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LANDSCAPE CHARACTERISTICS OF PUERTO RICAN VIREO (*VIREO LATIMERI*) NESTING HABITAT, WITH SOURCE-SINK IMPLICATIONS

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Resumen. – Características paisajísticas del hábitat de anidación del Bienteveo de Puerto Rico (*Vireo latimeri*), con implicaciones de fuente-sumidero. – El uso de fragmentos por parte de aves que anidan en bosques puede tener importantes consecuencias para la conservación de paisajes dinámicos. El endémico Bienteveo de Puerto Rico (*Vireo latimeri*) tiene una población reproductiva en el Bosque Estatal de Maricao en el suroeste de Puerto Rico, rodeado de una matriz mixta conteniendo pequeños fragmentos de bosque. Evaluamos si el Bienteveo de Puerto Rico estaba presente en los fragmentos rodeando la reserva forestal y relacionamos las características paisajísticas de estos fragmentos a la presencia o ausencia de la especie. Fotografías aéreas fueron clasificadas según 10 categorías y digitalizadas en un sistema de información geográfica. El área de estudio consistió principalmente de bosque cerrado (79.6%, incluyendo el Bosque Estatal de Maricao), tierras agrícolas (6.3%), desarrollo rural (5.1%), y pastizales (3.8%). Menores cantidades de desarrollo urbano, bosque abierto e intermedio, deforestación, roca expuesta y cuerpos de agua fueron identificados. Fragmentos aislados de bosque cerrado fueron evaluados para determinar la presencia del Bienteveo de Puerto Rico. La especie estuvo ausente en la mitad de los fragmentos examinados (7 de 14), y el resto estuvieron ocupados por una pareja o un solo macho. Sin embargo, ninguna de las características de los parches de bosque medidas predijo la presencia de los bienteveos. La baja densidad poblacional en los fragmentos, que variaban en área de 1,4 a 7,7 ha, sugiere que proveen hábitat marginal para la especie. En contraste, la gran extensión de bosque continuo en el paisaje provee hábitat más adecuado para el Bienteveo de Puerto Rico. Se necesitan estudios posteriores para determinar si los fragmentos actúan como sumideros o como sitios de paso hacia otros hábitats apropiados.

Abstract. – The use of fragments by forest-nesting birds can have important consequences for conservation in dynamic landscapes. The endemic Puerto Rican Vireo (*Vireo latimeri*) has a breeding population in Maricao State Forest in southwestern Puerto Rico surrounded by a mixed matrix containing small forest fragments. We assessed whether the Puerto Rican Vireo was present in the fragments surrounding the forest reserve and related the landscape characteristics of these fragments to the presence or absence of the species. Aerial photographs were classified according to 10 land-use categories and digitized into a geographic information system. The study area consisted mainly of closed forest (79.6%, including the Maricao State Forest), agricultural land (6.3%), rural development (5.1%), and pasture (3.8%). Smaller amounts

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of urban development, open and intermediate forest, barren land, exposed rock, and water bodies were identified. Isolated fragments of closed forest were surveyed for the presence of the Puerto Rican Vireo. The species was absent in half the fragments examined (7 of 14), and the rest were occupied by a pair or a single male. However, none of the measured patch landscape characteristics predicted the presence of vireos. The low population densities in the fragments, which ranged in area from 1.4 to 7.7 ha, suggest that they provide marginal habitat for the species. In contrast, the large expanse of continuous forest in the landscape provides more suitable habitat for the Puerto Rican Vireo. Further study is needed to determine whether the fragments are acting as sinks or stepping stones to other suitable habitat. *Accepted 17 January 2007*.

Key words: Forest fragments, *Vireo latimeri*, Puerto Rican Vireo, landscape characteristics, population sink, population source.

INTRODUCTION

While the stability of forest bird populations depends on their reproductive success in a particular habitat, the surrounding landscape influences as well (Opdam *et al.* 1994, Rosenberg *et al.* 1999, Villard *et al.* 1999). Habitat fragmentation and the close proximity of nesting grounds to croplands, pastures, roadsides, or residential areas can lead to poor breeding success due to higher levels of nest predation and parasitism, which ultimately lead to species declines (Hoover & Brittingham 1993, Hoover *et al.* 1995, Robinson *et al.* 1995 Major *et al.* 1999, Mörtberg 2001).

The endemic Puerto Rican Vireo (*Vireo latimeri*) is a small insectivorous species confined to forested habitats (Raffaele 1989). A long-term study showed that from 1973–1996 the Puerto Rican Vireo has been declining at a rate of 5% per year in Guánica State Forest (henceforth Guánica), a coastal forest reserve in the southwestern part of Puerto Rico (Faaborg *et al.* 1997). The main reasons for the decline are high nest predation and brood parasitism by the Shiny Cowbird (*Molothrus bonariensis*) (Woodworth 1997). Nevertheless, in Maricao State Forest (henceforth Maricao), a montane reserve 16 km north of Guánica, the species is free of cowbird parasitism (Tossas 2002). Studies of the reproductive success of the Puerto Rican Vireo suggest that Guánica is a potential population sink (Woodworth 1999) and Maricao is a potential source (Tossas 2002), as defined by Pulliam (1988). Accordingly, the source population may be producing a surplus of individuals that colonizes the sink. However, the continued decline of the Puerto Rican Vireo population in Guánica implies that surplus juveniles from Maricao are either insufficient to rescue the sink population or are dispersing elsewhere. It is possible that forest fragments closer to Maricao are also acting as sinks.

The area surrounding Maricao is characterized by low human densities and traditional agricultural practices, such as shade coffee plantations (Tossas pers. observ.), that act as buffer zones to forest birds against nest predators and parasites; few cowbirds have been observed in Maricao (Tossas 2002). This landscape matrix should favor the presence of the Puerto Rican Vireo, since its habitat preferences include secondary forests and shade coffee plantations (Raffaele *et al.* 1998).

The work presented here describes the landscape configuration of Puerto Rican Vireo habitat around Maricao, a potential source population in southwestern Puerto Rico, and examines the presence and abundance of the vireo in forest fragments isolated from the reserve. The main objectives were to: 1) categorize land uses surrounding Maricao which may represent potential Puerto Rican Vireo habitats; 2) determine whether

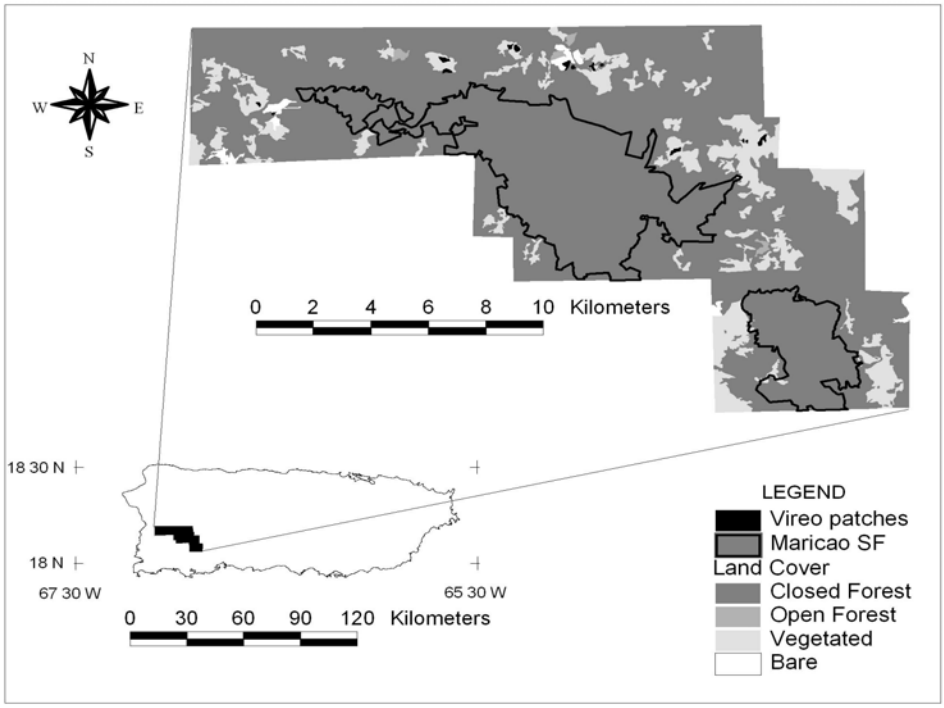

FIG. 1. Generalized land-use classification of the study area, Maricao, southwestern Puerto Rico. Land-cover categories on the map comprise the following land-cover classes described in the text: Closed Forest (intermediate forest, closed forest); Open Forest (open forest); Vegetated (agriculture, pasture, rural); Bare (barren, exposed rock, urban, water).

Puerto Rican Vireo breeding pairs were present in forest fragments outside the forest reserve; and 3) determine which landscape parameters best predict the presence of the Puerto Rican Vireo in the fragments.

METHODS

Study area. Maricao State Forest comprises 4150 ha in the western part of the Cordillera Central of Puerto Rico (Fig. 1). Elevations range from 150 to 875 m above sea level. Annual rainfall and temperature average 2326 mm and 21.7°C, respectively (Silander *et al.* 1986). The area encompasses three life zones: subtropical wet forest covers 65% of the area, subtropical moist forest another 33%, and lower montane wet forest occupies 2% (Ewel & Whitmore 1973).

Land-use characterization. Aerial photographs from 1997 and 1998 were used to identify forested areas and other land uses in the region. These images were the most recently available and accurately depicted the landscape at the time when the field work was conducted (2000–2001). The photos covered 19,382 ha including the forest reserve and adjacent lands where the vireos could potentially disperse. Photograph stereopairs at a nominal scale of 1:20,000 were analyzed using a mirror stereoscope. Polygons larger than 3 x 3 mm (equivalent to approximately 0.36 ha) were outlined on acetate overlays on the photos and

TABLE 1. Description of land-use categories used in aerial photography classification of the matrix surrounding Maricao State Forest, Puerto Rico.

Classes	Characteristics
Urban development	Towns, tightly built residential and commercial complexes with definite borders
Agriculture	Even, uniform plantations; symmetrically planted crops
Pasture	Grasslands with less than 20 % tree cover
Exposed rock	Landslides showing bedrock outcrops without vegetation
Barren land	Bare, stripped ground, lacking vegetation
Rural development	Houses spaced in a vegetated matrix
Water body	Ponds, lakes or large rivers
Open forest	20–50% forest cover
Intermediate forest	50–80% forest cover
Closed forest	80–100% forest cover

assigned to one of ten land-use categories (defined in Table 1): urban, agriculture, pasture, rock, barren land, rural, water, and open, intermediate, and closed forest. Forest categories were distinguished by the percentage of tree coverage present, from 20% tree cover in open forest to 100% in closed forest (Table 1). The classification was based on visual assessment of the photographs. The accuracy of the classifications was checked by field inspections done while conducting Puerto Rican Vireo surveys (see section "Puerto Rican Vireo fragment occupancy").

The polygons were transferred onto 1:20,000 scale U. S. Geological Survey topographic maps using a zoom transfer scope to correct for distortion. The polygons were then digitized into a geographic information system (GIS) package, Arc/Info version 7 (ESRI 1999a). The digitized data layers were transformed into Universal Transverse Mercator coordinates for accurate area measurements. A GIS layer was created with the land-use class and identification number of each polygon.

Puerto Rican Vireo fragment occupancy. Fourteen discrete forest fragments of different sizes were selected from the aerial photographs, keeping habitat variation as small as possible. Fragment selection was based on the following criteria: 1) they resembled the vegetation type of the forest reserve (i.e., intermediate and closed forest categories) where the Puerto Rican Vireo is commonly found; 2) were at least as large as the mean territory size known for vireo pairs in the forest reserve, 0.9 ha (Tossas 2002); 3) were isolated from the forest reserve by other land uses (e.g., agriculture, urban or rural developments); and 4) were accessible by roads or trails. Fragments were initially surveyed in 2000, but the Puerto Rican Vireo presence and abundance was determined after five to eight visits to each fragment in 2001. All visits were made in morning hours (07:00–11:00 h) during the breeding season (March to July).

On every visit, presence of the Puerto Rican Vireo was determined from visual or aural responses. The Puerto Rican Vireo song was played on a tape recorder for 10 min from the center of the forest fragment. This method allowed the detection of individuals because both males and females aggressively defend their territories from intraspecific intruders (Tossas 2002). Two observers searched the area for approximately 30 min after the song broadcast. The same procedure was repeated two or three times in different locations within a fragment depending on its

TABLE 2. Land-use categories surrounding Maricao State Forest, based on evaluation of aerial photographs from 1997–1998.

Land-use categories	No. of polygons	Area covered (ha)	Percent of total area	Median size of polygons (ha)	Range of polygon area (ha)
Urban	9	135	0.7	11.1	1.28–37.2
Agriculture	40	1225	6.3	7.1	0.40–347
Pasture	232	746	3.8	0.7	0.02–80.7
Exposed rock	72	52	0.3	0.2	0.02–16.5
Barren land	56	35	0.2	0.2	0.02–9.44
Rural	173	993	5.1	0.8	0.03–198
Water	1	21	0.1	–	–
Open forest	108	205	1.1	0.8	0.04–18.6
Intermediate forest	82	533	2.8	1.1	0.10–262
Closed forest[a]	20	15438	79.6	1.5	0.16–15402
Closed forest[b]	19	36	0.9	1.5	0.16–4.1
TOTAL[a]	793	19382	100.0	0.7	0.02–15402

[a]Including and [b]excluding the polygon of Maricao State Forest.

size. The number of individuals present, their sex (only males sing), and whether they were paired were noted. Adults were assumed to be paired if they actively defended the territory together, or if the territorial male was observed interacting with a female. Any indication of breeding activity (e.g., carrying nesting material or prey, presence of fledglings) was noted. If no nesting activity was observed, the presence of territorial pairs was assumed as potential breeding (Mörtberg 2001). The occurrence of Shiny Cowbirds was also recorded.

Characteristics of Puerto Rican Vireo fragments. Spatial parameters at the landscape scale were estimated from the GIS coverage transferred from ArcInfo to ArcView version 3.2 (ESRI 1999b). The number of polygons in each land-use category, their median size (ha), total area occupied (ha), and percent of the landscape covered were recorded. Further analyses related the presence-absence of the Puerto Rican Vireo to the following forest fragment characteristics: area (ha), perimeter (m), elevation (m a.s.l.), fragment configuration index (CI), and distance to continuous forest (m). The CI was defined as the ratio of the perimeter of a fragment to the circumference of a circle of the same area, while the distance to continuous forest was measured from the edge of the fragment to the edge of the nearest continuous forest that might function as a permanent source of dispersers. Continuous forest in the closed forest category was assumed to represent vireo habitat since it resembled the vegetation structure of the forest reserve. Fragment elevation was measured directly from the USGS topographic maps, while the rest of the variables were obtained from ArcView. Two further characteristics of the fragments were recorded, dominant land-use practice in neighboring fragments and presence of core habitat. A fragment was considered to have core habitat if the distance from its edge to the center of the fragment exceeded 200 m, the shortest distance between a Puerto Rican Vireo nest and forest edge observed in Maricao (A. G. Tossas unpbl.).

Statistical analysis. The effect of fragment met-

TABLE 3. Parameters of forest fragments used by the Puerto Rican Vireo in the vicinity of Maricao State Forest in southwestern Puerto Rico.

Fragments	Presence or absence of vireos	No. of cowbirds	Forest types	Land use in surrounding matrix
1	One pair	1	Closed	100% rural
2	Absence	1	Closed	45% rural, 55% urban
3	One male	1	Closed	100% agriculture
4	One male	0	Closed	50% agriculture, 25% pasture, 25% open forest
5	Absence	0	Closed	100% rural
6	Absence	0	Closed	100% rural
7	Absence	0	Intermediate	100% rural
8	One pair	0	Intermediate	83% agriculture, 17% rural
9	One pair	0	Closed	60% urban, 40% rural
10	One pair	4	Closed	60% urban, 40% agriculture
11	One pair	0	Closed	100% agriculture
12	Absence	1	Closed	100% agriculture
13	Absence	1	Closed	100% agriculture
14	Absence	1	Closed	100% agriculture

rics on the probability of Puerto Rican Vireo presence was analyzed using multiple linear regression analysis (Ott 1993) with the computer software SigmaStat (1995). Significance was set at the 0.05 level. In addition, the variables were compared between occupied and unoccupied fragments with a t-test following a normality test (SigmaStat 1995). Two multivariate analyses were performed on a subset of the metrics (area, CI, distance to forest, and elevation). These were principal components analysis (PCA) and non-metric multidimensional scaling (NMS) using PC-ORD v4.25 (MJM Software 1999).

RESULTS

Land-use characterization. In total, 793 polygons were identified in the study area. Most of the polygons were classified as pasture (n = 232), rural (n = 173) or open forest (n = 108; Table 2). Only 20 polygons consisted of closed forest, but this land-use type covered 79.6% of the area, with a total of 15,438 ha. Most closed forest was in one polygon consisting of the background matrix that included the forest reserve. When this polygon was excluded from the analysis, the remaining patches of closed forest covered less than 1% of the total area, with a median size of 1.5 ha (Table 2). The closed forest category was followed in importance by agriculture, rural development, and pasture, occupying 6.3%, 5.1%, and 3.8% of the total area, respectively. Other land uses combined occupied about 5% of the study area (Table 2).

Puerto Rican Vireo fragment occupancy and characteristics. Puerto Rican Vireos were present in half of the fragments visited (n = 7/14) (Table 3). Most individuals were detected when singing or when they replied to song playback with territorial displays. An equal number of occupied (n = 6) and unoccupied (n = 6) fragments fell within the closed forest category. Only one fragment in each of the occupied and unoccupied categories was found in the intermediate forest category. Five fragments contained one Puerto Rican

TABLE 4. Comparison of spatial parameters of fragments occupied and unoccupied by the Puerto Rican Vireo, including results of t-test.

Parameters	Occupied (n = 7)		Unoccupied (n = 7)		
	Mean	Range (min-max)	Mean	Range (min-max)	t (*P* value)
Area (ha)	3.27	1.11–4.97	2.21	0.56–5.54	1.130 (0.28)
Perimeter (m)	842	386–1157	623	276–1382	1.195 (0.26)
Elevation (masl)	389	110–670	499	85–760	–0.941 (0.37)
Configuration Index	1.876	1.46–2.25	1.723	1.47–2.34	1.017 (0.33)
Distance to continuous forest (m)	134	0–300	66	0–240	1.091 (0.30)

Vireo pair and two contained single males, thus resulting in a 71% pairing success. None of the occupied fragments was inhabited by more than one pair. Density of male territories was 0.25 males per hectare. From one to four cowbirds were observed in half of the patches, including three used by vireos (Table 3). Breeding activity was not observed in any of the fragments.

The distance between occupied fragments ranged from 220 m to 6.45 km, while occupied fragments were 92 m to 2.15 km from unoccupied fragments. Land–use practices around four of the occupied fragments consisted of a mosaic of agriculture, pasture, rural and urban lands, while the rest (n = 3) fell within 100% rural development or agriculture. One of the fragments with no vireos present was surrounded by equal amounts of rural and urban development, and the rest (n = 6) were embedded in 100% agricultural or rural matrices. The edge-center distance of the fragments ranged from 33 to 93 m, so none of them included core area. Occupied and unoccupied fragments did not differ statistically in their spatial features (Table 4). The distribution of the species was not affected by the characteristics of the landscape (Multiple linear regression, R^2 = 0.619, P = 0.212). Neither PCA nor NMS produced a significant separation of occupied and unoccupied patches on the ordination axes (Fig. 2).

DISCUSSION

Habitat fragmentation affects bird populations, particularly forest specialists, which avoid small fragments dominated by edge (Morse & Robinson 1999, Debinski & Holt 2000). However, the parameters measured in this study did not differ between occupied and unoccupied patches and thus it was not possible to determine Puerto Rican Vireo preferences. One possible reason for this is that the effects of fragmentation are negligible given the extensive closed forest cover in the region (80% of study area). Non-forest land cover types covered only 12% of the total area. As a consequence, fragments were not strongly isolated, thus facilitating high colonization rates.

An alternative explanation for the lack of a pattern in fragment selection is that vegetation age, structure and composition may be more important for determining abundance and breeding status (Blake & Karr 1987, Mörtberg 2001). The fragments in this study were of sufficient size to support several vireo territories, but only one pair or a single male was found even in the largest fragments. It is possible that habitat configuration and vegetation structure were more important than area or the other landscape characteristics measured in this study. All fragments had closed or intermediate canopy and were assumed to be potential Puerto Rican Vireo

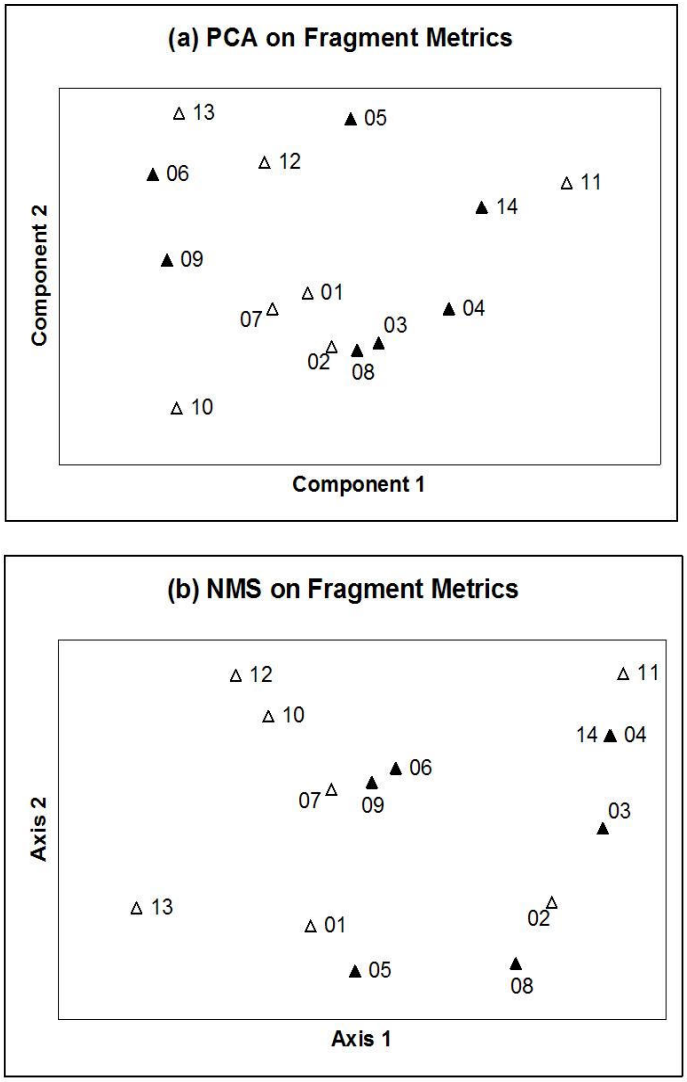

FIG. 2. Results of (a) principal components analysis and (b) non-metric multidimensional scaling of fragment metrics on Puerto Rican Vireo presence (filled symbols) or absence (open symbols).

breeding habitat. However, there is still little knowledge on the preferred microhabitat characteristics of the species, only that it favors woodlands with a well-defined understory layer, and is absent from disturbed, open habitats (Raffaele 1989, Tossas pers. observ.). By these criteria, all forest fragments studied contained suitable habitat.

The presence of Puerto Rican Vireo pairs in the fragments suggests the potential for breeding but none of the pairs was observed with fledglings. It is possible that nests in

fragments are more susceptible to parasitism and predation due to the lack of a protective core area, as is seen in other small forest bird species (Coker & Capen 1995, Wenny *et al.* 1993). Although the vireo population in Maricao is free of Shiny Cowbird parasitism (Tossas 2002), as expected in a landscape with a low level of fragmentation, cowbirds were recorded in half of the forest fragments visited. Their presence may be facilitated by higher fragmentation in the landscape matrix outside the forest reserve.

Several pairs could be sustained in the largest fragments examined based on their territory size in the forest reserve. However, only one pair or a single individual was found in any of the patches. It is possible that the lack of core area in the fragments keeps their carrying capacities low, thus acting as habitat sinks. Density of male territories in the fragments was 0.25 per ha, which is considerably lower than the 0.41–0.57 males per ha found in the forest reserve. Furthermore, pairing success was 20% lower than in the forest reserve, where it is 91% (Tossas 2002). Future work should determine if productivity in the fragments is insufficient to maintain a stable population or if other ecological characteristics, such as microhabitat configuration and prey availability, are responsible for the difference in pairing success (Burke & Nol 1998).

Tracts of continuous forest are required for forest birds to reproduce successfully (Wenny *et al.* 1993, Burke & Nol 1998). Thus, the relatively extensive forest cover in Maricao and its surroundings should provide sufficient breeding habitat for the Puerto Rican Vireo, assuming it satisfies the species' preferred vegetation features. In contrast, forest fragments around the natural reserve constitute a minimal amount of the total area and sustain very small population sizes. It is unknown whether these fragments represent ecological traps where the Puerto Rican Vireo is unable to reproduce successfully (Burke & Nol 1998, Mörtberg 2001), or if they are used as stepping stones facilitating dispersal to other areas of continuous forest (Debinski & Holt 2000). Further research is therefore needed to understand the role of forest fragments for the continued survival of the Puerto Rican Vireo.

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