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3 **LRH:** Gomez, Ortiz and Botero

4 **RRH:** Shade-Coffee Certification and Conservation

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7 **Effects of shade-coffee certification programs on bird, trees and butterfly diversity in**

8 **Colombia**

9 **Authors:** Juan Pablo Gomez^{1,2,4}, Elena Ortiz-Acevedo^{1,3}, Jorge E. Botero¹

10 ¹Conservation Biology Program, Cenicafe, Planalto, Km. 4, Antigua Vía a Manizales,
11 Chinchiná, Caldas, Colombia.

12 ²Department of Biology & Florida Museum of Natural History, University of Florida,
13 P.O.Box 117800, Gainesville, Fl 32611-7800.

14 ³McGuire Center for Lepidoptera and Biodiversity Research, University of Florida, P.O.Box
15 112710, Gainesville, Fl 32611.

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⁴Juan Pablo Gómez, jugomez@ufl.edu, gomez444@gmail.com

1 **Abstract**

2 In the last decade coffee certification programs have grown rapidly in Latin America,
3 encouraging producers to harvest coffee based on production standards intended to enhance
4 biodiversity conservation. However, few studies have tested whether such programs have a
5 positive conservation impact. To date, research has focused on comparing community
6 similarity between forests and plantations, but the question of whether certified plantations
7 provide refuges for biodiversity in regions where all the forest has been lost remains untested.
8 Here, we compare bird, butterfly and plant communities in highly deforested regions in
9 Santander, Colombia, to determine the potential conservation role of two certification
10 programs: Rainforest Alliance and Rainforest Alliance+Organic. We used 13 farms to census
11 birds, butterflies, and trees, and quantified structural characteristics of the shade. We found
12 little difference in most measures of diversity and composition of birds, butterfly and plant
13 communities between types of plantations. However, despite high variation across farms,
14 butterfly richness and abundance increased with the decrease in the use of pesticides in
15 plantations. These results suggest that reduced use of chemical compounds in certified coffee
16 plantations might enhance conservation of butterfly communities. The biodiversity associated
17 with these coffee plantations and the high deforestation rates in Santander, suggest that
18 irrespective of their certification type they provide the last refuges for biodiversity
19 conservation in this region.

20 **Keywords:** Agricultural landscape; non-certified; Rainforest Alliance; Rainforest plus
21 Organic; Santander.

22 **Resumen**

23 En la ultima década, los programas de certificación al café en América latina han crecido
24 rápidamente, motivando a los productores a sembrar café basado en estándares de producción

1 que promueven la conservación de la biodiversidad. Sin embargo, pocos estudios han
2 intentado comprobar si estos programas de certificación tienen un impacto positivo sobre la
3 conservación de la biodiversidad. Hasta la fecha, la mayoría de estudios se han enfocado en
4 comparar la similitud entre las comunidades de bosques y plantaciones, pero la pregunta
5 acerca del impacto que tienen las plantaciones certificadas en sobre la conservación de la
6 biodiversidad en regiones donde los bosques se han perdido por completo sigue sin respuesta.
7 En este estudio, comparamos las comunidades de aves, mariposas y plantas en una región con
8 alta deforestación en Santander, Colombia, con el fin de determinar el potencial para la
9 conservación de dos tipos de certificaciones al café: Rainforest alliance y Rainforest alliance
10 + Orgánico. Utilizamos 13 fincas, donde censamos aves, mariposas y plantas y además
11 cuantificamos las características de la estructura del sombrero. No encontramos diferencias
12 significativas en la mayoría de los índices de diversidad y composición de aves, mariposas y
13 plantas entre diferentes tipos de cafetales. Sin embargo, a pesar de la alta variación entre las
14 fincas, encontramos que la riqueza y abundancia de las mariposas aumentan con la
15 disminución en el uso de pesticidas en las plantaciones. Estos resultados sugieren que el uso
16 reducido de compuestos químicos en plantaciones certificadas promueven la conservación de
17 las comunidades de mariposas. La biodiversidad asociada a estas plantaciones de café y las
18 altas tasas de deforestación en Santander, sugieren que independientemente del tipo de
19 certificación, estas plantaciones proveen los últimos refugios para la conservación de la
20 biodiversidad en esta región.

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1 TROPICAL ANDES IS ONE OF THE MAJOR BIODIVERSITY HOTSPOTS IN WHICH ALMOST 7% OF THE
 2 TOTAL WORLD'S ENDEMIC PLANTS AND 6% OF TERRESTRIAL VERTEBRATES ARE FOUND (Myers
 3 *et al.* 2000). However, high deforestation rates are threatening the subsistence of this
 4 considerable portion of the world's biodiversity (Rengifo *et al.* 1997, Brooks *et al.* 2002).
 5 The increase of urban areas and fast conversion of land for agricultural use are likely to be
 6 responsible for the transformation of the natural vegetation cover (Allen & Barnes 1985,
 7 Etter *et al.* 2006, Grau & Aide 2008). Coffee plantations may be a great contributor to the
 8 deforestation rate given that they occupy 44% of the total permanent crops in northern Latin
 9 America (Perfecto *et al.* 1996). These facts advocate for the development of sustainable
 10 alternatives to mitigate the detrimental effect caused by such practices and alleviate the
 11 extinction rates of local biodiversity (Rengifo *et al.* 1997, Brooks *et al.* 2002).

12 Shade coffee plantations might be a sustainable alternative because they support
 13 greater species richness of multiple groups of organisms than coffee grown in full sun
 14 (Perfecto *et al.* 1996, Wunderle Jr & Latta 1996, Greenberg *et al.* 1997a, Perfecto *et al.*
 15 2007). In the past decade, research has focused on the differences in community composition
 16 and diversity between different types of shade coffee plantations, which are thought to
 17 contribute differentially to biodiversity conservation (Philpott *et al.* 2008). Birds, butterflies,
 18 ants and plants, are more diverse under less intensified shade coffee than mono-dominant
 19 shade plantations and in smaller households (Greenberg *et al.* 1997b, Mas & Dietsch 2003,
 20 Perfecto *et al.* 2003, Armbrrecht *et al.* 2005, Philpott *et al.* 2007, Philpott *et al.* 2008, Mendez
 21 *et al.* 2010, Goodall *et al.* 2014). These studies suggest that the increased diversity is the
 22 result of differences in shade and socio-economical characteristics between coffee
 23 plantations, and some may therefore have a high potential value for biodiversity conservation
 24 (Philpott *et al.* 2008, Mendez *et al.* 2010, Goodall *et al.* 2014).

1 Lately, certification programs for shade coffee plantations have been implemented in
2 several coffee-growing countries (Perfecto *et al.* 2005). Such certifications apply several
3 standards for producing coffee in an attempt to make the process environmentally, socially
4 and economically friendly (Perfecto *et al.* 2005, Philpott *et al.* 2007, Giovanucci *et al.* 2008,
5 Philpott *et al.* 2008). Rainforest Alliance certified coffee, for example, has to be produced
6 under a shade with foliage cover of at least 40%, represented by more than 80 trees and 12
7 native species per hectare and a double-layered canopy (Rice 2008, Sustainable Agricultural
8 Network 2011). Also, Rainforest Alliance certified coffee-producing farms have to conserve
9 forest remnants, reduce the use of chemical products, protect stream sides and encourage
10 their workers to preserve the environment by proactive behavior (Rice 2008, Sustainable
11 Agricultural Network 2011). Other types of certification programs such as organic
12 certifications are not generally related to shade production, but prohibit the use of chemical
13 products such as pesticides and/or fertilizers (Vandermeer 1995).

14 Although, these certification programs are presumably environmentally friendly, few
15 empirical data have been gathered to test the hypothesis that increased diversity and
16 complexity in shade cover increases biological diversity within coffee plantations (Hole *et al.*
17 2005, Philpott *et al.* 2008). Mas and Dietsch (2003, 2004) showed that bird and butterfly
18 communities were more diverse in certified plantations that had a higher shade complexity
19 (i.e. Bird Friendly Certification), but in another study, Philpott *et al.* (2007) showed that
20 diversity of birds and ants did not differ among plantations regardless of their shade
21 complexity and whether they were certified or not. Both of these studies agree with the fact
22 that no type of plantation sustains the diversity of natural forests, questioning the real
23 usefulness of certification programs in preserving biodiversity (Mas & Dietsch 2003, O'Brien
24 & Kinnaird 2003, Rappole *et al.* 2003, Mas & Dietsch 2004, Philpott *et al.* 2007). More
25 recently, Blackman and Rivera (2011) showed that there is little evidence to support the

1 claim that certification programs are beneficial for the environment. Given the disagreement
2 among these results, additional studies are needed before general conclusions can be drawn,
3 especially from regions of high conservation priority such as Colombia (Myers *et al.* 2000,
4 Blackman & Rivera 2011). Additionally, all of these studies have focused on the levels of
5 biodiversity sustained by certified coffee plantations only in comparison to natural forest
6 remnants. Thus the question remains how might certification programs help preserve
7 biodiversity in regions where natural forests have already been lost?

8 The Colombian Andes is a region with one of the highest conversion rates of natural
9 ecosystems due to agricultural and demographic land use (Etter & van Wyngaarden 2000).
10 In central Santander most of the landscape has been transformed to shade coffee plantations
11 leaving few to no remnants of natural forests (Guhl 2009). In the past decade many farms
12 have switched from highly intensified management of coffee to organic or certified programs,
13 which implement standards to make coffee production environmentally friendly (Guhl 2009).
14 This is one of Colombia's oldest coffee-growing regions (Palacios 1980) and most of the
15 coffee is grown under diverse and complex shade, making Santander Colombia's greatest
16 producer of certified coffee (Rainforest Alliance 2007, Guhl 2009, NaturaCert 2011). In
17 other cases, farms may implement different types of shade such as shaded monoculture (as
18 described by Moguel & Toledo 1999). These different types of shade programs found in the
19 same geographic region allow a comparison of the role of different certification programs in
20 biodiversity conservation.

21 In this study we test if farms with Rainforest Alliance and Rainforest Alliance plus
22 organic certifications support a higher diversity of birds, butterflies, and trees than uncertified
23 farms in the coffee-growing region of Santander. Specifically, we predicted that
24 communities of such organisms inhabiting certified farms should be more diverse than those

1 on non-certified farms. Additionally, shade structure and complexity should be higher in
2 certified plantations and less complex in non-certified plantations.

3 **METHODS**

4 *STUDY AREA AND SITE SELECTION.* - The coffee-growing region of Santander is located on the
5 northwestern slope of the Eastern Andes in Colombia at middle elevations between 1200 and
6 1800 m. It is characterized by having a bimodal precipitation regime with dry seasons
7 between July and August and December and January, with a mean annual precipitation of
8 1700 mm and a mean annual temperature of 20°C. Plantations in Santander differ from the
9 rest of Colombia because almost all coffee is grown under a diverse shade that is typical of
10 commercial polycultures (for detailed description of a commercial polyculture see Moguel
11 and Toledo 1999). This type of plantation has high shade tree diversity but is dominated
12 principally by legumes (*Inga* sp., *Erythrina* sp. and *Albizia* sp.), but some other non-legumes
13 (*Cupania* sp., *Trichanthera gigantea*, *Cedrela* sp., *Tabebuia* sp.) are also relatively abundant.
14 For decades farmers have kept this agricultural practice because the dry climatic conditions
15 and high solar radiation otherwise make it impossible to grow coffee (Instituto Geográfico
16 Agustín Codazzi 1996, Duran *et al.* 2004, Guhl 2009). For these reasons the region pioneered
17 the production of certified coffee in Colombia and during the last decade Santander has
18 become the most important producer of Rainforest Alliance certified coffee (Rainforest
19 Alliance 2007, Guhl 2009, NaturaCert 2011). On the larger scale, coffee plantations
20 dominate the landscape, along with cattle pastures and sugar cane, cassava and citrus
21 plantations.

22 Within the municipalities of Páramo, Valle de San José, San Gil, and El Socorro, we
23 selected 13 farms with at least 20 hectares of shaded coffee, except for two farms that had
24 less planted area. The farms selected had to be either non-certified or certified by one of two

1 types of certification: Rainforest Alliance certified (RA, hereafter) and Rainforest Alliance
2 and organic certified (RA+Organic, hereafter) and had been certified for at least five years.

3 *ORGANISM AND SHADE STRUCTURE SAMPLING.*- Within each farm we identified up to ten points
4 that were at least 100 meters apart from each other and 75 meters away from the plantation
5 border, where we censused birds, trees and butterflies (for a detailed summary of sample sizes
6 see Table 1). We carried out four censuses during two seasons: October - December 2005,
7 March - May 2006. During each season, each point was visited twice for a 10-minute period.
8 Censuses started at dawn and were conducted until 10:30 am. Every bird seen and heard
9 within a 25-meter radius was counted, but flying and nocturnal birds were excluded from the
10 analyses (Hutto *et al.* 1986). In each of the bird census points a 20 x 20 m vegetation plot
11 was constructed to evaluate shade structure where we measured height, identity and diameter
12 at breast height (DBH) of each tree as well as average canopy cover and tree density in each
13 plot. Height was quantified using a clinometer, DBH was measured using a metric tape and
14 canopy cover was recorded using a spherical densiometer. Finally, we sampled butterflies
15 during the driest season of 2007 (July) and the wet season of 2008 (March) using standard
16 Van Someren-Rydon traps in 24 points where birds and trees were censused. In each point we
17 set up two traps, one placed in the canopy and the other one in the understory (above and
18 below three meters) (DeVries 1987, 1988, DeVries *et al.* 1997). We used two types of baits,
19 decomposing fish and fermenting bananas, in order to take into account different butterfly
20 feeding guilds. These were assigned randomly to each trap in each point. We sampled each
21 trap and bait was changed once every 48 hours for a period of eight days in each field season,
22 for a total of eight samples per trap.

23 *STATISTICAL ANALYSES.*- To compare species richness among coffee plantations we constructed
24 abundance-based rarefaction curves using 100 bootstrap replicates (Gotelli & Colwell 2001).
25 To statistically test for differences in species richness we rarefied the number of species to

1 lowest number of individuals encountered across types of plantation. Additionally, we
2 calculated Chao 1 species richness estimator, especially for butterfly richness where
3 rarefaction curves did not appear to approach an asymptote. We computed the effective
4 number of species based on the Shannon and Simpson indices, which take into account
5 species richness and abundance. The effective number of species gives the number of species
6 that a locality would have if all of the species would be represented by the same number of
7 individuals. For the Shannon index, the effective number of species x is $x = e^{Shannon}$, and
8 for the Gini-simpson index the effective number of species is $x = \frac{1}{1-Simpson}$. The correction
9 to the indices allows us to directly interpret magnitude of the difference across types of
10 plantations (Jost 2006). Finally we calculated similarity between farms using the Chao-
11 Jaccard index, which accounts for unseen species (Chao *et al.* 2005). Using the Chao-Jaccard
12 dissimilarity index we performed a Non-Metric Multidimensional Scaling (NMDS) to
13 explore differences across farms. Diversity analyses were conducted the vegan package
14 (Oksanen *et al.* 2013) for R (R Core Team 2013). We then compared if farms with a
15 particular coffee type were more similar than farms across coffee types using a non-
16 parametric ANOVA (Kruskal Wallis test) and an Analysis of similarity (ANOSIM). To test
17 for differences in the shade structure (DBH, tree density, canopy height, canopy cover and
18 management index) among types of plantations, we used one-way ANOVAs and post-hoc
19 Tukey tests for those that showed significant differences after testing for the normality of the
20 variables.

21 Using the vegan package, we fitted five species abundance distributions models to the data
22 for each type of plantation: Null, Geometric series, Lognormal, Zipf and Mandelbrot. The
23 models differ in the shape of the curve mainly in predicting the number of species with
24 intermediate and low abundances. The fitting of such models allows us to evaluate the

1 similarity in community composition based on abundance and dominance patterns. We
2 selected the model that fits our data the best by using AIC.

3 We used a published database to classify bird species in twelve diet guilds that
4 represent the preferences of species (Karr *et al.* 1990). Such guilds were: FRI (Frugivores
5 insectivores), F (Frugivores), CF (Canopy Frugivores), UF (Understory Frugivores), GR,
6 (Granivores), I (Insectivores), CI (Canopy Insectivores), UI (Understory Insectivores), NEC
7 (Nectarivores), NI (Nectarivores Insectivores), OM (Omnivores), RAP (Raptors). We
8 performed the guild analysis only for birds because there are no published datasets for the
9 guilds of adult butterflies. Statistical significance was assessed by estimating the 95%
10 confidence interval for the mean; if confidence intervals overlapped then, we assumed no
11 differences in the mean number of species or individuals in each guild.

12 Following Mas and Dietsch (2003), we calculated a Management Index for each
13 vegetation plot sampled using four variables: mean diameter at breast height (DBH), number
14 of tree species tree density and mean tree height. This Management Index quantifies the level
15 of intensification that each certification has over the shade canopy and it is based on the
16 values that each variable measured has in a native forest. Because we did not have a native
17 forest for comparison, we assumed the maximum value of each variable in the entire sample
18 plots to indicate low intensification and recall “natural conditions”. Thus, by comparing the
19 least intensified value of each variable to the observed value in each plot we calculated the
20 amount of management a plot has relative to the expected “natural conditions”. For each
21 variable, the index varies between 0.0 and 1.0, where 0.0 means the plot is similar in that
22 variable to presumed “natural conditions” and 1.0 means that the plot is highly intensified.
23 After calculating the amount of management for each variable, all of these values were added
24 to obtain the Management Index of the plot. We only included four variables in the index:
25 DBH, number of tree species, tree density and tree height, because we did not have canopy

cover values for all of the plots. The Management Index for the plot therefore potentially varied between 0.0 and 4.0. We then used the mean values of the Management Index to compare the intensification between the types of plantations studied using a one-way ANOVA. Further, to evaluate if the level of intensification in the farm had an effect on birds and butterflies we calculated linear regressions between bird and butterfly richness, and abundance in each farm and the Management Index.

RESULTS

RA and RA + Organic farms had more butterfly and tree species than Non-Certified farms but differences were not significant (Kruskal-Wallis: Butterflies: Chi-squared = 4.57, df = 2, p = 0.1; Trees: Chi-squared = 1.53, df = 2, p = 0.46; Table 2; Figure 1; Table S1). In contrast, Non-Certified coffee plantations had more bird species than do certified plantations but again differences were not significant (Kruskal-Wallis: Chi-squared = 0.35, df = 2, p = 0.8; Table 2; Figure 1). There was no significant difference in the estimated or rarefied richness of birds, butterflies or trees across types of plantations (Kruskal-Wallis: Estimated richness: Birds: Chi-squared = 1.1, df = 2, p = 0.6; Butterflies: Chi-squared = 3.7, df = 2, p = 0.15; Trees: Chi-squared = 2.9, df = 2, p = 0.23; Rarefied Richness: Birds: Chi-squared = 1.01, df = 2, p = 0.6; Butterflies: Chi-squared = 0.85, df = 2, p = 0.65; Trees: Chi-squared = 1.52, df = 2, p = 0.46). Again, there was no difference in the effective number of species across types of plantations (Kruskal-Wallis: Shannon: Birds: Chi-squared = 1.2, df = 2, p = 0.6; Butterflies: Chi-squared = 3.42, df = 2, p = 0.18; Trees: Chi-squared = 1.95, df = 2, p = 0.37; Simpson: Birds: Chi-squared = 2.1, df = 2, p = 0.35; Butterflies: Chi-squared = 2, df = 2, p = 0.36; Trees: Chi-squared = 2.4, df = 2, p = 0.3). However, the overall abundance of butterflies was five times higher in RA + Organic plantations than in Non-Certified plantations and almost twice as high as RA plantations. When lumping farms across types of plantations, there was no difference in the rarefied number of bird species but RA and RA + Organic resulted to be

1 more species rich in trees and butterflies than non-certified plantations (Figure 1; Statistical
2 significance is given by the non-overlap in the 95% confidence intervals).

3 We found no significant difference in community structure between plantations. Chao-
4 Jaccard index did not show a higher species turnover between plantations across types
5 (Kruskal-Wallis; Birds: Chi-squared = 1.4, df = 1, p = 0.23; Butterflies: Chi-squared = 0.18,
6 df = 1, p = 0.66; Trees: Chi-squared = 0.45, df = 1, p = 0.49). This was corroborated by the
7 ANOSIM. The only difference is that RA + Organic certified farms resulted to be
8 significantly different among them in bird composition (ANOSIM: Birds; R = -0.17, p = 0.04;
9 Butterflies: R = 0.16, p = 0.52; Trees: R = 0.09, p = 0.21). Bird community structure resulted
10 to be similar according to the models fitted to the rank-abundance distributions. For all three
11 types of plantations, the best model was the Preemption model with exactly the same slope
12 (Figure 2A; Table S2). In turn, Non-Certified butterfly and plant communities resulted to
13 follow a Zipf model and RA and RA + Organic butterfly communities followed a Mandelbrot
14 and Zipf models. The best model that fitted plant communities in both types of certified
15 plantations was a lognormal model (Figure 2; Table S2). Finally, we found no difference in
16 the bird guild structure of birds across types of plantations. The distributions of number of
17 species and proportional number of individuals were almost identical among types of
18 plantations (Figure 3; Statistical significance given by the 95% confidence interval of the
19 mean shown by the error bars). There are some differences between species richness and
20 abundance of the guilds across plantations. Even though Insectivorous birds were more
21 species rich; Frugivorous and Insectivorous birds were more abundant (Figure 3). We provide
22 complete species lists for birds, trees, and butterflies present in each type of plantation in
23 Table S3, S4 and S5.

24 Shade structure was similar between the three types of coffee plantations (Table 3).
25 Specifically, we found no significant differences in DBH (ANOVA; n = 13, f = 0.67, p =

0.52), canopy cover (ANOVA; $n = 12$, $f = 0.72$, $p = 0.51$), tree density (ANOVA; $n = 13$, $f = 1.66$, $p = 0.23$) or tree height (ANOVA; $n = 13$, $f = 3.69$, $p = 0.06$). When summarizing all variables into the Management Index, we found that RA+Organic had the lowest and the non-certified plantations the highest values. Generally a high value of the Management Index is associated with a decrease in the shade cover. However, the differences between certified and non-certified plantations were not statistically significant (ANOVA; $n = 13$, $F = 2.63$, $p = 0.11$). Finally, butterfly and bird species richness and abundance were not related to management index (Table S6).

DISCUSSION

Overall, we found no evidence that RA and organic certification are better refuges for biodiversity than non-certified farms. Instead, certified and non-certified plantations provide similar types of habitat that can serve as refuge to biodiversity in a region where almost all of the forest has been lost. Even though we found no significant differences in birds, butterfly and tree richness or abundance it is interesting to note the steep increase in butterfly overall richness. This increase suggests that the high variance in Butterfly diversity between coffee plantations might drive the absence of statistical significance (See Table S1). The results are in line with previous studies that have reported that butterfly abundance and richness decrease sharply with increasing plantation intensification and less intensified plantations tend to have more species rich plant communities (Botero & Baker 2001, Mas & Dietsch 2003, Perfecto *et al.* 2003, Mas & Dietsch 2004). Birds showed an opposite trend to our predictions, suggesting that factors other than shade structure and agrochemical use dominate the response of birds to these types of conservation actions. Potentially, an increase in bird species diversity might depend on the landscape matrix composition and the amount of forest available around the plantations (Sisk *et al.* 1997). Alternatively, this result might suggest

1 that some certified plantations do not have the complexity necessary to improve bird
2 conservation (Philpott *et al.* 2007).

3 Overall we were surprised that most of our comparisons resulted to be non-significant,
4 especially in butterfly estimated richness and diversity. The sampling effort was exactly the
5 same for all of the farms and even then, we found a five fold increase in the number of
6 butterflies captures between Non-certified and RA + Organic farms. Great variance and low
7 sample size might have contributed on the absence of significant differences in abundance
8 and richness. The absence in turnover patters is most likely the result of butterflies in Non-
9 certified plantations are just a subset of the species from the other types of plantations that
10 can overcome pesticides or are more generalists in their larval stages. Thus, no turnover is
11 observed but just addition of new species with practices promoted by certification programs.

12 *OVERALL COMMUNITY STRUCTURE.*-The fact that bird communities follow a Preemption model
13 suggests that there is a high dominance of one or few species and the rest of the species are
14 represented by few individuals (Motomura 1932; Figure 2; Table S2). However, the effective
15 number of species suggests that the dominance is not very extreme given by the differences
16 between observed and effective species number (Table 2). In contrast, models of butterfly
17 communities suggest that for all communities, there are niche mechanisms operating in the
18 abundance of species. The Zipf and Mandelbrot models assume that some species have a
19 priori niche requirements for their presence and establishment in the communities (Frontier
20 1985, Wilson 1991). Pioneer species have little requirements in the community while species
21 from later successional stages need higher complexity in niche and resource availability.
22 Thus, late successional species should be represented by a lower number of individuals
23 within the community (Frontier 1985, Wilson 1991). Such result suggests that butterfly
24 communities in coffee plantations may be remnants of the diversity lost by deforestation even
25 in Non-Certified plantations. However, effective species number suggests a great inequality

1 in the abundance of species. Such high inequality is corroborated by the low values of the
2 third parameter in the Mandelbrot model of the RA plantations (Wilson 1991). The results are
3 intriguing and further research comparing forest and plantation butterfly diversity might
4 clarify our results. Unfortunately, the total absence of forest in the region did not allow us to
5 comply with this.

6 Plant communities in certified plantations follow a lognormal distribution (Figure 2;
7 Table S2). The lognormal distribution is characterized by low dominance and high number of
8 species with intermediate abundance. Most likely this is the product of the shade plantation
9 process and a certification effect in which shade species are selected to have about the same
10 abundance per hectare to comply with certification requirements. Few species such as *Inga*
11 *sp.* have high abundance in these plantations because they are planted in a slightly higher
12 density to improve nitrogen fixation and soil productivity.

13 *BIRD GUILD STRUCTURE.*- The fact that bird guild structure was identical across types of
14 plantations suggests that the slight differences in shade structure have little influence on bird
15 diversity. An interesting fact is a decoupling in the richness and abundance patterns. Types of
16 plantations have slightly different order of most abundant groups. For example in Non-
17 certified RA + Organic plantations the most abundant group was the Frugivorous
18 Insectivorous and in the RA the most abundant was the Insectivorous. However, the small
19 differences in abundance between types of plantations suggest that the mechanisms driving
20 the abundance of species is homogeneous across plantations. The fact that the insectivorous
21 birds dominate the community might be explained by the dominance of *Inga sp.* trees in the
22 canopy. These trees have extrafloral nectaries that attract high abundance and diversity of
23 insects.

24 *RELATIONSHIP BETWEEN BUTTERFLY AND PLANT COMMUNITIES.*-Our results regarding the
25 differences in Management Index are consistent with the hypothesis and previous evidence

1 that differences in shade structure between plantations should drive the increase in butterfly
2 diversity (Mas & Dietsch 2004). Despite that most of the results in butterfly diversity do not
3 significant differences, richness, abundance and composition suggest the opposite (Figure 1,
4 Figure 2, Table 2, Table S2). Other studies have reported a relationship between shade
5 characteristics and the diversity of organisms in coffee plantations and our results conform to
6 the pattern of decreased butterfly diversity in more intensified plantations (Greenberg *et al.*
7 1997b, Soto-Pinto *et al.* 2001, Perfecto *et al.* 2003, Armbrrecht *et al.* 2005, Philpott *et al.*
8 2008). However, it is unlikely that differences in shade structure alone cause such an increase
9 in the diversity of butterfly communities, especially if the differences between the types of
10 plantations were not significant. It is probable that differences in tree species richness also
11 play an important role in explaining these differences. We found that there was a higher
12 number of tree species in RA+Organic than those in non-certified plantations (Table 2). Thus,
13 because of strong dependency of butterflies on their host plants (Ehrlich & Raven 1964),
14 absolute plant species richness might explain the differences in butterfly community
15 composition between coffee plantations. Additionally, the preservation of streamsides and
16 herbaceous vegetation (as required by RA certification) could enhance the diversity of
17 butterflies by protecting their host plants in the certified plantations and creating suitable
18 habitats for these insects (Sparks & Parish 1995).

19 An alternative explanation for the differences in butterfly communities between the
20 types of plantations is the decreased use of pesticides and chemical fertilizers in certified
21 coffee plantations. Pesticides, herbicides and chemical fertilizers might directly affect
22 butterflies by killing the adults or immature stages, or indirectly, by reducing the availability
23 of host plants (Longley & Sotherton 1997). In fact, RA certified farms, which allow
24 moderate use of such chemical compounds, were intermediate in diversity of butterflies.
25 Consequently, our results might also be consistent with the latter explanation; nevertheless a

1 combination of the two factors could result in the increase of butterfly diversity in certified
2 plantations (Weibull *et al.* 2000). This result provides evidence to the positive effect of the
3 certification programs on butterfly diversity conservation, and to potential benefits to the
4 coffee growers in terms of enhanced profits through improved ecosystem services provided
5 by butterflies (Tscharntke *et al.* 2005, Sandhu *et al.* 2008). For example, high butterfly
6 diversity might directly benefit the plantations as pollination or weed control agents and
7 indirectly as potential food resources for birds that might enhance biological control of insect
8 pests or seed dispersal (Perfecto *et al.* 2004, Tscharntke *et al.* 2005, Klein *et al.* 2007, Sandhu
9 *et al.* 2008).

10 *TREE COMMUNITIES AND SHADE STRUCTURE.*-Shade structure as interpreted by the Management
11 Index between plantations was nearly significantly different between RA+Organic and non-
12 certified plantations. However, this pattern is more likely to be driven by the differences in
13 species richness and height of the shade. The rest of the variables were similar between
14 plantations suggesting that the structure of the shade is equivalent among treatments (Table
15 3). The similarity in shade structure might be the result of climate in the localities sampled.
16 These localities have the highest levels of light radiation in Colombia and have low levels of
17 rainfall and overall humidity (Instituto Geográfico Agustín Codazzi 1996). These
18 environmental conditions force coffee growers to maintain higher tree density and canopy
19 cover in coffee plantations even if they are not certified (Duran *et al.* 2004, Guhl 2009). Non-
20 certified plantations had decreased diversity of shade tree species and a higher abundance of
21 *Inga* sp. trees. *Inga* spp. trees provide a high quality of nectar in their flowers and extra floral
22 nectaries that attract a high number of insects, and insectivorous and nectarivorous birds
23 (Calvo & Blake 1998, Johnson 2000). This might explain why we found higher bird species
24 richness in non-certified plantations, although the differences between plantations were not
25 significant.

1 *IMPLICATIONS FOR CONSERVATION.*-This region of Santander has been highly affected by
2 deforestation, resulting in a landscape dominated by pastures, coffee and sugar cane
3 plantations. Such conversions occurred during the beginning of the 1900s leaving the region
4 with no natural forests for a long period of time (Federación Nacional de Cafeteros 1957,
5 Palacios 1980). This loss is observed in the absence of common forest bird species such as
6 woodcreepers (Furnariidae) and manakins (Pipridae) that are present in this type of
7 agroecosystem elsewhere (Greenberg *et al.* 1997a, Greenberg *et al.* 1997b, Calvo & Blake
8 1998, Johnson 2000, Perfecto *et al.* 2003). Despite the evidence that vegetation factors
9 influence the diversity of birds in coffee plantations we were unable to find this relationship
10 in our study sites (Philpott *et al.* 2008). This might also reflect the loss of source populations
11 of many forest species that might benefit from environmentally friendly practices of coffee
12 certification. As an evidence for this, we found that most of the bird species inhabiting the
13 three types of plantations have low sensitivity to human impact and are able to nest in or
14 prefer secondary vegetation habitats (Figure S1). However, the high diversity of migrant
15 species (21 species of forest nearctic migrants), the presence of several species that prefer
16 forest habitats and have high sensitivity to human impact, and the presence of endemic and
17 highly threatened species such as Niceforo's Wren, Chestnut-bellied Hummingbird, Golden-
18 winged Warbler and Cerulean Warbler, increase the value of these coffee plantations and
19 motivate coffee growers to improve the habitats for these species (Table S3).

20 Mid-elevations in the northern Andes have been subject to high deforestation rates
21 probably because of their productive soils and favorable climate (Myers *et al.* 2000). In the
22 Colombian Andes, more than 70% of the natural cover has been transformed to land for
23 agricultural use (Cavelier 1997). One of the main uses of this agricultural land is coffee
24 plantations which represent about 34% of the total permanent crop area, 6% of the total
25 export products and contributes almost 1.8% of Colombia's gross domestic product (Espinal

1 *et al.* 2005). Despite the fact that coffee production in Colombia has decreased in the last
2 decade, the total area occupied by plantations has increased (Figure S2). These statistics
3 suggest that it is highly unlikely that conversion of natural forests to coffee plantations will
4 stop or even decrease. In this case, shade coffee plantations might be the only alternative to
5 preserve the native biodiversity that still persists in these regions. In fact, Santander is the
6 only region in Colombia in which shade coffee is growing faster than pasture or any other
7 type of crops (N. Galindo *pers. comm.*).

8 In some cases, farmers obtain certification status with little changes to their crops.
9 Climatic conditions in the area force the coffee growers to maintain a dense and diverse
10 shade that is further co-opted to fulfill the requirements of the RA certification. However,
11 both organic and RA certification programs radically change the management of the
12 plantation by reducing and prohibiting the use of chemical fertilizers and pesticides. Other
13 features that are radically changed from the farms managements are the protection of stream-
14 sides and remnant natural vegetation with in the farm. It is very likely that without the
15 certification programs, such fragments and water protection is lost to coffee bushes for
16 increased farm production. In this way, promoting the improvement of shade coffee
17 plantations will enhance the conservation of biodiversity that is already happening in
18 Santander.

19 While we chose the farms to be homogeneous in size for appropriate comparison of the
20 levels of biodiversity sustained by each type of plantation, the region is characterized by a
21 high variance in farm size and socio-economical status of the landowners. However, as a
22 program of the Colombian Coffee Federation (FNC), the landowners receive assistance for
23 certification as groups of producers irrespective of the size of the land. Thus, the certification
24 is not applied only to the farm but to a group of nearby farms that are randomly inspected for
25 certification. Recent studies suggest that smaller coffee plantations might preserve higher

1 levels of biodiversity (Mendez *et al.* 2010, Goodall *et al.* 2014). In the case of this particular
2 region such fact might not apply because of the way FNC provide support to the growers.
3 However, a formal analysis to evaluate the influence of farm size on biodiversity
4 conservation in this region is still needed. Unfortunately, we do not have the appropriate
5 information at hand to provide some insight about the size influence. However, we might
6 speculate that the model of cooperative certification as used in the farms evaluated by the
7 present study might increase the impact of bigger farms to preserve biodiversity conservation
8 (Mendez *et al.* 2010, Goodall *et al.* 2014) by homogenizing practices across producers in the
9 same group.

10 Because of the uniqueness of coffee production in Santander, our results have to be
11 carefully interpreted. The climatic conditions and low soil productivity, compared to other
12 regions in Colombia, forces coffee growers to create deeper topsoil that enhances coffee
13 production. This means that, overall, shade-grown coffee plantations in Santander are
14 managed less intensively than in other places in Colombia or Latin America. These facts
15 perhaps explain why the impact of the certification programs on biodiversity was less than
16 might have been expected.

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- 4

- 1 **Table 1.** *Sample size and site selection used to evaluate the differences of bird, trees and*
- 2 *butterfly communities between certified and non-certified coffee plantations.*

	Certification	Number of Points Censused		
		Birds	Trees	Butterflies
<i>San Francisco</i>	non-certified	8	8	4
<i>San Jose</i>	non-certified	5	5	4
<i>Damasco</i>	non-certified	9	9	N/A
<i>Montebello</i>	non-certified	10	10	N/A
<i>Total non-certified</i>		32	32	8
<i>San Fernando</i>	Rainforest Alliance	10	10	N/A
<i>Morros</i>	Rainforest Alliance	10	10	4
<i>La Pradera</i>	Rainforest Alliance	9	9	N/A
<i>Los Sinchos</i>	Rainforest Alliance	10	10	N/A
<i>La Laguna</i>	Rainforest Alliance	10	N/A	4
<i>Total Rainforest Alliance</i>		49	39	8
<i>Buenavista</i>	Rainforest + Organic	10	10	N/A
<i>El Galapo</i>	Rainforest + Organic	9	9	4
<i>El Placer</i>	Rainforest + Organic	10	10	N/A
<i>Transvaal</i>	Rainforest + Organic	10	10	4
<i>Total Rainforest+Organic</i>		39	39	8
<i>Total</i>		110	110	24

3

Table 2. Mean $\pm$ 1 standard deviation in *abundance, richness and diversity of bird, butterfly and tree communities in non-certified and certified coffee plantations. No. of species and No. of individuals correspond to the observed data and Chao corresponds to the estimated number of species, Rarefied # of Species corresponds to the number of species rarefied to the smallest number observed in a plantation and Exp (Shannon) and 1/(1-Simpson) correspond to the effective species number based on the Shannon and Simpson diversity indices.*

	No. Species	No. Individuals	Chao	Rarefied # Sp.	Exp (Shannon)	1/(1-Simpson)
Birds						
Non-Certified	62 $\pm$ 8	236 $\pm$ 73	75 $\pm$ 12	53 $\pm$ 3	51.2 $\pm$ 6	45.02 $\pm$ 4
Rainforest	63 $\pm$ 10	263 $\pm$ 83	79 $\pm$ 14	51 $\pm$ 4	49.4 $\pm$ 9	42.43 $\pm$ 9
Rainforest+Organic	61 $\pm$ 6	246 $\pm$ 42	71 $\pm$ 9	50 $\pm$ 2	47.44 $\pm$ 4	40.43 $\pm$ 4
Tree						
Non-Certified	12 $\pm$ 6	262 $\pm$ 80	12 $\pm$ 8	11 $\pm$ 5	5 $\pm$ 3	3.2 $\pm$ 2
Rainforest	18 $\pm$ 6	237 $\pm$ 47	18 $\pm$ 8	17 $\pm$ 7	10 $\pm$ 5	6.0 $\pm$ 3
Rainforest+Organic	18 $\pm$ 7	256 $\pm$ 88	18 $\pm$ 11	17 $\pm$ 6	11 $\pm$ 6	7.9 $\pm$ 9.5
Butterflies						
Non-Certified	10 $\pm$ 1	33 $\pm$ 16	15 $\pm$ 3	8 $\pm$ 2	4.6 $\pm$ 1	2.96 $\pm$ 1
Rainforest	21 $\pm$ 2	96 $\pm$ 16	34 $\pm$ 4	9 $\pm$ 2	10.1 $\pm$ 3	6.87 $\pm$ 2
Rainforest+Organic	29 $\pm$ 8	158 $\pm$ 29	52 $\pm$ 28	10 $\pm$ 3	11.7 $\pm$ 8	6.93 $\pm$ 6

8 **Table 3.** Management index and shade structure values of each type of plantation.

	Management	Canopy		Canopy	
	Index	Height (m)	DBH (cm)	Cover (%)	Tree Density
<i>Non-Certified</i>	2.85 ± 0.92	10.51 ± 4.6	22.86 ± 7.23	83.45 ± 10.22	10.32 ± 5.64
<i>Rainforest</i>	2.44 ± 0.42	13.44 ± 1.36	24.76 ± 5.15	89.00 ± 4.18	10.96 ± 3.43
<i>Rainforest+Organic</i>	2.43 ± 0.53	12.45 ± 2.1	24.4 ± 5.28	84.87 ± 3.89	11.97 ± 2.72

9

10 **Figure Legends**

11 **FIGURE 1.** Species accumulation curves (upper panels) and NMDS of A,D) birds, B,E)
12 butterflies and C,F) trees in Rainforest+Organic, Rainforest and non-certified plantations in
13 Santander. Error bars represent the 95% confidence intervals of the rarefied estimated
14 number of species.

15 **FIGURE 2.** Species rank curves for A) Birds, B) Butterflies and C) Trees in Non-certified,
16 Rainforest and Rainforest+Organic certified plantations. The gray line shows the predictions
17 of the best fit model (Full results of the models are shown on Table S2)

18 **FIGURE 3.** A) Average number of species and B) average proportion of individuals in each
19 diet guild for the three types of coffee plantations. Error bars indicate 95% confidence
20 intervals of the mean. I (Insectivores), FRI (Frugivores insectivores), CI (Canopy
21 Insectivores), UI (Understory Insectivores), F (Frugivores), NI (Nectarivores Insectivores),
22 OM (Omnivores), GR (Granivores), UF (Understory Frugivores), RAP (Raptors), CF
23 (Canopy Frugivores), NEC (Nectarivores).

24

25 **FIGURE 1.**

26

27

28 **FIGURE 2.**

29

30

31 **FIGURE 3.**

32