The Importance of Management: Contributions of Live Fences To Maintaining Bird Diversity in Agricultural Landscapes

La Importancia del Manejo: Contribuciones de Las Cercas Vivas para Mantener la Diversidad de Aves en Paisajes Agrícolas

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Abstract. Adept management may help assure the capacity of agricultural lands to contribute to biodiversity conservation. However, we have limited understanding of how management of different elements within designated corridor areas influences resource use among wildlife and contributes to overall conservation value. This study explores how management of live fences within the Volcánica Central-Talamanca Biological Corridor influences bird diversity and resource use. Bird species visiting live fences were recorded for three management treatments: multistrata live fences (dominated by mature, un-pruned trees); simple live fences (dominated by immature trees, pruned regularly), and control (post-and-wire fences). Seventy-four resident and migratory bird species were observed across treatments. Species richness was highest in multistrata fences (28.67 ± 3.98, mean ± 1 SD) intermediate in simple fences (16.20 ± 2.59), and lowest in post-wire-fences (9.00 ± 2.94). However, ≥90% of migratory species and species that frequent forest patches and agroforestry plantations at the study site were observed in multistrata fences. In-fence behavior (perching, foraging, reproductive activity) was recorded for individuals actively using fences. Correspondence analysis showed that both foraging and reproductive behavior were more frequently associated with multistrata fences than simple or control fences. Live fences appear to provide important resources within a biological corridor. However, management that favors height and structural complexity, which characterize multistrata fences, enhance corridor use among a diverse range of bird species and may provide greater support for foraging and reproductive activities. Structurally complex live fences are expected to be particularly important for migrants and species that frequent forest and agroforestry patches.

Key words: agricultural landscapes, biodiversity conservation, Costa Rica, species composition, species richness, tropical bird assemblages.

Resumen. El manejo adecuado puede asegurar la capacidad de zonas agrícolas para mantener la biodiversidad y contribuir a la conservación. Sin embargo, tenemos conocimiento limitado de como el manejo de corredores biológicos y elementos dentro de ellos influyen el uso de recursos por la vida silvestre y contribuyen al valor de conservación de estas áreas. Se investigó como el manejo de cercas vivas dentro del Corredor Biológico Volcánica Central-Talamanca afecta la riqueza de aves y el uso de recursos. Las especies de aves visitando cercas fueron observadas en tres diferentes tratamientos: cercas vivas multiestrato, cercas vivas simples y control (alambre de púas). Setenta y cuatro especies de aves fueron observadas utilizando las cercas. La riqueza de especies fue más alta en las cercas multiestrato (28.67 ± 3.98, promedio ± 1 DE), intermedia en las cercas simples (16.20 ± 2.59) y baja en los controles (9.00 ± 2.94). Sin embargo, ≥90% de las especies migratorias y especies que utilizan parches de bosque o plantaciones agroforestales fueron observadas también en las cercas multiestrato. El comportamiento en la cerca (percharse, forrajear y reproducirse) fue registrado para los individuos utilizando las cercas activamente. Ambos comportamientos, reproducción y el forrajeo, están asociados con mayor frecuencia a las cercas multiestrato. Las cercas vivas son una fuente importante de recursos naturales dentro del corredor. Un manejo que favorezca la altura y complejidad estructural, características de las cercas multiestrato, proporciona recursos para un rango de especies diversas y puede favorecer actividades necesarias para sostener sus poblaciones.

Palabras clave: paisajes agrícolas, conservación de la biodiversidad, Costa Rica, composición de especies, riqueza de especies, ensamblaje de especies de aves tropicales.

Introduction

There is growing recognition of the need to evaluate the capacity of agricultural systems to support biodiversity conservation. This challenge is especially pressing in Mesoamerica, a biodiversity hotspot where approximately 80% of the region's vegetation has been converted to agriculture (Harvey *et al.*, 2008), and where the landscape has become increasingly fragmented (Laurance and Bierregaard, 1997; Harvey *et al.*, 2006). The survival of wildlife in agricultural areas and other fragmented habitats may ultimately depend on their ability to move through the landscape in order to access resources, maintain genetic diversity and ensure the reproductive capacity of populations (Petit *et al.*, 1995; Wiens, 1996; Laurance and Bierregaard, 1997; Buza and Thrall, 2000). Lack of movement between forest fragments for individuals of small populations may lead to local extinction (Andrén, 2004).

Establishing biological corridors has been proposed as a means to maintaining connectivity of habitat and ensuring the survival of animal populations (Bennett, 1999; Perlault and Lomolino, 2000). In addition, corridors can mitigate the negative effects of human impacts and fragmentation by connecting areas of otherwise isolated habitat (Soulé, 1991). However, the conservation value of corridors has been debated, largely due to lack of empirical data demonstrating their use by populations threatened by fragmentation (Hilty and Merenlender, 2004). In large corridors that encompass agricultural areas and various landuses, data on how the management of different elements within designated corridors influences resource use and movement among wildlife species is lacking. Management that determines composition and complexity of corridor elements is expected to be particularly influential given that some species may use vegetation strips and patches selectively, making use only of areas that are floristically diverse or of certain dimensions (Laurance and Laurance, 1999). Determining the influence of different management strategies upon corridor elements and corresponding resource use among local wildlife populations should be determined in order to correctly assess their contributions to conservation goals and to best advice land managers and planners.

Live fences are common elements in agricultural lands throughout Mesoamerica. They form linear networks of trees bordering cattle pastures and are dispersed throughout croplands and agroforestry systems (Harvey *et al.*, 2005). Live fences provide vertical complexity and tree cover in otherwise structurally simple pasture environments, which is an important landscape characteristic (Wiens, 1996). They may also provide resources for wildlife and connectivity among patches of remnant forest and agroforestry plantings (Estrada *et al.*, 2000; León and Harvey, 2006). Live fences are most commonly incorporated as productive features of farmlands, providing barriers to livestock movement, posts for new fences, fodder for livestock, timber and edible fruit (Sauer, 1979; Beer, 1987; Somarriba, 1995; Harvey *et al.*, 2005). However, the management varies according goals and objectives of individual land managers ranging from very simple, single species live fences that are regularly pruned, to highly complex, species rich live fences that are never pruned. These differences can have important influences on the contributions of live fences make to both the conservation value and productivity of farmlands.

Due to their potential productive and conservation roles, live fences have been widely promoted by conservation programs including the World Bank's Payment for Ecosystem Services initiative in Colombia, Nicaragua, and Costa Rica. Reviews of experiences with Payment for Ecosystem Services indicated high adoption rates of live fences and other elements used to promote conservation in agricultural landscapes (Pagiola *et al.*, 2005). However, existing studies emphasize adoption rates and other process variables while much work is still needed to understand ecological outcomes of live fence use and management. Currently, resource and land management agencies, environmental organizations, and government associations are debating how to boost biodiversity conservation in farmlands and cattle ranches by increasing the use of live fences and other farm features that are expected to have high conservation value. Field data is needed to determine whether these conservation interventions are having the desired ecological effects and to determine how their management can be improved to increase their usefulness to a diverse range of species.

We documented bird species in live fences, and their patterns of resource use, in the context of a landscape dominated by agriculture in Costa Rica's Volcánica Central-Talamanca Biological Corridor. Our first goal was to assess the effect of live fence management and structure on bird diversity because these characteristics are often tailored for productive aims. Distinct management approaches such as species selection and pruning intensity/frequency may not provide the same conservation benefits. Additionally, we studied the use of live fences by migratory birds and species observed in local forest patches and agroforestry plots to determine whether management approach affected the presence and activity of these groups of species in live fences. We used species data and observations of in-fence behaviors to explore contributions of live fences under different management to their conservation value for bird species in the corridor area.

Materials and Methods

We conducted this live fence study on farmlands at the Center for Tropical Agriculture Research and Higher Education (CATIE) in Turrialba, Costa Rica (approximately 2000 ha of agricultural area; lat 9°54' N, long 83°41' W). The study site is located within the Volcánica Central-Talamanca Biological Corridor, which encompasses 652,545 hectares in the provinces of Cartago and Limón and includes the transition area between Costa Rica's central mountain range and the Talamanca Mountains (Desanti, 2008). The region is located 600 m above sea level and experiences climate conditions typical of the humid tropics, receiving 2636 mm of precipitation annually and average temp of 22 °C. We chose live fences that divide cattle pastures and are bordered by sugar cane, agroforestry plantings, remnant trees and forest patches as this variety of landuses is representative of agricultural areas throughout the corridor. Prior to current use for cattle production, pastureland at the site was in sugar cane production. The pasture that surround the selected live fences have been in use for the last 10-15 years and were established by planting improved hybrid grass species (including *Brachiaria decumbens*, *B. radicans*) or were allowed to regenerate naturally. Live fences are dominated by planted tree species including: *Erythrina costarricense* (poró), *E. fusca*, *E. poeppigiana* (poró gigante), *Gliricidia sepium* (madero negro), *Pithecellobium longifolium* (sota caballo), *Trichantera gigantea* (nacedero), and *Miconia* sp. (canilla de mula).

We recorded presence and resource use of bird species in 18 fences, through a single point count station located near the midpoint of each of the 18 fences studied. We selected the fences according to three treatments designed to represent the range of management approaches commonly used by farmers in the region: 1) multistrata live fences (dominated by mature, un-pruned trees); 2) simple live fences (dominated by immature posts and trees pruned every 6-12 months), and 3) a control treatment comprised of post-and-wire fences. We included six replicates representing both north-south and east-west aspects in each treatment. We categorized the fences according to their average height and the radius of trees in the fences. Multistrata fences are composed of trees with mean height >6 m and mean canopy radius >4 m. Simple fences were composed of trees with a mean height <6 m and mean canopy radius <4 m. Both the simple and multistrata fences included recently planted posts with few branches and no canopy. The post and wire fences that we used as a control treatment in this study were characterized by wood or concrete posts ≤ 2 m tall with no living trees incorporated in the fence line. All fence treatments were strung with 3-5 strands of barbed wire as a barrier to animal movement.

We selected the fences so that there were sufficient replicates in each group and so that fence midpoints were ≥200 m apart to help ensure that the effects of each fence studied were independent of neighboring fences. There was a lack of control fences that fit these criteria, so three newly planted fences composed of live posts were trimmed to ≤2 m and stripped of vegetation at the start of the study period so that they were structurally similar to the other post-and-wire fences in the control treatment group. Active cattle pasture bordered each fence on at least one side although the landuse on the other side of the fence varied randomly across treatments.

We described the structural characteristics and composition of all the live fences in the study including all trees with >10 cm diameter breast height (dbh) along three randomly selected 10 m transects in each fence. We characterized the individuals as trees if they were >3 m in height and they had a developed canopy structure. We classified the trees that did not meet these characteristics as posts. All descriptive data are reported as raw means ± 1 standard deviation unless otherwise indicated.

We monitored bird species in fences at the study site from February to July 2009. We used ten-minute point counts to record all species visiting the fences as well as their behaviors (foraging, perching, or reproductive activity) while using the fences. We repeated the counts 10 times in each fence for a total of 100 minutes of observation. We marked birds not actively using the live fences (e.g. flying over head or perched nearby) only as present. We did not include species that could not be identified in estimates of species richness or in the calculation of the diversity indices, therefore our reported values are conservative (Luck and Daily, 2003). We recorded behavior opportunistically during each observation period, and did not record behavior if foliage blocked our view. We only recorded foraging and reproductive behavior when the individual was seen actively engaged in the activity (e.g. taking fruit, sampling nectar, copulating, carrying nest materials, feeding offspring). Sampling effort was gauged by reviewing species accumulation curves (Figure 1) generated with EstimateS software (Colwell, 2009).

In addition to testing for differences in overall bird diversity among fence type, we tested for differences in richness and abundance of migratory birds and species observed in local forest patches and agroforestry plantations. We used long-term monitoring data from a mist netting study conducted in different landuses at the same study (Martínez-Salinas and DeClerck, 2009) and identified 109 species captured in local forest patches and agroforestry plots. Of these, five of the species found in forest and 35 agroforestry species were observed in fences during point counts. Migratory species were identified using data in Stiles and Skutch (1989) and cross-referenced with migratory activity observed at the study site by Martínez-Salinas and DeClerck (2009).

We used analysis of variance (ANOVA) tests to evaluate relationships between overall species richness and abundances and structural characteristics of live fences, as these data met assumptions for normality of residuals (Shapiro-Wilk test at $p<0.05$) and homoestadicity (Levene, Browne-Forsythe, and O'Brien tests at $p<0.05$). However, we used a Poisson regression to further explore differences in species richness and abundance of individuals, including for migratory species and birds commonly seen in forest patches and agroforestry plots since the Poisson distribution was the best fit for point count data. We report Wald Chi-squared statistics for this distribution. We used Fisher's Least Significant Difference (LSD) test to examine pair-wise differences between all treatments after the Poisson regression showed significant differences. We transformed data on Shannon and Simpson diversity indices using a power transformation to meet statistical test criteria and we explored differences between treatments explored using ANOVA tests. Finally, we explored relationships between bird behavior and fence type using correspondence analysis, and report Pearson's Chi-squared statistics. All analyses were done at the 95% confidence level ($p<0.05$), and all descriptive data are raw means ± 1 SD unless otherwise noted.

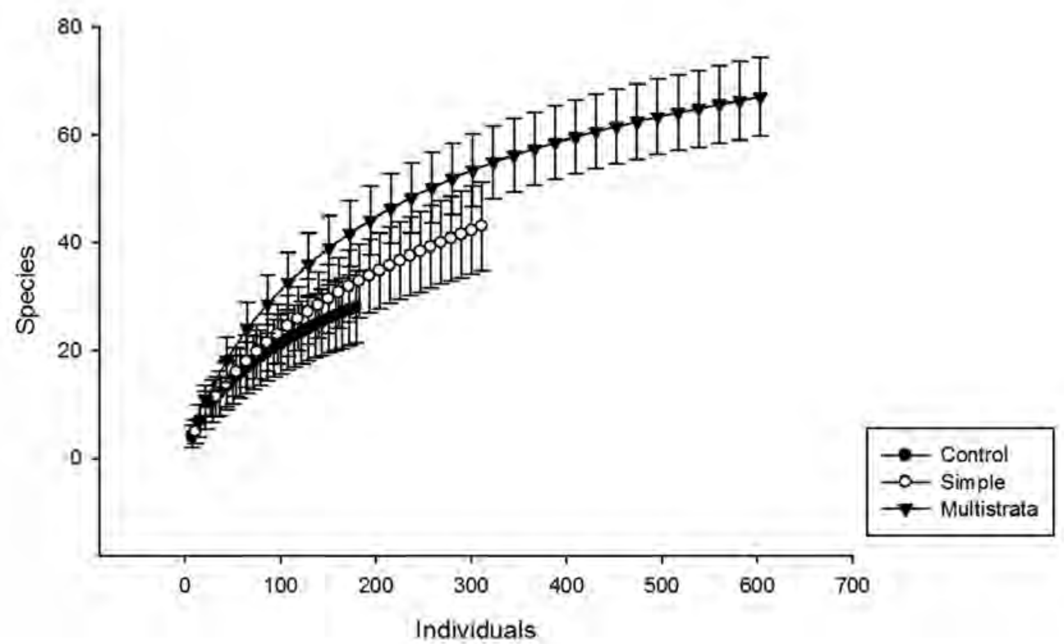


Figure 1. Species accumulation curves for control, simple and multistrata fences showing the relationship between number of species and individuals observed for each fence type. Multistrata fences have the highest species richness and individual observations among the three fence treatments. The shape of the curve (approaching an asymptote) suggests that sampling effort was sufficient to capture representative information on bird diversity in live fences.

Results

Our analysis of the trees in live fences supports the notion that these systems are biologically and structurally distinct. Overall tree species richness was low and trees present represented those planted by farm management with few exceptions. *Erythrina fusca* (poró) was the dominant species representing 63% and 49% of all trees and posts for simple and multistrata fences, respectively. We found that simple and multistrata fences differed significantly in height and canopy radius (ANOVA $F_{1,9}$ = 14.89 p<0.003, height; ANOVA $F_{1,9}$ = 17.48 p<0.002, canopy radius) but not in diameter breast height ($F_{1,9}$ = 3.30 p<0.102). Live fences did not differ in species richness or planting density $F_{1,9}$ = 3.30 p<0.102, species richness; $F_{1,9}$ = 0.163 p<0.695, planting density trees; $F_{1,9}$ = 0.001 p<0.968, planting density of trees and posts) (Table 1). Control fences differed significantly from both live fence treatments, as they included no planted trees and minimal levels of woody shrubs. Differences in fence structure, but not diversity or other characteristics, allowed us to test relationships between management altering height and canopy width and bird diversity and resource use in live and control fences.

We observed 122 species and 5227 individuals across all treatment groups during our point counts. Of these, 74 species and 1094 individuals were observed in the fences, where as the remainders were observed flying overhead, perched in nearby pasture or visiting adjacent landuses. We only include observations in fences in this analysis because the questions addressed by the study focused on how fence management influences diversity of bird species visiting the fences and using available resources.

Overall bird species richness was positively correlated with fence structure (ANOVA $F_{1,16}$ = 49.72, *p*<0.0001 (crown radius); $F_{1,16}$ = 50.74, *p*<0.0001 (fence height) (Figure 2). Species richness varied significantly by fence type (χ^2 = 71.48, 2df, *p*<0.0001) with a mean of 28.67 ± 3.98 species in multistrata fences compared with 16.20 ± 2.59 and 9.00 ± 2.94 in the simple and control fences respectively. The abundance of birds observed also varied according to the same pattern (χ^2 = 232.16, 2df, *p*<0.0001) with the highest number of individuals in multistrata fences (100.50 ± 20.19); intermediate numbers in simple fences (48.20 ± 6.30), and lowest in control fences (35.29 ± 21.75). Fisher's LSD comparisons showed significant differences among fence types for both species and individuals (Table 2).

Thirty-five species of birds frequently observed in forest patches and forest-like agroforests (cacao and multistrata coffee) were observed in live fences. The species richness of this group found in the live fences also varied significantly according to fence type (χ^2 = 62.34, 2df, *p*<0.0001). Multistrata fences hosted 13.16 ± 3.18 forest-agroforest species; simple fences, 4.6 ± 2.07; and control fences, 2.14 ± 0.89. Bird abundances also varied by fence type (χ^2 = 334.28, 2df, *p*<0.0001) with 56.66 ± 11.41 in multistrata fences, 15.6 ± 8.98 in simple fences, and 6.42 ± 2.22 in control fences. Fisher's LSD comparisons showed that a significant differences among group means (Figure 3).

For migratory birds, species richness and individuals abundances followed the same trends as those observed for species common to forest patches and agroforestry systems. The diversity and abundance of migrants varied significantly according to fence treatment (χ^2 = 20.24, 2df, *p*<0.0001 for species; χ^2 = 73.10, 2df, *p*<0.0001 for individuals). We observed 2.83 ± 1.69 migratory species in multistrata fences; 1.0 ± 0.70 in simple fences; and 0.14 ± 0.37 in control fences. Group means differed significantly between multistrata and control fences but not among simple fences and the other treatments according to Fisher's LSD tests. Overall observations for migratory individuals were low, but treatment groups differed: 8.33 ± 6.62 in multistrata fences, 2.0 ± 1.41 in simple fences, and 0.14 ± 0.37 in control fences (Figure 3). It is also important to note that migratory birds were only present for half of our sampling period since most migrants return to North America in April.

We calculated both Shannon and Simpson (reciprocal) Diversity Indices for the bird assemblages by fence type (Table 2) and found that both values differ significantly. Simpson values differed significantly (ANOVA $F_{2,17}$ = 10.51, p<0.0014); multistrata fences were more diverse than both simple and control groups according to Fisher's LSD tests: 17.07 ± 2.31 for multistrata fences; 11 ± 5.05 for simple fences, and 6.87 ± 3.67 for control fences. Shannon values were significantly different among all treatment groups (ANOVA $F_{2,17}$ = 36.31, p<0.0001): 2.98 ± 0.12 for multistrata fences, 2.41 ± 0.30 for simple fences, and 1.8 ± 0.38 for control fences.

Species behavior was recorded whenever unobstructed views allowed us to note individuals' activity in the fences. Correspondence analysis showed that both foraging and reproductive behavior was more frequently associated

Table 1. Fence structure and species composition for simple and multistrata live fences at the study site, based on trees and posts with dbh >10 cm. Tree species richness per fence was is relatively low and species represented almost exclusively those planted by farm management. Different letters following means indicate significant differences according to Fisher's LSD test, significance levels for ANOVA are reported for each fence characteristic.

VARIABLES	FENCE TYPE		SIGNIFICANCE LEVEL
	SIMPLE	MULTISTRATA	
Mean tree height (m)	5.02 ± 1.06 b	10.05 ± 2.72 a	p<0.003
Mean tree radius (m)	2.33 ± .42 b	4.63 ± 1.15 a	p<0.002
Mean tree dbh (cm)	37.4 ± 26.7 a	77.0 ± 83.7 a	p<0.102
Planting density trees only /10m of fence	3.3 ± 1.3 a	3.7 ± 1.4 a	p<0.695
Planting density trees & posts/10m of fence	7.8 ± 3.8 a	7.7 ± 3.5 a	p<0.968
Mean tree & post species richness	3.0 ± 1.5 a	4.1 ± 1.9 a	p<0.309
Five most common tree species present in live fences (% of species surveyed)	*Erythrina fusca* (62.7%) *Trichantera gigantea* (15.2%) *Erythrina costarricense* (9.3%) *Gliricidia sepium* (8.4%) *Vernonia patens* (2.5%)	*Erythrina fusca* (49.2%) *Trichantera gigantea* (17.1%) *Erythrina costarricense* (17.1%) *Miconia* sp. (5%) *Pithecellobium longifolium* (2.5%)	

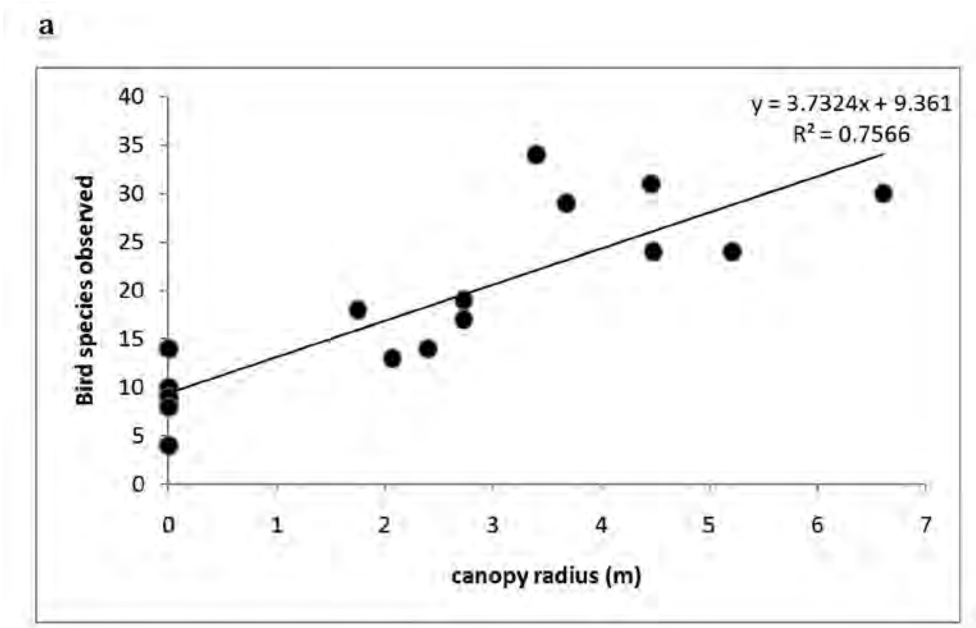
Table 2. Summary of the number of species and individuals of different groups of birds observed in each fence treatment. Different letters following means indicate significant differences according to Fisher's LSD test; significance levels for ANOVA are reported for each group of birds by fence treatment.

VARIABLES/ALL SPECIES	FENCE TYPE			SIGNIFICANCE
	CONTROL	SIMPLE	MULTISTRATA	LEVEL
Total species observed in treatment	29	38	57	
Species Richness per fence	9.00 ± 2.94 a	16.20 ± 2.59 b	28.67 ± 3.98 c	p<0.0001
Individuals per fence	35.29 ± 21.75 a	48.20 ± 6.30 b	100.50 ± 20.19 c	p<0.0001
Shannon Diversity Index	1.8 ±0.38 a	2.41 ± 0.30 b	2.98 ±. 12 c	p<0.0001
Simpson (reciprocal) Diversity Index	6.87 ± 3.67 a	11 ± 5.05 a	17.07 ± 2.31 b	p<0.0014
SPECIES FREQUENTING FOREST AND AGROFOREST				
Total species observed in treatment	6	17	33	
Species Richness per fence	2.14 ± 0.89 a	4.6 ± 2.07 b	13.16 ± 3.18 c	p<0.0001
Individuals per fence	6.42 ± 2.22 a	15.6 ± 8.98 b	56.66 ± 11.41 c	p<0.0001
MIGRATORY SPECIES				
Total species observed in treatment	1	3	9	
Species Richness per fence	0.14 ± 0.37 b	1.0 ± 0.70 ab	2.83 ± 1.69 a	p<0.0001
Individuals per fence	0.14 ± 0.37 a	2.0 ± 1.41 b	8.33 ± 6.62 c	p<0.0001

with multistrata fences than simple or control fences (χ^2 = 161.37, 2df, p<0.0001, foraging behavior; χ^2 = 20.12, 2df, p<0.0001, reproductive behavior) (Figure 4).

Discussion

Our results indicate that live fences are important landscape elements for birds in pasture-dominated agricultural areas, but more importantly, that their value



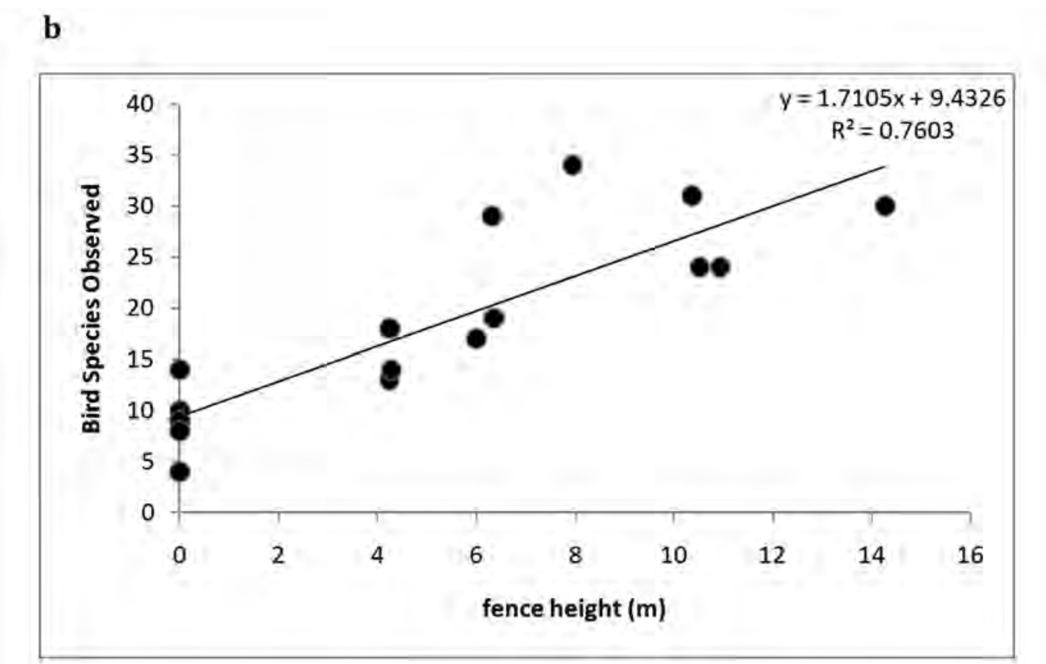


Figure 2. Relationship between bird species richness and live fence structure: a) canopy radius; b) height.

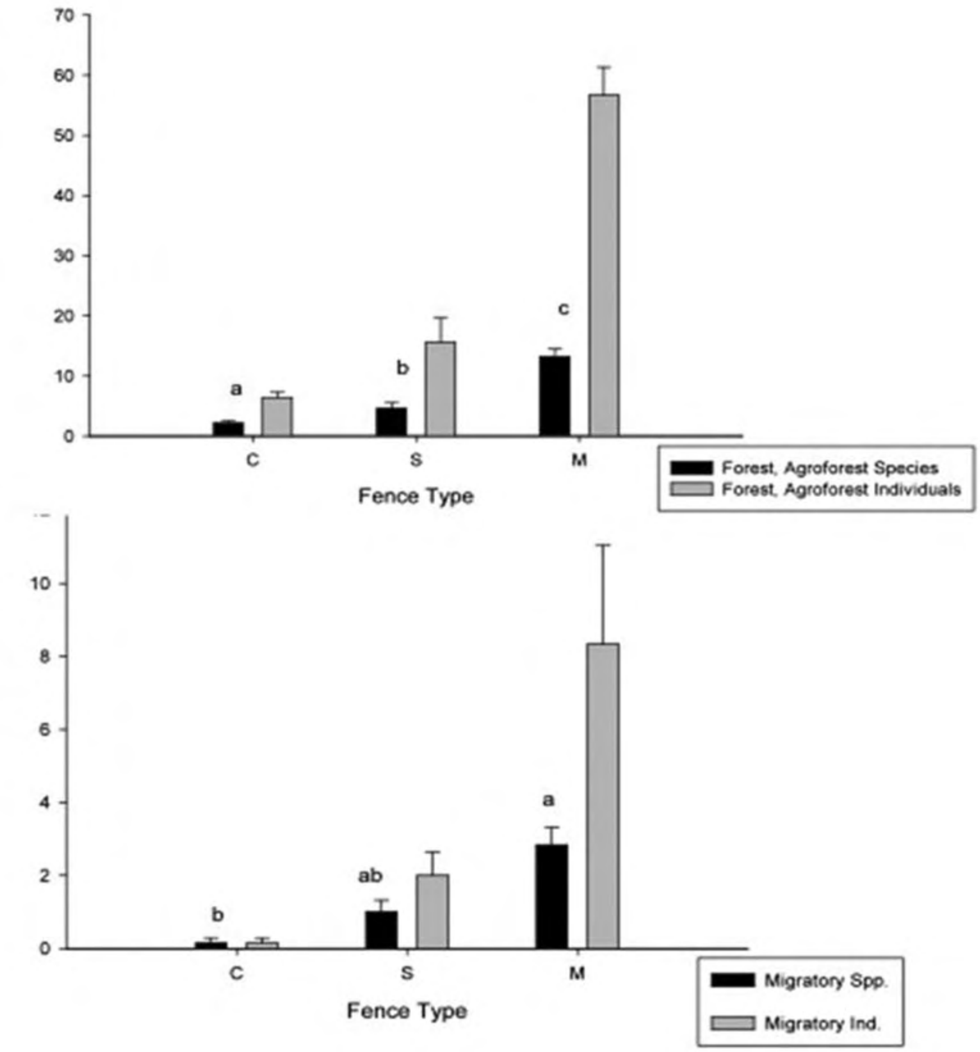


Figure 3. Summary of richness and abundance of forest and agroforest species and migratory species by fence type.

is directly related to their structure. Overall abundance and species richness of birds increases predictably with live fence management that favors structural complexity. Individual abundances approximately double and species richness was 1.75 times higher in taller, wider multistrata fences than simple fences. This finding mirrors patterns of species composition in naturally occurring vegetation corridors in the Australian rainforest (Laurance and Laurance, 1999) as well as riparian corridors in agricultural areas (Hilty and Merenlender, 2004).

We drew upon long-term monitoring data January 2008-present in diverse land uses (Martínez-Salinas and DeClerck, 2009) including forest patches and agroforestry plots (e.g. organic cacao and abandoned multistrata coffee) to determine which species locally common to forests and complex agroforests were using live fences while moving through agricultural lands. Of 109 forest and agroforest species seen in the area only 35 were observed in live fences during our point counts (Appendix 1). Members of the Emberizidae family (including *Oryzoborus funereus*, *Saltator maximus*, *Tiaris olivacea*, and *Volatinia jacarina*) were not included in the analysis as species common to areas of highest tree cover (although they have been observed in agroforestry landuses) because they are largely generalist species seen throughout the study site (including pastures and sugar cane fields) and are not likely to provide additional information about the quality of live fences as woody habitat quality (Stiles and Skutch, 1989).

Of the 35 species of bird frequently observed in forest patches and agroforestry landuses, 94% (33 species) were

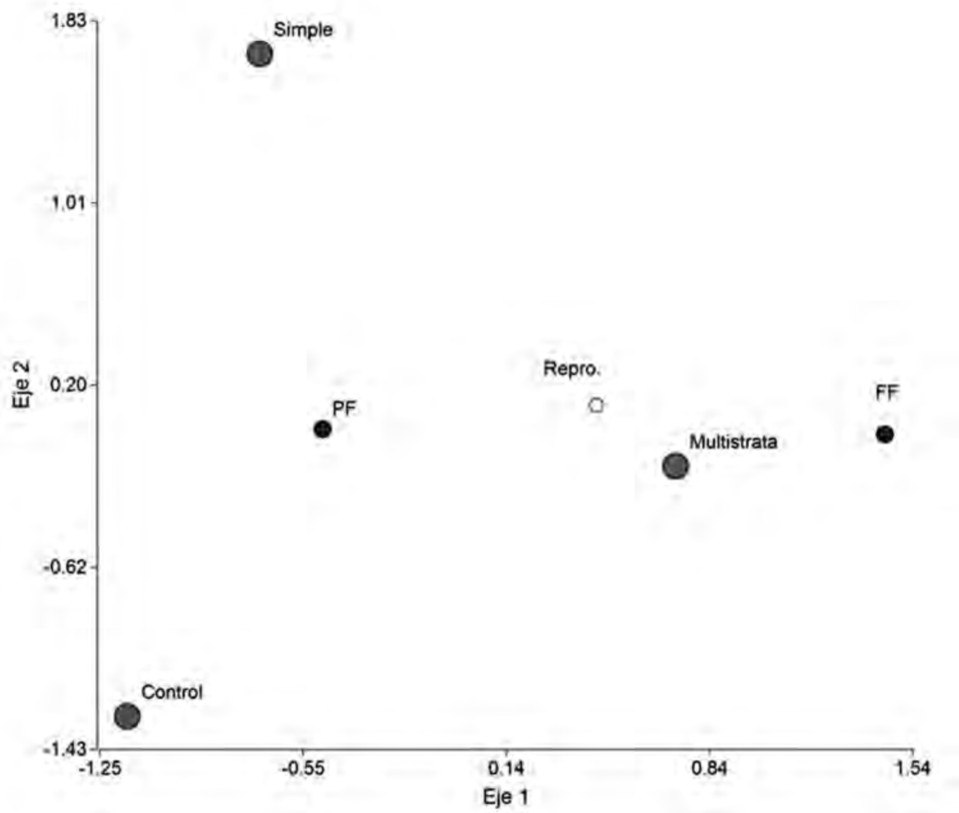


Figure 4. Correspondence analysis showed that both foraging (FF) and reproductive (Repo.) behavior were more frequently associated with multistrata fences than simple or control fences (χ^2= 161.37, 2df, *p*<0.0001, foraging behavior; χ^2= 20.12, 2df, *p*<0.0001, reproductive behavior). Perching (PF) behavior was observed in all fence treatments.

observed in multistrata fences, 49% (17 species) were observed in simple fences and 17% (six species) were observed in control fences. Results were similar for the 10 species of migratory birds observed in live fences: 90% of migratory species were observed in multistrata fences, 30% in simple fences, and 10% were observed in control fences. These trends suggest that multistrata fences may have significantly higher conservation value than other fence types as they host ≥90% of migratory birds and forest-agroforestry species observed across fence treatments. For example, the Blue-crowned Motmot (*Momotus momotus*) and White-line Tanager (*Tachyphonus rufus*) were never found in simple and control fences, but were occasionally observed in multistrata fences. Additionally, individual abundances of migrants and birds associated with areas of highest tree cover were more than 4-fold higher in multistrata fences than simple fences, most forest and agroforest bird species were rarely observed in control fences (Appendix 1). The most frequently observed agroforestry species seen in control fences was the Grey-crowned Yellowthroat (*Geothlypis poliocephala*), a generalist that is found in most landuses (including pasture and sugarcane) at the study site. However, individual abundances for this species were slightly higher in multistrata fences than control fences; this reflects use of a wide range of habitats rather than a preference for control fences.

Shannon and Simpson diversity index values reflect highest levels of bird diversity in multistrata fences. The Shannon diversity index takes into account both species richness and evenness (higher values represent higher numbers of species, but also greater equity among them (Barbour *et al.*, 1999) reflecting that both richness and evenness are higher in multistrata fences. The Simpson index scores reflect both diversity and dominance with

Appendix 1. Richness and abundance of individuals observed by fence type.

Species	Forest Species	Agroforest Species	Migratory Species	Individuals Observed Per Fence Type		
				Control	Simple	Multistrata
Amazilia tzacatl	x	x		1	5	27
Anthracothorax prevostii		x			1	5
Arremonops conirostris					2	3
Attila spadiceus		x				2
Basileuterus rufifrons		x			1	
Buteo magnirostris		x			1	4
Butorides s. viriscens					1	
Columba flavirostris				1	2	6
Columbina minuta				2		
Columbina passerina				1		
Columbina talpacoti				2		
Coragyps atratus						16
Crotophaga sulcirostris				5	9	16
Cyanocorax morio		x				14
Dendroica pensylvanica		x	x			4
Dendroica petechia		x	x		7	20
Dives dives						1
Dryocopus lineatus					1	
Egretta thula				6		
Elaenia flavogaster	x	x		8	6	25
Elanus caeruleus					1	
Empidonax alnorum		x	x	1	2	3
Euphonia hirundinacea		x				8
Florisuga mellivora		x				1
Geothlypis poliocephala		x		32	32	34
Geothlypis semiflava				1	2	
Heliomaster longirostris						1
Icterus g. galbula						1
Icterus spurius			x			14
Lepidocolaptes souleyetii		x				4
Leptotila verreauxi		x			1	1
Melanerpes hoffmannii						3
Mniotilta varia		x	x			1
Molothrus aeneus				1	1	6
Momotus momota	x	x				1
Myiarchus tuberculifer		x				3
Myiozetetes similis					1	13
Oporonis philadelphia		x	x		1	
Oryzoborus funereus				2	13	2
Pachyramphus polychopterus		x				2
Pionus senilis						3

Piranga rubra	x	x			1
Pitangus sulphuratus			1	2	11
Psarocolius montezuma	x			1	9
Quiscalus mexicanus					4
Ramphastos sulfuratus					1
Ramphocelus passerinii	x		1	14	10
Saltator atriceps					6
Saltator maximus					1
Sayornis nigricans			1	1	3
Seiurus noveboracensis	x	x			4
Sporophila aurita			34	33	12
Sporophila nigricollis			3	3	
Sporophila torqueola			10	7	
Stelgidopteryx serripennis			1	3	
Sturnella magna			2	7	
Sturnella militaris			2	5	
Tachyphonus rufus					6
Tangara larvata	x			2	3
Thamnophilus doliatus	x			2	
Thraupis episcopus	x				71
Thraupis palmarum	x				5
Thryothorus modestus	x			1	5
Tiaris olivacea			23	11	5
Todirostrum cinereum	x			3	33
Troglodytes aedon	x		3	5	48
Turdus grayi	x				19
Tyrannus melancholicus			4	3	22
Vermivora peregrina	x	x			2
Vireo flavifrons	x				3
Vireo flavoviridis	x				8
Volatinia jacarina			92	37	26
Wilsonia canadensis	x	x			1
Zonotrichia capensis			1		
Total Individuals Observed Per Fence			**247**	**244**	**603**

more abundant species weighted more heavily than rare species. The simple and control fences did not differ significantly according to this diversity index. This may be because both simple and control fences are most frequently visited by generalist species (e.g. granivores and generalist species that frequent pasture areas as well as perch in fences). Diversity indices are just one description of the community, on par with species lists or other metrics (Barbour *et al*., 1999). However, both indices suggest that multistrata fences may have the higher conservation value since we expect richness to be one of the best predictors of areas or patches with highest conservation potential (Bock *et al*., 2007).

Data from a mist netting study conducted in different plots at the same study site have shown that individual recaptures are less common in agroforestry plots and live fences than local forest patches (Martínez-Salinas and DeClerck, 2009). This suggests that agroforestry plots and live fences may facilitate movement between other elements of the agricultural matrix, but do not provide high quality permanent habitat. The behavioral observations collected during point counts support this finding. However they also suggest multistrata fences support more foraging and reproductive activities when compared to simple and control fences. This does not suggest that live fences can replace primary habitat, however it does reflect that fence management that allows for greater height and canopy width may provide significantly more resources to support activities needed to sustain bird populations during local movement and migrations.

Infrequent use and the absence of some species seen in forest patches and complex agroforests indicate that pasture dominated areas may be an impediment to movement for some species (Wood and Samways, 1991). Additionally, the absence of some species from areas that are predominately pasture suggests that the configuration of remaining habitat patches in the landscape may influence species distributions (Rickets *et al.*, 2001). Low detection of species associated with high tree cover and open gallery forest areas such as motmots, and some tanagers, indicates that pasture has a low connectivity value for these species. As agricultural areas, particularly cattle ranching systems, expand (Lutz and Daly, 1991; Harvey *et al.*, 2008) the occurrence and dispersal ability of bird species common to forest patches is likely to decrease unless conservation interventions are implemented (León and Harvey, 2006). If live fences and other connectivity measures are not implemented, species of conservation interest may be relegated to isolated forest patches and become prone to local extinctions.

Additional factors beyond height and canopy size may influence fence use among bird species. Due to low tree species diversity and dominance of planted species in the study area it was not possible to detect the effects of tree species richness on the richness and composition of bird assemblages. However, this consistency does allow the study to directly address effects of pruning, which following planting, is the main management intervention on fences and largely determines height and width variations within fences of similar species diversity. During the study period we noted that most of the species associated with forest patches and forest-like agroforestry plots were observed in fences that were close to forest patches or older agroforestry plots. Previous work indicates landscape context to be an important factor affecting bird species composition in agricultural areas (Luck and Daily, 2003). Currently a follow-up study and further analysis is underway to determine how landscape context influence the assemblages of birds visiting live fences, since effective conservation of local communities requires consideration of management influence in an appropriate landscape context (Cadenasso and Pickett, 2001).

These results should be considered within the context of the goals of the broader biological corridor area. While we focused on birds in an agricultural area within the corridor, the larger corridor includes agricultural and natural areas and multiple guilds of fauna. Other guilds may also benefit from increased tree cover in pasture areas (Laurance and Bierregaard, 1997; Harvey *et al.*, 2006) and may have greater sensitivity to vegetation composition, including association with particular plants. Further studies should investigate how corridor elements, including live fences, can be managed for structure and composition that favors use among diverse taxa. More information is also needed on the population dynamics and local movement of bird species that are forest dependent or semi-forest dependent, a group that has been categorized as the most threatened (Stotz *et al.*, 1996). This understanding will help assess their status in the region and determine how corridor management can best support their persistence.

The Volcánica Central-Talamanca Biological Corridor encompasses both agricultural and natural areas. Past studies have found that birds provide a suite of services ranging from pest predation in agroforestry plantations (Perfecto *et al.*, 2004) and seed dispersal promoting forest regeneration (Luck and Daily, 2003) that support both productive goals and natural ecosystem processes. We expect that management that supports diverse species assemblages will help support the availability of the wide range of ecosystem services they provide. In addition to the benefits increased tree cover provides in agricultural regions with large areas in cattle pasture, multistrata live fences provide resources needed to support more diverse assemblages of birds than other common fence types.

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