

BIODIVERSITY IN FOREST ECOSYSTEMS

Changes in plant species composition and litter production in response to roads and trails in the laurel forest of Tenerife (Canary Islands)

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Abstract

Road density has increased in the Canary Islands' forests during the last century, affecting an unknown amount of forested area. We studied road effects on vegetation in the relict laurel forest of Tenerife. We assessed edge effects on plant species richness, plant composition and litter production. Effects of anthropogenic corridors on vegetation differed between paved roads and unpaved trails. Opportunistic species (shade intolerant) dominated road edges, but composition differed among all sites. Multivariate analysis revealed convergence in species composition along the corridor-interior gradient. For trails, both species richness and litter production did not differ significantly between edge and interior. Road edge effects on vegetation were detectable only within the first 10 m towards the interior. This suggests that the main effects of roads and trails on species richness are limited to the immediate edge of the laurel forest. Litter fall along road edges was half that of the interior. However, no significant differences were detected due to the high variability of the data. A buffer of approximately 10 m would result in the reduction of the total area of the remaining undisturbed laurel forest. Based on these results, the building of new paved roads should not be considered. Low human population inflow into the Anaga Rural Park needs to be maintained on a sustainable basis. Forest managers should take these road/trail effects into account when planning new road openings in this ecosystem.

Keywords: DCA, disturbances, edge effect, laurel forest, species richness

Introduction

A growing interest has developed in the environmental costs of roads (Maddison et al. 1996). Road systems are a source of biotic and abiotic effects on the surrounding landscape (Bennett 1991) and the continued existence of these corridors results in enormous human activity (Forman & Alexander 1998). Roads sharply define and fragment forest ecosystems, and plant species composition and structure change from road edges to the surrounding interior (Łuczaj 1999; Cavieres et al. 2005). Also, spatio-temporal dynamics in the forest edge, whether of natural or anthropogenic origin, differ from those in the interior (Matlack 1994). A complete understanding of forest dynamics requires the study of these road edge areas where ecological processes differ from those occurring inside the forest (Ranney et al. 1981).

Islands often have fragile ecosystems due to, in many cases, long periods of isolation, and they are

prone to direct or indirect man-made alterations. Island evolution in isolation from continental biota means that they are particularly susceptible to the invasion of exotic species (Whittaker & Fernández-Palacios 2006). A remarkable number of invasive plant species has also been favoured by the road system in the last few decades (Reyes-Betancort et al. 1999). Several studies in oceanic islands reveal the important effects of roads on the native vegetation (Parendes & Jones 2000; Dahler 2005).

Attention has traditionally been focused on trees and shrubs, whereas herbaceous species have received much less attention (Burke & Nol 1998). These different components may vary in response to the opening of a road corridor. Thus, if we consider these groups separately it may shed light on the ultimate causes of variation along such gradients.

Species changes will affect the litter production as well as litter nutrient contents as an indirect response to disturbance (Hunter 1999). Changes in litter production in response to roads and trails will offer

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information about changes in the trophic structure of the forest.

Our main hypothesis is that paved roads (hereafter called roads) and unpaved roads (hereafter called trails) in one of the most emblematic ecosystems, the laurel forest, of the Canary Islands is affecting species composition and litter production. In this framework, the objectives of the present work are: (1) to elucidate the major changes in species composition due to roads and trails; (2) to reveal road and trail effects on species number and (3) to examine the changes in litter production in response to the corridor.

The results of this study will be important for determining the role of roads and trails in the laurel forest. They will also be useful for the design of restoration programs and management of protected areas.

Material and methods

Study site

The study was conducted in the Anaga Rural Park in the northeastern part of Tenerife, Canary Islands $(28^{\circ}19' \text{ N}, 16^{\circ}34' \text{ W})$. The park encompasses a 7- to 8-million year old basaltic massif (Ancochea et al. 1990) covering about 130 km². The park represents 7% of Tenerife's total area. We selected two sites in the park, representing weakly disturbed laurel forests of Anaga: "El Moquinal" on the windward slope (700 m altitude) and "Aguirre" (900 m altitude) on the leeward slope. Tenerife's evergreen laurel forest has been extensively exploited since the arrival of the Europeans in the fifteenth century (Parsons 1981). Only 10% of the forest remains; it has been formally protected since 1988, and currently experiences fewer human disturbances and no reduction in area. No data are available regarding the precise age of the forest, but aerial photographs from 1952 show the forest in its current state, in terms of both extent and physiognomy. In the 1940s, there was still some illegal, small-scale forest exploitation due to its protection schedule and public character.

The annual precipitation in the park is about 900 mm, but can be two-fold higher due to fog drip (Kämmer 1974). The mean annual temperature is close to 15°C, with minimal annual and daily fluctuations. There are no frost events. The seasons can be differentiated into winter and summer, but in most years differences between the two most extreme months are not large (differences between monthly averages: 8°C, 5% relative humidity and 100 mm of rain) (Ceballos & Ortuño 1976). The soils are classified according to the FAO in the order Entisol, suborder Orthens, being typical of high slope areas. They maintain a high degree of humidity due to the hydrate aluminium silicates and have a thick A horizon (Fernández-Caldas et al. 1985). The soil content in organic matter is high ($\sim 10\%$) and pH is around 5.5 (Fernández-Palacios & Arévalo 1998).

The trees of Anaga's laurel forest are 10–20 m high depending on the slope. Maximum heights are found at basin bottoms decreasing progressively towards the basin's borders. The laurel forest of Tenerife contains a total of 19 tree species (Santos 1990). Dominant species include *Laurus azorica*, *Erica scoparia*, *E. arborea* and *Prunus lusitanica*. The dominance of a given species depends on site conditions, with particularly *E. scoparia* in forest ridges, *L. azorica* in mesic zones and *E. arborea* in disturbed areas (MAPA 1973). Further information on stand composition, structure and environment in the study sites can be found in Arévalo et al. (2007). Nomenclature follows Hansen and Sunding's (1985) checklist.

Sampling design

We selected the main road and the main trail at each of the two sites: El Moquinal (El Batán road and Pedro Álvarez trail) and Aguirre (Cruz del Carmen road and La Estercolada trail). For each road/trail we established three random transects of different length and 10 m width (Table I), perpendicular to the road/ trail and beginning from the border of the road/trail. At 10 m intervals (starting from the edge of the road) we located a 10×5 m plot (the 10 m side parallel to the road) and measured tree density and diameter at breast height (dbh) for all individuals > 2.5 cm dbh (at 0 m, 10 m, 15 m, ...). Inside of each plot we centrally located a 2×3 m subplot. Within each subplot, we identified all herbaceous and woody species at ground level and estimated their cover by classes (1: traces, 2, >1%; 3, 1-2%; 4, 2-5%; 5, 5-10%; 6, 10-25%; 7, 25-50%; 8, 50-75%; 9, >75%). Transect lengths differed because we avoided intercepting steep ravines (that obstructed plot setting and assessment) and proximity to other corridor edges or non-forest habitats (see Table I for a complete description of transects). Mean values of the number of species from the three transects were graphically represented for the 6 m² plots (corresponding to the plots at the given distance for each transect), and 50 m^2 for the mean values of the number of tree species along the transect starting from the edge.

To assess variation in litter production along the corridor-interior gradient, we used litterfall trays located at a road (Batán) and a trail (Pedro Álvarez). Trays were located at 10 m intervals, starting at the road-trail edge. Trays consisted of mesh baskets 50 cm in diameter (0.22 m^2) , fixed in an iron frame 1 m above the ground. This method minimised litter

loss by wind or ground animals. The litter was collected at approximately bimonthly intervals for 3 years (January 1999–January 2002). After air-drying at room temperature for 7 days, litter was weighed, and separate records kept for photosynthetic, reproductive (fruits and flowers) and supporting (branches) tissues. Litter production can be considered as an indicator of the level of disturbance, and roads can modify the litter fall, thereby influencing the germination of species and species composition.

Statistical analysis

We used ordination techniques to explain patterns of community variation along the road-interior gradient (Gauch 1982). We applied detrended

Site	Road or trail name	Corridor type	Characteristics of the transects			
			Exposition	Mean altitude (m)	Slope (°)	Length (m)
El Moquinal	Batán	Road	SE	980	30	60
El Moquinal	Batán	Road	SE	980	30	60
El Moquinal	Batán	Road	SE	980	30	60
El Moquinal	Pedro Álvarez	Trail	NW	900	5	40
El Moquinal	Pedro Álvarez	Trail	NW	900	5	40
El Moquinal	Pedro Álvarez	Trail	NW	900	5	40
Aguirre	Cruz del Carmen	Road	S	1,000	35	60
Aguirre	Cruz del Carmen	Road	S	1,000	30	60
Aguirre	Cruz del Carmen	Road	S	1,000	30	60
Aguirre	Estercolada	Trail	SE	900	28	40
Aguirre	Estercolada	Trail	SE	900	28	40
Aguirre	Estercolada	Trail	SE	900	28	40



Figure 1. Mean total number of species in 6 m^2 plots and total number of tree species in 50 m^2 plots along the three transects from the road or trail to the forest interior. (a) Total no. of species, roads; (b) total no. of species, trails; (c) no. of tree species, roads; (d) no. of tree species, trails.

correspondence analysis (DCA; Hill & Gauch 1980) to analyse the variation and compositional turn-over along the transects. This approach helped us to explain the variation in species composition along the edge-interior gradient. For analysis and graphics on each road or trail, we used the combined data of species cover of the three transects of each site (each transect had plots of 6 m^2) at different distances, using the species mean cover of the three plots at each distance (in the pooled samples all the species were present).

We analysed differences in the total number of species and the number of tree species for the road-forest interior and the trail-forest interior gradient (60 m for roads and 40 m for trails) with an analysis of variance (p < 0.05). To determine where, along the transect, an apparent variation in the number of species (total number of tree species) could no longer be detected, we used the Helmert procedure, which compares the mean number of species at plot location edge (0 m) with the mean of the number of species at plot location 10 (10 m) by following

factor levels through 60 m in the case of the road and 40 m in the case of the trails (p < 0.05).

To test for differences between total annual litter fractions collected along the transect (the chosen road and trail) during the three years, we used the Wilcoxon test with sign, pairing the data from the same bimonthly period (it was not possible to analyse data with parametric analyses due to the lack of normality in many of the samples, n = 18, p < 0.05).

We performed all multivariate analyses with the CANOCO 4.5 package (ter Braak & Ŝmilauer 1998). Basic statistical methods were followed as given in Legendre and Legendre (1998) and were applied using the SPSS 10.0 statistical package (SPSS Inc. 1997).

Results

The pattern of change in the mean number of species along the edge-interior gradient differed between roads and trails. For the road-forest interior gradient, the average total species richness decreased from



Figure 2. Mean percentage cover of the species for the three transects from the corridor (0 m) to the forest interior, including shrubs, forbs, ferns and graminoids for (a) the road-forest interior gradient and (b) the trail-forest interior gradient. The mean covers for tree species only are shown for roads and trails in (c) and (d), respectively.

eight to four species in 6 m² plots (n = 7, F = 10.292, p < 0.01, Figure 1a). The Helmert's test indicated differences only between the distances 0–10 m (n = 7 distances to the road, D = 4.039, p < 0.01). For the trail-forest interior gradient, the average total number of species (five to four species) did not differ significantly along the transect (Figure 1b).

The number of tree species did not differ significantly along the road-forest interior or trail-forest interior gradient (p < 0.05). We found on average six to three species, and six to four species, respectively, in the 50 m² plots (Figure 1 c,d).

The mean cover of the species, graphically represented in stack bar diagrams, indicates the higher number of species in the transect at 0 m as compared with the other plots in the forest interior, as for the total species richness (Figure 2a) in the road-forest interior gradient. In the case of roadforest interior gradient of tree species, we detected some species only found in the border (at 0 m), such as *Ilex canariensis* (Figure 2c), a shade-intolerant species (Arévalo & Fernández-Palacios 1998). For the trail-forest interior gradient of species cover (Figure 2 b,d), the patterns were not as marked as in the road-gradient transect.

We graphically presented axis I (eigenvalue of 0.280 and a cumulative percentage of variance of

17.8%) and axis II (eigenvalue of 0.185 and a cumulative percentage of variance of 29.6%) of the DCA (with a total inertia of 1.64). We joined the first plot (the closest to the road or trail) of the transect with the last one using an arrow, although the distribution of the plots was not linear (Figure 3). The plots of each transect did not show a linear distribution with respect to either of the axes. Species composition revealed a great variability along roadtrail edges, around 2 DCA units, which indicates a high variability in species composition (Leps & Ŝmilauer 2003). Species composition was roughly constant along the trail-interior gradients at 10 m from the edge. The graph reveals the existence of a convergence in species composition along the gradient towards the interior.

Shade-intolerant species (Erica arborea, E. scoparia, Hedera helix and Rumex mauritanica) together with heliophilous species (Semele androgyna) were dominant at trail edges (Figure 4). Native ruderal (Galium scabrum, Origanum vulgare, Polycarpaea divaricata), annual (Luzula sp., Galium aparine) or exotic (Oxalis pes-caprae) species were dominant along road edges. These species were replaced towards the interior by the dominant trees Ilex canariensis, I. perado, Laurus azorica, Prunus lusitanica and Viburnum tinus. Among the herbaceous plants, Ranunculus cortusifolius was recorded frequently in



Figure 3. Sample plot scores along DCA axes I and II using the total species composition of the plots at different distances from each corridor (combined values of the three transects). Coordinates of the combined plots are represented in the graph. The third axis did not show any interpretable pattern. Letters indicate: "B" for Batán road (circles), "C" for Cruz del Carmen road (stars), "P" for Pedro Álvarez trail (rectangles) and "E" for Estercolada trail (x-mark). Numbers indicate distance from the corridor: 0 for 0 m, 1 for 10 m, 2 for 20 m, etc. Arrows join the first and the last plots of the combined transect for roads and trails at each site.



Species scores - Detrended Correspondence Analysis

Figure 4. Species scores along DCA axes I and II. Species abbreviations: AGAD, Ageratina adenophora; APBA, Apollonias barbujana; ARCA, Artemisia canariensis; ASON, Asplenium onopteris; ARVU, Arisarum vulgare; ERAR, Erica arborea; ERSC, Erica scoparia; GAAP, Galium aparine; GASC, Galium scabrum; HEEX, Heberdenia excelsa; HEHE, Hedera helix; HYGR, Hypericum grandifolium; ILCA, Ilex canariensis; ILPE, Ilex perado; IXCA, Ixanthus canariensis; LUsp, Luzula sp.; LAAZ, Laurus azorica; MYFA, Myrica faya; OCFO, Ocotea foetens; ORVU, Origanum vulgaris; OXPE, Oxalis pes-caprae; POTE, Polycarpaea tenneriffae; PEAP, Pericallis appendiculata; PEIN, Persea indica; PHNO, Phyllis nobla; PIEX, Picconia excelsa; PLAR, Plantago arborecens; PTAQ, Pteridium aquilinum; PRLU, Prunus lusitanica; RACO, Ranunculus cortusifolius; RUMA, Rumex mauritanica; SOsp, Sonchus sp.; SEAN, Semele androgina; SP1, SP1 (unidentified species); VITI, Viburnum tinus. Large size and bold letters are used for trees; large size, bold and italic letters are used for exotic plants. The rest of the species are heliophilous, annual and herbaceous.

the forest interior. The rest of the species did not reveal consistent patterns.

Average litter production along the corridorinterior gradient showed different patterns between roads and trails. Mean annual production (photosynthetic, reproductive and support fractions) was lower along road edges than in the forest interior at any distance. However, there was a high temporal and spatial variability in litter fall, and no statistical significant differences were observed between edge and interior for any corridor type (Figure 5).

Total necromass increased from the edge (400 g $m^{-2} y^{-1}$) to the interior (700–900 g $m^{-2} y^{-1}$), becoming constant at around 20 m. For trails, we detected no clear trends for any of the litter fractions

or for the total litter. Total annual litterfall ranged between 400 and 600 g m⁻² y⁻¹ along the transect (Figure 6).

Discussion

Roads and trails are abrupt discontinuities, contrasting with the wider and more diffuse edges common to many natural areas (Delgado et al. 2001), and road effects can penetrate long distances into the forest. These corridors may alter the forest matrix in different ways (Forman & Alexander 1998), depending on the species. We found different effects of roads and trails using the two parameters species richness and litter production.



Figure 5. Mean annual litter fall (average for 3 years in g m⁻²) at different distances from the road (standard deviation represented in error bars) for the baskets of the three plots at each site. Each graph represents a different fraction of the litter, the last one showing the values for the total litter collected. Note that graph (d) has a different Y axis scale.



Figure 6. Mean annual litter fall (average for 3 years in g m⁻²) at different distances from the trail (standard deviation represented in error bars) for the baskets of the three plots at each site. See also Figure 5.

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exotic species along edges, but the pattern rapidly stabilised towards the interior (10 m), where these species were almost absent. Species richness was subjected to great variation between corridor types, with no significant variability along the trail-interior gradient and a greater variation along the roadinterior gradient. Both roads and trails are in the same plant community, the laurel forest, with similar topographic variability. These differences can be attributed to the type of human corridor. Whereas tree species richness did not show any clear spatial pattern, total species richness clearly decreased along the road-forest interior gradient. For exotic species, corridor edges provide new habitats and facilitate plant dispersal (Benninger-Truax et al. 1992). It is difficult for these species to colonise the laurel forest interior, as they are dependent on

disturbances and openness in the canopy (Arévalo et al. 2005) where several native tree species dominate (Arévalo & Fernández-Palacios 1998). However, we only found two exotic species in the border of the road corridor (*Oxalis pes-caprae* and *Ageratina adenophora*).

Total plant species richness was mostly altered by

the contribution of native ruderal, heliophilous or

Variation in species composition along the corridor-interior gradient was high both between corridor types and among sites, with a clear species turnover for both roads and trails. The presence of the disturbance corridor clearly increased variability in species composition at the corridor edges. The larger, although non-linear, changes were produced within the first 10 m. Compositional convergence processes between transects are likely to occur at this scale, suggesting a limitation of the disturbance effects to the corridor proximity (Figure 4).

Although monthly variation in litter production was large, road edges showed lower production than the interior, whereas necromass production along trail-interior gradients did not show any clear trend. Litter fall is larger at the road transects than at the trail transects as a direct effect of the bigger fragmentation (Nakane 1975) of the canopy by the road building, and that increases the wind effect on the forest interior.

The above results suggest that edge effects (in terms of species richness, composition and litter fall) of roads and trails extend at least 10 m inside the forest. In the case of roads a decrease in the number of species is apparent (Figure 1a), while for trails, although there is no decrease in species richness, a turnover of species could be detected by the ordination analysis (Figure 2). This means that the amount of laurel forest actually affected by roads goes beyond the actual area covered by the roads. This influence should be considered together with other major road effects, e.g., creation of artificial

ecotones, sources of pollution, barriers to animals and plants, and sources of mortality (Schonewald-Cox & Buechner 1992).

Roads have a greater effect than trails. However, while both are affecting species distribution and composition in the forest, the second does not appear to alter the number of species. This is probably related to the different traffic density that supports each type of corridor, less than 10 vehicles/ day for trails and more than 600/day for roads (Pulido & Utrilla 1984).

Roads and trails in the Canarian laurel forest permit visitor contact with relatively remote areas and allow local inhabitants to move across the territory. However, a deeper understanding of the effects of these anthropogenic corridors at the local and regional scales is required to integrate road planning (Kuiken 1988) and management with the aim of conserving the value of the laurel forest.

Acknowledgments

This work is part of a research project on laurel forest dynamics funded by the Canarian Government (Consejería de Política Territorial, Viceconsejería de Medio Ambiente, Sección de Áreas Protegidas). We thank Jerry Husak for help with the manuscript. We appreciate the criticism and suggestions that highly improved the quality of this manuscript provided by the editor Martin Diekmann and two anonymous reviewers.

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