polak et al. 2013). Birds are more likely to occupy territories in ecotones, as these areas may abound in safe nesting sites and hiding places (Morelli et al. 2014). More abundant food resources are available in such habitats, especially for insectivorous birds (Wiącek et al. 2015).

This study and the recent articles have shown that vehicle traffic and road noise on Tenerife can adversely affect the occurrence and abundance of some specialised and disturbance-sensitive bird species, the richness of which was lower in areas with higher noise levels (Delgado et al. 2008; Delgado et al. 2021). It was found that species like Canarian Blackbird, Bolle's Pigeon, Tenerife Robin, Tenerife Blue Chaffinch and Tenerife Goldcrest deliberately avoided the vicinity of roads. A feature common to these birds was a preference for patches of forest habitat, particularly pine or laurel forests, which are endangered native habitats on Tenerife (Carrascal 1987; Carrascal and Palomino 2002; Carrascal and Palomino 2005; Delgado et al. 2008; Seoane et al. 2011). The fact that birds avoid colonising places close to busy and noisy roads, demonstrated in recent research and in this research, is of particular concern as many of the species in this group are rare and endemic ones with slow reproduction rates (Delgado et al. 2021). In the context of the projected increase in tourist numbers and greater pressure from vehicle traffic on Tenerife (Sacramento et al. 2022), the long-term functioning of sustainable and stable populations of these endemic species may be threatened. In addition, remodelling of the bird assemblage is to be expected.

There are some weak points in the methodology used in this study (see Johnson et al. 2022) and the results of this study should be treated with caution, however. The observed differences in the number and distribution of the avian populations near roads in Tenerife could be due to a number of factors not taken into considered in these analyses. The study was conducted in short period of annual cycle and in tropics and sub-tropics there is often considerable variability in the demographic parameters, vocal and non-vocal activity and timing of reproduction in birds during whole annual cycle (Da Silva et al. 2017; Ducrettet et al. 2020). What could have further complicated the interpretation is the fact that in the present study it was not controlled the impact of the vegetation effect on a breeding community of birds. Some other factors related with edge effect as: competition, predation, microclimate conditions could also affect and modify the observed pattern of bird distribution (McCollin 1998). However, to minimise this potential variation, the study was carried out in the homogenous patches of habitat.

Some studies relating to the tropics and subtropics have revealed a negative relationship between noise levels and avian species richness and density (Da Silva et al. 2017; Avalos et al. 2020; Konstantopoulos et al. 2020). It is possible that the decline in bird numbers near roads is a consequence not of a single factor, but rather of a combination of various disturbance factors generated by traffic (Polak et al. 2013; Johnson et al. 2022). Many researchers emphasise that birds may avoid colonising areas near roads because of the fear of collisions, light pollution and visual disturbance, increased predation and habitat deterioration (Ortega and Capen 1999; Slabbekoorn and Peet 2007; Šálek et al. 2010; Summers et al. 2011; Johnson et al. 2017; Hennigar et al. 2019).

CONCLUSIONS

We observed the negative impact of roads on some subtropical birds, including threatened species. This study has shown that road vehicle traffic on Tenerife is modifying the island’s bird community to a significant extent. Species richness was found to be depleted in areas most exposed to noise pollution. Seven (41%) of the 17 most abundant species in the assemblage avoided colonising areas near roads. These were mainly endemic habitat-specialised species that prefer patches of laurel and pine forests, which are scarce and endangered on the island.

Minimising the negative impact of road vehicle traffic in vulnerable ecosystems on tropical and subtropical islands, though extremely difficult, is not impossible (Collinson et al. 2019). In such situations, rational plans and long-term strategies need to be drawn up by politicians and various institutions, especially NGOs, foundations and communities (Benitez-López et al. 2010). It is important to raise environmental awareness and make people conscious of the threats that roads pose in the natural environment (Johnson et al. 2022). When planning new roads it is important to avoid routes that may cut across large patches of the most valuable habitats and protected areas, as this always leads to the negative consequence of habitat fragmentation (Johnson et al. 2017). The busiest main roads should be routed away from sensitive patches of natural areas (Sacramento et al. 2022), but where this is not possible, the construction of tunnels, overpasses and physical (noise) barriers should be considered (Wiącek et al. 2015). In turn, efficient and rational vegetation design is important near existing roads – here there should be no plants that could attract fruit- or nectar-eating birds (Orłowski 2008).

In conclusion, further studies should also be undertaken of the impacts of roads on the ontogenic and autoecologic levels, because we have fairly extensive knowledge of the relationship between noise intensity and avian density, distribution and species richness of tropical avifaunas. Nevertheless, we know relatively little of how rapid expansion of transport networks and fragmentation may affect different aspects of demography and breeding ecology of avian species occurring near roads and railways in subtropical and tropical ecosystems. In the future and more detailed research the focus must now be on assessing the productivity, stress level, mortality rate of avian populations living in roads vicinity.

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Competing interests: MP and JP declare that they have no conflict of interest.

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