SUMMER ABUNDANCE AND ECOLOGICAL DISTRIBUTION OF PASSERINES IN NATIVE AND EXOTIC FORESTS IN SÃO MIGUEL, AZORES

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SUMMARY.—*Summer abundance and ecological distribution of passerines in native and exotic forests in São Miguel, Azores.*

Aims: To assess the influence of native and exotic forests on the ecological distribution and abundance of forest bird species on São Miguel Island, Azores, during the breeding season.

Location: Forests in the eastern part of São Miguel Island, Azores.

Methods: Point-counts were conducted in two exotic forest habitats (copses of *Pittosporum undulatum* and plantations of *Cryptomeria japonica*) and in the native laurel forest. Program DISTANCE was used to estimate ecological densities (birds/ha) for five bird species per forest type. Mist-netting was carried out to assess the relative abundance of birds in four plots representing different altitudes and a gradient of infestation by exotic plants.

Results: Nine bird species were recorded during the point-counts, and six of them occurred in the three forest types. Goldcrest *Regulus regulus azoricus* was the most generalist and abundant species in all forest types and the endemic Azores bullfinch *Pyrrhula murina* the most specialist, occurring only in native forest. Both point counts and mist-netting showed higher diversity and equitability in areas/plots with native forest, although species richness was not higher than in exotic forests. Mist-netting results showed highest diversity and equitability in the mid-altitude native forest plot.

Conclusions: Birds showed a higher relative abundance in native than in exotic forests. Goldcrest was the most abundant species in *C. japonica* forest whereas the distribution of the Azores bullfinch was heavily restricted by the spread of exotic forest. This study demonstrates the importance of the native forest, particularly at mid altitudes, for the maintenance of a more homogeneous bird distribution in São Miguel Island, Azores.

Key words: ecological densities, exotic forest, laurel forest, Macaronesia, mist-netting, oceanic islands, *Pyrrhula murina*, point-counts.

RESUMEN.—Abundancia estival y distribución ecológica de los passeriformes en el bosque autóctono y exótico de San Miguel, Azores.

Objetivos: Valorar la influencia de los bosques autóctonos y exóticos en la distribución ecológica y abundancia de las especies de aves en los bosques de la isla de San Miguel, Azores, durante la época reproductiva.

Localidad: Bosques en la parte oriental de la isla de San Miguel, Azores.

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Métodos: Mediante conteos puntuales en dos hábitats de bosque exótico de *Pittosporum ondulatum* y plantaciones de *Cryptomeria japonica* y también en el bosque autóctono de laurisilva. Se utilizó el programa DISTANCE para la estimación de densidades ecológicas (aves/ha) para cinco especies en cada tipo de bosque. Se utilizaron redes japonesas para estimar la abundancia relativa de aves en cuatro lugares representativos con diferentes altitudes y un gradiente de invasión de plantas exóticas.

Resultados: Se encontraron nueve especies mediante los conteos puntuales, estando seis de ellas en tres tipos de bosque. El reyezuelo sencillo *Regulus regulus azoricus* se mostró como la especie más generalista y abundante en todos los tipos de bosque y, el endémico camachuelo de las Azores *Pyrrhula murina* como la más especialista, apareciendo solamente en el bosque autóctono. En los conteos puntuales y trampeado con redes japonesas, los dos mostraron una diversidad y equitabilidad más alta en los bosques autóctonos, aunque la riqueza específica no fue más alta que en los bosques exóticos. Los resultados de los trampeos con redes mostraron la diversidad y equitabilidad más alta en el punto de bosque autóctono de altitud mediana.

Conclusiones: Las aves mostraron una abundancia relativa más alta en los bosques autóctonos que en los exóticos. El reyezuelo sencillo fue la especie más abundante en el bosque de *C. japonica*, mientras que el camachuelo de las Azores está más restringido por el incremento del bosque exótico. En este estudio se demuestra la importancia del bosque autóctono, especialmente en altitudes medias, para el mantenimiento de una distribución aviar más homogénea en la isla de San Miguel, Azores.

Palabras clave: bosque exótico, bosque de laurisilva, conteos puntuales, densidades ecológicas, islas oceánicas, Macaronesia, *Pyrrhula murina*, redes japonesas.

INTRODUCTION

Oceanic island habitats have been destroyed, homogenised and altered by man ever since human colonisation (Steadman, 1995; Groom *et al.*, 2006). For instance, island sites have three times more exotic plant species than mainland sites with the same area (Lonsdale, 1999). As a consequence, the native biodiversity of island communities has been deteriorating at an alarming rate (Groom *et al.*, 2006), with islands being subject to the majority of bird extinctions worldwide (Johnson and Stattersfield, 1990; Steadman, 1995).

All nine islands of the Azores were once covered with native evergreen forests (Fructuoso, 1561; Godman, 1870) which, together with the Canary and Madeira Islands, are considered relics of the Tertiary forests of southern Europe (Tutin, 1953; see, however, Emerson, 2002). Eight of the eleven native Azorean tree species are endemic to the Azores and two are endemic to the Azores and Madeira (Haggar, 1988). Despite the high ecological value of this habitat (Dias, 1996; Gil, 2005), the majority of the native laurel forests in the Azores have been cleared for pasture or afforested, mainly with the exotic Japanese red cedar *Cryptomeria japonica*. Furthermore, the recently introduced aggressive exotic plants Australian cheesewood *Pittosporum undulatum*, kahili ginger *Hedychium gardneranum* and lily-of-the-valley tree *Clethra arborea* led to major changes in the floral composition of the remaining forest fragments (Sjögren, 1973; Haggar *et al.*, 1989; Ramos, 1996a; Dias, 1996; Silva, 2001).

All passerines breeding in the Azores are of Palearctic origin (Cramp, 1992; Cramp and Perrins, 1994). From the confirmed 12 breeding passerine species, one, the canary *Serinus canaria*, is endemic to Macaronesia and other, the Azores bullfinch or priolo *Pyrrhula murina*, is endemic to São Miguel Island. Most other species are represented by endemic subspecies (Cramp and Perrins, 1994). Apart from the Azores bullfinch, which is largely restricted to the native high-altitude cloud

forest (Ramos, 1996a), there is no information on the abundance and distribution of the other passerine species in relation to forest types. The majority of the other common forest passerines such as blackbird *Turdus merula azorensis*, blackcap *Sylvia atricapilla gularis*, chaffinch *Fringilla coelebs moreletti,* goldcrest *Regulus regulus azoricus* and robin *Erithacus rubecula* seem to be fairly generalist (Bannerman and Bannerman, 1966; Ramos 1998). Because alien forest tend to be dominated by a few abundant species of introduced plants, we expect them to offer less resources (berries, seeds and insects) than native forests (Heleno *et al.*, 2009), therefore we expect differences in bird abundance in relation to forest type.

Point-counts and mist-netting are two of the most commonly used techniques for quantifying avian species richness and relative abundances (Wang and Finch, 2002; Faaborg *et al.*, 2004). When properly used, point-counts can accurately assess species richness, relative abundance, and population trends, having been recommended as the standard method for monitoring birds (Ralph and Scott, 1981; Ralph *et al.*, 1995; Dobkin and Rich, 1998). Mist-netting can be a more effective tool for detecting presence of undergrowth bird species, particularly secretive species or those that vocalize infrequently (Karr, 1981; Ralph *et al.*, 1993; Dunn and Ralph, 2004), even if it can produce substantial differences in the capture rates of birds with identical abundance (Remsen and Good, 1996).

Apart from some information on densities in different habitat types in the Canary Islands (Carrascal, 1987; Carrascal *et al.,* 1992; Tellería and Carrascal, 1994; Valido *et al.,* 1994; Carrascal and Palomino, 2005; García-del-Rey and Cresswell, 2005), there is virtually no information on forest habitat use by passerines in the Macaronesian Islands. This baseline information is extremely important for the conservation and management of native forests in these islands, given their ac-celerated loss and alteration. The main objectives of this paper are: (1) to estimate the abundance of birds in the three most common forest types in São Miguel (native forest, *P. undulatum* copses and *C. japonica* plantations) using point-counts, and (2) to evaluate the ecological distribution and abundance of birds along a gradient of infestation by exotic plants with mist-netting. This study also increases the knowledge on the ecology of forest bird species in the Macaronesian islands and it has important implications for the conservation of forest birds in the Azores.

MATERIAL AND METHODS

Study area

The Azores archipelago is composed of nine inhabited islands located in the middle of the Atlantic Ocean. Our study area spread over 12 km^2 in Serra da Tronqueira, in the eastern part of the São Miguel Island (37º 47' N, 25º 13' W), and ranged from 320 to 850 m a.s.l. (fig. 1). Serra da Tronqueira is a mountainous district with steep ground densely vegetated with native and exotic flora (Ramos, 1995; Silva, 2001; Gil, 2005). Native vegetation in the east of São Miguel has been cleared for pasture and afforested mainly with *C. japonica*, or taken over almost completely by *P. undulatum* on slopes along streams up to 500 m and by *H. gardneranum* on disturbed ground and streams. *C. arborea* is scattered widely through the whole remnants of native forest (Ramos, 1996a; Silva, 2001). Slightly invaded patches of native forest remain only above 500 m in the cloud zone (Silva, 2001).

Sampling was concentrated in the northeastern part of São Miguel because this area holds the last significant native forest in the island, and nearby plantations of *C. japonica* and *P. undulatum* copses were chosen in order to coincide with the main distribution area of the Azores bullfinch (Ramos, 1996a) and minimise
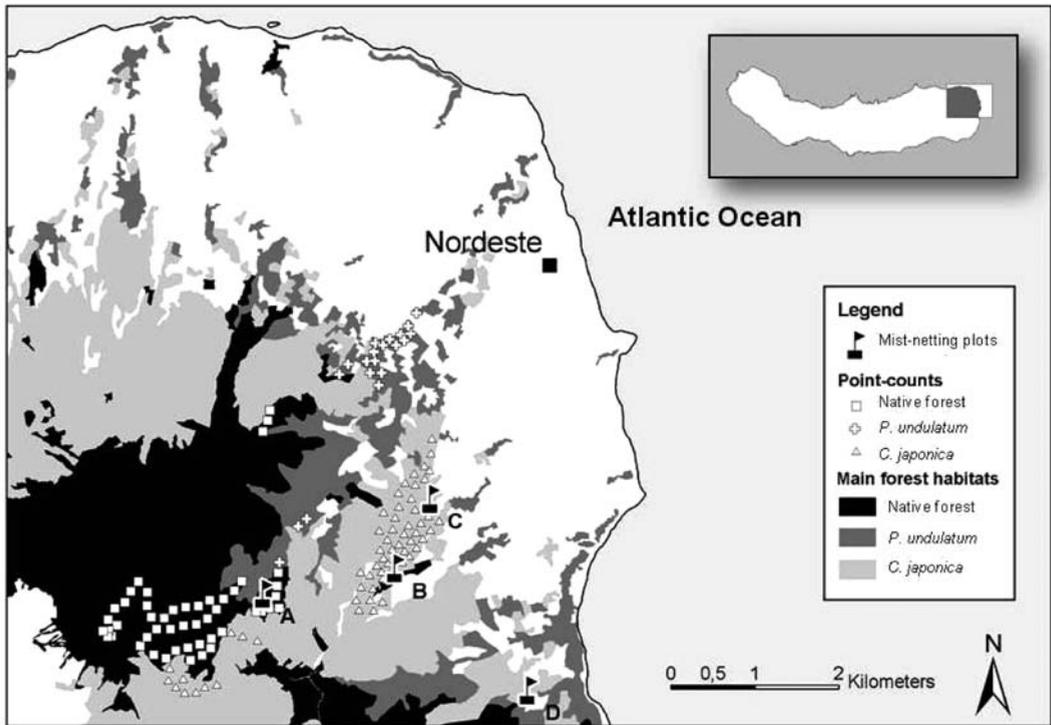
Fig. 1.—Map of Serra da Tronqueira in eastern São Miguel Island with the location of point-counts and mist-netting plots.
[Mapa de la sierra de Tronqueira en el este de la isla de San Miguel, con la localización de los puntos de muestreo y captura.]

spatial variability. Moreover, the structure of *C. japonica* plantations is very similar throughout São Miguel, so that our study area is likely to be highly representative of this habitat. As for copses of *P. undulatum*, those outside Serra da Tronqueira are mainly small corridors, where it would be difficult to place sampling points.

For taxonomic classification of plant species we followed *Flora Europaea* (Tutin *et al.*, 1964; Tutin *et al.*, 1978) and Sjögren (1973).

Point-counts

The abundance of bird species was evaluated in three different forest types (native forest, *P. undulatum* copses and *C. japonica* plantations; see fig. 1) using the point-counts method (Bibby *et al.*, 1992).

Native forest sites had a dense canopy, 4 - 6 m tall, of *Erica azorica, Ilex perado azorica, Juniperus brevifolia, Laurus azorica, Prunus lusitanica azorica, Vaccinium cylindraceum, Viburnum tinus subcordatum* and *C. arborea*, and a high density understorey of *Calluna vulgaris, Culcita macrocarpa, Hedera azorica, Myrsine africana, Osmunda regalis, Pteridium aquilinum, Rubus sp.*, *Smilax canariensis* and *Woodwardia radicans*.

P. undulatum copses were composed predominantly of *P. undulatum* with a dense canopy 6 – 8 m tall. Some *Persea indica*, *Acacia melanoxylon* and *Myrica faya* were scat-

tered within *P. undulatum* patches. There was a dense undergrowth comprising a 1.5 – 3 m tall layer of *H. gardneranum, Leycesteria formosa, P. aquilinum, Rubus sp.* and *W. radicans*.

C. japonica plantations had a high density of 12 – 18 m tall trees with a low density understory 1.5 – 3 m tall composed mainly of *C. arborea*, *H. gardneranum*, *C. macrocarpa*, *P. aquilinum* and *W. radicans*.

Point-counts were conducted between 07:00 and 11:00 hours from 23 July to 22 September 2005. Point-counts were carried out approximately at 150 m intervals. Counts were made one minute after arriving at the point to allow birds to settle down from any disturbance caused by the arrival of the observer. All birds heard or seen within a 50 m radius during a five minute period were recorded and their metric distance to the observer estimated. It has been documented (Ramos, 1995; Ramos, 1996a) that the Azores bullfinch has a higher abundance in native forest. Previous density estimates for the Azores bullfinch used eight minute point-counts (Ramos, 1996a; Farragolo *et al.*, 2003) and we used the same time period for this species in native forest in order to compare our results with previous estimates. For all other species the data used for the calculation of density estimates was collected during the first five minutes only.

Only 20 point-counts were done in *P. undulatum* because these copses are relatively narrow along streams and it was not possible to establish more point-count locations. The number of points in native forest and *C. japonica* plantations was 49 and 60, respectively.

Mist-netting

Four plots (A, B, C and D) were chosen to represent different levels of infestation by alien plants (see location in fig. 1 and description in table 1). Plots A, B and C were at a decreasing mid-altitude range, from 670 to 530 m a.s.l., and plot D was at a lower altitude, 320 – 390

m. Lower altitude plots showed a higher degree of infestation by exotic plant species (table 1). All the plots had the same area (approximately 0.75 ha) and were located along small forestry roads.

To measure vegetation composition and foliage density surrounding the mist-nets, we carried out four transects parallel to each net location, 0.5 m and 3 m distant from each side of the mist-nets. We recorded all the contacts of vegetation (distinguishing between native and exotic species, trees and shrubs) with a horizontal rope placed at chest height (Bullock, 1997; table 1).

Constant effort mist-netting was carried out during six days in each plot from 23 July to 22 September 2005, totalling 24 sessions. Four 12 m, two 9 m and three 6 m mist-nets (2.6 m height, 36 mm mesh) were opened 15 min before sunrise and remained open for five hours. Nets were placed randomly in relation to topography and locations of fruiting plants, factors that might influence capture rates. The same net locations were used in all sessions. All birds captured were ringed with metal rings and recaptured birds were excluded from the analysis.

Data analysis

Species richness (S) was defined as total number of species present in each community. Diversity indices were calculated for each forest type and mist-netting plot. To describe bird diversity we used the Shannon-Wiener index (H). The Shannon-Wiener index is defined as H = -Σ ($P_i \cdot \ln P_i$), where P_i is the number of individuals of a given species divided by the total number of individuals of all species observed. This index increases either by having more unique species, or by having greater species evenness. Using species richness and the Shannon-Wiener index, we calculated a measure of evenness as $E = H/\ln S$. With an equal proportion of all species the evenness is

TABLE 1

Description of the mist-netting plots. Vegetation composition and density were measured in four transects parallel to each net location, 0.5 m and 3 m distant from each side of the mist-nets (see methods).

[Descripción de los lugares de ubicación de las redes. La composición y densidad de la vegetación se valoró en cuatro transectos paralelos a cada localización de la red, distantes 0,5 m y 3 m a cada lado de la misma (ver métodos).]

	Altitude (m)	Slope	Characterization	Vegetation composition	Vegetation density	
					0.5 m	3 m
Native forest						
Plot A	620 – 670	High (30 – 38º)	Pure native forest (*C. vulgaris, I. p. azorica, J. brevifolia, L. azorica, M. africana, P. l. azorica, Rubus sp., V. cylindraceum, V. t. subcordatum*)	93.6 % native 6.4 % alien	1.1 contacts/m (45 % trees/ 55 % shrubs)	1.6 contacts/m (93 % trees/ 7 % shrubs)
Plot B	570 – 600	Low (0 – 7º)	Invaded native forest (*C. arborea, E. azorica, H. gardneranum, I. p. azorica, J. brevifolia, L. azorica, L. formosa, M. africana, V. t. subcordatum*)	49.7 % native 50.3 % alien	0.7 contacts/m (37 % trees/ 63 % shrubs)	1.6 contacts/m (38 % trees/ 62 % shrubs)
Exotic dominated forest openings						
Plot C	530 – 585	High (23 – 30º)	Old landslide surrounded by plantations of *C. japonica* and occupied mainly by exotic species (*A. melanoxylon, C. vulgaris, C. japonica, H. gardneranum, L. formosa, Rubus sp.*)	5.9 % native 94.1 % alien	0.5 contacts/m (52 % trees/ 48 % shrubs)	0.9 contacts/m (37 % trees/ 63 % shrubs)
Plot D	320 – 390	Very high (38 – 46º)	Patch of exotic *H. gardneranum* with few trees of *A. melanoxylon* and *C. japonica*, surrounded by sparse copses of *C. japonica* and *P. undulatum*	0.2 % native 99.8 % alien	2.5 contacts/m (100 % shrubs)	3.6 contacts/m (100 % shrubs)

one, but as dissimilarity increases evenness decreases (Pielou, 1975; Waite, 2000). Differences in diversity indices among forest types were analysed with bootstrap. The original sample of n values was used to generate 100 new samples, each of the same size, by repeating the original sample with replacement (Waite, 2000).

Analysis of variance (ANOVA), followed by post-hoc Tukey tests ($\alpha = 0.05$), were used to test for differences in the number of species and in the mean number of individuals (of all species) detected per station among forest types. Data were log-transformed for normality and homogeneity of variances. To test for differences in the number of individuals of bird species among forest types we used a Kruskal-Wallis test because variance was not homogeneous, even after data transformation. Chi-square tests were used to test for differences in the number of individuals of each species captured by mist-netting among plots.

A principal components analysis (PCA) was performed to describe patterns in the bird species composition among forest types. The number of individuals of each bird species per point (log-transformed) were used as dependent variables. Therefore, data for the PCA was a 129 x 7 matrix (49 points in native forest, 20 points in *P. undulatum* and 60 points in *C. japonica* x seven bird species). Goldfinch *Carduelis carduelis* and grey wagtail *Motacilla cinerea patriciae* had four and one detections, respectively, and were eliminated from the PCA. All statistical analyses were conducted using STATISTICA version 6.0 (Statsoft, 1996).

Density estimates from point counts data were computed using the program DISTANCE version 5.0 (Thomas *et al.*, 2006). A minimum of 60 detections is recommended to estimate density with a reasonable degree of accuracy (Buckland *et al.,* 2001). However, we included analysis of species with only 30 detections, acknowledging the lower reliability of these results. Uniform and half-normal key functions with cosine series expansion were test-ed, and the best models were selected on the basis of the Akaike Information Criteria (AIC) (Akaike, 1974).

Results

The total area sampled, obtained by multiplying the number of point-counts in each habitat type by the area covered by each point with a radius of 50 m, was 38.5 ha in native forest (49 points), 15.7 ha in *P. undulatum* copses (20 points) and 47.1 ha in *C. japonica* plantations (60 points). Although nine species of birds were recorded by both methods, point-counts and mist-netting, species composition differed among forest types and plots (table 2). Con-

Table 2

Species richness and diversity (mean ± standard deviation of 100 samples obtained by bootstrap) for birds detected with point-counts and captured with mist-nets (S = Species richness, H = Shannon-Wiener index, E = Shannon-Wiener equitability coefficient).
[Riqueza y diversidad de especies (media ± desviación estándar de 100 muestras obtenidas por remuestreo) para las aves detectadas en los puntos de captura con las redes. (S = riqueza de la especie, H = índice de Shanon-Wierner, E = coeficiente de equitabilidad de Shanon-Wierner).]

	S	H	E
Point-counts			
Native forest	7	1.50 ± 0.04	0.77 ± 0.02
P. undulatum	8	1.40 ± 0.11	0.68 ± 0.05
C. japonica	8	1.00 ± 0.05	0.48 ± 0.02
Mist-netting			
Native forest			
Plot A	6	1.34 ± 0.11	0.75 ± 0.06
Plot B	8	1.76 ± 0.09	0.84 ± 0.04
Exotic dominated forest openings			
Plot C	8	1.40 ± 0.16	0.67 ± 0.08
Plot D	8	1.45 ± 0.15	0.70 ± 0.07

Mean number of individuals/point ± standard deviation for each bird species (N = Native species, I = Introduced species, E = Endemic species) per forest type. The number of detections in each forest type can be obtained by multiplying these values by the number of point-counts. Species abundance among forest types are compared with a Kruskal-Wallis test (data log-transformed).

[Número medio de individuos/punto ± desviación estándar para cada especie de ave en cada tipo de bosque (N = especie nativa, I = especie introducida y E = especie endémica). El número de detecciones en cada tipo de bosque se puede obtener multiplicando sus valores por el número de puntos de muestreo. La abundancia de especies entre los tipos de bosque se comparó con el test de Kruskal-Wallis (datos transformados logarítmicamente).]

Species	Point-counts			$H_{2, 126}$	p
	Native forest	*P. undulatum*	*C. japonica*		
Azores bullfinch *Pyrrhula murina* (E)	0.35 ± 0.75	–	0.02 ± 0.13	18.10	< 0.001
Blackbird *Turdus merula* (N)	0.61 ± 0.64	0.65 ± 0.88	0.22 ± 0.45	13.75	0.001
Blackcap *Sylvia atricapilla* (N)	0.78 ± 0.82	0.70 ± 0.73	0.02 ± 0.13	42.34	< 0.001
Canary *Serinus canaria* (N)	0.24 ± 0.56	0.05 ± 0.22	0.03 ± 0.18	7.91	0.019
Chaffinch *Fringilla coelebs* (N)	1.76 ± 1.13	0.75 ± 0.91	1.35 ± 1.29	11.64	0.003
Goldcrest *Regulus regulus* (N)	3.27 ± 1.47	2.45 ± 1.19	2.25 ± 1.27	13.69	0.001
Goldfinch *Carduelis carduelis* (I)	–	0.10 ± 0.31	0.03 ± 0.18	4.71	0.095
Grey wagtail *Motacilla cinerea* (N)	–	0.05 ± 0.22	–	5.45	0.066
Robin *Erithacus rubecula* (N)	0.18 ± 0.44	0.10 ± 0.31	0.03 ± 0.18	5.44	0.066

cerning the native passerine species [note that the goldfinch was introduced to São Miguel at the end of XIXth century (Cramp and Perrins, 1994)], we found seven species in the three forest types, six in plot A, eight in plot B and seven in plots C and D.

Native forest had the highest diversity and *C. japonica* plantations the lowest. The equitability coefficient indicates also that the abundance of the bird species was more homogeneous in native than in exotic forests (table 2). Concerning mist-netting, plot B had the highest diversity and plot A the lowest. Nevertheless, the equitability coefficient indicates that the distribution of the total number of individuals by the different species was more homogeneous on both plots with native forest (table 2).

With the point-counts method the mean number of species detected per station differed among forest types (3.5 ± 1.1 species in native forest, 2.8 ± 1.3 in *P. undulatum*, 1.9 ± 0.7 in *C. japonica*; $F_{2, 126} = 33.56$, p < 0.0001). The post-hoc Tukey test detected significant differences in the mean number of species per station among all forest types. The mean number of individuals detected per station also differed among forest types (7.2 ± 2.1 individuals in native forest, 4.9 ± 1.5 in *P. undulatum*, 4.0 ± 1.8 in *C. japonica*; $F_{2, 126} = 31.42$, p < 0.0001). Again the Tukey test detected significant differences among all forest types.

The Kruskal-Wallis test showed significant differences in the mean number of individuals per point among the three forest types for six of the nine bird species, with the other three species being close to significance (table 3). The mean number of Azores bullfinch observed in native forest was much higher than those in the other two forest types, where this species was virtually absent. The occurrence of goldfinch, grey wagtail and robin did not dif-
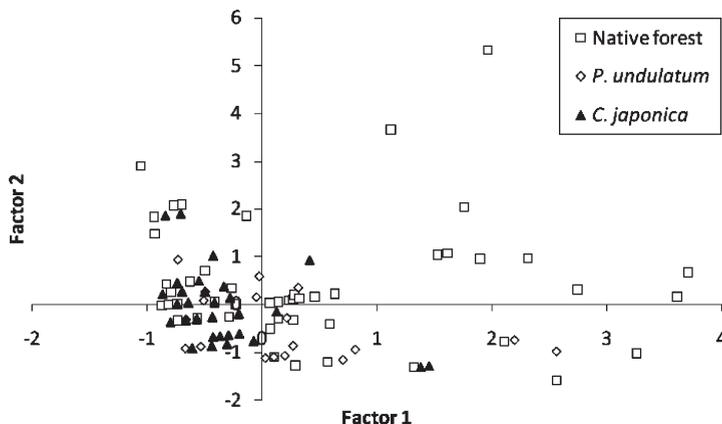
FIG. 2.—Factor scores for each point-count, according to habitat type, in the two first factors extracted by a Principal Component Analysis of the log-transformed bird numbers of each species per count. Distance between points indicates degree of similarity among the number of individuals of each species present in each point. The first principal component separates points in *C. japonica* plantations (without robin and Azores bullfinch) from native forest and partially from *P. undulatum* copses. The second separates points near clearings from those in more dense vegetation (where the canary is absent).

[Marcador de factores de cada punto de muestreo, de acuerdo con cada tipo de hábitat, en los dos primeros factores extraídos por un Análisis de Componentes Principales de la transformación logarítmica del número de aves de cada especie por conteo. La distancia entre puntos indica el grado de similitud entre el número de individuos de cada especie presente en cada punto. El primer componente principal separa plantaciones de C. japonica *(sin petirrojo y camachuelo de las Azores) del bosque autóctono y parcialmente de setos de* P. undulatum. *El segundo separa los puntos cerca de los aclarados de aquellos con vegetación más densa (donde el canario está ausente).]*

fer significantly among the three forest types, most likely due to a lack of power to detect differences as a consequence of small sample size (total number of detections lesser than 15).

The PCA (fig. 2) reduced the original 129 x 7 matrix to three independent principal components that explained 23.6 %, 17.8 % and 15.7 % of the variance, respectively (eigenvalues of 1.65, 1.25 and 1.10). The first component was positively correlated with robin (0.78) and Azores bullfinch (0.66) numbers, the second component positively correlated with canary numbers (0.79) and the third component positively correlated with goldcrest numbers (0.80). The first axis clearly separates *C. japonica* plantations from native forest and partially from *P. undulatum* copses (fig. 2). The second axis

appears to segregate points with clearings from those without clearings (i.e. dense forest where the canary is absent) of any forest type. The third axis separates points of any forest type with goldcrest from those without goldcrest.

Densities were obtained for five species in native forest, one in *P. undulatum* and two in *C. japonica* (table 4). Goldcrest, which was conspicuous in all three forest types, had much higher densities in native forest.

The total number of individuals captured differed significantly among the four plots (p < 0.025) and the number of captures differed significantly among plots for each species tested (blackbird, canary, chaffinch and goldcrest; table 5). Goldcrest was the most frequently captured species in plots with native forest, where-

TABLE 4

Density estimate per forest type for bird species with more than 30 detections. All calculations used five minute point-counts, except for the Azores bullfinch, in which eight-minute counts were used (see text). Series expansion order (cosine adjustments) for each key function are shown in brackets. SE – Standard error. df – Degrees of freedom.

[Densidad estimada en cada tipo de bosque de cada especie de ave con más de 30 detecciones. En todos los cálculos se usaron conteos de cinco minutos, excepto en el camachuelo de las Azores, que fueron de ocho minutos (ver texto). El orden de expansión de series (ajuste coseno) para cada función clave se muestra entre paréntesis. SE = error estándar. df = grados de libertad.]

	No. of detections	Density (birds/ha)	Key function	SE	df	95 % Confidence intervals	
Native forest							
Azores bullfinch	30	1.90	Uniform (1, 2)	0.79	44.01	0.85	4.25
Blackcap	38	0.99	Uniform	0.15	48.00	0.73	1.34
Chaffinch	86	5.97	Half normal (2)	1.54	106.31	3.61	9.86
Goldcrest	160	52.88	Half normal (2)	5.59	186.39	42.96	65.09
P. undulatum							
Goldcrest	49	6.57	Uniform (1,2,3)	4.42	48.42	1.93	22.42
C. japonica							
Chaffinch	81	2.69	Uniform (1)	0.57	135.07	1.78	4.06
Goldcrest	135	8.02	Uniform (1)	0.75	136.13	6.66	9.65

as in the exotic forest plots chaffinch and canary were the most captured. Captures of canaries were lower in the highest altitude plot (plot A) and higher in the lowest altitude plot (plot D). Azores bullfinch was caught only in plots with native forest and goldfinch was caught only in the exotic forest plots.

DISCUSSION

In this study we covered the breeding season of passerines in the largest forested area of the island of São Miguel, including the largest fragment of native laurel forest and the only area of occurrence of the Azores bullfinch. We described the differential use of forest types by passerines in São Miguel, and highlighted the importance of native forest to maintain a high-

er species' relative abundance and a more homogeneous distribution. Nevertheless, specific patterns detected here, mainly density estimates, may differ from those in other areas of São Miguel or in a different year. For instance, it is known that species such as the blackcap can make movements along the altitudinal gradient, mainly from higher altitudes in summer to lower altitudes in winter (Neves *et al*., 2004), and habitats throughout the year (Martín and Lorenzo, 2001), thereby seasonal densities may differ from those presented here.

It is well known that the number of species characteristic of oceanic island habitats is small (Cody, 1985). From the 12 breeding passerine species known to São Miguel only nine species were observed in this study. Most passerine species of São Miguel have a broad ecological distribution, occupying all forest

TABLE 5

Number of mist-netted birds of each species in the four study plots. Captures among plots are compared using Chi-square tests (cases where expected captures were smaller than 5 were excluded).
[Número de aves de cada especie capturadas en las redes en los 4 lugares de estudio. Las capturas entre lugares se compararon mediante test de Chi-cuadrado (se excluyeron los casos en los que las capturas esperadas fueron menores de 5).]

| | Number of captures | | | | | |
| | Native forest | | Exotic dominated forest openings | | | |
Species	Plot A	Plot B	Plot C	Plot D	χ^2_3	p
Azores bullfinch *Pyrrhula murina*	4	2	–	–	–	–
Blackbird *Turdus merula*	14	8	8	1	10.94	0.025
Blackcap *Sylvia atricapilla*	–	5	6	6	–	–
Canary *Serinus canaria*	–	8	3	23	36.82	0.001
Chaffinch *Fringilla coelebs*	5	14	40	5	51.38	0.001
Goldcrest *Regulus regulus*	22	26	1	3	38.00	0.001
Goldfinch *Carduelis carduelis*	–	–	5	1	–	–
Grey wagtail *Motacilla cinerea*	1	5	2	1	–	–
Robin *Erithacus rubecula*	2	5	4	6	–	–
Total	48	73	69	46	9.93	0.025

habitats studied here, as well as pasture, hedgerows and other habitats not surveyed (*pers. obs.*), which is a characteristic of habitat-niche expansion in island habitats presumably due to the species impoverishment of island ecosystems (Blondel *et al.*, 1988). Nevertheless, there were strong associations between the abundance of several bird species and distinct forest types.

Goldcrest was the most generalist species and the most frequently detected in the three forest types. It was also the most frequently captured species in the two plots with native forest, which supports the fact that it reaches higher densities in native forest. However, the density estimate of goldcrest in native forest (52.88 birds/ha) must be overestimated, as this species seemed to approach the observer, es-

pecially in the dense understory of the native forest. Goldcrest was also abundant in *C. japonica* plantations and *P. undulatum* copses, and was captured in the two forest opening plots dominated by exotic plant species. On the other hand Azores bullfinch was the most specialist species, present almost exclusively in native forest (a single individual was detected in *C. japonica* plantations in a marginal area about 200 m from the nearest patch of native forest). The strong dependence of the Azores bullfinch from the food resources of the native forest has been well documented (Ramos, 1995; Ramos, 1996b). Canary showed a similar pattern in terms of habitat specialization but selecting open areas dominated by exotic vegetation at low altitudes.

The relative abundance of all species occurring in native forest was higher in this habitat than in the two exotic forest types. This is an expected consequence of the greater availability of food resources in native forest (Ramos, 1995; Neves *et al.*, 2004; Heleno *et al.*, 2009). In *P. undulatum* copses, *Leycesteria formosa* and *Persea indica* were the only fruit-bearing plants present during summer, a fact that could explain significantly higher densities of frugivorous birds (blackbird and blackcap) in *P. undulatum* copses than in *C. japonica* plantations, where fruits are absent.

The strong association between suitable food sources and bird ecological distribution is also revealed by the PCA which suggested that a) birds relying to a great extent on fruits (robin, blackcap and Azores bullfinch; Ramos, 1995; Ramos, 1998; Neves *et al.*, 2004) were absent from *C. japonica* plantations; b) granivorous birds (canary and chaffinch) occurred in points of any forest type as long as they had clearings and (c) insectivorous birds, especially goldcrest, occurred in dense native and exotic forests.

For the majority of the species, the two methods used in this study provided concordant results. Differences between point-counts and mist-netting data should reflect species-specific differences in behaviour (e.g., singing and foraging; Blake and Loiselle, 2001), and also the fact that plots C and D were within small clearings, which seemed important to explain the higher captures of species that use open areas to forage (canary and chaffinch; Ramos, 1998). Both methods showed a higher diversity and equitability in areas/plots with native forest, although species richness was not always higher. Mist-netting showed a higher diversity and species evenness in mid-altitude native forest, represented by plot B. At this elevation the climate conditions are not as harsh as those at higher altitudes allowing, for example, a higher production of seeds by herbaceous plants (Ramos, 1995), which provide important food resources for passerines during summer (Ramos, 1998). A decline in the number of bird species with elevation has been reported for other cloud forests (Blake and Loiselle, 2000). Mid-altitude native forest in the Azores, and particularly in São Miguel, has almost disappeared as a consequence of habitat conversion to pasture, invasions by exotic plants and plantation of *C. japonica* (Dias, 1996).

High population densities in species-poor environments are characteristic of insular ecosystems (Blondel *et al.*, 1988). Our results are similar to those reported for other Atlantic islands. According to García del Rey and Cresswell (2005), maximum density estimates in good habitat for the endemic blue chaffinch *Fringilla teydea teydea* on Tenerife, Canary Islands, were 6.7 and 6.5 birds/ha (in two different native pine forests). Our estimates for the Azores chaffinch in native forest were similar (5.97 birds/ha) but lower in *C. japonica* plantations (2.69 birds/ha). Carrascal and Palomino (2005) obtained also higher density estimates for bird species in the laurel forest than in other habitats of Tenerife Island, although they obtained lower bird density estimates than those presented here.

Densities obtained for the Azores bullfinch in native forest (1.90 birds/ha) where consid-

erably higher than the density estimates from Ramos (1996a) in 1991, 1992 and 1993 (0.58, 0.46 and 0.48 birds/ha, respectively), and those obtained by the LIFE-Priolo project in 2002 and 2003 (0.40 and 0.41 birds/ha) (Farragolo *et al.*, 2003). One explanation for this is that in previous censuses, point-counts covered different types of vegetation on the same analysis, and not only native vegetation.

The ecological distribution of forest birds in São Miguel is important in providing support for the indispensable protection of Serra da Tronqueira (considered a Special Protection Area under the European Union Birds Directive because of the endemic Azores bullfinch). This study demonstrates the importance of the native forest, in particularly the mid-altitude native forest, allowing higher bird densities and also the maintenance of native bird species. The importance of mid-altitude native forests should be considered in programs of habitat restoration. Specific managing strategies for this habitat should involve the control of invasive exotic species (*C. arborea*, *H. gardneranum* and *P. undulatum*) and the restoration of the native laurel forest. The elaboration of a forest management plan, focussed on the conversion of *C. japonica* areas to their original laurel forest, would allow this economic activity to be compatible with nature conservation.

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