

Bird communities in two oceanic island forests fragmented by roads on Tenerife, Canary Islands

Juan D Delgado^{1,2*}, José R Arévalo¹ and José María Fernández-Palacios¹

¹ Departamento de Ecología, Universidad de La Laguna, 38206 La Laguna, Tenerife, Islas Canarias, Spain

² Departamento de Física Básica, Universidad de La Laguna, 38206 La Laguna, Tenerife, Islas Canarias, Spain

* Corresponding author, e-mail: jddelgar@ull.es

Although most studies on road effects on birds have been conducted on continental grounds, road fragmentation on oceanic islands is often heavier. We assessed variation in bird communities near (≤ 25 m) and far (>100 m) from forest roads dividing laurel and pine forests on Tenerife, Canary Islands. Line transects were used as the census technique. We compared community structure and species responses between both forests, and among forest interior and edges of paved and unpaved roads. We analysed richness and diversity of species in these different situations, and tested for significance in bird community descriptors and species abundance responses to road proximity. The bird community of the laurel forest showed significantly higher average population density, richness, diversity and evenness than that of the pine forest. None of the two forests showed significant differences in community descriptors between edge and interior, except for a higher evenness along unpaved roads in the laurel forest. However, the bird community showed more overall abundances, richness and diversity on unpaved than on asphalt road edges in laurel forest. Excepting two passerines (*Turdus merula* in laurel forest and *Phylloscopus canariensis* in pine forest), all species had similar abundances on road edges and forest interior regardless of forest type. Most species might be regarded as forest generalists. Changes detected between edge and interior on road-fragmented forests were, overall, small at the bird community level. Managers should consider the effects of road edge and road type on the more sensitive species in present and future road planning.

Introduction

The effects of road fragmentation on bird communities are a main concern for most ecologists, conservationists and environmental authorities (see e.g. Bennet 1991, Brotons and Herrando 2001, Cassady 2003), but also increasingly politicians, farmers and stakeholders (Wilkie *et al.* 2000, Forman *et al.* 2002, Laurance *et al.* 2004, Bishop and Myers 2005). At both regional and local scales, the road network influences the landscape structure and its appreciation by researchers have focused from concrete, local effects (i.e. edge, barrier and corridor) to regional or even global effects (Forman *et al.* 2002). Reported effects of roads on the avifauna vary from absence of net impact to significant negative or positive changes in abundance and/or species richness (Lynch and Saunders 1991, Gutzwiller and Barrow 2003). The bulk of research on road effects on birds has been focused on continental ecosystems worldwide, especially on tropical and temperate forests, agro-ecosystems and managed road-verge vegetation (Laursen 1981, Arnold and Weeldenburg 1990, Meunier *et al.* 1999). On the contrary, road effects on the bird communities on small oceanic islands remain largely unknown. Almost axiomatically, island ecosystems in general and their avifaunas in particular are considered intrinsically fragile. However, evidence for negative, positive or neutral effects of roads on oceanic-island bird communities and species is scarce. Bird communities in the Mediterranean region contain numerous species that are historically tolerant or prone to use edge habitats. In addition, in recent times, the proliferation of

human infrastructures, especially roads, is causing dramatic changes in the species composition and structure of bird communities. This process extends perhaps with a heavier negative impact to fragile island habitats (Whittaker 1998).

The Canary Islands are a Mediterranean-type ecosystem with a history of human disturbances caused by the aboriginal population, though the heavier, transforming disturbances came later from the arrival of Europeans and subsequent population expansion and urbanisation (Delgado *et al.* 2001a). Road fragmentation of the Canary Islands woodlands, mostly Tertiary-relict refugia of international importance such as Atlantic laurisilva (evergreen or laurel forest) and Canarian pine (*Pinus canariensis*) forests, has increased dramatically in the last few decades (Delgado *et al.* 2001a, Martín and Fernández-Palacios 2001). At the same time, the impact upon the Canarian avifauna has increased and 35.5% of the terrestrial bird species (c. 27 out of 76) are threatened (García Casanova *et al.* 2001). Among threatening factors, high road densities imply serious damage for island avifaunas, especially for sensitive forest specialists such as palaeoendemic fruit pigeons (*Columba* spp.). The pigeons *Columba bollii* and *C. junoniae* have disappeared from the island of Gran Canaria due to massive forest destruction (Martín and Lorenzo 2001). Paved road density in the Canary Islands reaches 1.67 km per km², doubling the continental Spanish average (0.8 km per km²) (Martín and Fernández-Palacios 2001). Total area occupied by roads on Tenerife exceeds 5700 ha (c. 3% of the island

area), despite around 40% of the island area being legally protected. For the whole archipelago, paved plus unpaved road density grows up to 6 km per km², and the process is still ongoing. However, the effects of roads on these islands' bird communities have not been assessed so far.

Our aims were: (1) to assess bird community composition, density, richness and diversity patterns in laurel and pine forests fragmented by roads on Tenerife, Canary Islands; (2) to compare the structure of the bird community between road edges and the forest interior to assess whether road proximity promotes variation in bird assemblages; and (3) to compare the responses in abundance (population density) of species between road edges and forest interior, and between road types; for particular species shared by both forests, we also compared, between ecosystems, their patterns of abundance alongside roads and in forest core areas, since the same species could experience a different effect of road proximity depending on forest type.

Methods

Study area

To study bird community composition and structure, we conducted censuses along secondary asphalt and unpaved roads, and tracts of interior native laurel and pine forests on Tenerife (Canary Islands, 28–29° N, 16–17° W). These forests form altitudinal belts, with laurel forest between 500–1 000 m altitude on the windward slope and pine forests between 800–2 300 m on both windward and leeward slopes. Laurel forest transects were located in the Anaga Rural Park (Las Mercedes-Aguirre-El Moquinal, north-east aspect), and pine forest transects were located in the Corona Forestal Natural Park (La Esperanza [north-east], Vilaflor-Granadilla-Arico [south], and La Guancha-Icod-Garachico [north]) (Figure 1).

The laurel forest is a 10–20 m high canopy dominated by the trees *Laurus azorica*, *Myrica faya*, *Ilex canariensis*, *Erica arborea* and *Prunus lusitanica*. The understorey is formed mainly by tall shrubs (up to 4 m), mainly *Viburnum tinus*, ferns and tree saplings and seedlings. A richer plant community forms along the road edges with *Rubus* spp., *Plantago arborescens*, *Ageratina adenophora*, *Phyllis nobla*, *Hypericum* spp. and others. The laurel forest of Anaga is formed by a mosaic of second-growth patches (mostly on steep slopes and ridges) interspersed with mature and developed forest with tall and close canopy (especially on valley bottoms and gentle slopes). All the study areas selected in laurel forest were in patches never exploited for wood or which experienced such disturbances more than 50 years ago. Especially in the Anaga laurel forest, the degree of forest transformation can be higher near roads, and roads can encourage human access to previously unconnected areas and further disturbances. However, we selected, far enough from roads, interior forest areas that were, compared to edge forest tracts, of great conservation value and resembling old-growth forest conditions.

The pine forest is formed by *Pinus canariensis* in the overstorey (up to 30–40 m high), and the understorey is dominated by *M. faya* and *E. arborea* in La Esperanza, and by *Chamaecytisus proliferus*, *Adenocarpus viscosus* and *Lotus campylocladus* in Vilaflor-Granadilla and Arico.

For asphalt roads, traffic intensity in 1997 averaged 6 303 vehicles d⁻¹ in the laurel forest (Las Mercedes) and 4 618 and 1 016 vehicles d⁻¹ in two pine forest sites (La Esperanza and Vilaflor, respectively) (Cabildo de Tenerife 1998). We lack traffic intensity data for unpaved roads of the study area but it is much lower than for asphalt ones. On other parts of the island, in laurel forest near leisure areas, average densities of 97 vehicles d⁻¹ have been recorded for dust trails (Brito and Lucía 1995). The speed limit for cars is 50 km h⁻¹ for asphalt roads and 30 km h⁻¹ for unpaved forest tracks. Other human activities along forest roads in the study area that may cause a disturbance to birds include quad driving (whose noise pollution is higher than that of common cars), cycling and walking, often in moderately large groups (guided walks, especially on unpaved tracks).

The bird species censused

Most species recorded in this work were Passeriformes (8 species), Columbiformes (3 species) and Piciformes (1 species). Some species not detected in our censuses may be indicators of transitional zones between forest and scrubland (which were avoided), such as Blackcap (*Sylvia atricapilla heineken*) and Sardinian warbler (*S. melanocephala leucogastra*) (Valido and Delgado 1996). Some migratory species contribute seasonally to the forest bird communities, such as Turtle Dove (*Streptopelia turtur*), which uses the Canarian forests for breeding (Martín and Lorenzo 2001).

Among the Canarian forest birds recorded in this work, three are Canarian endemic species (Bolle's Pigeon *C. bollii*, chiefly a laurel forest dweller; the Blue Chaffinch *Fringilla teydea*, a pine forest species; and the Canary Islands Chiffchaff *Phylloscopus canariensis*, an ubiquitous species present in both forests); two are Makaronesian endemics (Canary *Serinus canarius* and Berthelot's Pipit *Anthus berthelotii*); and five belong to Canarian-endemic subspecies (*Erithacus rubecula superbus*, *Parus caeruleus teneriffae*, *Fringilla coelebs canariensis*, *Regulus regulus teneriffae* and Great Spotted Woodpecker *Dendrocopos major canariensis*) (Martín and Lorenzo 2001). Morphological, bioacoustical and molecular evidence is leading to assign the rank of species to some of these subspecies, viz. the Canary Islands Chiffchaff *P. canariensis* (Helbig *et al.* 1996), the Tenerife Goldcrest *R. teneriffae* (Sibley and Monroe 1990), the Canarian Robin *E. superbus* (Bergmann and Schottler 2001) and the Ultramarine Tit *P. teneriffae* (Salzburger *et al.* 2002).

Due to limitations inherent to the census procedures (line transects) employed, some species were not censused, although they were observed in some areas outside or within transects: Buzzard *Buteo buteo insularum*, Sparrowhawk *Accipiter nissus granti*, Kestrel *Falco tinnunculus canariensis*, Plain Swift *Apus unicolor unicolor* and Woodcock *Scolopax rusticola*. As censuses were directed to diurnal species, nocturnal raptors (Long-eared Owl *Asio otus canariensis* and Barn Owl *Tyto alba alba*) were not assessed.

Bird surveys

All censuses were performed in the breeding season of April–June 1999. Bird communities were compared within each forest type between forest interior (>100 m from any

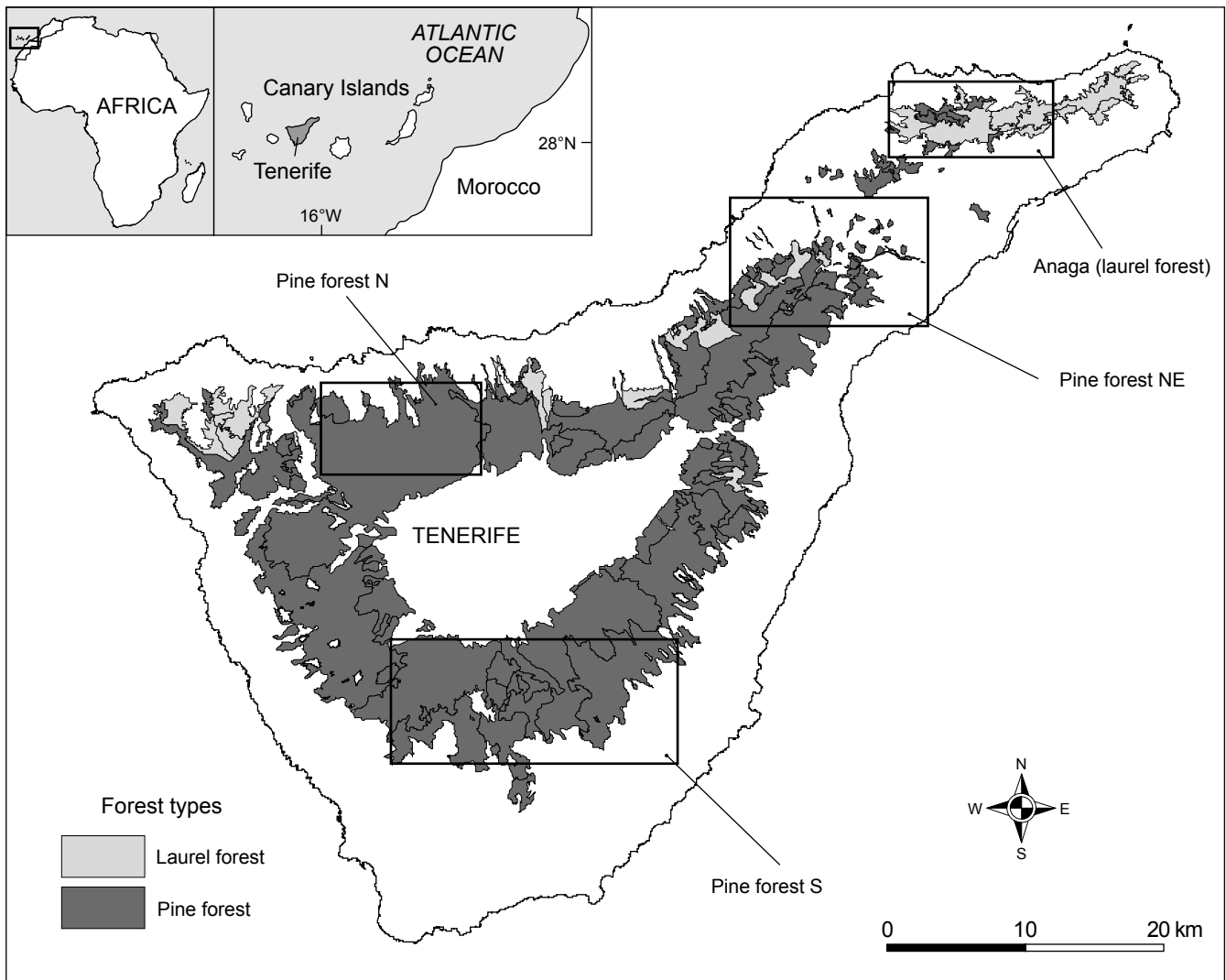


Figure 1: Map of Tenerife and areas (rectangles) surveyed for birds in laurel and pine forests

edge, core areas) and the forest margins (0–25 m) close to road edges. We studied two relatively narrow road types, asphalt roads (6–7 m width) and unpaved or dust trails (4–8 m width). We used the line-transect method with a fixed band of 25 m at both sides of the observer's progression line (Bibby *et al.* 1992). This census band width was thought to be adequate for Canarian forests. Larger widths (i.e. 50 or 100 m on each observer's side) are inadequately broad unless a sparse bird population exists, and the bird populations in the Canarian forests are considered differentially dense. In the field, each transect unit was divided into subunits of 50 × 100 m (0.5 ha), and milestones (trees, rocks, signposts) were identified every 100 m. The total transect length was 11.5 km in the pine forest ($n = 115$ subunits of 0.5 ha) and 9 km in the laurel forest ($n = 90$ subunits), covering a total area of 57.5 and 45 ha, respectively. Transects were placed at more than 100 m from other inherent (natural) ecotones (e.g. transitional vegetation pine-summit scrub, mid-altitude scrublands), induced (anthropogenic) edge habitats (agricultural land, urban

areas and powerline corridors), to minimise their overlapping effects. Vegetation transition zones between pine and laurel forest were also avoided. Transect selection procedure intended to avoid all these overlaps and this limited the types of forest habitats surveyed.

Each contact was computed as one individual bird to avoid overestimating abundance of the more conspicuous species. No extrapolation to the number of pairs present was made. We did not account for group sizes, as most species were not flocking in the study areas. Censuses started at dawn (c. 07:00) and lasted for 3–4 h, weather permitting (absence of strong wind and no rain). Each transect was walked once and slowly (c. 1–1.5 km h⁻¹), stopping to identify and note every individual bird seen or heard within the band (Bibby *et al.* 1992). Special attention was given to the spatial discrimination of visual and auditory contacts. Some birds made an eventual use of the road pavement for foraging and thus road width was included within the census band. Census units were distributed as equally as possible, between forest interior (>100 m from

any edge type), along asphalt roads in the laurel forest, and along unpaved roads in the pine forest.

Statistical analysis

For each forest and habitat (asphalt or unpaved road edges vs interior), we calculated: (1) density (birds 10 ha⁻¹), species richness (S , species number); (2) diversity (Shannon's H'), a function of the relative frequency of different species; (3) uniformity or evenness of the distribution of individuals per species (Shannon's $E = H'/\ln S$); and (4) the Simpson's dominance index ($D = \Sigma p_i^2$). We tested for significance in pairwise and multiple comparisons of the univariate descriptors and species abundances with the Mann-Whitney U and the Kruskal-Wallis tests.

Results

We recorded 342 and 528 birds from nine and 11 species in laurel and pine forests, respectively (Table 1). Some species were recorded at only one forest ecosystem (pine forest: *F. teydea*, *C. livia* and *D. major*; laurel forest: *C. bollii*). Seven species were detected in both forests, namely *S. canarius*, *F. coelebs*, *P. canariensis*, *R. regulus*, *T. merula*, *E. rubecula*, *P. caeruleus* and *S. turtur*. Two passerines, *P. canariensis* (28%) and *P. caeruleus* (25%), were the dominant species in terms of relative abundance in laurel and pine forest, respectively. Two finches, *F. coelebs* (13%) and *F. teydea* (12%), showed similar abundances in laurel and pine forests, respectively. One species in laurel forest (*S. turtur*) and two

Table 1: Summary of bird composition and overall numbers recorded in different forest habitats. Total transect length (in km) is indicated below habitat type

Bird species	Asphalt road	Forest interior	Unpaved road	Overall
Laurel forest				
Total transect length (km)	2.9	3.5	2.6	9
<i>Phylloscopus canariensis</i>	28	37	31	96
<i>Regulus regulus</i>	21	27	11	59
<i>Parus caeruleus</i>	4	6	9	19
<i>Erithacus rubecula</i>	14	13	11	38
<i>Turdus merula</i>	15	19	29	63
<i>Fringilla coelebs</i>	11	17	17	45
<i>Columba bollii</i>	2	7	3	12
<i>Serinus canarius</i>	0	7	2	9
<i>Streptopelia turtur</i>	1	0	0	1
Overall	96	133	113	342
Pine forest				
Total transect length (km)		7.9	12.2	20.1
<i>Phylloscopus canariensis</i>		37	23	60
<i>Regulus regulus</i>		78	122	200
<i>Parus caeruleus</i>		41	51	92
<i>Turdus merula</i>		0	3	3
<i>Fringilla coelebs</i>		0	2	2
<i>Serinus canarius</i>		17	35	52
<i>Streptopelia turtur</i>		3	7	10
<i>Fringilla teydea</i>		17	32	49
<i>Dendrocopos major</i>		8	8	16
<i>Columba livia</i>		9	33	42
<i>Anthus berthelotii</i>		0	2	2
Overall		210	318	528

in pine forest (*A. berthelotii* and *F. coelebs*) were detected only once. The bird community of the laurel forest showed, on average (on an individual transect basis), twice the diversity, evenness, species richness and density per sample than that of the pine forest, and these differences were all significant (Table 2). The species dominance pattern was not significantly different between forests.

We did not find significant differences in univariate descriptors of forest bird communities between interior and road edges in both forests. One exception was evenness, which was significantly higher along unpaved roads in the laurel forest and at pine forest interior (Table 2).

We did not detect significant differences between asphalt road edges and forest interior in the laurel forest ($p > 0.1$). However, bird communities differed between both road types. Species richness, diversity, and density were significantly higher along unpaved than along asphalt road margins, whereas species dominance was higher along asphalt roads than along unpaved roads (Table 2). The distribution of abundance among the different species revealed a higher uniformity along unpaved road edges than at core or interior laurel forest areas. In the pine forest, we detected no significant differences between unpaved road edges and forest interior ($p > 0.1$) (Table 2).

Only two species showed significant differences between road edge and forest interior. In the laurel forest, *T. merula* presented higher abundance along unpaved roads than near asphalt roads or in the forest interior (Kruskal-Wallis test: 6.59, $p = 0.037$). In the laurel forest, *C. bollii*, *F. coelebs*, *R. regulus* and *S. canarius* presented relatively higher abundances at core or interior areas than along road margins, although differences were not statistically significant ($p > 0.05$). In this forest, *S. canarius* was recorded only four times, two in the forest interior and two along road edges, commonly in small flocks of two to five birds. The remaining species did not differ, or were only slightly more abundant, along road edges than in the laurel forest interior (*P. canariensis*, *P. caeruleus* and *E. rubecula*).

In the pine forest, only *P. canariensis* was significantly more abundant in the pine forest interior than along unpaved roadsides (Mann-Whitney U (Z) test = 3.497, $p < 0.001$). Other species showing relatively higher abundances in the pine forest interior compared to unpaved road edges were *P. caeruleus* and *R. regulus* (not significantly different; $p > 0.05$). *Columba livia*, *S. canarius* and *F. teydea* were relatively more frequently observed along unpaved roadsides than in the pine forest interior (not significantly different; $p > 0.05$).

Only *P. canariensis* differed in response to road proximity depending on forest type, having significantly higher abundances in the pine forest interior compared to edges, and no apparent response to edge in laurel forest. The remaining six passerine bird species shared by both forests exhibited statistically similar abundances between edge and interior, regardless of forest type.

Discussion

Our results suggest that, in terms of composition, diversity and abundance of individual species and overall bird

Table 2: Summary of bird community statistics derived from abundance data (mean \pm SD) and tests. *U* = Mann-Whitney *U* test; K-W = Kruskal-Wallis test

Statistic	Forest types			Laurel forest			Pine forest		
	Laurel forest (<i>n</i> = 90)	Pine forest (<i>n</i> = 105)	<i>U</i>	Asphalt road (<i>n</i> = 29)	Unpaved road (<i>n</i> = 26)	Forest interior (<i>n</i> = 35)	Unpaved road (<i>n</i> = 64)	Interior (<i>n</i> = 41)	<i>U</i>
<i>S</i> , species richness	2.63 \pm 0.15	1.36 \pm 0.14	2424***	2.24 \pm 1.5	3.04 \pm 1.31	2.66 \pm 1.33	0.32 \pm 0.48	0.44 \pm 0.50	1086.5 ^{ns}
Shannon's <i>H'</i>	0.82 \pm 0.05	0.37 \pm 0.05	2609.5***	0.65 \pm 0.53	0.98 \pm 0.46	0.83 \pm 0.5	0.32 \pm 0.44	0.47 \pm 0.49	1111.5 ^{ns}
Shannon's <i>E</i>	0.75 \pm 0.04	0.38 \pm 0.05	2852***	0.66 \pm 0.45	0.85 \pm 0.32	0.75 \pm 0.38	0.37 \pm 0.39	0.45 \pm 0.37	1033.5*
Simpson's <i>D</i>	0.46 \pm 0.03	0.40 \pm 0.04	4108 ^{ns}	0.53 \pm 0.3	0.40 \pm 0.22	0.46 \pm 0.26	1.23 \pm 1.46	1.56 \pm 1.32	1134.5 ^{ns}

* *p* < 0.05; *** *p* < 0.001; ^{ns}, not significant; significant test outcomes are highlighted in bold

abundance, the breeding bird community next to road margins does not differ strongly from that inhabiting interior forest in two Tenerife forest ecosystems. This could be explained as an effect of the generalist character of these birds that exhibit a great plasticity and an opportunistic exploitation of resources across the island habitat mosaic, where edge habitats proliferate (Forman 1998, Imbeau *et al.* 2003). It is often supposed that oceanic island avifaunas are inherently fragile and contain highly specialised taxa (Williamson 1981, but see Walter 2004). Contrastingly, it has been also pointed out that island species experience ecological release (Lack 1969), and that this could widen the niche breadth (Schluter 1988). These latter traits are not, paradoxically, typical of the traditionally considered 'fragile' island avifaunas. Our results, especially regarding most passerines in road-fragmented forests on Tenerife, are more in agreement with the latter of the two hypotheses (robustness and pervasiveness of birds in island forests fragmented by infrastructures; see Walter 2004). Moreover, the same or similar bird species inhabiting near forest roads in the continent show contrasting patterns in the direction of a negative response to roads (i.e. fragility; e.g. Brotons and Herrando 2001).

Most species present in laurel and pine forests, which occur also on continental ecosystems in the Mediterranean Basin (of which the Canary Islands are a constituent part), are considered forest generalists by some authors (i.e. Brotons and Herrando 2001). Not exceptionally, the same species can behave very differently depending on study spatial or time scale, habitat type or vegetation structure, especially regarding edges (Arnold and Weeldenburg 1990, McCollin 1993). Classification of birds as edge or interior species is strongly dependent on the particular species requirements, ecosystem type and vegetation structure, and hence the classification for one area may not hold for another (Báldi 1996, Villard 1998, Schmiegelow and Mönkkönen 2002).

Most passerines and some non-passerines have a history of adaptation to edge habitats in the Palaearctic (e.g. Báldi 1996). Homogenisation of the forest ecosystems and their animal communities, at the island scale studied here, can be due to a large extent to anthropogenic and inherent edge influences, and thus can be a result of increased road density and access facilitation for human activities and other road-associated disturbances (Forman 1998, Whittaker 1998). Whether the actual extreme degree of forest transformation by roads and other infrastructures on Tenerife can be a reason for generalised composition and abundance of the bird assemblages cannot be ascertained with our present data. Density compensation in these island passerines (Wright 1980), along with intrinsic appetite for resource-rich marginal areas such as roads, may contribute to explain the overall homogeneity observed in these forest bird communities.

With the line transect method, the visibility and detection probability of *C. bollii* (and probably others) were likely higher on road edge transects than on laurel forest interior transects, so we might have underestimated pigeon abundance inside the forest. In this case, the actual road edge effect might be stronger than that perceived for this

scarce species. In Madeira, the Madeira laurel pigeon (*Columba trocaz*) is known to frequent interior forest with tree species typical of mature old-forest formations, but also are prone to using patches formed by non-native trees, including agricultural areas (Oliveira and Jones 1995). Although it is reported that Canarian-endemic fruit pigeons use quiet edge habitats and orchards for foraging (Martín and Lorenzo 2001), they are wary of human activity and thus may be deterred from foraging, calling, and/or nesting next to busy roads. Other effects of the road gap (microclimate changes, reduced food availability or exposure to predators) might also influence presence and abundance of these pigeons in forest patches next to roads (Delgado *et al.* 2001b, 2005, 2007).

For forest interior species, such as the endemic pigeon *C. bollii*, that are negatively affected by reduced habitat quality, this could mean reduced density along road edges (Valido and Delgado 1996, Martín *et al.* 2000). Although this relict species prefers to nest on forest slopes and to forage on valley bottoms, it can use also more disturbed forest patches, as it performs ample within-island, altitudinal trips in search of food (Martín *et al.* 2000). The high road density and traffic load in their natural habitats may cause severe disturbances to the populations through interruption of these routes and by facilitating penetration of their main introduced predators (ship rats) (Martín *et al.* 2000, Delgado *et al.* 2001b), whereas increased fruit availability along road edges is not perhaps enough compensation due to the pigeon behaviour of avoidance of busy roads.

Regulus regulus, *D. major* and *P. caeruleus* have been regarded mostly as forest dwellers in other areas (woodland and matorral, France, Meunier *et al.* 1999; pinewood surrounded by farmland, Iberian peninsula, Brotons and Herrando 2001; deciduous forest, Japan, Kurosawa and Askins 2003). On the contrary, *E. rubecula* and *T. merula* were relatively more abundant on edge habitats in both Canarian forests. These two omnivorous birds have been reported to prefer habitat edges to interior areas in other regions (Meunier *et al.* 1999, Kurosawa and Askins 2003). In addition, *P. canariensis* and *P. caeruleus* behaved neatly as interior species in the pine forest, but did not apparently prefer the laurel forest interior to the road edge. Compared to the laurel forest, the pine forest is a poorer environment due to a lower plant diversity, diminished food resources (especially for forest insectivores), and harsher climate (extreme temperatures, aridity and sun radiation). Such conditions may be aggravated alongside roads due to physical properties of the roadbed (e.g. heat island and dry dust projection), making insectivorous passerines prefer pine forest interior.

The Tenerife subspecies *D. major canariensis* is a pine forest specialist and builds nests on dead pines far from roads toward the forest interior, as well as on paved and unpaved road edges (Delgado *et al.* 2000). In continental areas, Fuller (1988) and Kurosawa and Askins (2003) found *D. major* in greater abundance in the forest interior, and Meunier *et al.* (1999) reported it mainly from outside road sites. Related species are also known to suffer density reductions within 40–1500 m from heavily used roads in Europe (i.e. Lesser Spotted Woodpecker *D. minor*;

Reijnen *et al.* 1995). However, two woodpeckers of the genera *Picus* and *Picoides* did not experience a reduction in nesting success with proximity to agricultural edges in China (Deng and Gao 2005). Despite its requirements for large and continuous forest areas (Brotons and Herrando 2001) and the disturbances occurring next to roads, *D. m. canariensis* exploits these edges and other ecotones successfully (Delgado *et al.* 2000). We lack studies on the reproductive success of *D. m. canariensis* along roads, but several generations could occupy the same nest located less than 5 m from the edge of an asphalt road in Tenerife (JDD pers. obs.). It seems that nest site availability (dead pines) is a major factor determining population density in *D. m. canariensis* (Delgado *et al.* 2000), and the management by eliminating dead pines to avoid accumulation of burning fuel may cause a reduction in the number of nest sites along roads.

The type of road corridor (unpaved, paved or powerline) has been shown to have a significant effect on particular bird species, community composition and nesting guilds (Rich *et al.* 1994). In our study, the bird communities were better discriminated by the proximity to different types of road surface (asphalt vs unpaved) in the laurel forest, where both road types were surveyed. Several intrinsic traits distinguishing asphalt and unpaved roads may determine some of these differences in the bird communities. At first, unpaved roads are less used by motor vehicles than asphalt roads. Motorised traffic is much lower on unpaved roads than on asphalt roads, where traffic disturbance may be most intense and permanent on birds breeding and foraging on these edges. This may contribute to comparatively higher bird diversity and richness near unpaved roads in our study forests. In other areas, the abundance of many bird species is not reduced near roads if traffic load is low (Reijnen *et al.* 1995), as in the unpaved roads of this study. Nevertheless, in areas with a great traffic load such as highways, even some of the forest generalist species recorded in Canarian forests show significant reductions in occurrence (e.g. *T. merula*, *E. rubecula*, *P. caeruleus*; Brotons and Herrando 2001). In this sense, the relatively quiet unpaved roads of our study might cause a significantly lower impact in habitat quality for the bird community than busier asphalt roads studied elsewhere (Forman and Alexander 1998, Forman *et al.* 2002).

As a suggestion for management, environmental impact assessments of road schemes in the Canarian forests should be addressed paying attention to bird responses at both the community and species level in the Canaries. When assessing impacts of new road projects or road improvements on the bird community, authorities should make an effort in examining the contrasting susceptibilities to road proximity and intensity of use of forest generalist species, some of them inherently prone to exploit road corridors, and endangered specialists (i.e. endemic fruit pigeons), which have more strict forest continuity requirements. Measures oriented to reduce traffic and to enhance habitat continuity and extension (e.g. by closing unnecessary forest trails and unpaved roads) would favour such forest-demanding birds without disadvantages for the conservation of the more generalist species.

Acknowledgements — We thank two anonymous referees for improvements and comments on an earlier draft.

References

- Arnold GW and Weeldenburg JR** 1990. Factors determining the number and species of birds in road verges in the wheatbelt of Western Australia. *Biological Conservation* 53: 295–315
- Báldi A** 1996. Edge effects in tropical versus temperate forest bird communities: three alternative hypotheses for the explanation of differences. *Acta Zoologica Academiae Scientiarum Hungaricae* 42: 163–172
- Bennet AF** 1991. *Roads, roadsides and wildlife conservation: a review*. In: Saunders DA and Hobbs RJ (eds) *Nature Conservation 2: the Role of Corridors*. pp 99–118. Surrey Beatty and Sons, Sydney
- Bergmann HH and Schottler B** 2001. Tenerife Robin *Erithacus (rubecula) superbus* – a species of its own? *Dutch Birding* 23: 140–146
- Bibby CJ, Burgess ND and Hill DA** 1992. *Bird Census Techniques*. Academic Press, London
- Bishop JA and Myers WL** 2005. Associations between avian functional guild response and regional landscape properties for conservation planning. *Ecological Indicators* 5: 33–48
- Brito MC and Lucía V** 1995. *El Bosque de Agua García*. Turquesa, Tenerife
- Brotons L and Herrando S** 2001. Reduced bird occurrence in pine forest fragments associated with road proximity in a Mediterranean agricultural area. *Landscape and Urban Planning* 57: 77–89
- Cabildo de Tenerife** 1998. *Mapa de intensidades medias diarias de tráfico*. Año de estudio 1997. Servicio Técnico de Carreteras, Cabildo de Tenerife, Santa Cruz de Tenerife
- Cassady C** 2003. Comparative permeability of roads, rivers, and meadows to songbirds in Banff National Park. *Conservation Biology* 17: 1151–1160
- Delgado G, Naranjo JJ, Delgado JD and González M** 2000. Datos sobre la distribución y estatus del pico picapinos (*Dendrocopos major* L, 1758) en Tenerife (Aves: Picidae). *Vieraea* 28: 155–167
- Delgado JD, Arévalo JR and Fernández-Palacios JM** 2001a. *Fragmentación de los ecosistemas forestales*. In: Fernández-Palacios JM and Martín Esquivel JL (eds) *Naturaleza de las Islas Canarias: Ecología y Conservación*. pp 173–179. Turquesa, Santa Cruz de Tenerife
- Delgado JD, Arévalo JR and Fernández-Palacios JM** 2001b. Road and topography effects on invasion: edge effects in rat foraging patterns in two oceanic island forests (Tenerife, Canary Islands). *Ecography* 24: 539–546
- Delgado JD, Arévalo JR and Fernández-Palacios JM** 2005. Patterns of artificial nest predation by exotic rats in a fragmented subtropical forest (Tenerife, Canary Islands). *Journal of Natural History* 38: 2661–2669
- Delgado JD, Arroyo NL, Arévalo JR and Fernández-Palacios JM** 2007. Edge effects of roads on temperature, light, canopy cover, and canopy height in laurel and pine forests (Tenerife, Canary Islands). *Landscape and Urban Planning* 81: 328–340
- Deng W-H and Gao W** 2005. Edge effects on nesting success of cavity-nesting birds in fragmented forests. *Biological Conservation* 126: 363–370
- Forman RTT** 1998. *Land Mosaics: the Ecology of Landscapes and Regions*. Cambridge University Press, Cambridge
- Forman RTT and Alexander LE** 1998. Roads and their major ecological effects. *Annual Review of Ecology and Systematics* 29: 207–231
- Forman RTT, Sperling D, Bissonette JA, Clevenger AP, Cutshall CD, Dale VH, Fahrig L, France R, Goldman CR, Heanue K, Jones AJ, Swanson FJ, Turrentine T and Winter TC** 2002. *Road Ecology: Science and Solutions*. Island Press, Washington, DC
- Fuller RJ** 1988. *A comparison of breeding bird assemblages in two Buckinghamshire clay vale woods with different histories of management*. In: Kirby KJ and Wright FJ (eds) *Woodland Conservation and Research in the Clay Vale of Oxfordshire and Buckinghamshire*. Research and Survey in Nature Conservation 15. pp 53–65. Nature Conservancy Council, Peterborough
- García Casanova J, Rodríguez Luengo JL and Rodríguez Piñero C** 2001. *Especies amenazadas*. In: Fernández-Palacios JM and Martín JL (eds) *Naturaleza de las Islas Canarias: Ecología y Conservación*. pp 167–172. Turquesa, Santa Cruz de Tenerife
- Gutzwiller KJ and Barrow WC** 2003. Influences of roads and development on bird communities in protected Chihuahuan desert landscapes. *Biological Conservation* 113: 225–237
- Helbig AJ, Martens J, Seibold I, Henning F, Schottler B and Wink M** 1996. Phylogeny and species limits in the Palearctic Chiffchaff *Phylloscopus collybita* complex: mitochondrial genetic differentiation and bioacoustic evidence. *Ibis* 138: 650–666
- Imbeau L, Drapeau P and Mönkkönen M** 2003. Are forest birds categorised as “edge species” strictly associated with edges? *Ecography* 26: 514–520
- Kurosawa R and Askins RA** 2003. Effects of habitat fragmentation on birds in deciduous forests in Japan. *Conservation Biology* 17: 695–707
- Lack D** 1969. The numbers of bird species on islands. *Bird Study* 16: 193–209
- Laurance SGW, Stouffer PC and Laurance WF** 2004. Effects of road clearings on movement patterns of understory rainforest birds in central Amazonia. *Conservation Biology* 18: 1099–1109
- Laursen K** 1981. Birds on roadside verges and the effect of mowing on frequency and distribution. *Biological Conservation* 20: 59–68
- Lynch JF and Saunders DA** 1991. *Responses of bird species to habitat fragmentation in the wheatbelt of Western Australia: interiors, edges and corridors*. In: Saunders DA and Hobbs RJ (eds) *Nature Conservation 2: the Role of Corridors*. pp 143–158. Surrey Beatty and Sons, Sydney
- Martín JL and Fernández-Palacios JM** 2001. *Conservación y desarrollo: el difícil equilibrio*. In: Fernández-Palacios JM and Martín JL (eds) *Naturaleza de las Islas Canarias: Ecología y Conservación*. pp 423–428. Turquesa, Santa Cruz de Tenerife
- Martín A, Hernández MA, Lorenzo JA, Nogales M and González C** 2000. *Las palomas endémicas de Canarias*. Consejería de Política Territorial y Medio Ambiente de Canarias, SEO-Birdlife, Santa Cruz de Tenerife
- Martín A and Lorenzo JA** 2001. *Aves del Archipiélago Canario*. Francisco Lemus, La Laguna
- McCollin D** 1993. Avian distribution patterns in a fragmented wooded landscape (North Humberside, UK): the role of between-patch and within-patch structure. *Global Ecology and Biogeography Letters* 3: 48–62
- Meunier FD, Verheyden C and Jouventin P** 1999. Bird communities of highway verges: influence of adjacent habitat and roadside management. *Acta Oecologica* 20: 1–13
- Oliveira P and Jones M** 1995. Population numbers, habitat preferences and the impact of the Long-toed Pigeon, *Columba trocaz*, on agriculture. *Boletim do Museu Municipal do Funchal* 4: 531–542
- Reijnen R, Foppen R, ter Braak C and Thissen J** 1995. The effects of car traffic on breeding bird populations in woodland. III. Reduction of density in relation to the proximity of main roads. *Journal of Applied Ecology* 32: 187–202
- Rich AC, Dobkin DS and Nile LJ** 1994. Defining forest

- fragmentation by corridor width: the influence of narrow forest-dividing corridors on forest-nesting birds in New Jersey. *Conservation Biology* 8: 1109–1121
- Salzburger W, Martens J and Sturmbauer C** 2002. Paraphyly of the Blue Tit (*Parus caeruleus*) suggested from cytochrome b sequences. *Molecular Phylogenetics and Evolution* 24: 19–25
- Schluter D** 1988. Character displacement and the adaptive divergence of finches on islands and continents. *American Naturalist* 131: 799–824
- Schmiegelow FKA and Mönkönnen M** 2002. Habitat loss and fragmentation in dynamic landscapes: avian perspectives from the boreal forests. *Ecological Applications* 12: 375–389
- Sibley CG and Monroe BL** 1990. *Distribution and Taxonomy of Birds of the World*. Yale University Press, New Haven
- Valido A and Delgado JD** 1996. *Estudio sobre la comunidad de aves de la laurisilva en la Isla de Tenerife (Islas Canarias)*. SEO-Birdlife, Viceconsejería de Política Territorial del Gobierno de Canarias, Santa Cruz de Tenerife
- Villard M-A** 1998. On forest-interior species, edge avoidance, area sensitivity and dogmas in avian conservation. *Auk* 115: 801–805
- Walter HS** 2004. The mismeasure of islands: implications for biogeographical theory and the conservation of nature. *Journal of Biogeography* 31:177–197
- Whittaker RJ** 1998. *Island Biogeography: Ecology, Evolution and Conservation*. Oxford University Press, New York
- Wilkie D, Shaw E, Rotberg F, Morelli G and Auzel P** 2000. Roads, development, and conservation in the Congo Basin. *Conservation Biology* 14: 1614–1622
- Williamson MH** 1981. *Island Populations*. Oxford University Press, Oxford
- Wright SJ** 1980. Density compensation in island avifaunas. *Oecologia* 45: 385–389