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BIRD ASSEMBLAGE COMPARISON IN SMALL FRAGMENTS OF DIFFERENT SHAPE AND SIZE

Juan-S. León-Lleras and Alberto Acosta.
Unidad de Ecología y Sistemática (UNESIS), Departamento de Biología, Facultad de Ciencias, Pontificia Universidad Javeriana. Bogotá, Colombia.

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Author(s):
Juan-S. León-Lleras and Alberto Acosta.
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Corresponding Author:
Juan-S. León-Lleras.
Unidad de Ecología y Sistemática (UNESIS), Departamento de Biología, Facultad de Ciencias, Pontificia Universidad Javeriana. Bogotá, Colombia.
E-mail: juanleon@javeriana.edu.co
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Abstract

Little has been published on a small-scale (x < 100 ha) about the independent impact of the shape and size of fragments on community structure of any biological group. Only studies in large scale, in temperate ecosystems, have been performed. Here, the bird community structure was assessed in small High-Andean tropical forest fragments (x < 100 ha). Through direct observation using belt transects we compare bird composition, density, richness and diversity between fragments of three different sizes (10.1 ha < x < 100 ha, 1.1 ha < x < 10 ha and x < 1 ha) and two shapes (polygonal and elliptical). We found that density values differed significatively when comparing shape and size, been higher in smaller and elliptical fragments. Bird richness, Shannon, Fisher-alpha and dominance indexes differed regarding size but not fragment shape. Bird composition changed with fragment shape but not with size. The results coincide with studies conducted in larger fragments (over 1000 ha) in which, bird community composition, density and diversity may be responding to both, fragment shape and size. This emerging pattern observed for birds in the High-Andean forest at small scale should be confirmed experimentally as well as replied in other biological groups and tropical ecosystems.

Keywords: Fragmentation; shape; size; assemblage; bird communities; urban ecosystem; High-Andean forest; Colombia.

INTRODUCTION

Habitat fragmentation can be understood as a process of discontinuity where the spatial distribution, the use of resources and environmental conditions affect the reproduction or survival of the species (MacArthur & Wilson 1967, Murphy & Noon 1992, Wiens et al. 1997, Brooks et al. 1999, Franklin et al. 2002, Lloyd & Stuart 2008, Magrach et al. 2012). This process has been described as one of the major threats to global biodiversity (Simberloff 1974, Kolb 2005, Levey et al. 2005). Fahrig (2002) proposes that habitat fragmentation should be divided into two distinct components: habitat loss and fragmentation. Fragmentation is known to alter the size, shape, degree of isolation, edge effects and habitat quality of the fragments, among others, which affect the structural and functional complexity of ecosystems (Saunders et al.. 2001, Jaña Prado et al. 2006), the number of species and population size, which has been confirmed in bird communities (Willson et al. 1994, Rozzi et al. 1996, Cornelius et al. 2000, Rau & Gantz, 2001), mammals (Sanderson et al. 2002 Acosta-Jamett et al.. 2003) and amphibians (Acosta-Jamett & Simonetti 2004).

The effect of fragmentation on biota was initially described by the fragment size, later and independenly, by the shape (Fahrig 2002, 2007, Lindenmayer et al. 2010 Sevillano et al. 2011), through the analysis of geometric forms (classical Euclidean shapes), irregularity, perimeter, radius, and fractal dimension, among others (Turner 2005). Similarly, other abiotic and biotic variables such as the effect of distance and landscape configuration (Kennedy & Marra 2010), micro-climate changes (Fahrig 2002, Turner 2005), ethological disturbance (territoriality, predation, competition, dispersal, nesting, foraging response; Pokluda et al. 2001, Hewson & Noble 2007, Cherkaoui et al. 2009) and the extent of mobility of the organisms (Arango 1990, Ibarra-Macias 2011, Rytwinski & Fahrig 2012, Amos et al. 2012 and Pavlova et al. 2013) have been related to changes in the structure and function of communities in fragmented landscapes.

In tropical forests, fragment size has influenced bird extinction (Mc.Donald & Kirkpatrick 2003, Laurance et al. 2012), migratory processes, richness (Navjot et al. 2004, Guldemond & Aarde 2010) and composition (Haddad & Weldon 2005, Kennedy & Marra 2010). Island biogeography theory states that larger fragments of continuous habitat enable higher richness than smaller fragments (MacArthur & Wilson 1967, Helzer & Jellinsky 1999, DeFries et al. 2005) because broad perimeters favor colonization processes and diminishes the

probability of local extinction (Magura et al. 2001, Canale et al. 2012). Moreover, a larger area provides more available resources, habitats and micro-habitats to sustain larger sized populations (Begon & Harper 1996, Sodhi et al. 2004). According to Mc.Garigal et al. (2009) and Grashof-Bokdam et al. (2009), smaller, adjacent fragments increase connectivity and the aggregative effect (limited available area) on individuals, producing higher richness and density.

The effect of fragment size on biotic communities has been studied more extensively than fragment shape (Fahrig & Goodwin 2002, Ewers & Didham 2006). Shape not only determines the fragment's longitude but also the abiotic edge parameters (e.g. temperature, light, humidity; Ries et al. 2004, Turner 2005, Adeney 2009, Shake et al. 2012). These parameters can produce changes in species distribution, composition and abundance to which the individuals may or may not adjust (Gascón et al. 2000, Harris & Reed 2002, Boscolo & Metzger 2011). Fragment shape, according to Forman & Gordon (1986) and Helzer & Jelinski (1999), is a determinant factor in species richness and density within a fragment. The perimeter's convolutions and irregularities affect the amount and the quality of available habitat (core area) for species to carry out their life cycles and reach their minimal viable density, as well as minimize the Allee effect (achieving partner), predation and disease (Lees & Peres 2010, Porter-Bolland et al. 2012). Fragments with long perimeters have complex (irregular) shapes; the turns, protrusions, notches and geographic features affect the overall core area of the fragment. These irregularities are determined using indeces such as PARA (Perimeter Area Ratio) or FRAC (Fractal Dimension Index) (Solka et al. 1994). The higher the index of irregularity (e.g., small fragments) the larger the edge habitat and the smaller the fragment core area (Laurance 1999), making the species in the outer edges of the patch (matrix effect) more susceptible and visible to predators (Haddad & Weldon 2005), disease or parasites (Sebaio et al. 2010), threatening their reproductive success (nest predation) and survival (Trujillo & Ahumada 2005). In conclusion, fragment shape may determine population and community structure and diversity (Srivastava & Starzomski 2007, Yamaura et al. 2008).

Approximately 90 % of the studies we reviewed concerning the effect of fragment shape and size on different communities have been conducted in study areas between 20 and 2000 km^2 (2000 – 200000 ha); most of them were conducted in large ($x \geq 2000$ ha; Fahrig 2004) or medium (500 ha $\leq x \leq$ 2000 ha) sized fragments (relevant papers in Suppl. 1).

After searching in several databases (Scopus, Isi Web of Knowledge, SciELO, Latindex, Redalyc, Google Academics) we found few studies framed at smaller spatial scale ($x \leq 500$ ha). Reid (2012) employed a spatial scale of 120 ha and suggested the influence of fragment shape on bird diversity, but not on its richness. Similarly, Tinoco et al. (2013) suggested a direct or indirect influence of small fragments on bird composition and diversity in the High-Andean forest at Ecuador. In conclusion, there are few theory build at small scale for the tropical High-Andean forest, and much less in remaining forest fragments close to residential areas and influenced by human development.

Because landscape fragmentation is an unending process, which progressively makes forest fragments smaller, understanding its impact on biota becomes vital, particularly to corroborate whether the theorethical pattern established to date is the same in smaller scales. For that reason, we established as a study case the following question for the High Andean tropical forest, can the bird community structure change when compared small fragments with different shape and size categories?

METHODS

Study area

The Andean region has been drastically transformed; activities like deforestation, livestock farming, agriculture and the development of large cities have intensely fragmented its habitats (Fandiño & Wyngaarden 2005). The department of Cundinamarca has undergone the transformation from High-Andean forest to a landscape of grasslands, farms and residential areas (Salazar-Mejía 2010); the relicts of secondary High-Andean forest left behind after anthropogenic intervention are small and isolated fragments (the average distance between fragments was 35 m; 15-160 m range). According to local inhabitants and space-temporal analysis with remote sensors, the forest relict has suffered a similar fragmentation processes caused by permanent human intervention starting in the 90`s (housing, roads, recreation, gardening and pets). Flora such as *Weinmannia tomentosa, Drimys granadensis, Quercus sp., Juglans neotropica, Rapanea sp., Clusia multiflora* and *Alnus acuminata* species from the Asteraceae, Ericaceae, Lauraceae, Melastomataceae and Rubiaceae families predominate in the forests (details in Suppl. 1), in three tiers of dense undergrowth (low light) made up of smaller woody trees < 10 m and DBH under 20 cm. Abundant epiphytic plants such as mosses and small leafed plants such as bromelians and orchids cover their branches and trunks. A 20-30 cm thick bed of decomposing leaf litter covers the ground. Fragments under 1 ha are predominated by two strata: smaller shrubs under 5 m and herbaceous layer (grasses), while fragments over 10 ha have trees higher than 10 m and three strata.

This High-Andean forest enclosed an exclusive residential condominium in the town of Guasca (Cundinamarca, Colombia) at 4° 47 'N. 73° 55' W (Figure 1). The 72.5 ha study area (Figure. 1) included all the existing native forest and fragments (total 14) within the limits of the condominium. Of the total area,

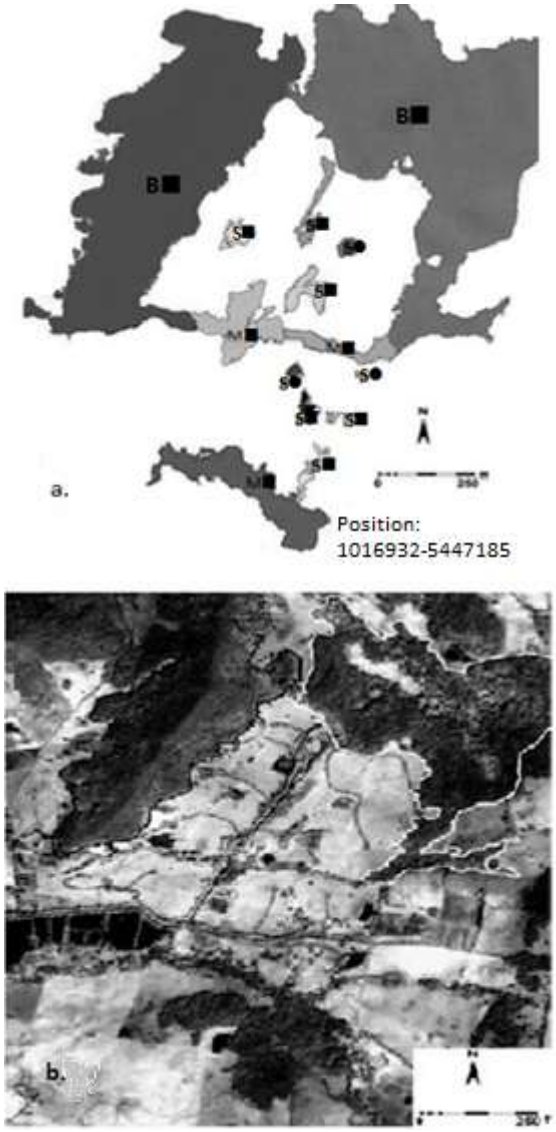

FIG. 1. a). Study area (polygon map-contour fragments) with fragments classified by shape and into two categories defined by Ilwis ® program; polygonal (■) and elliptical (●), and size into three categories: large (B => 10 x <20 ha), medium (M > 1 x < 10 ha) and small (S x = < 1ha). b). Satellite image fragments High-Andean forest embedded in the matrix, corresponding to grassland, hedgerows, gardens and residential condominium "Altos de Potosi.

43.4 ha (60 % coverage) were High-Andean forest and 29.1 ha (40 % coverage) were the lawns and gardens surrounding the small fragments, which create the matrix. These forest fragments are located at an altitude of about 2710m, the average temperature there is 13 °C (ranging from 4 to 33 °C) and the relative humidity is 75 %. We measured the average temperature and relative humidity using an EBC thermometer-hygrometer; in the morning, temperature ranged from 8 to 18 °C and humidity from 95 to 78 %, in the afternoon, temperature was between 14 and 17 °C and humidity between 73 to 53 %.

We demarcated the fragments using an Ikonos satellite image ® Esc. 1:1200 Res. (10 x 10m). This image was digitized to obtain a map of polygons, using Ilwis ® to establish landscape metrics (area and perimeter) and to define size and shape grouping of the forest fragments, *a posteriori*. Fragment size categories were determined using a logarithmic scale following Mc.Garigal et al. (2009), Harwood & MacNally (2004), Moilanen & Nieminen (2002), in which small was defined as $x \leq 1$ ha, medium as 1.1 ha $\leq x \leq 10$ ha, and large as 10.1 ha $\leq x \leq 100$ ha. The study area was divided into two large fragments, three medium fragments and nine small fragments (Figure 1). To determine shape categories on the polygon map of fragments (Ilwis® program), we first superimposed the classical Euclidean geometric figure that best fit the shape of the fragment (Farigh 2002, Turner 2005, Mc.Garigal et al. 2009). Then, to confirm whether this or another geometric shape was the best fit for the fragment, we calculated and equated the total area of the superimposed geometric figure (expected) to the actual area of the fragment (observed). We selected the geometric figure that yielded the least difference with the actual area (Ilwis®) of the forest fragment (Mc.Garigal et al. 2009). We identified two fragment shapes within the study area using this strategy, elliptical and polygonal following Imre & Rocchini (2009).

We documented bird species composition through direct observation (binoculars Bushnell Falcon Power View® 10x50). Sampling was carried out in all 14 fragments between 05:00 and 09:00, and 15:00 and 18:00. To identify them, we used Birds of Colombia (Hilty & Brown 2000), Birds of the Bogota Savannah field guide (Bohorquez 2000). Collections using mist nets were not conducted as visual and auditive records achieved a more comprehensive and representative inventory in a shorter time (Stiles & Roselli 1998).

To ensure adequate sampling and capture the greatest amount of richness and visual and auditive records (used as an estimate of the relative bird abundance-density), of the bird community on site, we employed two sampling strategies, depending on fragment size. For large and medium fragments, we used a combination of circular plots of 20 m in diameter (314 m^2) located consecutively on linear transects. For small fragments, we estimated the dependent variable by following the perimeter of the fragment, using a 20 m wide transect band. For large and medium fragments, bird species were registered from a position in the center of the plot, by observing their presence and number during four minutes (Alvarez el al. 2006). In the first large fragment, six lineal transects of 95, 231, 289, 290, 300, 231 and 308 m in length, separated by at least 40 m were placed perpendicularly to the fragment's longest point, resulting in a total of 59 – 20 m plots (equal to 6 ha = 0.06 km^2). In the second large fragment, five transects 190, 251, 261, 270 and 490 m were created, totaling 68 plots (8 ha = 0.08 km^2). Using this strategy, 40 % of the effective area of the large fragments was sampled. In the first medium

fragment, two transects of 91 and 115 m and five plots of 20 m in diameter (1.87 ha = 0.018 km^2) were quantified; this achieved a sampling of 93 % of its total area. Because of their reduced size, to sample three medium and nine small fragments, we employed the second strategy, which consisted of recording the species observed along the fragment perimeter, from the edge of the fragment to a maximum distance of 20 m inside the fragment (Álvarez et al*.* 2006). One hundred percent of the total effective area was sampled in each of these 11 fragments.

The cumulative bird richness observed *in situ* was equivalent to the expected nonparametric estimators of species richness. This shows the effectiveness of the sampling effort (intensity of seven hr / day) for the community in the studied fragments.

Bootstrap replics for CHAO 2 = 56.2 +/- 1.9. Jackknife 1 = 56.3 +/- 1.1 and Jackknife 2 = 55.9 +/- 2.3 suggest that total bird community is approximately 58 species, of which we observed 57 (98 % of the expected bird community). Similarly, in large fragments, 47 species of the expected 47-48 (CHAO 2 = 47.77; Jackknife 1 = 47.28; Jackknife 2 = 47.47) were seen, reaching 95 % of bird community, by quantifying 17 ha of the 37 ha total in large fragments (45 % of the area). In medium fragments, 38 species of the 39 expected (CHAO 2 = 38.28; Jackknife 1 = 27.19; Jackknife 2 = 27.28) were found, achieving 97 % of bird community quantification, by quantifying 4.4 ha of the 4.4 ha in the category (100 % sampled). Lastly, in small fragments, 33 species of the 34 expected (CHAO 2 = 34; Jackknife 1 = 21.19; Jackknife 2 = 22.14) were found, achieving 97 % of bird community, by quantifying two of the two ha in the category (100 %) sampling.

Because different sampling efforts were used for each grouping of fragments, and to allow statistical comparison, bird richness and bird records were standardized per hectare (used as an estimate of the relative abundance), fragments were used as replicates (independent, physically separed; Watson 2003) for both size and shape categories. Shannon-Weaver, Fisher-alpha, dominance and uniformity indexes were also calculated to verify if they differ with fragment size or shape.

Statistics

Dependent variables did not showed normal distribution neither the assumptions to apply parametric test (i.e. homogeneity). Therefore, a nonparametric Kruskal-Wallis test ($P < 0.05$) was employed to compare bird density, richness, Shannon-Weaver, Fisher-alpha, dominance and uniformity indexes between the three size categories (Sevillano-Rios et al*.* 2011). Paired Mann-Whitney (*U*) tests were also used to contrast relative density, richness, Shannon-Weaver, Fisher-alpha, dominance and uniformity indexes with shape (polygonal vs. elliptical). Bird species composition was qualitatively compared between the fragments, to determine which species were common or unique.

RESULTS

We detected 754 bird records distributed in 57 species and 21 families (Table 1), including an endemic species: the Silvery-throated Spinetail (*Synallaxis subpudica*); an endemic subspecies, Crested bobwhite (*Colinus cristatus bogotensis*); three migratory species; Tennessee warbler (*Oreothlypis peregrina*). Blackburnian warbler (*Setophaga fusca*) and the Smoke-colored Pewee (*Contopus fumigatus*); and three species of nocturnal birds of prey; Barn owls (*Tyto alba)*; *Strix albitarsus,* Rufous-banded Owl; and Tropical Screech Owl (*Megascops choliba*). The best represented was the Thraupidae family with 11 species (nectar, fruit and occasionally small insectivores) followed by the Trochilidae (hummingbirds, primarily nectar-feeding).

Overall, most of the bird species recorded (30) had low densities, 23 had intermediate densities and only five species were dominant (Table 1). Large fragments included 58.1 % of individuals observed (430 of 754 totals), medium 20.5 % (152) and small 21.3 % (158). Meanwhile, polygonal fragments presented 72.4 % of the birds (536) while elliptical fragments, 8.7 % (65). The density of all the birds was different when comparing large, medium and small fragment size (Kruskal-Wallis $H_{(189)}$; $P < 0.01$); small fragments differed from the other two by presenting higher density. Similarly, density differed when comparing the elliptical and polygonal shaped fragments (Kruskal-Wallis $_{(201)}$; $P = 0.001$), exhibiting higher density in elliptical fragments.

Nine unique species were found in the large fragment category, three in the medium size, and three in the small fragments; this demonstrates a direct relationship between the size of the fragment and the number of unique species (Table 1). Regarding the shape, 17 unique species were recorded in polygonal fragments and two in elliptical fragments. Common bird species, accounted for 40 % of the community, according to fragment size, while for shape common birds accounted for only 16 %.

Although absolute richness was higher in larger fragments than in smaller ones (Table 1), standardized richness showed that small fragments had higher relative species richness. Meanwhile, elliptical fragments presented greater richness than polygonal fragments. When comparing the different fragment sizes, large, medium and small, standardized average bird community richness did not differ (Mann-Whitney $U=13.1$, $P = 0.087$, $n = 14$), nor did it differ when comparing polygonal and elliptical shaped fragments (Mann-Whitney $U=9.2$, $P = 0.11$, $n = 14$).

Shannon and Fisher-alpha diversity indices were higher in large fragments, while dominance was higher in small fragments (Table 1). Diversity indices showed no difference when comparing polygonal and elliptical

TABLE 1: Composition, total abundance (Abd) and bird density (D = Individuals / ha). Fragment by category, by size and shape. The density of each species to the total study area (72.5ha) is presented in the last column. Bird diversity of fragments is calculated at the end of the table. Species are classified (with superscript) as the logarithm of the total abundance: Dominant = D (> x 10 log abundance). Middle = I (1-10 of log abundance), rare = R (0.1-1 the log abundance) and exclusive by category. Blank = species not present. SD = Standard.

	Size								Shape						
	Large			Medium			Small			Polygonal			Elliptical			Density
Species	Abd	D	SD	Abd	D	SD	Abd	D	SD	Abd	D	SD	Abd	D	SD	
^{R}*Colinus cristatus*	1	0.06	0.04							1	0.04	0.68				0.01
^{R}*Megascops choliba*							1	0.7		1	0.04	0.68				0.01
^{R}*Tyto alba*	1	0.06	0.67													0.01
^{R}*Strix albitarsus*	1	0.05	0.67													0.01
^{R}*Caprimulgus longirostris*				1	0.9	0.07				1	0.04	0.68				0.01
^{I}*Patagioenas fasciata*	6	0.30	0.49	5	1.5	0.35	7	41.7	77.7	6	0.24	0.54				0.25
^{D}*Zenaida auriculata*	20	0.55	0.11	6	3.3	1.63	11	181.7	608.6	28	1.12	0.08	7	11.7	7.57	0.51
^{I}*Eriochnemis vestita*	10	0.50	0.12	3	2.4	0.99	24	248.9	643.6	22	0.88	0.08	3	5.0	2.83	0.5
^{I}*Colibri coruscans*	11	0.55	0.35				12	21.2	41.7	18	0.72	0.20	1	1.7	0.49	0.3
^{I}*Lesbia nuna*	6	0.22	0.59	2	0.9	0.07	1	2.8		7	0.28	0.51				0.1
^{I}*Metallura tyrianthina*	9	0.24	0.59	1	0.8	0.14	1	7.8		7	0.28	0.51				0.15
^{I}*Eriochnemis cupreoventris*	2	0.06	0.63	2	1.0	0.07	1	0.7		3	0.12	0.62	2	3.3	1.63	0.07
^{R}*Colibri thalasynus*	1	0.05	0.11							1	0.04	0.68				0.01
^{R}*Ensifera ensifera*	1	0.05	0.07										2	3.3	1.63	0.01
^{R}*Chaetocercus mulsant*	1	0.06	0.32							2	0.08	0.65				0.01
^{R}*Picoides fumigatus*	2	0.11	0.66							2	0.08	0.65				0.03
^{R}*Colaptes rivolii*							1	352.8								0.01
^{I}*Grallaria ruficapilla*	13	0.32	0.46	6	1.5	0.35	1	70.0	66.3	15	0.6	0.28				0.26
^{R}*Grallaria rufula*	1	0.05	0.67	1	0.6	0.28				2	0.08	0.65				0.03
^{R}*Grallaria squamigera*	1	0.06	0.66	1	0.6	0.28				2	0.08	0.65				0.03
^{I}*Notiochelidon murina*	15	0.41	0.35	4	1.8	0.57	3	4.2	2.1	22	0.88	0.08				0.3
^{I}*Scytalopus griseicollis*	19	0.51	0.32	5	1.4	0.28	2	2.8	4.2	17	0.68	0.23	2	3.3	1.63	0.36
^{I}*Synallaxis subpudica*	18	0.47	0.48							10	0.4	0.42	2	3.3	1.63	0.25
^{R}*Margarornis squamiger*	2	0.11	0.66	1	0.9	0.07							1	1.7	0.49	0.04
^{I}*Elaenia frantzii*	15	0.83	0.37	4	2.2	0.85	1			13	0.52	0.34	2	3.3	1.63	0.28
^{D}*Mecocerculus leucophrys*	41	1.10	0.07	16	3.9	2.05	6	3.5	7.8	46	1.84	0.59	3	5.0	2.83	0.87

Table 1 Contd

[R]*Ochthoeca fumicolor*							1	34.6					1	1.7	0.49	0.01
[R]*Contopus fumigatus*				2	0.7	0.21				2	0.08	0.65				0.03
[I]*Ampelion rubrocristatus*	1	0.05	0.62	2	1.8	0.57	3	12.7	7.8	5	0.2	0.57				0.08
[R]*Henicorhina leucophrys*	3	0.11	0.64				2	2.1		1	0.04	0.68				0.06
[I]*Troglodytes aedon*	15	0.35	0.42	2	1.1	0.07	5	10.6	19.7	5	0.2	0.57				0.28
[D]*Turdus fuscater*	27	1.49	0.35	19	5.1	2.90	22	199.4	695.5	59	2.36	0.96	9	15.0	9.90	0.94
[D]*Anisognatus igniventris*	33	0.84	0.04	19	4.7	2.62	11	244.7	809.9	50	2	0.71	4	6.7	4.03	0.84
[D]*Diglossa humeralis*	32	0.86	0.10	11	3.0	1.41	9	24.7	36.6	41	1.64	0.45	2	3.3	1.63	0.72
[I]*Diglossa cyanea*	18	0.48	0.37	1	0.8	0.14	2	70.0	66.3	13	0.52	0.34				0.29
[I]*Diglossa albilatera*	3	0.06	0.55	5	2.2	0.85	5	7.1	11.3	7	0.28	0.51	2	3.3	1.63	0.17
[R]*Tangara vasorii*	3	0.08	0.64	1	1.1	0.07				2	0.08	0.65				0.06
[R]*Tangara vitriolina*	4	0.22	0.65							4	0.16	0.59	4	6.7	4.03	0.06
[R]*Diglossa lafresnayii*	1	0.06	0.12							1	0.04	0.68				0.01
[I]*Conirostrum rufum*	6	0.16	0.54	5	1.2	0.14	4	14.1	19.6	13	0.52	0.34				0.21
[R]*Catamenia anallis*				1	0.8	0.14	2	16.3		1	0.04	0.68				0.04
[I]*Carduelis spinescens*	22	0.59	0.29	6	1.5	0.35	8	159.1	562.2	21	0.84	0.11	15	25.0	16.97	0.5
[R]*Astragalinus psaltria*	1	0.05	0.66	1	0.9	0.07	1	4.9		3	0.12	0.62				0.04
[I]*Zonotrichia capensis*	17	0.94	0.32	8	2.7	1.20	10	157.7	562.9	27	1.08	0.06	4	6.7	4.03	0.48
[I]*Hemispingus superciliaris*	6	0.16	0.63							4	0.16	0.59				0.08
[R]*Atlapetes schistaceus*	2	0.06	0.66	1	0.6	0.28				1	0.016	0.70				0.04
[R]*Atlapetes pallidinucha*				2	1.1	0.07	1	352.8		2	0.08	0.65	1	1.7	0.49	0.04
[I]*Arremon torquatus*	4	0.08	0.63	2	1.6	0.42	1	34.6		4	0.16	0.59				0.08
Myiothlypis nigrocristata	16	0.41	0.42	1	0.6	0.28	3	12.0	22.2	21	0.84	0.11				0.28
Oreothlypis peregrina	1	0.05	0.66	2	0.9	0.07				1	0.04	0.68	1	1.7	0.49	0.04
[I]*Myioborus ornatus*	5	0.13	0.59	2	1.8	0.57				4	0.16	0.59				0.1
Setophaga fusca	2	0.10	0.66				1	0.7		2	0.08	0.65				0.04
[I]*Sturnella magna*	6	0.16	0.55	2	1.6	0.42	4	24.0	56.6	9	0.36	0.45	1	1.7	0.49	0.17
[R]*Icterus chrysater*	2	0.10	0.66										2	3.3	1.63	0.03
[R]*Amblicercus holocericeus*	1	0.06	0.67	1	0.8	0.14										0.03
[R]*Pheucticus aureoventris*							4	2.1		1	0.04	0.68				0.03

Table 1 Contd

Total Species	48	37	35	48	22	57
Abundance	428	154	172	530	71	754
% Sp. Exclusive	16	5	5	30	4	
Dominance	0.045	0.061	0.065	0.053	0.091	
Shannon	3.34	3.14	3.06	3.25	2.73	
Evenness	0.86	0.86	0.86	0.83	0.88	
Fisher	13.87	15.45	13.28	12.81	10.92	
CHAO-1	58	43	51	53	24	

shapes: Shannon (Mann-Whitney U = 19.0, P = 0.24, n = 14), Fisher-alpha (Mann-Whitney *U* = 16, P = 0.43, n = 14), dominance (Mann-Whitney *U* = 18, P = 0.306, n = 14) or equity (Mann-Whitney *U* = 18, P = 0.30, n = 14). In contrast, when comparing size categories, the results differed for Shannon (Kruskal-Wallis $H_{(14)}$ = 9.42, P = 0.0008), Fisher-alpha (Kruskal-Wallis $H_{(14)}$ = 9. 44, P = 0.0089) and for dominance (Kruskal-Wallis $H_{(14)}$ = 8.17, P = 0.016). Small fragments showed higher Shannon and dominance values and larger fragments showed lower values, while equity was alike in the comparison (Kruskal-Wallis $H_{(14)}$ = 4.24, P > 0.05).

DISCUSSION

Density and diversity indixes were statistically different when compared large, medium and small fragment as well as polygonal and elliptical fragments. Bird composition varied between all fragment categories, but community richness and diversity indixes did not.

Bird community records in the High-Andean forest was on average four times higher in elliptical (mean 22 +/- 0.46 individuals / ha) than in polygonal fragments (mean 5.4 +/- 0.54 individuals / ha). According to the established theory, elliptical fragments exhibit greater density than those with irregular or polygonal shapes (elongated); this has been corroborated in different spatial scales, for different forest types and species (Suppl. 2). For example, higher density in elliptical fragments has been observed, on a large (Ewers & Didham 2006) and medium scale, for birds in temperate forests in England (Haskel et al. 2002), and in the lowland forests of North Carolina (Shake et al. 2011). Only one small-scale (less than 8 km^2) study on subtropical forest insects has been conducted in Japan, where round-elliptical fragments recorded higher density than polygonal shaped fragments (Koike & Soga 2012). Turner (2005) has explained the lower density of organisms in complex, irregular fragments; she states that these fragments have a higher area-perimeter index, with a further reduction in the core area of the fragment and an increase in the amount of habitat at its edge and thus on its edge effect.

Srivastava and Starzomski (2007) and Ewers & Didham (2007) suggest that a smaller core and unfit edge area exerts greater pressure on bird survival, reproduction, fitness and density due to an increase in intra and interspecific competition (Helzer & Jelinski 1999) or predation (Kennedy & Marra 2010). The core area of the elliptical fragments in our study was not only larger than the core area inpolygonal fragments, but it also had more strata (herbaceous to arboreal) and larger trees (DBH > 15 cm), which possibly benefit bird nesting, perching, and feeding (Leon JS pers. observ.), increasing micro-habitats, resources and species density of the community. The significance of the core area is illustrated by the case of the Pearled Treerunner (*Margarornis squamiger*) whose density declined substantially in polygonal fragments, partially due to the absence of large trees (DBH > 20 cm.; Table 1). Srivastava & Starzomski (2007) demonstrated that fragments shapes not adhering to classical Euclidean geometry, also prompt the reduction in species population size between 10 and 100 %. This depends on the level of response and resilience of the species to the edge effect, which implicates changes in forest structure and in its microclimate at the edge of the fragment and can benefit or harm the species (Turner 2005). Similarly, the fragment edge can create a habitat for species that require certain resources and conditions (Hardt & Forman 1989, Corlett et al. 2011). This could be the case of conspicuous, generalist and opportunistic bird species in the study that benefit from seeds, flowers and berries found in the transitioning logged forest and grassland such as the Scarlet bellied mountain Tanager (*Anisognatus igniventris*), the Lesser Goldfinch (*Astragalinus psaltria*), the Rufous-

collared Sparrow (*Zonotrichia capensis*), the Sparkling Violetear (*Colibri coruscans*), the Glowing Puffleg (*Eriocnemis vestita*), the Scrub Tanager (*Tangara vitriolina*),the Black-and-Blue Tanager (*Tangara vassorii*), the Great Thrush (*Turdus fuscater*) and the White-Browed Brush Finch (*Arremon torquatus*).

Bender et al. (1998) and Aslan (2012) attribute a decrease in density of some species to the reduced supply of specific resources at the fragment edge. For other less generalist species, a decrease in density could be attributed to higher exposure to parasites (e.g. high density of grassland ticks on the Slaty Brush-finch (*Atlapetes schistaceus*; Leon JS pers. observ) and predation by owls (Leon JS pers. observ.), hawks and some mammals (Sodhi et al.. 2004, Lindemayer et al.. 2010, Sevillano et al.. 2011) such as the weasel (*Mustela frenata*) and the fox (*Cerdocyon thous*; Leon JS. pers. observ.). Those factors synergistically decrease the survival and the nesting success of individuals closer to the fragment edge (40-60 m; Shake et al. 2012). Another cause for low density can be the high mobility of some species during foraging (Arango 1990, Harris & Reed 2002); this could be the case of the Scarlet-bellied Mountain-Tanager (*Anisognatus igniventris*), the Pale-naped Brush-finch (*Atlapetes pallidinucha*) and the Rufous-collared Sparrow (*Zonotrichia capensis*), which are all common and sometimes abundant species (Bohorquez et al. 2000). The average density of the bird community differed in respect to the compared fragment sizes (between 0.008 and 0.019 km^2); in some cases, inversely proportional to fragment size, sometimes by up to one order of magnitude. Using a spatial scale of 4.9 km^2, Franco et al. (2005) also found a lower density of birds in larger fragments of the Colombian Andean forest. Winter et al. (2006) found an inverse relationship at a 30 km^2 scale, in boreal mountain forests in the U.S. The results are consistent at all spatial scales (Table 1) and for other biological groups such as amphibians (Helzer & Jellinsky 1999, DeFries et al. 2005).

Turgeon et al. (2010) explained the increase of population density as an effect of the gradual reduction of fragment size. At landscape level, there are other variables to explain the inverse relationship between fragment size and species density. Laurence & Yensen (1991) and Adeney et al. (2009) consider functional connectivity as the key, which enables the movement of the species.

Although, the spatial scale of this study was small ($x \leq$ 100 ha), others such as Ibarra-Macias et al. (2011), demonstrated that even distances under 30 m between forest fragments were significant in limiting the movement of six species of birds belonging to the Troglodytidae, Thraupidae, Emberizidae, and Furnariidae families. Magrach et al. (2012) also observed a decrease in the mobility rate of three bird species: the White-crested Elaenia (*Elaenia albiceps*), the Green-backed firecrown (*Sephanoides sephaniodes*) and the Austral Thrush (*Turdus falklandii*) across distances under 30m. The same families of the bird species quantified in these two studies were also identified in the community observed in this study in fragments at distances between 8 and 200 m. These mobility barriers present in small areas affect population size and dynamics, migration rates, foraging behaviors (Cherkaoui et al. 2009), species diversity within the fragments and the probability of local extinction (Fahrig 2002). The assumptions of high movement rates in the small and scattered fragments of the High-Andean forest have been demurred by studies conducted by Gillies & St. Clair (2010), Tremblay & St. Clair (2011), Amos et al. (2012) and Pavlova et al. (2013) in other types of forests, which confirm the existence of the same barrier effect for birds and mammals across small fragments. Rytwinsky & Fahrig (2012) demonstrated that even 5 to 7 m wide roads, such as those in our study area, affect mobile species even more than low mobile species. However, further studies on connectivity and the existence of potential mobility barriers for different species are still necessary.

Bird composition varied more due to fragment shape than to fragment size. Regarding the shape variable, a lower number of common species and a higher number of unique species were found; the opposite was so regarding size (Table 1). We want to make special emphasis on preliminary results obtained using greater sampling efforts in similar High-Andean forest confirm that shape also affected bird composition (Leon J.S. unp. Data). Studies by Hanski & Ovaskainen (2000), Adeney et al. (2009), Benitez-Lopez et al. (2010) have concluded that the degree of landscape fragmentation and human intervention in the forest is reflected in the absence of certain species; such is the case of diurnal raptors (Betts et al. 2010, Shake et al. 2012). In this study, none of the following distinctive High-Andean forest prey species were observed: the White-tailed Kite (*Elanus leucurus*) the Broad-winged Hawk (*Buteo platypterus*) the Roadside Hawk (*Rupornis magnirostris*), the Sharp-shinned Hawk (*Accipiter striatus*) and Falcons (*Falco* sp.). Similarly, large species such as guans (*Penelope* sp.), toucans (*Aulacorhynchus* sp. and *Andigena* sp.) and species associated with large trees (DBH > 20 cm. Hilty & Brown 2001) were also absent. No large species such as Barn Owl (*Tyto alba*), the Rufous-banded Owl, (*Strix albitarsus*) and the Tropical Screech Owl were present in small fragments. The studies suggest that organism size affects their occurrence, as a result, larger animals will have smaller densities than small animals and their presence may be correlated with the availability of habitat and resources (nutritional requirements), concomitant with the size of the fragments (Sekercioglu et al. 2008).

Shannon-Weaver and Fisher-alpha diversity indices offered differences between fragment size categories; the highest diversity was shown in large fragments, followed by medium and then smaller fragments; dominance presents the opposite. These results are consistent with the theory established, among others, by Laurence & Yensen (1991) and Laurence et al. (2012),

and emphasize the importance of preserving large fragments. Larger fragments, with vaster perimeters, enable the colonization of new species (theory of island biogeography, MacArthur & Wilson 1967). They offer a larger habitats and microhabitats to support greater richness (Brooks et al. 1999, Yamaura et al. 2008) and provide sufficient and assorted resources to maintain different populations of similar size. This contrasts small fragments in which species dominance was marked (e.g. Great Thrush, Scarlet-bellied Mountain-Tanager, and the Lesser Goldfinch). Meanwhile, Shannon-Weaver and Fisher-alpha diversity did not differ between elliptical and polygonal fragments, despite the latter's slight tendency to be higher. This disparity may be explained by results by Yamaura et al. (2008), in which short and elongated (polygonal) fragments have short radial distances from their center (core) towards their edges, supporting a greater number of edge species than elliptical fragments. Conversely, elliptical fragments support more species towards their center; these species are usually larger (Pearled Treerunner. 18 - 22 g.), but not abundant. This result contrasts the theory by Betts et al. (2006) and Porter-Bolland et al. (2012), and others, that establishes that elliptical shaped fragments typically support higher diversity levels than fragments of other shape. Equivalence may be determined by the sampling effort or the combined effect of shape and size (many, small, polygonal fragments embedded in the matrix; Ramirez et al. 2003). The scientific community has precariously studied the effect of fragment size and shape on the variables of diversity; usually, shape is considered a secondary variable or independent of size (Yamaura et al. 2008, Rytwinski & Fahrig 2012).

In this study, species richness did not vary statistically with fragment size. The number of species contained in the fragments remains statistically unchanged; however, a replacement of species for certain niches does occur (redundancy of species in the system). The result may also be a product of the chosen study area (range), combined with the number, spatial distribution design and distance of the fragments remaining after logging activities (Grashof-Bokdam et al. 2009). Haila (1983) and Mc.Garigal (2009) suggest that small remnant fragments are representative samples of the richness of the larger fragments of which they were part. However, despite the initial insignificant influence of richness on change, Ries et al. (2004) and Guldemond & Aarde (2010) and Reid et al. (2012) confirmed its effect on the communities in space or in time.

The shape and size of the fragments studied in the High-Andean forest, on a sampling scale of less than 100 ha, could affect in additive or synergistical way community variables such as density, composition and bird diversity; however the interaction of those independent variables has not been addressed in the literature due to the limitations in having an effective experimental design (e.g. spatial heterogeneity, fragments origin, replicates etc). Further research is necessary in small scale fragments to confirm the theory established when using larger spatial scales (Ewers & Didham 2007, Hewson & Noble 2009, Koike & Soga 2012).

CONCLUSION

In conclusion, composition, density and diversity indexes were different when compared fragment size (between 0.08 and 19.4 ha) and composition and density differed with fragment shape (polygonal, elliptical). In contrast, richness was similar between shape or size fragment categories. The findings on a scale of less than 100 ha, may help to support the already established theory for a scale of over 1000 ha. However, further experimental studies are required to verify any causal relationships. Results based on shape categories are similar to the obtained in a subsequent work under the same kind o forest, same bird communities and same region, but with a more extensive sample effort and temporal field phase (Leon-Lleras 2013 Unp.Data).

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Supplementary Table 1: Studies evaluating the effect of size and shape of fragments, information organized in three spatial scales (Fahrig 2004) and taxa (B = bird; I = insects; M = Mammals; F = fish; W = amphibians; R = reptiles). Note that only the study of Reid *et.al* (2012) used a scale of less than 200ha.

Escale (Ha.)			Biological group	Authors
<500Ha	>500-<2000Ha	>2000Ha		
		>100000	F	Boren JC. (1999)
		9000	B	Boscolo & Metzger (2011)
		30000	B	Cherkaoui (2009)
		33257	M	Grubb & Reunanen (2005)
		>5000	B.R.M	Ewers & Didham (2006)
		147630	B	Guldemond & Aarde (2010)
	2000		M	Haskel *et.al* (2002)
		150000	B	Kattan (1994)
500		4000	I	Pokluda *et.al* (2011)
		200000	B	Knick y Rottemberry (1995)
		120000	B	Lindemayer *et.al*(2010)
		>2000	B	Murphy & Noon (1992)
		21000	R	Smolensky &Fitzgerald (2011)
		44500	F	Uchida y Inoe (2009)
		41170	B	Farigh *et.al* (2011)
		>3000	B	Watling *et.al* (2009)
		10000	R	Garden *et.al* (2010)
	1918		F	Turgeon *et.al* (2010)
		160000	B. An. M	Yamaura (2008)
	1100		B	Tremblay & St. Clair (2011)
120			B	Reid *et.al* (2012)

Supplementary Table 2: Plant species that provide resources for birds in High-Andean forest fragments “Altos de Potosi”, location and presence of the species in the fragment, relative abundance and height. Uncommon = <10 individuals. Common => 30 individuals.

Species	**Common name**	**Resource**	**Location**	**Fragment**	**Abundance**	**Height (m)**
Abatia parviflora	Duraznillo	Perch. seeds	Borders	All	Less Common	12
Alnus acuminata	Aliso	Perch. nest site.	Borders	Higher Fragments	Common	6-9
Bacharis bogotensis	Ciro	Perch. nest site	Borders	All	Less Common	1-2
Bacharis latifolia	Chilca	Perch. nectar, Nest	Borders	All	Common	2
Brungmansia arborea	Borrachero blanco	Nectar	Borders e interior	Smaller Fragments	Common	<5
Bucquetia glutinosa	Chorne	Perch. Nest	Borders	All	Common	<4
Chusquea sp.	Chusque	Perch. Nest	Interior (>20m. border)	Higher Fragments	Common	3-5
Citharexylum subflavescens	Cajeto	Seeds. perch Nest	Interior	Higher Fragments	Common	8-10

Supplementary Table 2: Contd

Clusia multiflora	Gaque	Nectar. perch Nest	Interior	Higher Fragments	Common	6-8
Dahlia imperialis	Dalia silvestre	Nectar	[1]Border - [2] Interior.	[1]Higher fragments [2]Smaller Fragments	Common	2
Drimys granadensis	Canelo de páramo	Perch. Seeds. Nest	Interior (>20m. border)	Higher Fragments	Less Common	20
Duranta mutisi	Espino	Seeds. perch. Nest	Border	Higher Fragments	Common	2
Espeletia grandiflora	Frailejón	Nectar. seeds	Interior	Higher Fragments	Less Common	1-1.5
Eugenia foliosa	Arrayán	Perch. Nest	Interior - border	Higher Fragments	Less Common	15
Hypericum brathys	Chite		Border		Common	1-1.5
Lupinus sp	Chocho	Perch. Nest. seeds	[1]Border. [2]Interior	[1]Higher fragments and medium; [2] más small	Common	<5
Monochaetum myrtoideum	Angelito	Nectar fruits.	[1]Border. [2]Interior	[1]Higher fragments medium; [2] smaller	Common	2-3
Myrciantes leucoxila	Arrayán de castilla	Perch. Nest	Interior	Higher fragments medium	Less Common	12-15
Ocotea calophyla	Amarillo	Perch sedes nest	Interior	Higher Fragments	Less Common	8-12
Piper bogotense	Cordoncillo	Seeds perch.	Interior	Higher fragments	Less Common	20
Polymnia piramidalis	Arboloco	Seeds nectar. Nest	Interior	All	Less Common	12-15
Rapanea ferruginea	Espadero	Perch. Nest	[1]Border. [2]interior	[1]Higher fragments and medium; [2] small	Common	3
Weinmannia tomentosa	Encenillo	Seeds perch. Nest	Interior	Higher fragments.	Common	25
Xilosima spiculiferium	Corono	Perch. Nest.	[1]Interior. [2]border.	[1]Fragments más small; [2] Higher fragments and medium	Common	10

Supplementary Table 3: Birds species recorded in the High-Andean forest (presence = x blank = no). Community of birds observed in the study area (Potosi. Colombia) compared to other parts of Colombia and South America. Note that the Colombian coffee region has more species of birds, probably caused by increased sampling effort and area.

Species	**Potosí Colombia 4° 47´ N- 73° 55´ W**	**Carpanta Colombia 4°70N-73°-73´W**	**Génova Colombia 4°-16´N 75°78´W**	**Megantoni Perú 12° 26´S- 72°78´W**	**Los Llinizas Ecuador -0°70´S-79°05´W**	**Monte de la Mina Cotapat Bolivia -16°62´S- 65°33´W**
Anas flavirostris			x			
Anas discors				x	x	x
Coragyps atratus		x		x	x	
Cathartes aura			x		x	
Colinus cristatus	x		x			
Bubulcus ibis		x	x	x	x	x
Accipiter striatus		x	x	x	x	

Supplementary Table 3: Contd

Rupornis magnirostris			x		x	x
Buteo polyosoma			x			
Buteo platypterus			x		x	
Geranoaetus melanoleucos			x			
Oroaetus isidori			x		x	
Phalcoboenus carunculatus			x			x
Polyborus plancus			x		x	
Falco sparverius			x			
Chamaepetes goudotti			x			
Penelope montagnii			x		x	
Vanellus sp			x			x
Rallus semiplumbeus		x				
Gallinago nobilis		x	x			x
Tringa solitaria			x	x	x	
Pionus tumultuosus			x			
Pionus chalcopterus			x		x	
Leptosittaca branickii			x		x	
Hapalopsittaca fuertesi			x			
Amazona mercenaria			x			
Bolborhynchus ferrugineifrons			x		x	
Patagioaenas fasciata	x	x	x	x	x	
Zenaida auriculata	x	x	x			x
Columba livia			x	x	x	x
Tyto alba	x	x	x			
Megascops choliba	x		x	x	x	
Megascops albogularis		x	x			x
Strix albitarsus	x			x		
Glaucidium jardinii		x	x	x		
Caprimulgus longirostris	x	x	x	x		
Uropsalis sp.			x		x	
Orochelidon murina	x	x	x	x	x	x
Notiochelidon cyanoleuca			x		x	
Hirundo rustica			x		x	x
Streptoprocne zonaris			x		x	
Aglaeactis cupripennis			x		x	x
Chlorostilbon mellisugus			x		x	x
Eriocnemis mosquera			x			
Heliangelus exhortis			x			x
Coeligena torquata			x		x	
Coeligena lutetiae			x		x	
Chalcostigma herrani			x		x	
Lafresnaya lafresnayi			x			
Phaethornis syrmatophorus			x		x	
Adelomyia melanogenys			x			

Supplementary Table 3: Contd

Opisthoprora euryptera			x		x	
Boissonneaua flavescens			x		x	
Colibri coruscans	x	x	x	x	x	x
Colibri thalasynus	x		x		x	
Lesbia nuna	x		x		x	
Lesbia victoriae			x			
Metallura tyrianthina	x		x	x		x
Eriocnemis cupreoventris	x	x	x		x	
Eriocnemis vestita	x	x	x		x	
Lafresnaya lafresnayi		x	x		x	
Ramphomicron microrhynchum		x	x	x	x	
Ensifera ensifera	x		x		x	
Chaetocercus mulsant	x	x	x	x		
Aglaeactis cupripennis			x			
Coeligena helianthea		x	x			
Pharomachrus auriceps			x		x	
Trogon personatus			x			
Momotus momota			x		x	
Andigena hypoglauca			x			
Andigena nigrirostris			x			
Campephilus pollens			x		x	
Melanerpes formicivorus			x			
Piculus rubiginosus			x			
Veniliornis nigriceps			x		x	x
Lepidocolaptes affinis			x			
Picoides fumigatus	x	x	x	x	x	x
Colaptes rivolii	x	x	x			x
Grallaria ruficapilla	x	x	x			
Grallaria rufula	x		x		x	
Grallaria squamigera	x		x			
Grallaricula lineifrons			x			
Grallaria milleri			x			
Grallaria ruficapilla			x			
Grallaria quitensis			x		x	
Grallaria nuchalis			x		x	
Cyanocorax yncas			x			
Cyanolyca viridicyana			x			x
Cinclus leucocephalus			x			
Scytalopus unicolor			x			
Scytalopus griseicollis	x	x	x	x		
Dendrocincla tyrannina		x	x			
Margarornis squamiger	x	x	x		x	x
Synallaxis azarae		x	x			x
Synallaxis unirufa			x		x	

Supplementary Table 3: Contd

Synallaxis subpudica	x		x				
Asthenes flammulata			x		x		
Lepthasthenura andicola			x				
Schizoeaca fuliginosa			x				
Pseudocolaptes boissonneautii			x			x	
Hellmayrea gularis			x		x		
Phyllomyias nigrocapillus		x	x				
Elaenia frantzii	x	x	x	x			
Mecocerculus leucophrys	x	x	x	x			
Contopus fumigatus	x			x			
Ochthoeca fumicolor	x	x	x				
Ochthoeca rufipectoralis		x					
Phyllomyias uropygialis			x		x	x	
Anairetes agilis			x				
Ochthoeca diadema			x				
Pseudotriccus ruficeps			x		x		
Myarchus cephalotes			x				
Myotherestes striaticollis			x				
Pyrrhomyas cinnamomea			x				
Sayornis nigricans			x		x	x	
Mecocerculus poecilocercus			x				
Mecocerculus stictopterus			x		x		
Ampelion rubrocristatus	x	x	x				
Pipreola arcuata			x			x	
Pipreola rieferii			x				
Cinnycerthia unirufa		x			x		
Troglodytes aedon	x	x	x		x		
Troglodytes solstitialis			x				
Cranioleuca albiceps						x	
Cinnycerthia unirufa			x		x		
Cinnycerthia peruana			x		x		
Cistothorus platensis			x				
Catharus ustulatus			x				
Henicorhina leucophrys	x	x	x	x	x		
Turdus fuscater	x	x	x	x	x		
Mimus gilvus			x		x		
Vireo leucophrys			x		x		
Hemispingus melanotis		x	x				
Hemispingus superciliaris	x	x	x			x	
Hemispingus verticalis		x	x				
Hemispingus calophrys						x	
Hemispingus xantophthalmus						x	
Anisognathus flavinucha			x		x		
Anisognathus igniventris	x	x	x			x	

Supplementary Table 3: Contd

Anisognathus igniventris			x				
Anisognathus lacrymosus			x				
Buthraupis eximia			x		x		
Buthraupis montana			x				
Thraupis cyanocephala		x	x			x	
Catamblyrhynchus diadema		x	x		x	x	
Chlorornis rieferii			x		x	x	
Cnemoscopus rubrirostris			x				
Conirostrum albifrons			x				
Conirostrum rufum	x	x	x		x		
Conirostrum sitticolor	x	x	x			x	
Diglossa albilatera	x	x	x				
Diglossa albilatera			x				
Diglossa careulescens			x		x		
Diglossa cyanea	x	x	x		x	x	
Diglossa humeralis	x	x	x	x			
Diglossa lafresnayii	x	x	x				
Diglossa sittoides		x	x				
Dubusia taeniata		x	x				
Dubusia castaneoventris						x	
Euphonia xanthogaster			x				
Hemispingus atropileus			x		x		
Hemispingus superciliaris			x				
Hemispingus verticalis			x				
Chlorospingus ophthalmicus						x	
Iridisornis rufivertex			x				
Iridisornis jelsskii						x	
Myioborus miniatus			x				
Myioborus ornatus			x		x		
Myiovorus melanocephalus						x	
Pipraeidea melanonota			x				
Piranga olivacea			x		x		
Piranga rubra			x			x	
Piranga rubriceps			x				
Sericossypha albocristata			x				
Tangara vasorii			x				
Tangara vassorii	x	x	x			x	
Tangara vitriolina	x		x	x	x		
Tangara xanthocephala			x				
Thraupis cyanocephala			x				
Creurgops dentatus						x	
Urothraupis stolzmanni			x				
Atlapetes rufinucha						x	
Atlapetes gutturalis			x			x	

Supplementary Table 3: Contd

Arremon brunneinucha		x	x	x	x		
Arremon torquatus	x	x	x				
Astragalinus psaltria	x	x	x				
Atlapetes pallidinucha	x	x	x				
Atlapetes schistaceus	x	x	x				
Myiothlypis nigrocristata	x	x	x				
Myiothlypis luteoviridis						x	
Myiothlypis signata						x	
Carduelis magellanicus			x		x		
Carduelis spinescens	x	x	x	x	x		
Catamenia analis	x		x				
Catamenia inornata		x	x		x	x	
Setophaga fusca	x		x	x	x	x	
Icterus chrysater	x		x	x			
Amblycercus holosericeus	x	x	x			x	
Cacicus leucoramphus						x	
Myioborus ornatus	x	x	x				
Myiotheretes striaticollis		x	x				
Pheucticus aureoventris	x		x		x		
Phrygilus unicolor			x				
Sicalis luteola			x				
Sturnella magna	x	x	x				
Vermivora peregrina	x		x	x			
Zonotrichia capensis	x	x	x	x	x		