CONSERVACION DE AVIFAUNA EN PLANTACIONES COMERCIALES

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Andrea Nájera Acevedo

Director de Tesis:
Dr. Javier A. Simonetti

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Andrea Nájera Acevedo

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Director de Tesis:

Dr. Javier A. Simonetti ____________________

Comisión de evaluación de la tesis:

Dr. Mauricio Canals ____________________

Dr. Rodrigo Vásquez ____________________

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RESUMEN

Dadas las tendencias demográficas y económicas en el mundo, la humanidad enfrenta el reto de mantener la capacidad de la Biósfera de proveer bienes y servicios, mientras conservamos simultáneamente biodiversidad tanto dentro como fuera de áreas protegidas. En ese marco, y enfocándonos en aves, esta tesis tiene tres aproximaciones que podrían ayudar a avanzar hacia ese propósito. En el primer capítulo, evalúo si las aves amenazadas de Guatemala son un subconjunto al azar de la avifauna local, considerando su afiliación taxonómica, tamaño corporal, dieta y distribución geográfica. En el segundo capítulo, evalúo si la complejidad en plantaciones podría enriquecer los ensambles de aves, y si ellos responden diferentemente, dependiendo de su taxonomía, tamaño corporal, y dieta. En el último capítulo, mediante una aproximación experimental, modifico el sotobosque de una plantación de palma de aceite, y analizamos las respuestas de las aves a esta alteración. Los hallazgos principales incluyen los siguientes (1) las aves amenazadas de Guatemala no están distribuidas al azar ni taxonómica ni geográficamente, teniendo algunos grupos más amenazados de lo que se esperaría por azar. (2) dentro de plantaciones, la riqueza y abundancia de aves son significativamente mayores en aquellas estructuralmente complejas que en las simplificadas, independientemente del tipo de cultivo. (3) plantaciones de palma de aceite con sotobosque albergan más riqueza y abundancia de aves que aquella que carecen de el. Por lo tanto, dejar o implementar deliberadamente cierta complejidad estructural en plantaciones, podría satisfacer la actual necesidad de hacer la producción de bienes de consumo una industria más limpia, ayudando en la sostenibilidad de la biósfera.

ABSTRACT

Given current demographic and economic trends, we are facing the challenge of maintaining the capacity of the Biosphere to provide goods and services while at the same time conserving biodiversity, in and outside protected areas. In that framework, and focusing on birds, this thesis takes three approaches that would help advance toward that purpose. In the first chapter, we assessed whether threatened birds of Guatemala are a random subset of the local avifauna, considering their taxonomic affiliation, body size, diet and geographic distribution. In the second chapter, through a meta-analysis, we tested if structural complexity of plantations could enhance bird species assemblages, and if they respond differently pending on their taxonomy, body size and diet. In the last chapter, we take an experimental approach, modifying the understory in an oil palm plantation, and analyzing the birds´ responses to this alteration. Main findings include the following: (1) endangered bird species in Guatemala are neither taxonomically nor geographically randomly distributed, some groups being more endangered than what would be expected by chance alone. (2) Within plantations, both bird richness and abundance are significantly higher in complex than in structurally simple ones, independently of the type of crop, and (3) oil palm plantations with understory are capable of holding more bird richness and abundance than those lacking it. We conclude that leaving or deliberately implementing structural complexity within plantations could satisfy the current need of making commodity production a cleaner industry, aiding in the biosphere's sustainability.

GENERAL INTRODUCTION

Land surface required to grow commodities has increased substantially to support the growing demands by Human populations. If current trends continue unabated, 10^9 ha of natural ecosystems would be further converted to agriculture by year 2050 (Tilman et al. 2001). This land conversion is a significant driver altering Earth's ecosystems, including biodiversity loss (Donald 2004, Foley et al. 2005). As a consequence, attempts to maintain the capacity of the Biosphere to provide goods and services while at the same time conserving biodiversity are an urgent task (Hartley 2002).

Land transformation affects species in different ways, such as reducing habitat availability or increasing its susceptibility to hunting, rendering some groups of species more threatened than what would be expected by chance alone (Russell *et al.,* 1998; Owens & Bennett, 2000). Understanding variables that selectively affect extinction proneness is mandatory to properly focus conservation efforts on more susceptible species (e.g., Carter *et al.*, 2000). Within this framework, in the first chapter I will explore whether threatened birds of Guatemala are a random subset of the avifauna, considering their taxonomic affiliation, body size, diet and geographic distribution as traits that might impinge upon their susceptibility to extinction (Gaston & Blackburn, 1995). Departures from randomness will enable to pinpoint species groups and sites that require special attention regarding their conservation, particularly regarding habitat availability, the presumed main threat impinging upon birds.

As the likelihood of protecting large areas for biodiversity seems low, its conservation shall be also attempted in productive landscapes (e.g., Perfecto & Vandermeer, 2008). Increasing evidence suggests that commercial plantations can support some native biodiversity, even providing occasional habitat for vulnerable species (Hartley 2002; Lindenmayer & Hobbs 2004; Simonetti 2006). The occurrence of fauna in commercial plantations is presumed to be associated with structural characteristics, such as the occurrence of undergrowth or multiple vegetation strata. In fact, understory vegetation is often regarded as the single best predictor of animal diversity within plantations, as it may provide food and shelter for birds, beetles and mammals for instance (López & Moro 1997; Grez et al. 2003; Lindenmayer & Hobbs 2004; Aratrakorn et al. 2007). On this regard, through a meta-analysis of available information, in the second chapter I tested if structural complexity of plantations could enhance bird species assemblages and if they respond differently pending on taxonomic affiliation, body size and diet.

If undergrowth plays a significant role, species richness and abundance should be consistently higher in complex than in simplified plantations, independently of the type of crop, and this could become a straight suggestion for managing plantations in a way that aids in biological conservation outside protected areas.

Despite the abundance of claims that structural complexity in plantations is a key variable for enhancing bird biodiversity, experimental approaches studying its effect are still scarce or nill. In Chapter 3, I performed one such experimental test, modifying the understory of an oil palm plantation and analyzing the birds´ responses to these changes in eastern Guatemala. Oil palm (*Elaeis guineensis*) is one of the most rapidly expanding crops in tropical regions, and in the main producing countries, it represents the major cause of loss of natural forests and of the decline of endangered species (Donald 2004). If the understory are key for birds, species richness and abundance should be greater in a plantation with abundant understory and would decrease with its removal. Unraveling variables impinging upon biodiversity in oil palm plantations might aid in advancing managerial procedures to fulfill both, the production of highly demanded commodities and the conservation of biodiversity in productive landscapes.

The development of management practices allowing plantations to support and conserve biodiversity while maintaining similar levels of profitability is yet to be achieved, and unraveling variables enhancing the occurrence and survival of wild species in plantations is then a mandatory step towards this purpose (Tews et al. 2004; Stephens & Wagner 2007; Tscharntke et al. 2008). To achieve it, basic knowledge regarding the ecology of threatened birds and the conservation value of managed forests and agricultural systems must be urgently pursued. We expect this research will contribute towards this goal.

Capítulo I

ENDANGERED BIRDS OF GUATEMALA: A RANDOM SUBSET OF THE AVIFAUNA?

ABSTRACT

Identifying attributes that selectively affect species vulnerability to extinction is necessary to focus conservation efforts on more susceptible species. Through a literature review, we assessed whether threatened birds of Guatemala are a random subset of the avifauna, considering their taxonomic affiliation, body size, diet and geographic distribution. We found that Guatemalan endangered bird species are neither taxonomically nor geographically randomly distributed. Large bodied species and Orders Psittaciformes, Galliformes, Falconiformes and Ciconiformes are among the most endangered groups, and the Pacific slopes host more threatened birds than what would be expected according to its territorial extension. Research and conservation efforts ought to be oriented toward these species and regions to safeguard Guatemalan avifauna.

Keywords: Aves, species vulnerability, non-random threats

INTRODUCTION

Extinction risk does not equally affect all bird species, some bird groups being more or less threatened than what would be expected by chance alone (Russell *et al.,* 1998; Owens & Bennett, 2000). Understanding variables that selectively affect extinction proneness is required to properly focus conservation efforts on more susceptible species (e.g., Carter *et al.*, 2000). Biological attributes such as body size, diet and habitat use, might interact with external factors such as habitat loss or hunting, rendering some species more susceptible to threats than others; large body sized species, habitat specialists, and carnivores are associated with higher extinction vulnerability (Owens & Benett, 2000; Gaston & Blackburn, 1995).

The avifauna of Guatemala is severely threatened. Thirty out of 77 families contain 60% or more of their species threatened. At the species level, 46% (223) out of 484 resident bird species of Guatemala are regarded as threatened (Eisermann & Avendaño, 2006). Habitat loss is considered the main menace to birds, with declines in area of occupancy or habitat quality triggering population size reduction (according to species reports in UICN, 2008). Cost/effective conservation actions require prioritizing taxa and geographic areas in order to focus actions and funding (e.g., Carwardine *et al.*, 2008). However, if threats on Guatemalan birds are randomly distributed along the avifauna, or if there are some identifiable traits that make some species more vulnerable than what would be expected by chance alone, are yet to be assessed. Otherwise, conservation efforts might be misplaced.

Here, we explore whether threatened birds of Guatemala are a random subset of the avifauna, considering their taxonomic affiliation, body size, diet and geographic distribution, factors that do impinge upon extinction proneness (Gaston & Blackburn, 1995). If threats are randomly distributed, more speciose Orders should hold more threatened species than poorer Orders. Further, threatened species should be distributed along body sizes and diets, proportional to the species richness for each size and diet class. Similarly, biomes covering larger areas, and then supporting richer bird assemblages, should hold more threatened species than geographically restricted biomes, comparatively poorer in species. Departures from randomness will enable to pinpoint taxa, species groups, or biomes that require special attention regarding their conservation.

METHODS

To test departures from randomness, we compared if the observed frequency of threatened species per taxonomic richness, body size, diet class and geographic area, differed from the expected frequency, assuming that the proportion of threatened species would be the same as the expected distribution based on their proportional richness (Kattan, 1994).

We classified each of the 484 resident bird species according to their taxonomic affiliation to ordinal level (Howell & Webb, 1995), average body size, diet and IUCN conservation status (Eisermann & Avendaño, 2006; IUCN, 2007), as well as their distribution in the seven recognized biomes of Guatemala following Eisermann & Avendaño (2006) and Howell & Webb (1995; biome classification follows Villar, 1994).

To analyze if threats are randomly distributed across taxonomic affiliation, we tested if the number of threatened species per Order differs from what would be expected if they were endangered in proportion to the overall threatened avifauna of Guatemala. That is, 46% of each

Order. Similarly, we tested if the proportion of endangered birds does not differ among size class and diet categories. Body size and diets were obtained from (Howell & Webb, 1995).

To assess if endangered species are randomly distributed across Guatemala, we estimated the percentage of the country surface occupied by each biome and quantified the number of endangered species per threat category (vulnerable, endangered, critically endangered) occurring in each biome. Such figure was compared to the expected number of threatened species based on the proportion of the total avifauna supported for each biome.

RESULTS AND DISCUSSION

Species vulnerability is associated to taxonomic affiliation (X^2= 37.1; df= 13; p <0.0004; Table 1). Psittaciformes, Galliformes, Falconiformes and Ciconiformes hold more endangered species than expected while fewer than expected Apodiformes and Passeriformes are threatened according to their representation in the Guatemalan avifauna. (Secuential X^2= 9.78; df= 6; p=0.13). All 15 Psittaciformes species are threatened, while 79% of Galliformes, 72% of Ciconiformes and 71% of Falconiformes species are regarded of conservation concern (Table 2).

Table 1. Number of threatened birds species of Guatemala. Figures are the observed and expected number per taxonomic orders. Some taxa were grouped in order to attain the requirements of the X^2 test that does not permit expected numbers smaller than 5. * denotes taxa who significantly depart from random expectations.

ORDER	Observed (expected)
Podicipediformes, Pelecaniformes, Anseriformes and Charadriformes	9 (5.5)
Caprimulgiformes and Cuculiformes	6 (7.3)
Tinamiformes and Trogoniformes	7 (5.0)
Strigiformes	10 (7.8)
Piciformes	11 (7.8)
Passeriformes	88 (112.8)
Apodiformes	9 (19.8)*
Ciconiformes	13 (8.2)*
Coraciformes	5 (5.0)
Falconiformes	24 (15.6)*
Galliformes	11 (6.4)*
Gruiformes	8 (5.9)
Columbiformes	7 (8.2)
Psittaciformes	15 (6.9)*
Total	223

Table 2. Number of threatened bird species of Guatemala according to IUCN categories. Figures are for the 30 bird families that have 60% or more of their species endangered (after Eisermann & Avendaño, 2006). CR=Critically Endangered, EN=Endangered, VU=Vulnerable.

FAMILY	CR	EN	VU	% of the family threatened
Accipitridae	3	3	14	74.1
Anatidae	2		2	100
Psittacidae	2		13	100
Momotidae	2		3	71.4
Odontophoridae	1	1	4	85.7
Strigidae	1	1	8	62.5
Ciconidae	1		1	100
Euripigidae	1			100
Nyctibidae		1	1	100
Ardeidae		1	10	91.7
Parulidae		1	9	66.7
Cracidae		1	3	66.7
Dendrocolaptidae			12	100
Ramphastidae			3	100
Buconidae			2	100
Formicaridae			2	100
Phasianidae			1	100
Galbulidae			1	100
Pelecanidae			1	100
Burhinidae			1	100
Recurvirostridae			1	100
Charadriidae			1	100
Heliornitidae			1	100
Certhidae			1	100
Peucedramidae			1	100
Cotingidae			1	100
Regulidae			1	100
Aramidae			1	100
Trogonidae			5	71.4
Furnaridae			5	71.4

Threatened species exhibit larger body sizes than those regarded as of Least Concern ($F_{3,316}$ = 13.74, p<<0.001; Table 3). On average, Critically Endangered species are 2.4 times larger than Least Concern species, and their body size significantly differs from all other categories ($HSD_{316, 337}$ p<0.03 for all comparisons; Table 3). Large bodied species are persecuted for trade and have low reproductive rates which might account for their higher endangerment (Owens &

Bennett, 2000). In fact, large bodies is a common attribute of endangered Neotropical birds (Kattan, 1992, 1994), suggesting that larger species might need special attention. Endargement though, is unrelated to food habits (X^2= 7.2; df= 6; $p > 0.30$), contrasting with birds in tropical forests of Colombia, where frugivorous and insectivorous species are more endangered (Kattan, 1994). Body size of Critically Endangered species

Table 3. Average body size of the resident Guatemalan birds, according to their UICN category.

IUCN category	Number of species	Body size (cms ± se)
LC	97	23.8 (±1.3)
VU	193	27.4 (±1.4)
EN	16	36.7 (±5.5)
CR	14	55.9 (±9.2)

Geographic distribution of threatened Guatemalan birds does not occur at random (X^2 = 198.8; df =4; $p << 0.01$). The Subtropical Humid Forest, located over the Pacific slope, contains 4 times more threatened species than what would be expected according to its surface (Table 4). This biome supports 32% of the threatened species in an extension equivalent to only 4.2% of the Guatemalan territory.

Table 4. Threatened bird species by biogeographic regions of Guatemala. Figures are the observed and the expected number of species (Observed number of species according to Eisermann & Avendaño, 2006). * denotes biomes that significantly depart from random expectations.

Region	Biome in the region (aprox)	% of the country that it occupies	Observed threatened species (% of the total avifauna threatened)	Expected threatened species for such an area
Atlantic lowlands and Atlantic slopes	Tropical humid forest, tropical rainforest and pine savanna	52.4	161 (72.2)	225
Highlands	Mountain broadleaf forest and mountain conifer forest	26,4	102 (45.7)	113
Pacific slopes*	Subtropical humid forest	4,2	73 (32.7)	18
Pacific lowlands*	Tropical humid Savanna	10,9	71 (31.83)	47
Interior valleys	Thorn scrub	6,1	22 (9.86)	26

In short, Guatemalan threatened birds are not a random subset of the country's avifauna, as endangered species are neither taxonomically nor geographically randomly distributed. Large bodied species, Psittaciformes, Galliformes, Falconiformes and Ciconiformes are among the most endangered groups, and the Pacific slopes host more threatened birds than what would be expected according to its territorial extension. These patterns should direct both research and conservation efforts.

Conservation plans ought to be supported by scientific and technical information (Pullin *et al.*, 2004). Information regarding threatened Guatemalan birds though is scanty at best (see Appendix 1 in Eisermann & Avendaño, 2006). On a per species bases, within Families containing Critically Endangered species, published scientific information regarding them, does not differ from that available for other less or non threatened species (1.8 vs 1.7 papers/species of Critically Endangered and other species, respectively; $z = -0.37$; $p = 0.36$). Not a single publication is available on conservation of Critically Endangered Anatidae, Rallidae and Strigidae nor *Eurypyga helias*, the single species of the Eurypygidae. The single publication on *Colinus nigrogularis*, a Critically Endangered Quail, refers to the description of a new subspecies in 1932. Since then, no other information has been gathered. Even within Critically Endangered taxa information is skewed. For instance, for the two CR Psittacidae species, 13 out of 18 published papers are available for *Ara macao* contrasting to just five devoted to *Amazona oratrix* (see Apendix 1 in Eisermann & Avendaño 2006, for the full bibliography on Guatemalan birds from 1577 up to 2004). The paucity of information weakens the preparation and implementation of conservation plans. Therefore, there is a clear need to focus research on the most susceptible and endangered taxa.

Geographically, the Pacific slopes region (Subtropical Humid Forest) is a prime target for conservation efforts. Although all species found there can be also found in other biomes, mainly in the Atlantic region and Guatemala's highlands, conservation efforts ought to be increased in the Pacific slope as protected areas cover just 227 ha of this biome, compared to 325.000 ha formally protected in the Atlantic region (Tropical humid and rainforest biomes; CONAP, 2006). Guatemala has more than 190 official protected areas, and new areas are being established, including a growing number of private reserves (CONAP, 2006). Some of them are being established in the Pacific slopes, offering specialized birdwatching tours (e.g. Tarrales Natural Private Reserve) contributing to protect the endangered avifauna. However, the total surface added to the Guatemala system of protected areas is progressively smaller, as total covered areas has stabilized around 3,300,000 ha over the last decade (IARNA *et al.*, 2006). As the likelihood of protecting larger areas seems low, biodiversity conservation shall be also attempted in productive landscapes, outside protected areas (e.g., Perfecto & Vandermeer, 2008). To achieve it, basic knowledge regarding the ecology of threatened birds and the conservation value of managed forests and agricultural systems must be urgently pursued.

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Capítulo II

ENHANCING AVIFAUNA IN COMMERCIAL PLANTATIONS

ABSTRACT

The occurrence of fauna in commercial plantations is often associated with structural complexity such as understory or multiple vegetation strata within them. Through a meta-analysis, we tested if structural complexity of plantations could enhance bird species assemblages, and if bird assemblages respond differently pending on taxonomic affiliation, body size and diet. We recorded 165 cases in 31 countries with forest-crop comparisons, and 39 cases in 12 countries comparing between plantations with different complexity. Bird richness, but not abundance, was higher in forests than in plantations. Within plantations, both bird richness and abundance were significantly higher in complex than in structurally simple ones. Taxonomic representation and body sizes do not differ between forest and crop, but insectivorous birds are depressed in plantations. Within plantations, all taxonomic and dietary groups have more species increasing than decreasing as a response to complexity. Birds responses are not affected by their body size. Independently of the type of crop, structural complexity is generally correlated with increases in bird richness and abundance across plantations. Enhancing habitat complexity might mitigate their impact and contribute to offer habitat for some native species.

KEY WORDS: meta-analysis, birds, understory, structural complexity, agro-forestry

INTRODUCTION

Achieving biodiversity conservation outside protected areas is an increasing need. World-wide current demographic and economic trends demand more territories to grow commodities, leaving fewer habitats to be allocated to protected areas. Furthermore, current parks and reserves will not suffice to protect a significant fraction of biodiversity. Therefore, to use the semi-natural and productive matrixes for biological conservation is currently not only a challenge, but also a pressing need (Daily 2001; Foley et al. 2005).

Increasing evidence suggests that commercial plantations can support some native biodiversity, even providing occasional habitat for vulnerable species. Therefore, plantations could contribute to biodiversity conservation (Hartley 2002; Lindenmayer & Hobbs 2004; Simonetti 2006). Plantations embrace a continuum from structurally simple monocultures to more heterogeneous stands supporting understory vegetation that might comprise native plant species (Hartley 2002). Developing management practices so plantations could support and conserve biodiversity while maintaining similar levels of production and profitability is yet to be achieved. Unraveling variables enhancing the occurrence and survival of wild species in plantations is then a mandatory step towards this purpose (Tews et al. 2004; Stephens & Wagner 2007; Tscharntke et al. 2008).

The occurrence of native fauna in many agro-forestry systems, such as coffee and oil palm plantations, is presumed to be associated with structural characteristics within the plantation, such as the existence of understory or multiple vegetation strata (Aratrakorn et al. 2006). In fact, understory vegetation is often regarded the single best predictor of animal diversity (e.g. birds, mammals, beetles) within plantations, as understory may provide food and shelter for native species (López & Moro 1997; Grez et al. 2003; Lindenmayer & Hobbs 2004; Aratrakorn et al. 2006).

If the structural complexity of the habitat impinges positively on faunal species richness and abundance (Tews et al. 2004), they ought to be larger in forests than in plantations. In the same token, plantations with well developed understory or multiple vegetation strata ought to support more native species than those structurally simple ones. Here, we tested if the structural complexity in plantations could be enhancing their avian species assemblages. These hypotheses were tested through a meta-analysis focusing in the responses of bird assemblages to habitat complexity, including forests, structurally complex as well as simplified plantations. We considered plantations as structurally complex if they had multiple vegetation strata, while those having only the crop stratum were classified as simplified plantations.

Biological attributes such as body size, diet and habitat preferences might render some species more susceptible to structural changes in plantations (e.g., large bodied species and habitat specialists are more vulnerable to habitat modifications; Owens & Benett 2000). In this framework, we also explored if birds respond differently to structural complexity in plantations regarding its taxonomic affiliation, body size and diet habits. Unraveling variables impinging upon biodiversity in plantations, both structural and biological ones, will allow advancing managerial procedures to fulfill both, the production of highly demanded commodities and the conservation of biodiversity in productive landscapes.

METHODS

We searched ISI Web of Knowledge Database for literature that correlated bird species diversity with plantations, using "plantation* + bird*" as search terms. We included studies from January 2003 to July 2008, and selected only those articles that compared bird richness and/or abundance between natural habitats and croplands or plantations differing in complexity (presence vs absence of understory or multistrata vs single strata). We accounted each comparison as one case. Therefore, in publications where authors report multiple comparisons, more than one case could be extracted from the same article. Information recorded was the type of plantation, type of forest, and bird richness and abundance.

To synthesize primary research data, we used Vote-counting, categorizing responses in an expected vs an unxpected direction regarding a specific hypothesis (Rosenberg et al. 1997). The proportions of studies depicting results in each direction is then evaluated, and the category with the largest proportion in assumed to be the statistical trend summarizing the primary literature, and used as evidence to support or refute a given hypothesis (Rosenberg et al. 1997).

We compared bird richness and abundance between forests and plantations and between plantations of different levels of structural complexity. First, we assessed the response of the whole bird assemblage. For each case, we registered how the bird assemblage responded to structural simplification from forest to cropland (response to the loss of vegetational strata) or to structural complexity within the plantation (response to the increase of vegetational strata), in terms of increases or decreases in mean and total richness and abundance. To evaluate the consistency on these responses, we analyzed the data with a sign test, both for the crop-crop as for the forest-crop responses. Increases in bird richness or abundance in more complex habitats were regarded as "positive" response.

Second, we assessed if bird assemblages responded differently to plantations, pending on taxonomic affiliation (at the ordinal level), body size and diet. Here, we focused our analysis to oil palm plantations, currently one of the fastest growing plantations in the world, with data from Malaysia forest and croplands (from Koh & Wilcove 2008 and Peh et al. 2005, 2006).

Third, within plantations of the same commodity but differing in structure, we analyzed if bird responses to structural complexity could be explained by chance alone or if a particular group was more or less favored by structural complexity within plantations, pending on taxonomic affiliation, body size and diet.

RESULTS

A total of 244 papers were published during the 2003-2008 period. From these studies, 71 publications reported quantitative information on bird richness and abundance suitable for analyses (Appendix 1 and 2). Fifty-eight articles focused on forest-crop comparisons, and only 19 compared different conditions of a given plantation. Seven articles had comparisons both forest-crop and crop-crop. Experimental approximations to evaluate the effects of structural complexity on bird assemblages in plantations are scarce, with only two studies carried out. For comparisons between natural vegetation and crops, we recorded 165 cases in 31 countries. Regarding comparisons between plantations with different complexity, we recorded 39 cases, in 12 countries (complete list available as supplementary material). The most frequent crop types included forest plantations (especially Conifers), and coffee.

Bird richness was significantly higher in forests than in plantations. Seventy-eight out of 108 cases (72%) exhibited higher species richness in forest than in croplands, regardless of plantation type (Sign test $p < 0,01$; Table 1). No difference was found for bird abundance between forest and crops. The number of cases showing higher or lower abundance as a response to habitat simplification are not statistically different (Sign test $p = 0.88$; Table 1).

Table 1. Increases and decreases in bird richness and abundance (in number of cases) as a response to structural simplification occurring after forest conversion to cropland and structural complexity within plantations.

	Response to structural simplification			Response to structural complexity		
	Increases	Decreases	p	Increases	Decreases	p
Richness						
Total	30	78	0,0001	20	6	0.01
Mean	11	58	< 0.0001	13	3	0.02
Abundance						
Total	24	22	0.88	11	1	0.01
Mean	18	18	0.86	16	3	0.01

Bird richness and abundance were significantly higher in complex plantations than in structurally simple ones. Twenty out of 26 (77%), and 11 out of 12 (92%) cases exhibited higher species richness and abundance, respectively, in more complex than in less complex croplands, regardless of plantation type (Sign test p = 0.01 and 0.02; Table 1). In other words, the presence of understory or multiple vegetation layers generally trigger increases in bird richness and abundance across plantations.

In forest-oil palm comparisons, although Galliformes and Trogoniformes are completely absent in the plantation, the taxonomic representation does not differ between forest and crop. Galliformes and Trogoniformes account for only 6% of the avifauna in forests (Table 2; chi-square = 0.53; p = 0.76). Differences do emerge in the proportion of bird species in each dietary group (Table 2; chi-square = 6.87; p = 0.03). In plantations, insectivorous birds are 0.6 times less frequent than in forests, while, frugivorous and granivorous birds are 1.3 and 3.3 more common at plantations, respectively (Table 2). Regarding body size, bird species who inhabit forests are 1.2 times larger than those that survive in plantations, but these differences are not statistically significant (mean size ± SE= 27.1 ± 2.6 vs 22.5 ±2.3 cm, respectively; U = 1804; p= 0.52). Finally, oil palm plantations host only one of the six vulnerable species present in native forest, and 1.4 more least concern (LC) species (IUCN 2008) than those inhabiting surrounding forests.

Table 2. Percentage of species per Orders and dietary groups, present in forest and oil palm plantations (data from Peh et al. 2005, 2006).

	% in forest	% in oil palm
Orders		
Passeriformes	65.4	61.1
Piciformes	9.4	8.3
Coraciformes	7.5	11.1
Cuculiformes	6.3	2.8
Columbiformes	3.8	8.3
Galliformes	3.1	0.0
Trogoniformes	2.5	0.0
Psittaciformes	1.9	8.3
Diet		
Insectivores (I)	56.6	36.1
Frugivores (F)	23.9	30.6
IF	4.4	8.3
Carnivores	3.8	8.3
Nectarivores	3.1	5.6
Granivores	2.5	8.3
IG	2.5	0.0
IN	2.5	2.8
Omnivores	0.6	0.0

Comparing plantations with different structural complexity, all taxonomic and dietary groups have consistently more species increasing than decreasing as a response to complexity within the plantation (Table 3; Wicoxon p = 0.03 and p = 0.04, respectively). On the contrary, mean body sizes of birds are not statistically different in more and less complex plantations (17.0 (SE 0.78) and 16.6 (SE 0.74) cms. respectively; Sign Test p = 0.6).

Table 3. Percentage of species per Orders and dietary groups, that increase/decrease as a response to structural complexity within plantations.

	Increasing (%)	Decreasing (%)
Orders		
Passeriformes	66	29
Galliformes	89	11
Columbiformes	77	0
Coraciformes	43	43
Apodiformes	71	28
Cuculiformes	67	33
Piciformes	75	19
Strigiformes	0	67
Trogoniformes	100	0
Falconiformes	67	11
Caprimulgiformes	0	100
Psittaciformes	100	0
Tinamiformes	100	0
Diet		
Insectivores	64	31
Omnivores	80	16
Frugivores	86	13
Granivores	43	43
Nectarivores	67	33
Carnivores	58	25

DISCUSSION

Commodity plantations are no substitute for natural forests. They support modified assemblages and fewer species than natural habitats (Donald 2004; Koh & Wilcove 2008; Harvey & Gonzalez-Villalobos 2007). However, plantations with more complex structures hold more species than simple ones, regardless of the type of plantations, opening a way to turn croplands environmentally friendlier, particularly facing reduced opportunities for conserving low disturbed habitats. As with other taxa, bird species richness is reduced when natural forests are replaced by croplands, and although bird abundance does not appear to be different in plantations and forest, the hosted assemblage in crops is modified (Harvey & Gonzalez-Villalobos 2007).

Structural complexity within plantations enhances avifauna in croplands, promoting more bird richness and abundance. Resources provided by multiple vegetation layers in plantations are yet to be assessed, but such a vegetation benefit birds of all dietary habits, Orders, and body sizes, suggesting that independently from the type of crop, structural complexity will generally trigger higher richness and abundance of avian assemblages in plantations.

When forest is converted to oil palm plantations, large-bodied species are more affected than small ones as also happens with the majority of vulnerable species, which does not thrive in plantations. This reinforces the fact that the communities held in commodity production systems are highly modified in comparison to original forest. The trophic structure in oil palm plantation is also different where insectivores being less abundant in plantation. Severe insect pest outbreaks occur occasionally in oil palm plantations (Zeddam et al. 2003; Koh 2008a), and the use of pest-control agrochemicals could be then causing a reduction in insect abundance in plantations and as a consequence, a reduction in insectivorous birds. However, most companies are adopting an integrated pest management control, which promotes practices such as establishing plants and native tree species to attract insect predators (Koh 2008a), fostering the value of plantations as habitat for bird species.

At the landscape scale, more variables (such as plantation shape, distance to the native forest, and type of surrounding matrix) can affect biodiversity within a plantation (e.g. Koh 2008b), but at the local scale, our review confirms the importance of multiple vegetation strata as a driver that could help croplands host more avian biodiversity than that held in simplified plantations. A mandatory step ought to be experimentally demonstrated that understory vegetation does promote biodiversity within plantations and determine the proximal factors behind such enhancement. Up to date, only two studies had experimentally modified structural variables (Cruz-Angon & Greenberg 2005; Chapter 3). The removal of understory vegetation reduces bird diversity and abundance, hypothesizing that such a decline could relate to a reduction in food or shelter provision, but these factors must be tested, as they could explain changes not only in species richness and abundance, but also in the trophic and size structure of the assemblages thriving in plantations.

Management practices allowing or promoting understory or structural complexity ought to be promoted to shift the biodiversity impoverished croplands to a less hostile condition, contributing to biodiversity conservation. A key issue will be the payoff of such initiative compared to keep business as usual. Improving plantations for biodiversity might be highly attractive for managers, as they could provide several benefits for the community and the industry owners, beside potential pest controllers. Among them, environmentally friendly plantations can expedite certification hence accessing to a more environmentally conscious market, as well as offering education for peasant populations living close to plantations, among others (e.g., Turner et al. 2008). However, solid information assessing that complex plantations adapted to support some biodiversity maintain their yields and profitability is also urgently needed. Despite these shortcomings in information, leaving or deliberately implementing structural complexity within plantations could satisfy the current need of making commodity production a cleaner industry, aiding in the biosphere's sustainability.

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APPENDIX 1

Publications used for Vote-Counting, that comapred plantations vs native forest

Plantation	Country	Authors	Year	Reference
Pine	Argentina	Lantschner, M. et al.	2008	Biodiversity & Conservation 17: 969-989
Timber	Colombia	Ríos, M. et al.	2008	Ornitología Neotropical 19: 295-303
Timber	Colombia	Lentijo, G. & G. Kattan	2005	Ornitología Colombiana 3: 51-61
Timber	Kenya	Munyekenye F.B. et al.	2008	Ostrich 79: 37-42
Timber	Comoros	Sontag W. & M. Louette	2008	Journal of Ornithology 148: 261-267
Pine and Eucalyptus	Australia	Haslem, A. & A. Benett	2008	Agriculture, Ecosystems and Environment 125: 191-203
Conifer	Argentina	Paritziz, J. & M. Aisen	2008	Forest Ecology and Management 255:1575-1583
Agroecosistem	Kenya	Laube, I. et al.	2008	Journal of Ornithology 149: 181-191
Timber	Japan	Yamaura, Y. et al.	2008	Ecological Research 23: 317-327
Pine	South Africa	Malan, G. et al.	2007	South African Journal of Wildlife Research 37: 158-158
Coffee and Cacao	Cameroon	Smith, T. et al.	2008	Molecular Ecology 17: 58-71
Conifer	Canada	Woodley, S. et al.	2006	Canadian Field Naturalist, 120: 298-306
Eucalyptus	Brazil	Barlow, J. et al.	2007	PNAS 104:18555-18560
Coffee	Mexico	Philpott, S. et al.	2007	Conservation Biology 21: 975-985
Timber	Czech Republic	Salek, M. et al.	2007	Acta Ornithologica 42: 89-97
Eucalyptus	Australia	Kavanagah, R. et al.	2007	Austral Ecology 32: 635-650
Conifer	Japan	Yamaura, Y. et al.	2007	Journal of Forest Research 12: 298-305
Eucalyptus	Australia	Loyn, R. et al.	2007	Biological Conservation 137: 533-548
Cacao	Panama	Van Bael, S. et al.	2007	Biodiversity and Conservation 12: 2245-2256
Cacao and Banana	Costa Rica	Harvey, C. & J. Gonzalez	2007	Biodiversity and Conservation 16: 2257-2292
Cacao	Brazil	Faria, D. et al.	2007	Biodiversity and Conservation 15:587-617
Pine	United States	Basett, C.A. & P. Stouffer	2006	Journal of Wildlife Management 70: 1013-1019
Eucalyptus	Brazil	Barlow, J. et al.	2007	Biological Conservation 136: 212-231
Rubber	Indonesia	Beukema, H. et al.	2007	Agroforestry Systems 70:217-242
Allspice	Nicaragua	King, D. et al.	2007	Biodiversity Conservation 16:1299-1320
Timber	Guatemala	Rottenberg, J.	2007	Auk 124: 316-330
Coffee	Mexico	Gordon, C. et al.	2006	Agriculture, Ecosystems and Environment 118: 256-266
Pine	Spain	Santos, T. et al.	2006	Basic and Applied Ecology 7: 483-495
Pine and Araucaria	Argentina	Zurita, G.A. et al.	2006	Forest Ecology and Management 235: 164-173
Citrus and coffee	Jamaica	Johnson, M.D. et al.	2006	Conservation Biology 20:1433-1444
Rubber and Oil Palm	Malaysia	Peh, K. et al.	2006	Diversity and Distributions 12: 572-581
Conifer and agricultural land	Belgium	Paquet, J.Y. et al.	2006	Forest Ecology and Management 227: 59-70
Timber and Tea	Malaysia	Soh, M. et al.	2006	Biological Conservation 129: 149-166
Coffee and Cardamom	India	Raman, S.	2006	Biodiversity and Conservation 15: 1577-1607

Oil Palm and Rubber	Thailand	Aratrakorn, S. et al.	2006	Bird Conservation International 16: 71-82
Yerba Mate	Paraguay	Cockle, K. et al.	2006	Biodiversity and Conservation 14: 3265-3288
Pine	Indonesia	Sodhi, N. et al.	2005	Bird Conservation International 15: 173-191
Cacao, Coffee, Banana and annual crops	Cameroon	Walert, M. et al	2005	Ecological Applications 15: 1351-1366
Coffee	India	Bhagwat, S. et al.	2005	Ecology and Society 10:8-48
Coffee, cacao, allspice and citrus	mexico	Estrada, A. & R. Coates-Estrada	2005	Biodiversity and Conservation 14: 1719-1734
Eucalyptus	Madagascar	Watson, J. et al.	2005	Biodiversity and Conservation 14: 523-545
agricultural land	Bahamas	Currie, D. et al.	2005	Caribbean Journal of Science 41: 88-100
Timber	Australia	Kanowski, J. et al.	2005	Forest Ecology and Management 208: 359-372
Coffee	Puerto Rico	Gleffe, J. et al.	2006	Ornitología Neotropical 17: 271-282
Cacao	Venezuela	Verea, C. & A. Solorzano	2005	Ornitología Neotropical 16: 1-14
Timber	Colombia	Durán, S. & G. Kattan	2005	Biotropica 37: 129-135
Maize	Indonesia	Sodhi, N. et al	2005	Biological Conservation 122: 547-588
Pine	Chile	Vergara, P. & J. Simonetti	2004	Oryx 38: 383-388
Rubber	Singapur	Castelletta, M. et al.	2004	Biological Conservation 121: 135-155
Cacao and maize	Indonesia	Walert, M. et al.	2004	Conservation Biology 18: 1339-1346
Pine	Spain	Maícas, R. & J. Fernández	2004	Forest Ecology and Management 195: 267-278
Coffee	Mexico	Tejeda-Cruz, C. & W. Sutherland	2004	Animal Conservation 7: 169-179
Eucalyptus and agricultural land	Australia	Hobbs, R. et al.	2003	Agroforestry Systems 58: 195-212
Timber	Czech Republic	Remes, V.	2003	Conservation Biology 17: 1127-1133
Coffee and pine	Panama	Petit, L. & D. Petit	2003	Conservation Biology 17: 687-694
Coffee	Mexico	Perfecto, I. et al.	2003	Biodiversity and Conservation 12: 1239-1252
Cottonwood	United States	Wilson, R. & D. Twedt	2003	American Midland Naturalist 149: 163-175
Eucalyptus	Tanzania	John, J. & J. Kabigumila	2007	Ostrich 78: 265-269

APPENDIX 2

Publications used for Vote-Counting, that comapred structurally complex vs simplified plantations

Plantation	Country	Authors	Year	Reference
Coffee	Costa Rica	Florian, E. et al.	2008	Ornitología Neotropical 19: 541-548
Timber	Belgium	Warnaffe, G. & M. Deconchat	2008	Biodiversity and Conservation 17: 1041-1055
Coffee	Mexico	Philpott, S. et al.	2007	Conservation Biology 21: 975-985
Eucaliptus	Australia	Kavanagh, R. et al.	2007	Austral Ecology 32: 635-650
Coffee	Mexico	Dietsch, T. et al.	2007	Biotropica 39: 232-240
Timber	Guatemala	Rottenberg, J.	2007	Auk 124: 316-330
Coffee	Mexico	Gordon, C. et al.	2006	Agriculture, Ecosystems and Environment 118: 256-266
Timber	Ireland	Wilson, M. et al.	2006	Bird Study 53: 225-236
Timber	Spain	Camprodon, J. & L. Brotons	2006	Forest Ecology and Management 221: 72-82
Coffee	Dominican Republic	Komar, O	2006	Bird Conservation International 16:1-23
Coffee	Mexico	Komar, O	2006	Bird Conservation International 16:1-23
Coffee	Costa Rica	Komar, O	2006	Bird Conservation International 16:1-23
Coffee	Dominican Republic	Komar, O	2006	Bird Conservation International 16:1-23
Rubber and Oil Palm	Thailand	Aratrakorn, S. et al.	2006	Bird Conservation International 16: 71-82
Timber	Taiwan	Yuan, H. et al.	2005	Zoological Studies 44: 393-402
Coffee	Mexico	Cruz-Angón A. & R. Greenberg	2005	Journal of Applied Ecology 42: 150-159
Coffee	Mexico	Perfecto, I. et al.	2004	Ecology 85: 2677-2681
Coffee	Mexico	Tejeda-Cruz, C. & W. Sutherland	2004	Animal Conservation 7: 169-179
Coffee	Mexico	Perfecto, I. et al.	2003	Biodiversity and Conservation 12: 1239-1252
Agriculture	Tunisia	Selmi, S. & T. Boulinierb	2003	Biological Conservation 110: 285-294
Pine	Chile	Vergara, P. & J. Simonetti	2006	Biodiversity and Conservation 15: 3937-3947

Capítulo III

CAN OIL PALM PLANTATIONS BECOME FEATHERY?

ABSTRACT

Despite the abundance of claims that structural complexity in plantations is a key variable for enhancing bird biodiversity, experimental approaches are still scarce or nill. Here, we performed one such experimental test, modifying the understory of an oil palm plantation in eastern Guatemala and analyzing the birds´ responses to these changes. Oil palm (*Elaeis guineensis*) is one of the most rapidly expanding crops in tropical regions, and in the main producing countries, it represents the major cause of loss of natural forests and of the decline of endangered species. Our results show that oil palm plantations with understory are capable of holding more bird richness and abundance than those lacking it. We conclude that leaving or implementing structural complexity within plantations could satisfy the current need of making commodity production a cleaner industry, fulfilling both, the production of highly demanded commodities and the conservation of biodiversity in productive landscapes.

INTRODUCTION

Land surface required to grow commodities has increased substantially to support growing demands from Human populations. If current trends continue unabated, 10^9 ha of natural ecosystems would be converted to agriculture by 2050 (Tilman et al. 2001). This land conversion is a significant driver altering Earth's ecosystems, including biodiversity loss (Donald 2004, Foley et al. 2005). Therefore, a challenge to be met is to maintaining the capacity of the Biosphere to provide goods and services while conserving biodiversity. Protected areas will not suffice to ensure long-term conservation of biological diversity. Therefore, it shall also be attempted in productive and semi-natural areas (Hartley 2002).

Plantations in fact might support some native biodiversity, playing a subsidiary role in conservation providing an occasional habitat, even for endangered species (Estades & Temple 1999; Daily et al. 2001; Simonetti 2006). Agricultural systems can support native fauna depending on structural characteristics such as the existence of understory or multiple vegetation strata within the plantation, including prevalence of epiphyte or the presence of leguminous crops, as they might provide food and shelter for native species (Greenberg et al. 1997; Grez et al. 2003; Lindenmayer & Hobbs 2004; Aratrakorn et al. 2007). The presence of fauna in croplands is also affected by the proximity to native forests surrounding the plantation, and the amount of forest remnants left within them (Estades & Temple 1999; Koh 2008a).

Among commodities, vegetable oils and oils seeds have an increasing demand in global markets, not only for food industry, but for the increasing biofuel demand as well (USDA 2008). Compared to other oleaginous crops, oil palm (*Elaeis guineensis*) has the highest yield per area and is one of the most rapidly expanding crops in tropical regions. The global area for oil palm cultivation has more than triple, increasing from 3.6 million ha in 1961 to 13.2 million ha in 2006, an expansion rate of 246.000 ha/year occurring mostly in southeast Asia, Africa and Latin America (FAO 2007; Koh & Wilcove 2008). In the main producing countries, oil palm plantations are the major cause of loss of natural forests and of the consequent decline of endangered species, such as the Sumatran Orangutan (*Pongo abelii*; Donald 2004). In general, fauna assemblages supported by oil palm plantations are depauperated in comparison to natural forests (Donald 2004 Aratrakorn et al. 2006, Koh & Wilcove 2008). Consequently, the production of palm oil, the top-selling vegetable oil in the World, has had a poor environmental record (Donald 2004). Given its economic importance and ubiquity in the food and oleochemical business, as well as its current and projected expansion as a biodiesel feedstock, there is both a potential and a need to develop better practices to reduce its environmental impacts, including maintaining biodiversity within the plantations (Stone 2007; Turner et al. 2008), with initiatives such as the Round Table on Sustainable Palm Oil (RSPO 2005).

Despite the current demographic and economic trends, information to advance management techniques for maintaining biodiversity within the plantations is scarce at best. In fact, in the last decades, less than 1% of publications on oil palm are related to biodiversity and species conservation, and little research has been done to quantify the impacts on biodiversity of different management systems in oil palm plantations (Donald 2004; Koh 2008*a*; Turner et al. 2008).

Despite the presence of a well developed understory is advanced as an enhancer of species richness in oil palm plantations (Aratrakorn et al 2006), experimental demonstration has yet to be undertaken. In this framework, we experimentally assessed the importance of undergrowth for a bird assemblage in an oil palm plantation in Guatemala. If the understory significant enhance bird species richness and abundance, these ought to be larger in a plantation with developed understory compared to those exhibiting nil or poorly developed vegetation. Further, bird species and abundance should decrease if understory is removed from plantations exhibiting such vegetation. To evaluate these hypotheses, our experimental approach consisted in modifying the undergrowth and analyzing bird responses to changes in understory development. As species response might be coupled to migratory habits, dietary guild and vulnerability status, we also analyzed bird response according to these features (Pimm et al. 1988). Experimentally testing if bird biodiversity is enhanced in oil palm plantations with well developed understory will provide a clue for achieving biodiversity conservation outside protected areas rendering croplands more environmentally friendly.

METHODS

Study area

Our study site is an oil palm plantation located at El Estor, eastern Guatemala. The plantation is located between two protected areas (Bocas del Polochic Wildlife Refuge and Sierra de las Minas Biosphere Reserve). The oil palm plantations in this region reach ~ 6.000 ha, producing 32 metric tons of fruit and 8 metric tons of oil per hectare, one of the highest productivities for any palm plantation worldwide (INDESA 2007).

Bird surveys

Bird surveys were carried out during January and February 2008, in 15 randomly selected plots, under two different conditions: plots with understory (n = 10), where the undergrowth was dense and extensive, and plots without understory (n = 5), where undergrowth was little or absent (*sensu* Aratrakorn et al. 2006). Point counts had a fixed ratio of 25 m and were located at least 100 m apart; we surveyed birds between 6:00 and 10:00 a.m., registering all bird species observed during sampling periods of five minutes (Ralph et al. 1999).

Experimental design

To evaluate if bird diversity is affected by the understory in the plantation, our experiment evaluated bird richness and abundance before and after removing the understory from randomly selected plots, comparing bird´s assemblages with that of the remaining sampling plots – both with and without understory- considering them as controls. To evaluate if the understory affects bird species differentially, we also analyzed the species dietary group (Howell & Webb 1995), vulnerability, and residence status (Eisermann & Avendaño 2006) before and after the understory removal.

To establish a baseline before the understory manipulation, we surveyed the 15 fixed radius plots on three consecutive mornings (Cornelius et al. 2000). Right after this assessment, we removed the understory from six randomly selected plots (experimental plots), cutting all the vegetation and leaving them similar to those plots lacking understory (no understory plots). Other four plots remained with the understory unmanaged (control plots). After 10 days, we conducted a second survey on three consecutive days, in the same hours as in the baseline sampling. Number of species and individuals were analyzed with repeated measures analysis of variance, and planned comparisons between plots with understory vs. without understory, with understory vs. with experimental understory, and with experimental understory vs. without understory.

To evaluate if species losses occurr in a particular order according to the different understory conditions, we assessed the nestedness of bird assemblages. A nested pattern emerges if bird richness and composition at a given treatment is actually a smaller subgroup contained in a larger assemblage (Ulrich & Gotelli 2007).

RESULTS

Twenty-three bird species from 14 families occur at the oil palm plantation at El Estor. All but one species inhabits oil palm plots with developed understory, and only 12 species are present in plots without understory (Table 1). Most species registered are resident (61%) and insectivores (48% of species). Regarding conservation status 78% are regarded of Least Concern. Species never recorded in plots lacking undergrowth include two locally vulnerable species, *Turdus assimilis* and *Malacoptila panamensis* (Table 1; Eisermann & Avendaño 2006). Bird composition was not nested among experimental, control and no-understory plots ($T = 20.4°$, $z = -0.54$; $p > 0.05$), suggesting that within oil palm plantations species losses occur at random among plots of differing understory cover.

Table 1. Bird assemblages at oil palm plantations, El Estor, Guatemala. Residence status (Res) is R for residents and M for migratory species. Local vulnerability (Vuln) is LC for least concern, NT for near threatened and VU for vulnerable species with the UICN criteria. Marks (x) indicate if the species were recorded in plots with or without understory (with, without) and also those species that were recorded in the experimental plots pre but not post the understory removal (lost w/exp).

Family	Species	Res	Dietary guild	Vuln	With	Lost w/exp	Without
Accipitridae	*Buteo magnirostris*	R	Carnivore	LC	x	X	
Accipitridae	*Buteogallus anthracinus*	R	Carnivore	NT			X
Columbidae	*Zenaida asiatica*	R	frugivorus, granivorous	LC	x		
Trochilidae	*Amazilia tzacatl*	R	Nectarivorous	NT	x		x
Trochilidae	*Phaethornis longirostris*	R	Nectarivorous	LC	x		x
Bucconida	*Malacoptila panamensis*	R	Insectivorous	VU A3c	x		
Picidae	*Melanerpes aurifrons*	R	Insectivorous	LC	x	X	
Formicaridae	*Cercomacra tyrannia*	R	Insectivorous	LC	x		
Tyrannidae	*Empidonax sp*	M	Insectivorous	LC	x		x
Tyrannidae	*Pitangus sulphuratus*	R	Insectivorous	LC	x		
Troglodytidae	*Thryothorus maculipectus*	R	Insectivorous	LC	x	X	
Turdidae	*Hylocychla mustelina*	M	insectivorus, frugivorous	LC	x		x
Turdidae	*Turdus grayi*	R	insectivorus, frugivorous	LC	x		x
Turdidae	*Turdus assimilis*	R	insectivorus, frugivorous	VU A3c	x	X	
Mimidae	*Dumetella carolinensis*	M	insectivorus, frugivorous	LC	x		x
Parulidae	*Wilsonia citrina*	M	Insectivorous	NT	x		x
Parulidae	*Dendroica magnolia*	M	Insectivorous	LC	x		x
Parulidae	*Wilsonia pusilla*	M	Insectivorous	LC	x		x
Parulidae	*Setophaga ruticilla*	M	Insectivorous	LC	x		x
Parulidae	*Dendroica pensylvanica*	M	Insectivorous	LC	x	X	
Thraupidae	*Piranga rubra*	M	Frugivorous	LC	x		
Emberizidae	*Sporophila torqueola*	R	granivous, insectivorous	LC	x	X	
Iceridae	*Psarocolius montezuma*	R	frugivorous, nectarivorous	LC	x	X	x

Bird richness is 3.6 higher in plots with understory than in those lacking it ($F_{2,12}$= 10,0, p = 0.03; Figure 1). In the baseline count, the number of species recorded at experimental plots was similar to the control plots ($F_{2,56}$= 4.43, p = 0.55), but 3.1 times higher than in plots without understory (p= 0.03). After undergrowth removal, the number of species in experimental plots decreased significantly by 41% ($F_{2,83}$= 9.40, p= 0.01), but did not differ from those plots lacking understory (p= 0.09).

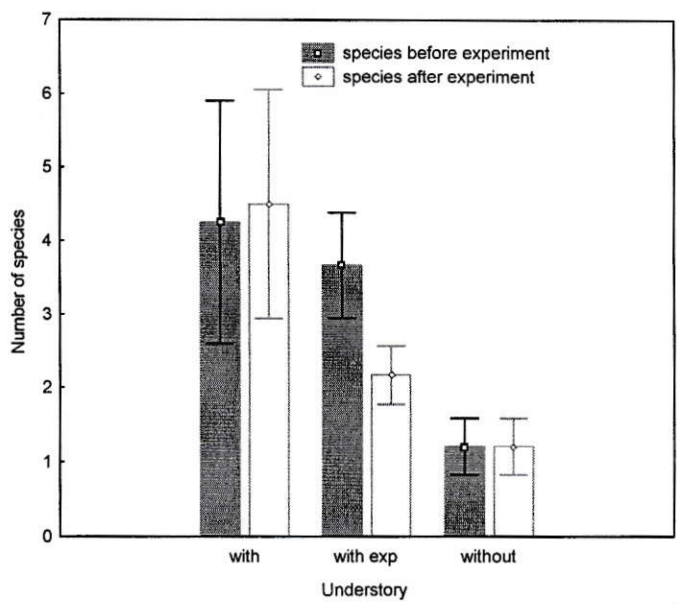

Figure 1. Species numbers in all treatments before and after the manipulation of understory (Mean + SE). The group "with exp" (with experimental understory) is in which the undergrowth was removed.

Mean total number of individuals was 3.2 times higher in plots with understory than in plots without understory. Differences are marginally significant though ($F_{2,12}$= 3.4, p = 0.06; Figure 2). In the baseline count, the number of individuals in experimental plots was similar to control plots ($F_{1,12}$= 0.03, p = 0.84), but marginlally higher ($F_{1,12}$= 4.09, p = 0.06) than in the cleared plots. After undergrowth removal, the number of individuals in the experimental plots significantly decreased by 60% compared to control plots with understory ($F_{1,12}$= 6.85, p = 0.02) but did not differ from plots without undersory ($F_{1,12}$= 0.007, p = 0.93; Figure 2).

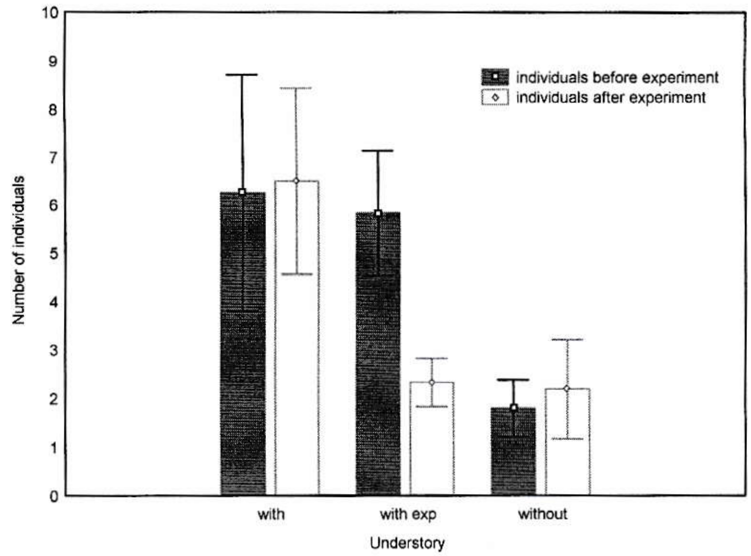

Figure 2. Numbers of bird individuals in all treatments before and after the manipulation of understory (Mean + SE). The group "with exp" (with experimental understory) is in which the undergrowth was removed.

Distance from native forest affects neither bird species richness nor abundance. Mean number of species was similar among plots near (less than 200 m) and far away from the forest edge (over 200 m apart; $t = 0.72$; $p = 0.48$ and $t = 0.90$; $p = 0.38$), pre and post experiment, respectively. Similarly, bird abundance did not differ among plots near and far the forest edge prior to ($t = 0.95$; $p = 0.35$) or after the experimental removal of the understory ($t = 0.53$: $p = 0.59$). Therefore, both bird richness and abundance are higher in vegetated than in oil plam plots without understory plots and the number of species and individuals declined after the understory was removed in the experimental plots.

DISCUSSION

The opportunity for setting aside new or enlarging existing protected areas -particularly in the tropics- is increasingly limited; beside the challenge to support current parks and reserves, a new quest is to achieve biodiversity conservation in productive landscapes (Hartley 2002). Turning croplands environmentally friendlier therefore is a step toward this goal. Oil palm plantations are reputed as harsh upon biodiversity, diminishing richness of several groups such as beetles, butteflies and birds (Chung et al. 2000, Koh 2008a). The existence of a well developed understory could minimize this impact, contributing to conserve some biodiversity (Aratrakorn et al. 2006). In fact, the experimental manipulation of the understory abundance demonstrates that enhancing such vegetation might have significant benefits for birds.

Understory vegetation beneath oil palms, as set forward by several authors (e.g. Aratrakorn et al. 2006) in fact impinge upon bird richness and abundance. Understory could be providing food resources, refuge and breeding sites for birds and other species, as occurs in other commercial plantations such as coffee, pine, eucalyptus, cacao and rubber. At these plantations, understory is also suggested as a significant source of food and shelter for species, thus enhancing biodiversity in these productive areas (Greenberg et al. 1997, Grez et al. 2003, Aratrakorn et al. 2007, Harvey & Gonzalez 2007).

At EL Estor, the undergrowth and the resources it might be providing, benefits even vulnerable species (*T.assimilis* and *M. panamensis*), two species reported to live in primary forests only (Eisermann & Avendaño 2006). Guatemala resident birds appear to be more affected by the absence of understory than migrant species. Nine out of eleven missing species at understory devoided plots are resident ones, including the two vulnerable species, suggesting that they are more prone to become locally extinct than migratory species, contrary from what is usually assumed (Pimm et al. 1988).

Commercial plantations support only a fraction of the biodiversity that was once held in the natural ecosystems they replaced. Oil palm for instance supports about 10% of the original assemblage (see Donald 2006; Aratrakorn et al. 2006; Koh & Wilcove 2008). Adopting management procedures to enhance biodiversity within plantations may not be either technically difficult nor financially costly as it might seems, as biodiversity within plantations could provide environmental services for the community and the industry owners (Turner et al. 2008).

The dominance of insectivorous species (70% of species feed on insects) could be a key issue to promote the development of understory vegetation in oil palm plantations. Herbivorous insects were usually controlled by pesticides but currently there is a tendency to adopt biocontrol procedures. Several plant species are planted in order to attract insect predators and parasitoids in order to reduce insect abundance, precluding pest outbreaks (Koh 2008b). Allowing the spontaneous development of understory vegetation might also contribute to insect control as bird richness and abundance are enhanced in such plantations. Birds do reduce insect abundance (e.g., Koh 2008b), hence as with other plant species, insectivorous birds might contribute to the natural pest control, strengthening justifications for conserving biodiversity in this agricultural landscape (Koh 2008*b*).

Further, oil palm plantations with enhanced understory might even function as corridors between natural ecosystems. At El Estor, such management could favor the connectivity among bird populations at the two protected areas set apart by the plantations, hence integrating productive areas into current conservation efforts. Thus, leaving or building up understory vegetation at oil palm plantations ought to be encouraged. A missing point that must be urgently unraveled is whether such vegetation affects the productivity of plantations.

Vegetation multilayers in agricultural systems appear to be very important for achieving biodiversity conservation in productive lands, and a feasible management measure particularly if it does not comprise their yield. Oil palm plantations can actually become environmentally friendlier, by leaving or promoting understory within them, combined with undertaking other practices previously identified (RSPO 2005; Koh & Wilcove 2007; Koh 2008*a*). This practice could be another step toward satisfying the current need of making commodity production a cleaner industry, aiding in the biosphere's sustainability.

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GENERAL CONCLUSIONS

Land transformation does affect birds in different ways. Threatened birds in Guatemala are not a random subset of the country's avifauna, as endangered species are neither taxonomically nor geographically randomly distributed. Large bodied species and Psittaciformes, Galliformes, Falconiformes and Ciconiformes are among the most endangered groups. Regarding geography, the Pacific slopes host more threatened birds than what would be expected according to its territorial extension. These patterns should direct both research and conservation efforts, not only in protected areas, but also in productive landscapes (e.g., Perfecto & Vandermeer, 2008), especially after recognizing that the likelihood of protecting larger areas seems low, and the demand for commodity production increases.

Within plantations, structural complexity generally triggers increases in bird richness and abundance, independently of the type of crop. It is evident that plantations are no substitute for forests, but enhancing complexity across plantations might mitigate their impact and contributes to offer habitat for some native species. These management practices ought to be promoted to shift the biodiversity impoverished croplands to a less hostile condition, contributing to biodiversity conservation.

For Oil palm plantations in particular, we have provided experimental evidence on the role of understory for increasing bird diversity. This crop can actually become environmentally friendlier, by leaving or promoting understory, and this could be a step toward satisfying the current need of making palm oil production a cleaner industry.

Management practices allowing or promoting understory or structural complexity besides improving plantations for biodiversity, might also be highly attractive for managers, as they could provide several benefits (certification, education, etc) for the community and the industry owners, beside potential pest controllers (e.g., Turner et al. 2008). A key issue will be the payoff of such initiative compared to keep business as usual. Solid information assessing that complex plantations adapted to support some biodiversity maintain their yields and profitability is still urgently needed, but we can already say that leaving or deliberately implementing structural complexity within plantations could satisfy the current need of making commodity production a cleaner industry, aiding to the biosphere's sustainability.

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