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The influence of habitat complexity and landscape context on the biodiversity conservation value of cacao agroforests in Waslala, Nicaragua

by

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DEDICATORY

To my parents

and all cacao growers of Waslala

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BIOGRAPHY

Boris Miguel Arevalo Jimenez was born in Belize. He obtained a Bachelor of Science from the University of Belize in 2005, with a major in Biology. During the past four years he worked as an environmental consultant for organizations such as Belize Environmental Consultancies Ltd. and Belize Tropical Forest Studies. Major tasks included environmental impact assessments, biological inventories, rapid ecological assessments and the development of protected areas' management plans. During the last two years he has distributed his time between being an environmental consultant and a tour guide, guiding expeditions for scientists interesting in the natural history of Belize, especially for the collection of flora specimens. The author has participated in various workshops related to Belize's natural resources management and sustainable development. In 2009, he initiated his postgraduate studies at the Tropical Agronomical Centre for Investigation and Higher Education (CATIE), obtaining a Master's degree in Management and Conservation of Tropical Forests and Biodiversity in 2010.

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La deforestación de los bosques naturales ha conllevado a investigar el papel que juegan los agroecosistemas en la conservación de la biodiversidad. Cultivos agrícolas bajo sombra, como los sistemas agroforestales de cacao, se ven prometedoras en la conservación de la biodiversidad en matrices agrícolas. El objetivo de la investigación fue evaluar dos elementos críticos para la conservación de la biodiversidad: complejidad de hábitat y contexto paisajístico. Comprobamos el impacto tanto independiente como en conjunto de estos elementos sobre la avifauna y herpetofauna registrada en los sistemas agroforestales de cacao en Waslala, Nicaragua.

Para examinar el efecto de estructura de hábitat y contexto paisajístico, muestreamos 36 cacaotales y 6 fragmentos de bosque secundario, cuales se utilizaron como hábitat de referencia. Nosotros medimos la composición botánica y estructura de hábitat utilizando parcelas de 20 × 50 m. Utilizando las variables de composición botánica y estructura de hábitat se identificaron tres tipologías de los sistemas agroforestales de cacao, mediante un análisis de conglomerados. Estas tipologías se clasificaron en un gradiente de complejidad de hábitat, yendo de lo más simple a lo más complejo: cacao-banano, cacao dos-estratos y cacao diversificado.

El contexto paisajístico y su efecto sobre la biodiversidad, se analizo a diferentes escalas, utilizando “buffers” con radios de 500, 1000, 1500, 2000, 2500 y 3000 metros, donde se cuantifico la cobertura forestal. Caracterizamos la avifauna utilizando puntos de conteo con radios fijos de 25 m. Nosotros muestreamos la herpetofauna basados en la metodología de Whitfield.

Se observaron un total de 2914 aves perteneciendo a 174 especies, 195 anfibios de 12 especies y 258 reptiles perteneciendo a 19 especies. De las 174 especies de aves, 158 fueron registradas en los cacaotales, mientras que las 12 especies de anfibios y 18 de las 19 especies de reptiles fueron registradas en los cacaotales. Se registro la mayor riqueza de aves en el cacao diversificado (34.92 ± 1.75) que en cacao-banano (25.5 ± 2.57) y cacao dos-estratos (29.18 ± 1.53), mientras que los bosques secundarios registraron una riqueza intermedia. La riqueza (F = 0.66, p = 0.5847) y abundancia (F = 1.59, p = 0.2087) de anfibios no varió entre las tipologías. Registramos diferencias significativas para la riqueza (F = 3.29, p = 0.0315) de reptiles pero no para la abundancia (F=2.52, p = 0.0735). Mayor riqueza de reptiles se registro en cacao-banano y bosques secundarios, mientras que en el cacao diversificado se registro la menor riqueza. El análisis de similitud indico diferencias significativas en base a la composición de especies de aves (r = 0.3111, p = 0.00009990), anfibios (r = 0.1147, p = 0.047395) y reptiles (r= 0.157, p = 0.015998). Sin embargo las diferencias fueron distintas para cada taxón. Riqueza y abundancia de árboles e índice de estructura vertical (índice de Thiollay) fueron los mejores predictores de la riqueza y abundancia de aves; mientras que la riqueza y abundancia de anfibios tuvo una relación negativa con el porcentaje de suelo desnudo. La riqueza de reptiles no fue explicada por las variables de composición y estructura de hábitat; sin embargo la abundancia obtuvo una relación positiva con la abundancia de Musaceae y presencia del sotobosque. Las métricas de paisaje fueron ineficientes en explicar la riqueza, abundancia y diversidad de aves, anfibios y reptiles. Esto puede ser a consecuencia del alto grado de fragmentación y homogeneidad del paisaje.

El presente estudio demuestra el valor de conservación de la biodiversidad que juegan los sistemas agroforestales de cacao complejos en estructura y composición botánica, pero enfatiza la idea que no son substitutos de los bosques naturales ya que no proveen los recursos necesarios para especies especialistas de bosque. Esto fue evidente ya que los bosques registraron la mayor riqueza de aves especialistas de bosque.

Palabras claves: biodiversidad, sistemas agroforestales de cacao, avifauna, herpetofauna, fragmentación, paisaje

SUMMARY

Arevalo, BM. 2010. The influence of habitat complexity and landscape context on the biodiversity conservation value of cacao agroforests in Waslala, Nicaragua. Thesis Mag. Sc. CATIE, Turrialba, CR. 88 p.

The rapid rate of deforestation and its implications on biodiversity conservation has lead to investigate the role that agroecosystems play in biodiversity conservation. Shaded crops, such as cacao agroforestry systems, are promising anthropogenic habitats for biodiversity conservation within an agricultural matrix. The objective of this study was to examine the effect of two critical elements for biodiversity conservation in agricultural landscapes: habitat structural complexity and landscape context. We tested the independent and combined impacts of these effects on birds, amphibians, and reptiles found in cacao agroforestry systems of Waslala, Nicaragua.

To examine the effect of habitat structure and landscape context, we sampled 36 cacao systems and 6 secondary forest fragments, used as reference systems. We measured habitat floristic and structural complexity using a 20 × 50 m quadrant and identified three agroforestry systems utilizing habitat floristic and structural complexity variables through a cluster analyzes. These systems can be classified along a gradient of complexity going from structurally simple to diverse systems: Cacao-Banana, Two-Strata Cacao and Diversified Cacao agroforests.

To test the effect of landscape context on biodiversity conservation, we measured the proportion of secondary forest cover at six different radii from the sample point: 500, 1000, 1500, 2000, 2500 and 3000 meters. We characterized avian community composition using 25 m fix radius point counts. We sampled the herpetofauna by following Whitfield's methodology.

During the study, we observe a total of 2914 birds belonging to 174 species, 195 amphibians from 12 species and 258 reptiles from 19 species in all habitats. Of the total 174 bird species recorded, 158 occurred within cacao agroforests, while the 12 of the amphibian species and 18 of the 19 reptile species recorded were found within cacao systems. We recorded the greatest mean bird richness in Diversified Cacao systems (34.92 ± 1.75) than in both Cacao-Banana (25.5 ± 2.57) and the Two-Strata (29.18 ± 1.53) systems, while Secondary Forest had an intermediate richness. Amphibian mean richness (F = 0.66, p = 0.5847) and abundance (F = 1.59, p = 0.2087) showed no significant difference among treatments; while reptile mean richness was significantly different among treatments (F = 3.29, p = 0.0315) but not for abundance (F=2.52, p = 0.0735). Greatest mean reptile richness occurred in both cacao-banana systems and secondary forests, while diversified cacao systems had the lowest mean richness. Global ANOSIM results showed significant differences for bird (r = 0.3111, p = 0.00009990), amphibian (r = 0.1147, p = 0.047395) and reptile (r= 0.157, p = 0.015998) species composition among habitats. However, these differences differed by taxa. Tree richness, abundance and vertical structure complexity index (Thiollay's Vegetation Index) were best predictors of bird richness and abundance, while amphibian richness and abundance were negatively related to percentage of bare ground. Reptile richness did not respond to any habitat variable measured, while abundance had a positive relationship with understory cover and Musaceae abundance. On the other hand the landscape metrics calculated were not efficient in explaining bird, amphibian and reptile species richness, abundance and diversity. This may result as a consequence of landscape homogeneity and high degree of forest fragmentation.

This study shows the biodiversity conservation value of floristic and structural complex cacao agroforestry systems but stress the idea that such habitats are no substitute to natural forests as they fall short in providing habitat and food resource to most forest affiliated species. This was evident as secondary forests supported greatest richness and abundance of forest specialist birds.

Key words: biodiversity, cacao agroforests, avifauna, herpetofauna, fragmentation, landscape

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ABBREVIATIONS AND ACRONYMS

AIC: Akaike’s Information Criterion
AFS: Agroforestry System
ANOSIM: Analysis of Similarity
ANOVA: Analysis of Variance
CATIE: Centro Agronómico Tropical De Investigación y Enseñanza
cm: centimetre
DBH: diameter at breast height
ETM+: Enhance Thematic Mapper Plus
GLM: Generalized Linear Model
ha: hectare
IUCN: International Union for the Conservation of Nature
Km: kilometre
m: metre
m.a.s.l.: metres above sea level
MANOVA: Multivariate Variance Analysis
MEA: Millennium Ecosystem Assessment
PCA: Principal Component Analysis
PCC: Proyecto Cacao Centroamérica

1 INTRODUCTION

Anthropogenic activities are fundamentally, and to a significant extent irreversibly causing biodiversity loss (Bennett 2004; McNeely and Scherr 2008). These changes have been occurring more rapidly in the past 50 years than at any other time in human history. The drivers responsible for this biodiversity loss accompanied by the concomitant change in ecosystems' services are indicating a steady increase with no indications of a decline (MEA 2005; Butchart *et al.* 2010). This has lead to a rapid rate of deforestation resulting in a race among conservationists to protect remaining forest remnants that are increasingly being isolated by an expanding agricultural matrix (Reitsma *et al.* 2001). These trends have led a growing number of scientists to investigate the role that agroecosystems play in providing habitat for tropical organisms (Lindell *et al.* 2004; Dahlquist *et al.* 2007; Cassano *et al.* 2009).

Within tropical agricultural landscapes, there is significant amount of area managed as agroforestry systems (SAF). These systems are characterized by a diverse structural complexity, providing critical resources (food and habitat) necessary for the conservation of many varieties of biodiversity (Alcorn 1990; Perfecto *et al.* 1996). Although evidence suggests that these systems are not a substitute for natural forests (Rice and Greenberg 2000; Butchart *et al.* 2010; Milder *et al.* 2010), these economically important anthropogenic habitats are gaining increasing conservation value with the continued deforestation of tropical forest (Pimentel *et al.* 1992; Cassano *et al.* 2009). Shaded agroforests, such as cacao SAF, provide habitat for some forest dependent species (Greenberg *et al.* 2000; Rice and Greenberg 2000; Greenberg 2008; Cassano *et al.* 2009) but their conservation value has been questioned due to their local scale of occurrence and because they essentially provide habitat and food for more generalized species (McNeely and Scherr 2008). Thus it is essential to understand which attributes contribute to conservation of forest dependent species.

Some biodiversity studies in cacao AFS show that biodiversity can be substantially higher than in other non-shaded agricultural systems even supporting some forest dependent species (Greenberg *et al.* 2000; Reitsma *et al.* 2001; Philpott *et al.* 2004; Cassano *et al.* 2009). Cacao agroforests vary in their structural and botanical complexity, two factors that play an important role in determining their conservational value (Reitsma *et al.* 2001; Harvey and Gonzalez Villalobos 2007; Deheuvels *et al.* in Prep.). Many studies to date have confirmed the importance of plant compositional and structural complexity on biodiversity conservation in agroforests (Greenberg *et al.* 2000; Reitsma *et al.* 2001; Perfecto *et al.* 2004; Faria *et al.* 2007; Clough *et al.* 2009; Deheuvels *et al.* in Prep.), however less understood is the contribution of the greater landscape context (Florian 2005; Ranganathan *et al.* 2007). In addition, the spatial context of cacao agroforests in regards to the immediate landscape, particularly their distance to natural habitats, can determine the level of biodiversity being supported (Ricketts 2001; Tasser *et al.* 2009).

Agroforests apart from providing habitat can act as important corridors or stepping stones particularly if located between forested areas. For example, an agroforest placed between reserves, or forest patches may contribute to connectivity, or an agroforest adjacent to a forest may play a buffering role, increasing the core area of the forest patch (Clough *et al.* 2009), increasing species permeability in a fragmented and human modified matrix (Murphy and Lovett-Doust 2004; Umetsu and Pardini 2007). In the island biogeography and metapopulation theory, a matrix of altered habitats is regarded as homogeneous and inhospitable (Vandermeer and Carvajal 2001) but recently, several authors have pointed out that landscape connectivity depends not only on the distance between remnants, but also on the presence of corridors, stepping stones and on the permeability of the matrix to the movement and occurrence of species.

The objective of this study is to evaluate and compare the effect that structural complexity and landscape context has on the conservation value of cacao agroforests in Waslala, Nicaragua.

1.1 Study objectives

1.1.1 General objective

- To examine the effect that structural complexity and landscape context has on the biodiversity conservation value of cacao AFS in Waslala, Nicaragua.

1.1.2 Specific objectives

- Evaluate the effect that landscape structure and composition has on the ability of cacao agroforest to maintain biodiversity.
- Characterize avian and herpetofauna diversity and composition supported by cacao agroforest.
- Compare avian and herpetofauna diversity among the different habitats studied.
- Evaluate the effect that habitat structure and composition has on the ability of cacao agroforests to support avian and herpetofauna diversity.

1.2 Study hypothesis

- ✓ The level of biodiversity sustained by cacao agroforests is positively correlated with the structural complexity of the plantation.
- ✓ The degree and repartition of forest cover in the landscape has a positive effect on the degree of biodiversity present in cacao plantations.
- ✓ An increase in the amount of forest cover in the landscapes have a positive relationship on the ability of cacao plantation in supporting biodiversity.

2 LITERATURE REVIEW

2.1 Community ecology

2.1.1 The Theory of the Island Biogeography

The Theory of Island Biogeography focuses on presence or absence of species in relation to patch (island) area (MacArthur and Wilson 1967). It suggests that larger islands (patches) are able to support greater species diversity (MacArthur and Wilson 1967) but decreases with increasing distance between patches. The theory stresses the role of area and geographical isolation as the main factor affecting biodiversity by affecting their colonization and extinction rates (MacArthur *et al*. 1972).

This idea can be applied to cacao agroforests because these are typically of limited size, embedded in an agricultural matrix with varying distance from remnant forests, affecting species richness and population density (McNeely and Scherr 2008). Root (1973) and MacArthur *et al.* (1972) propose two hypotheses explaining the relationship between animal population density and area. The first is the resource concentration hypothesis (Root 1973) and the second is the density compensation hypothesis (MacArthur *et al*. 1972). The first hypothesis suggests that animal population density is greater in larger areas because such areas are able to sustain higher amounts of critical resources (habitat, food, nesting and roosting site) than smaller parches (Root 1973). In contrast, the density compensation hypothesis proposes that individual species occurring in patches occur at greater densities on smaller patches in comparison to larger ones, due to the low species richness that can be sustained by these patches, reducing interspecific competition (MacArthur *et al*. 1972). The density compensation hypothesis stresses that larger patches have low population density as a consequence of high species richness indicating a negative patch area effect on density (MacArthur *et al*. 1972).

2.1.2 Habitat heterogeneity and cacao agroforests

Cacao agroforests, are considered structurally diverse agricultural habitats able to sustain some forest dependent species (Greenberg *et al.* 2000; Reitsma *et al.* 2001; Faria *et al.* 2007; Harvey and Gonzalez Villalobos 2007; Greenberg 2008; Clough *et al.* 2009). This conservation value is attributed to the variability in their structural and compositional complexity (Faria *et al.* 2006; Abrahamczyk *et al.* 2008). Agroforests maintaining a complex floristic composition, such as the rustic cacao systems, offer more resources to birds and other animals, than structurally homogenous habitats (Somarriba and Harvey 2003; Perfecto *et al.* 2004; Faria *et al.* 2007; Harvey and Gonzalez Villalobos 2007; Greenberg 2008). The degree of species richness supported by structural and floristically heterogeneous cacao agroforests can be explained by the habitat heterogeneity hypothesis (Cramer and Willig 2005). The hypothesis suggests that there exists a positive linear effect between habitat structural and floristic heterogeneity and species diversity due to an increase in the number of niches that can be filled favouring specialization and decreasing interspecies competition for available resources (Cramer and Willig 2005; Koh *et al.* 2006). Greenberg *et al*. (1995) suggests that maintaining habitat heterogeneity can be a means of conserving species richness in agricultural landscapes, allowing high species richness conserves both forest dependent and generalist species (Laiolo 2002).

Plant species diversity and density determine the physical structure of terrestrial habitats having an impact on the distribution and interactions of fauna (Cramer and Willig 2005; Koh *et al.* 2006). In this regard it is important to acknowledge the conservation value of many cacao agroforests due to their structural and floristic complexity within agricultural dominated landscapes (Schroth and Harvey 2007). MacArthur (1955) found that habitat structural complexity is more important than its floristic composition in maintaining forest bird diversity. However we must be critical in drawing conclusions on such findings, especially for cacao agroforests as these vary not only in structural and floristic composition but as well in their spatial distribution within the landscape, as what is perceived to be adequate habitat for one species may be perceived as habitat fragmentation for another species (Tews *et al.* 2004).

2.1.3 Landscape spatial configuration and heterogeneity

Landscape spatial configuration is defined as the specific arrangement of spatial elements or patch structure in the landscape (Turner *et al.* 2001). Configuration has implications on the conservation value of a landscape (Chardon *et al.* 2003). In highly fragmented landscapes species' survival rates are determined by their ability to disperse thus maintaining structural connectivity between remnant patches lowers the extinction risk of wild populations (Bennett 2004; Schroth and Harvey 2007). Connectivity of habitat patches within a landscape has therefore become a key issue in biodiversity conservation.

Habitat spatial heterogeneity has been recognized as an important factor in animal population dynamics (O'Neill *et al.* 1988; McGarigal and Cushman 2005; Castilla *et al.* 2009; Fraterrigo *et al.* 2009). These authors argue that although theoretical studies have suggested that space is a critical factor affecting species distribution and existence, spatial models indicate that patch configuration influences population dynamics. Spatial configurations of habitat can affect population dynamics by altering the likelihood that organisms will locate and gain access to patches suitable for occupancy (Wiens *et al.* 1993; Fahrig 2003). Because colonization is controlled by organisms' mobility, patch isolation as a consequence of fragmentation can be detrimental to the persistence of dispersal-limited species (Fraterrigo *et al.* 2009). An understanding of the processes driving species richness and of the scales at which they operate is crucial for conserving biodiversity in agricultural landscapes (Dauber *et al.* 2005).

2.1.4 Landscape fragmentation

Fragmentation and loss of natural habitats are of global concerns due to negative implications on biodiversity conservation (Lauga and Joachim 1992; Wiens *et al.* 1993; Fraterrigo *et al.* 2009). Anthropogenic activities have modified the natural environment to the point that the most common landscape is a mosaic of human settlements, farmlands and fragmented natural ecosystems surrounding protected areas (Cox *et al.* 2004; Fitz-Gibbon *et al.* 2007). As is the case for Waslala, habitat fragmentation has been so great that presently it has a pastureland matrix, where natural forests represent only 11 to 15% of the total land cover (CATIE 2009).

Habitat fragmentation is an active and dynamic process resulting in the reduction in size and isolation of natural systems over time (Cox *et al.* 2004). According to Bennett (2004) and Cox *et al*. (2004), "fragmentation" is defined as the changes that occur when contiguous natural habitats are broken into small and scattered remnants. Fragmentation begins as a gap surrounded by natural vegetation, which has little effect on species composition, structure and richness but as the gap size and degree of isolation between remnants increase, natural communities become heavily impacted causing conservation concerns (Ritters *et al.* 1997; Ritters *et al.* 2000; Fitz-Gibbon *et al.* 2007).

According to Bennett (2004), fragmentation is characterized by: a) loss of natural habitat in the landscape, b) natural habitat size reduction, c) isolation of habitat fragments and, d) human use of the matrix surrounding isolated fragments increase and intensified. This process leads to the formation of marked edges (abrupt transitions between natural vegetation and adjacent altered habitat) creating a distinctive contrast in the structural and floristic composition between different patches (Kupfer *et al.* 2004; 2006). Marked edges impact species movement patterns through the landscape affecting species ability to colonize adequate habitats and by limiting their access to food (Hinsley *et al.* 1996; Alderman *et al.* 2005).

2.1.5 The Matrix effect

The landscape's matrix refers to the dominant mosaic of land cover including pastures, croplands, plantations and secondary forests in which remnant forests are isolated from each other (Umetsu and Pardini 2007). The matrix impacts biodiversity through what is known as the "matrix effect" acting as a filter for the movement of organisms through the landscape (Kupfer *et al.* 2004; 2006).

The matrix in human dominated landscapes were seen as static, homogeneous and inhospitable acting as an obstacle in landscapes' structural and functional connectivity (Vandermeer and Carvajal 2001) but recently, several authors have pointed out that landscape connectivity is determined not only by the distance among remnants, but also by the matrix degree of permeability to the movement, occurrence and colonization of species (Murphy and Lovett-Doust 2004; Umetsu and Pardini 2007). For example, in Waslala this concept is important because the landscape is dominated by an agricultural matrix that will directly impact diversity in forest remnants and cacao agroforests as the distance between these increases.

The matrix influences species diversity (Gascon *et al.* 1999; Kupfer *et al.* 2006; Haynes *et al.* 2007a; Haynes *et al.* 2007b) by altering their needs through resource depletion (Berry *et al.* 2005; Haynes *et al.* 2007a; Haynes *et al.* 2007b) and by affecting their mobility in the landscape (Ricketts 2001). However, the matrix is not homogeneous, its characteristics and impacts on the natural environment are as a consequence of the intensity and extent of the land uses within it (Umetsu and Pardini 2007). Berry *et al.* (2005) state that in order to develop effective and concrete conservation strategies in human dominated landscapes it is essential to consider both the composition of patches and their configuration within the matrix.

2.2 Ecological consequences of habitat fragmentation

The major impact of fragmentation is species loss due to habitat loss and size reduction (Cox *et al.* 2004; Fitz-Gibbon *et al.* 2007; Moser *et al.* 2007; Mapelli and Kittlein 2009); larger fragments conserve greater diversity of flora and fauna compared to small and isolated patches (MacArthur and Wilson 1967); Kupfer *et al*. 2004). When species become isolated in a fragment, their survival depends on fragment size, quality and spatial configuration of remnants (Brouwers and Newton 2009), species' dispersal ability and population dynamics (Lauga and Joachim 1992; Castelletta *et al.* 2005).

Reduction in habitat cover, patch size and connectivity have been argued to have negative effects on tropical forest species (Castelletta *et al.* 2005; Develey and Metzger 2006) but the response to these parameters is dependent on species' perception of habitat. Uezu *et al* (2005) found that frugivorous birds in the fragmented Brazilian Atlantic forest were more affected by patch size than insectivorous species, being more abundant in interconnected forests. Some authors suggest that forest bird species survival in fragmented landscapes with limited suitable habitats (less than 30% of habitat cover), depends on the size and structural connectivity among remaining patches (Andren 1994; Metzger and Decamps 1997; Uezu *et al.* 2005).

2.3 Cacao agroforests

According to McNeely and Scherr (2008), agroforestry refers to the system of land use in which harvestable trees or shrubs are grown among or around crops or on pastureland, as a mean of preserving or enhancing productivity; this is done simultaneously or in a sequential manner in order to make the best use of the available resources. This concept encompasses a wide array of practices that include tree polyculture with crops, live fences, shade stripes of vegetation along water ways, kitchen gardens, and multistory to multispecies home-gardens (Somarriba and Harvey 2003). Cacao agroforests can be defined as shade grown cacao farms in which other plants, including timber trees, fruit trees and food crops, are grown together with cacao (Asare 2006).

2.4 Cacao agroforests in Mesoamerica

In Central America cacao agroforests are in the hands of small indigenous farmers. Cacao growers under the scope of Proyecto Cacao Centroamérica (PCC) cultivate 7,996 hectares producing around 1,515 tons of certified cacao, with an aggregated value of 2.12 million U.S. dollars per year (PCC 2007). These plantations coincide with the Atlantic Mesoamerican Biological Corridor and with other key biodiversity conservation areas (Somarriba and Harvey 2003). Countries such as Belize, Nicaragua and Panama include cacao production as a poverty alleviation strategy through the concept of crop diversification (PCC 2007).

According to PCC (2007) cacao agroforests occur at altitudes between 30-900 m above sea level, with farm size ranging from 0.2 to > 5 ha per farm. Average size is 1 ha. These agroforestry systems have an average density of 200 to 900 cacao plants per hectare depending on the country and can contain up to 125-145 tree species in their shade canopy (based on a 25 ha cacao agroforest assessment by country), while average tree density is 122 per ha^{-1} with a range of 85-198 tress per ha^{-1} (PCC 2007). Many of these trees additionally serve as sources of firewood, lumber, medicine and fruits (Somarriba and Harvey 2003). Shade trees are of varying heights, but are distributed among 50:30:20 % of the total density in three vertical strata (low strata <10 m; medium strata 10-20 m and high >20 m) (PCC 2007). The cacao plantations of Nicaragua are among those having greatest tree diversity of all six countries investigated in the PCC project.

2.5 The conservation value of cacao agroforestry systems

In general, agroecosystems dominate tropical landscapes, where isolated forest remnants are embedded in an agricultural matrix (Pimentel *et al.* 1992; Cassano *et al.* 2009). Many forest species interact with the surrounding agricultural landscape, especially in agroforestry systems, where forest dependent species are able to exploit available resources (Abrahamczyk *et al.* 2008; Greenberg 2008) but it is important to underscore that agroforests are not substitutes for natural forests but provide secondary habitats for organisms (Reitsma *et al.* 2001; Asare 2006; Harvey and Gonzalez Villalobos 2007; Schroth and Harvey 2007; Cassano *et al.* 2009). Because of their diverse shade tree composition (PCC 2007), agroforests provide critical resources for wildlife (Greenberg *et al.* 2000), they are promoted as conservation tools especially within biological corridors and in buffer zones of protected areas where they act as transition zones reducing edge effect and increasing connectivity within the matrix (Bos *et al.* 2007; McNeely and Scherr 2008; Clough *et al.* 2009). Although cacao AFS are recognized as biodiversity friendly agricultural systems it is still uncertain if these agroecosystems provide adequate forested habitat and sustainable resources or serve as second class habitats increasing wildlife movement permeability within an otherwise hostile matrix (Faria *et al.* 2006; Kupfer *et al.* 2006; Lozada *et al.* 2007).

Rustic and highly diverse cacao agroforests are able to support moderated diversity of forest dependent species, while serving as adequate habitat for more generalists (Greenberg *et al.* 2000; Rice and Greenberg 2000; Faria *et al.* 2007). The ability of cacao agroforests to support forest dependent species is highly dependent to their structural complexity and spatial configuration in regards to forest remnants (Somarriba and Harvey 2003; Harvey and Gonzalez Villalobos 2007). Greenberg (2008) and Abrahamczyk *et al*. (2008), support the idea that cacao agroforests found close to forest fragments support more forest dependent bird and other animal species than do isolated agroforests. Young (1994), (cited by Faria *et al*. 2007) makes a similar statement for invertebrates, including cacao pollinators.

2.6 Avian diversity in cacao agroforestry systems

Many avian diversity studies in cacao agroforests have shown substantially greater diversity than found in other non-shaded agricultural systems that include some forest species (Greenberg *et al.* 2000; Reitsma *et al.* 2001; Perfecto *et al.* 2004; Faria *et al.* 2006; Faria *et al.* 2007; Harvey and Gonzalez Villalobos 2007; Schroth *et al.* 2007; Cassano *et al.* 2009).but support more generalist species. In Mexico Greenberg (2008) found that structurally complex cacao agroforests and remnant forests share a high proportion of common species, both resident and migratory, including forest-dependent migrants. This study also coincides with the results obtained by Robbins *et al.* (1992) in Belize were the cacao plantations had the most similar migrant assemblage to natural forest than other agricultural land uses.

In Southeastern Costa Rica, Reitsma *et al.* (2001), compared avifaunal diversity in forests, abandoned cacao and managed cacao plantations and reported 130, 131, and 144 total species respectively. Abandoned and managed cacao had significantly more individual birds than forest but forest specialists occurred less in cacao plantations. Reitsma *et al*. (2001) found that cacao density, canopy height, canopy cover, shade tree abundance and diversity as well as distance from forest had an effect on forest dependent bird diversity. Clough *et* al (2009) conclude that many forest specialists are unlikely to exist in cacao plantations without the immediate proximity of natural forest. Frugivores and nectivores, generally being forest specialists, show a remarkable decrease in diversity as distance between cacao agroforests and remnants increase but not the case for insectivorous (Reitsma *et al.* 2001; Clough *et al.* 2009).

2.7 Cacao agroforests' and landscapes' context role in herpetofauna conservation

Herpetofauna are important ecological indicators and play a critical role in the demonstrating the effect of land use change on biodiversity (Bell and Donnelly 2006). Bell and Donnelly (2006) report that amphibians and reptiles are not severely affected by forest fragmentation as they reported 75% of forest dependent species in remnants studied. Russell *et al*. (2002) and Loehle *et al.*(2005) suggest that amphibian diversity is more dependent upon the availability of water bodies in the landscape than on the size and shape of the forest remnants, due to their unique reproductive requirements. This statement is conclusive with that of Bell and Donnelly (2006) who state that anuran diversity in a given habitat is highly dependent on the availability of breeding habitats.

Vallan (2000) suggests that edge effect has negative implications on anuran diversity due to changes in microclimatic conditions. Consequently, anurans are affected due to their permeable skin, shell-less eggs and aquatic habitat requirements. This assumption is contradictory to Dixo and Martins (2008), who found that despite the variation in structure between forest interior and edge, no significant differences were found in herpetofaunal abundance, richness and diversity between forest edge and interior.

Limited research has been conducted within cacao agroforests to evaluate their contribution to herpetofauna conservation (Wanger *et al.* 2009). It is highly suspected that cacao agroforests are essential agricultural habitats for the conservation of amphibians and reptiles due to their high structural diversity. A study conducted by Wanger *et al*. (2009) in Central Sulawesi, Indonesia found that 50% of all identified herpetofauna species within cacao AFS were forest specialists; stressing the important role that cacao agroforests play in the conservation of these taxa. The investigators conclude that high species diversity is a consequence of the structural complexity and high degree of fallen logs and thick leaf litter supported by these systems; this investigation also supports the assumption made by Loehle *et al.* (2005). Dixo (2001) (cited by Faria *et al*. 2007) in his study conducted in Una, Brazil, found no difference in the abundance and species richness of leaf-litter herpetofauna between cacao agroforests and forest remnants.

Although the conservation value of cacao agroforests is highly dependent on intrinsic habitat characteristics the landscape context upon which they are found also plays a crucial role in this matter (Ryan *et al.* 2002). Research by Faria *et al* (2007) in cacao agroforests of Bahia, Brazil indicate that there is higher herpetofaunal diversity in cacao agroforests within a landscape with limited forest cover but when forest cover increases within the landscape, these agroecosystems become less important for biodiversity conservation. Overall they report that 81% of the total anuran species and 85% of reptiles reported to occur in forest fragments were recorded in the cacao agroforests.

3 METHODOLOGY

3.1 Site description

We conducted the study in the municipality of Waslala located in the extreme southeast of the North Atlantic Autonomous Region of Nicaragua. Its geographic centre is 13^{o}20' north latitude and 85^{o}22' west longitude, with an extension of 1,333 km^{2} and mean altitude of 420 m above sea level. Waslala has a tropical moist climate with annual temperatures oscillating between 18 and 26° C and mean annual precipitation ranging between 2000 and 3000 mm (CATIE 2009). To the north and east, it is bordered by the municipality of Siuna; to the south by Rio Blanco and Rancho Grande; and to the west by the municipalities of Cua, Bocay and Rancho Grande (CATIE 2009). It is found within the buffer zone of BOSAWAS Biosphere (being one of the largest protected area in Central America with an extension of 20,000 km^{2}, translating to 14% of the total Nicaraguan territory) and also borders Cerro Banacruz Nature Reserve. According to the Holdgridge's life zone classification system, Waslala can be classified as very humid subtropical forest, now dominated by a matrix of agricultural lands with remnant semidecidious broadleaf forests (Figure 1).

Waslala's topography characterized as undulating to rolling hills with 32° slopes (Philipp and Gamboa 2003) making the area unsuitable for agriculture even though most of Waslala's population is engaged in traditional agriculture which consists of the main economic activity in the region. In recent years cattle ranching have shown a steady increase (Proyecto CATIE-Mesoterra 2009).

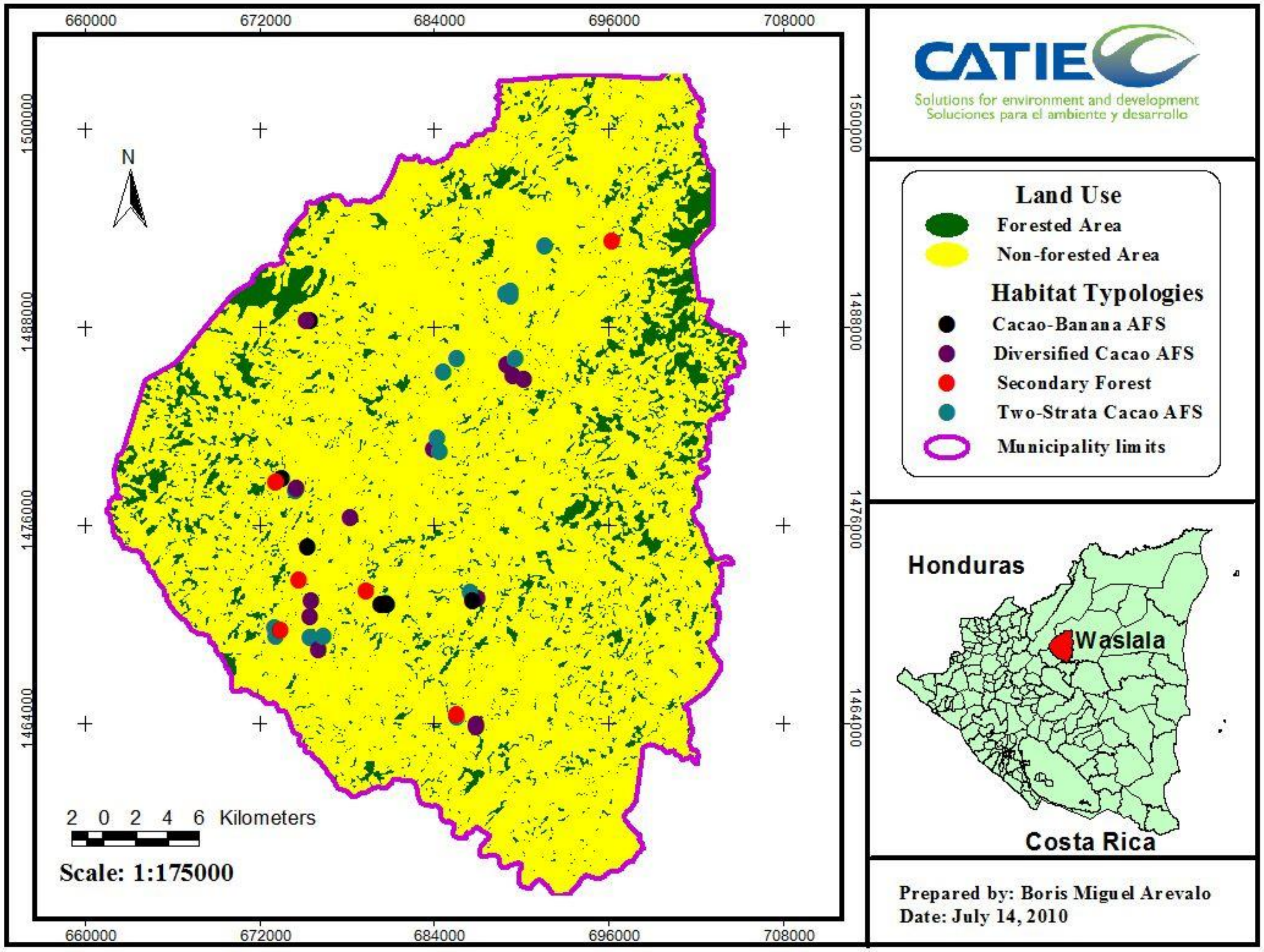

Figure 1. Land use map of Waslala, Nicaragua.

3.2 Cacao agroforest selection

For this study, we selected a total of 36 cacao agroforests and 6 secondary forest remnants. These patches were distributed among 16 communities throughout the municipality (Annex 1) in a sampling network established by the PCC. Criteria use to select the sampling units included willingness of the proprietor to participate and accessibility to the site. The mean area of sampled cacao agroforests was1.01 ± 0.55 ha, with a minimum and maximum area of 0.40 and 2.5 ha respectively. Mean area for the forest remnants was 6.84 ha with a minimum and maximum area of 2.5 and 14.8 ha respectively.

3.2.1 Habitat structural and floristic complexity

We characterize floristic composition by establishing a 20 × 50 m (0.1 ha) sampling parcel in the "central" point of each cacao plantation. The central point was visually estimated and selected whether the 0.1 ha plot would fit allowing the maximum distance from the plantation's edge, in order to reduce edge effect. The 0.1 ha sampling unit was subdivided into 10 subunits each measuring 10 × 10 m. Within each 0.1 ha sampling units, all trees with a diameter $\geq$ 10 cm were identified and recorded, dbh and height were measured. All cacao trees were counted, height was visually estimated and trunk perimeter was measured at 30 cm above ground. All the above data was collected by undergraduate students working under PCC. Additional measurements taken included: number of flowering and fruiting trees.

Using the central point of each resulting 10 × 10 m quadrant, we measured percentage canopy and ground cover. Percentage canopy cover was measured using a spherical densitometer. A total of 4 readings were taken in each sub-parcel, using the plots' cardinal points as references, from these readings; we used an average as the measured canopy cover for the sampling unit. We visually estimated ground cover. We achieved this by randomly placing a 1 × 1 m frame at the "central" point of each of the 10 × 10 m quadrants, then proceeded to estimated percentage herbaceous, bare ground and leaf-litter cover; an average value was reported for each 0.1 ha sampling site.

Structural vertical heterogeneity was measured using Thiollay's (1992) methodology. A mean value was used for each strata, while the total structural vegetation index was calculated as a sum of all the mean strata values.

3.2.2 Cacao agroforestry types based on structural parameters

In order to identify different structure types of cacao agroforests, we developed a typology through a cluster analysis using Wards method with Euclidean Distance calculated based on habitat structural (leaf litter %, shade %, Thiollay's Vertical Structure Index) and compositional (Weed Cover %, Musaceae abundance and basal area, cacao abundance and basal area, tree abundance, richness and basal area) variables. We indentified these variables to be explaining most of the variability among typologies through a Principal Components Analysis (PCA), where the results were graphed in a biplot to visualize typologies' associations with habitat and structural variables. We tested for statistical difference between habitat typologies by conducting a Multivariate Variance Analysis (MANOVA).

3.3 Landscape characterization

We characterized the landscapes into two categories, forest and non-forest, by using 7 band Landsat ETM+, with 30 m resolution, from 2001 and 2005 satellite images. A 2001 image was used to compensate for the damages found in the 2005 image as a consequence of satellite failures. We were limited to a bionomial classification because of the image's resolution. Forested areas were those areas possessing forest cover (secondary forest, secondary growth, dense agroforests), while non-forested areas included areas lacking tall-dense vegetation (agricultural fields, open and slightly shaded pastures, human settlements). Segregation between vegetated (forested) from non-vegetated (non Forested) areas was visually achieved during the manual digitalization of the image.

We converted the Waslala vector map to raster format. We used the buffer extension from ArcView GIS 3.3 to create nested plots of 500, 1000, 1500, 2000, 2500 and 3000 m radii. These plots correspond to circular area plots of 78.5, 314.2, 706.5, 1256, 1962.5 and 2826 ha respectively (Figure 2). We clipped each buffer using the GeoProcessing extension. Once the buffer around each of the 42 plots was clipped, we characterized the landscape within nested plot by calculating percent forest cover, forest patch density, distance to the nearest forest patch and mean patch area using a 4 and 8 neighbour rule in Fragstats 3.3 (Table 1). To calculate the landscape metrics, physical directories were created for each buffer, which were later utilized to create a "*batch file*" also a "*class property file"* was created which had the codes and description of the land cover types.

We calculated distance from the central point of the sampling units to the nearest forest edge using a straight line, as this will be the minimum distance to be travelled by an organism moving for one patch to the next.

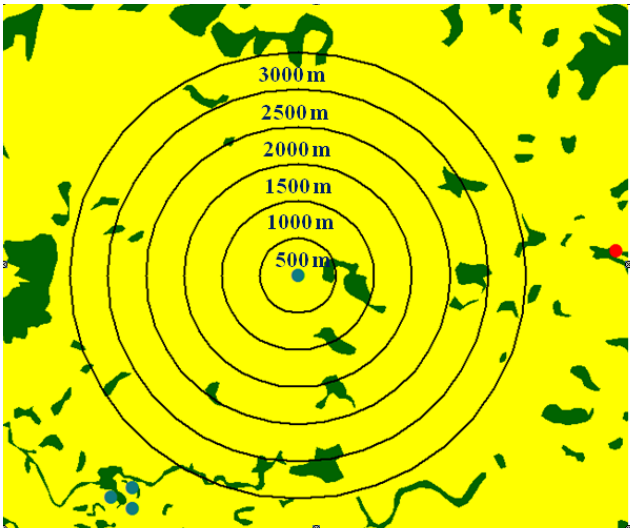

Figure 2. Design of the spatial arrangement of concentric circles (buffers) around each sampling unit (blue dot), where landscape metrics were calculated.

Table 1. Description of the landscape metrics calculated using the software Fragstat 3.3 for each of the established buffers around each sampling unit.

Landscape variables	Description
% forest cover	% forest cover found in each buffer
Distance to the nearest forest patch	Distance to the nearest forest patch measured in straight line from the center of the study plot to the edge of forest.
Mean patch area	Mean area of all forest patches in each buffer.

3.4 Characterization of avian and herpetofauna communities

3.4.1 Avian communities characterization

In each of the 42 sampling units, we established a 25 m fixed-radius point count in order to measure avian diversity. We established the point counts at the center of the plantation for the cacao agroforests, whereas in the secondary forest fragments these were placed as far from the forest edge as possible (minimum distance was 70 m). The distance from the edge depended on the size of the fragments as well as on the topographic conditions of the terrain (Figure 3). The 25 m fixed-radius point counts are a standard technique for bird surveys in tropical habitats allowing fast and efficient sampling of avian communities (Wunderle 1994; Ralph *et al.* 1996).

We visited each point count four times; two visits were conducted during the mornings and two during the evenings. Point count surveys were conducted for 60 consecutive minutes, starting five minutes after arrival to the site. To assure its efficiency, the sites were reached as quietly as possible. The point counts surveys were conducted between 05:30 and 10:00 and for another 60 minutes between 14:30 and 18:30. The total observation time per point count was 120 minutes (60 minutes × 2 times/day × 2 days); giving a total of 240 minutes per site throughout the study period. For each 60 minute point count the following data were collected: species, number of individuals of the species, method of detection, location or strata of occurrence, bird’s activity and sex if possible. The bird surveys were conducted between the months of February and June of 2010. Bird species seen or heard flying overhead or flying through the point counts were recorded in a different data sheet and were not considered in the statistical analysis of the data. We conducted statistical analysis on bird species richness and abundance observed within the limits of the point counts.

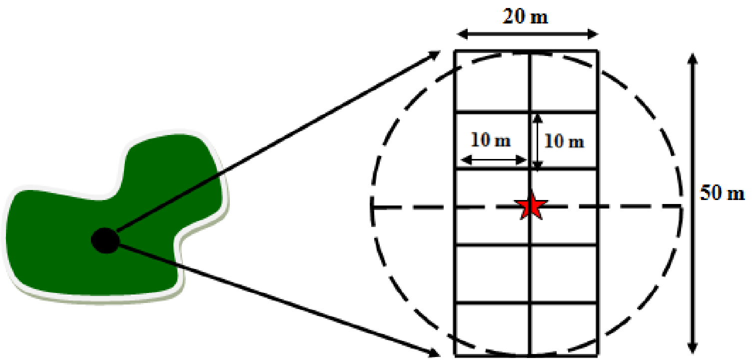

Figure 3. Sampling plot design, doted circle represents the point counts; grid represents the sampling parcels (20 m × 50 m) used for structural complexity and floristic composition measures for each site; red star represents center point of study site; green polygon represents cacao field; filled black dot represents the location of sampling parcel within the cacao field.

3.4.2 *Characterization of herpetofauna communities*

We used herpetofauna data provided by PCC in this study. Byron Molinares collected these data. A set of 8 sub-parcels of 5 m × 5m each were located within the 50 m x 20 m grid used for structure measures. Subplots were separated by a distance of 10 m from each other (Figure 4). He employed an active search in a zigzag pattern searching for reptiles and amphibians in the leaf litter and on tree trunks up to 2 m height. The surveys were conducted during the mornings between 9:00 AM to noon, and during the night from 20:00 to 24:00. Four surveys were conducted, two during the rainy season (November to December, 2009) and two during the dry season (April to May, 2010). The center of these herpetofauna survey plots were the same as those used for the avian point counts.

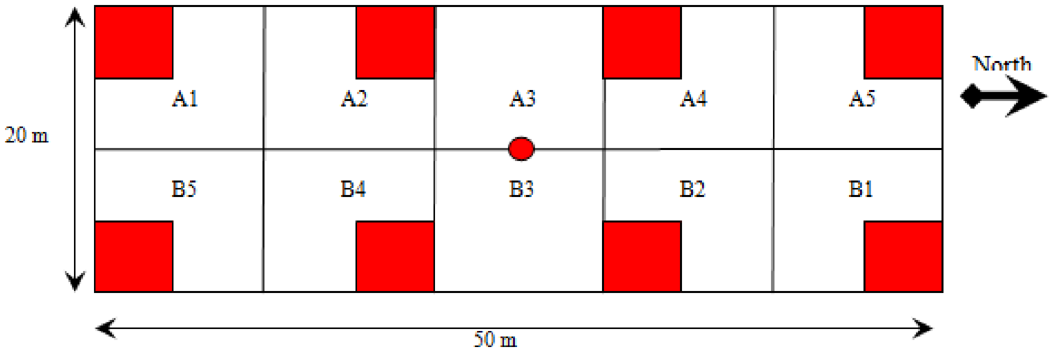

Figure 4. Representation of herpetofauna sampling plot design; grid = vegetation sampling plot; filled red squares = 5 m × 5m herpetofauna survey sub-parcels; filled red dot = central point of sampling plot.

The sampling design and method was based on Whitfield *et al* (2007). Field identification of species was based on morphological characteristics following the field identification guides of Solórzano (2004) and Savage (2002). Detailed photographs were taken of the individuals that were difficult to classify for cross reference, and identification in the laboratory.

3.4.3 Avian composition

We classified bird species into guilds (Table 2) according to Stiles (1985), Stotz *et al.* (1996), Lee Jones (2003) and Stiles & Skutch (2003). The assignation of species to foraging strata was based on Philpott *et al*. (2009). Species categorized as understory foragers are those primarily reported as foraging on the forest floor and understory; canopy foragers are species that forage primarily on the middle to upper canopy, while both-strata foragers were species considered to be aerial foragers or that forage both in the understory and canopy layers. Additionally bird species were classified into dietary guilds following Stiles and Skutch (2003) and Lee Jones (2003) as follows: insectivores (species that feed almost exclusively on invertebrates), frugivores (species that feed more than half of the time on fruits or on the seeds of fruits while on trees), nectivores (birds that feed more than half the time on nectar), omnivores (birds that feed on a mixed diet of arthropods, fruits, nectar, or seeds), granivores (birds that feed on seeds) and carnivores (birds that feed on flesh, such as hawks and owls).

We further categorized birds according to degree of forest dependence based on Stiles (1985). Species were separated into forest specialist (species exclusively found in forests or that need of more than 50% forest cover for their survival), forest generalists (species that persist in fragmented forests with less than 50% forest cover and occur in forest edges, provided that some canopy trees remain in deforested areas) and generalists (bird species that require no forest for survival but can persist in secondary growths, thickets, agricultural lands and favour deforestation). To further investigate the role that cacao agroforest play in the conservation of birds, we categorized birds into high, medium and low degree of sensitivity to human disturbances based on Stotz *et al*. (1996).

Table 2. Guild classification schemes used to study avian composition supported by cacao agroforests.

Strata of occurrence	**Foraging**	**Dietary**	**Forest dependence**	**Sensitivity to human disturbances**
Understory Middle canopy Upper canopy	Understory Canopy Both Strata	Insectivores Frugivores Nectivores Omnivores Granivores Carnivores	Forest specialists Forest generalists Generalists	Low Medium high

3.4.4 Avian and herpetofauna composition and diversity within each habitat

We combined the data collected for birds during the two sampling dates to obtain species richness and abundance per sampling unit. For each sampling unit species richness (S), evenness (E), Shannon-Wiener Diversity Index (H), Simpson Index (D) and Margalef Index (D_{mg}) were calculated utilizing the statistical program ESTIMATES 8.0 (Colwell 2010) and InfoStat (Grupo Infostat 2010)**.** The formulas and description of these indexes are explained in Table 3. We did the same as above with the herpetofauna data.

We constructed rank-abundance curves for each habitat in order to evaluate species abundance distributions in relation to dominant and rare species. We used rarefaction curves were to account for differential sampling efforts individually for the avian and herpetofauna studies. The rarefaction curves were constructed utilizing the S_{obs} (mao tau) results obtained from the statistical program EstimateS 8.0 (Colwell 2010). The Clench's model (Clench 1979) was employed in order to estimate the expected number of species in each habitat and to determine sampling efficiency. To achieve this the S_{obs} obtained from EstimateS were utilized to do a non-linear regression in InfoStat, utilizing the Clench's Model: $S(n) = (a*n) / (1 + (b*n))$, where '*S'* denotes species richness, '*n'* is the number of samples pooled, *a* and *b* are constants; from the results of this model the intercept of the curve on the 'Y' axis (*a*) and slope of the curve (*b*) were utilized to calculated expected richness. Estimated species richness by habitat was obtained by employing the formula:

$$\boldsymbol{Estimated\ Species\ Richness = {}^{a}/_{b}}$$

Where:

a = the intercept of the curve on the 'Y' axis

b = slope of the curve

Table 3. Diversity indices measured and their respective formula and description.

Diversity Index	Formula	Explanation
Shannon-Wiener (H')	$H' = \Sigma p_i \ln p_i$	Accounts for the abundance and evenness of species present. The proportional abundance of species *i* divided by the total number of individuals in the sample (*pi*) is calculated and multiplied by the natural logarithm of the proportion (ln*pi*). The values of H' range between 0 and log S.
Simpson Index (D)	$D = \sum p_i^2$	Shows the probability that two species randomly selected in a sample are of the same species. It takes into account the representativeness of species with a higher importance value without evaluating its contribution to the rest of the species. Where p_i = proportional abundance of specie ***i.***
Evenness (E)	$E = H'/\ln(S)$ $0 \leq E \leq 1$	Shows the relationship between the abundance of each species and how evenly these individuals were distributed among species. When the value of **E** is close to zero (0), means that one specie dominates the community and when it approaches 1, all species shared similar abundance.
Margalef Index (D_{Mg})	$D_{Mg} = (S - 1)/\ln(N)$	Shows the relationship between the number of species and the number of individuals. The index will vary with the number of individuals. Values closer to zero mean that there are few species. Where ***S*** = # of species and ***N*** = total # of individuals.

Source: adapted from Moreno (2001).

We conducted indicator species analysis with PCORD 5.1 (McCune and Mefford 1999) using Dufrene and Legendre's method with 1000 permutations to identify the characteristic species in each of the habitats studied.

3.4.5 Avian and herpetofauna richness, abundance and diversity comparison between habitats

To compare mean avian and herpetofauna richness, abundance and diversity among habitats we used simple ANOVA with LSD Fisher mean comparisons. Variables that did not met the ANOVA assumptions (independence, normality and variance equity) were rank transformed. Avian and herpetofauna species richness, abundance, diversity indices (H', D', D_{Mg} and E), in addition the birds foraging and dietary guilds as well as degree of forest dependence and sensitivity to human disturbances were regarded as dependent variables. We used ANCOVA to determine if the co-variables (structural and compositional complexity of habitats) affect bird and herpetofauna abundance, species richness and diversity across different habitats. InfoStat (Grupo Infostat 2010) was used to conduct these analysis.

The sampling structure was according to a randomize design, whose ANOVA model was:

$$\Upsilon_{ijkl} = \mu + T_i + \mathcal{E}_{ijkl}$$

where:

Υ_{ijkl} = observed response of the variable of interest

μ = general mean

T_i = habitat typology effect

$\mathcal{E}_{ijkl}$ = error term, which is independent, randomized and having a normal distribution with a mean of zero and a constant variance.

We conducted an Analysis of Similarity (ANOSIM) to compare species composition between habitat types. ANOSIM was performed using the statistical software R, using Bray-Curtis similarity distance with 10,000 permutations (R Development Core Team 2008). To identify if there were difference based on species composition among habitats, we conducted a global ANOSIM. We followed this with a pair wise ANOSIM in order to identify the habitats that differed from each other.

3.4.6 Avian and herpetofauna community relationship with habitat complexity and landscape context.

To explain the relationship between avian communities with habitat complexity and landscape structure, we utilized simple linear regressions. We first constructed a Classification-Regression Tree; variables retained (variables explaining more variability in the data set) were used as regressors. With the retained habitat variables from the Classification-Regression Tree, we constructed a dendrogram using Pearson's similarity distance; this to exclude correlated variables. Habitat variables included in the regression models were: bare ground (%), shade

(%), weed cover (%), tree density, tree richness, total basal area, Musaceae density, Musaceae basal area, cacao density and basal area, cacao height and Thiollay's index of vertical heterogeneity. We include slope and altitude for herpetofauna. Distance to water bodies, distance to the nearest forest patch, percentage of forest cover, mean forest patch area and forest patch density were the landscape metrics we used as regressors. The variables retained in the model were based on their CP Mallow's index and Akaike's Information Criterion (AIC) used to examine model's goodness of fit. Dependant variables were squared root transformed if the model's mean quadratic error (ECMP in Infostat) was considered relatively high.

To explore the relationship between herpetofauna diversity and habitat and landscape metrics, we used simple linear regressions using generalized linear models (GLM), utilizing Poisson Distribution due to the many zeros found in the herpetofauna data. This analysis was conducted using the statistical program R (R Development Core Team 2008).

We complete correlation analyses to explore the relationship between avian and herpetofauna species composition and habitat structural and compositional variables. First we computed a Principal Coordinate Analysis on species composition to reduce data dimensions, utilizing Bray-Curtis distance. The total number of axis retained had to explain at least 80% of the variance. Using the axes from the Principal Coordinate Analysis, we conducted a Spearman's Correlation Analysis for avian composition and Pearson's Correlation for herpetofauna composition data with habitat structural and compositional variables.

4 RESULTS

4.1 Landscape characterization

Of the 1333 km^2, of territory that comprise Waslala, 263 km^2 (24%) were under some type of forest cover (tall vegetation) while 1070 km^2, were comprised of agricultural lands (agricultural matrix dominated by basic grain crops and pastures). Mean forest patch area was 13.6 ha with minimum and maximum areas of 0.3 and 715 ha respectively. Although there were relatively large forest patches only 14% of all forest patches were >20 ha.

Even though mean forest patch area increased with increasing buffer size as a consequence of reduced landscape truncation, the percent forest cover within each buffer remained constant at all extensions used (ANOVA: F = 0.6, p = 0.66), varying between 13 to 15%. Euclidian mean distance to the nearest forest patch was significantly different among the buffers (ANOVA: F = 3.10, p = 0.0098) (Table 4). Highest Euclidian distance was recorded for buffers 1500, 2500 and 3000, on the other hand lowest distance was registered for buffers 500 and 1000, while buffer 2000 had an intermediate distance from the centre of the sampling units to the edge of the nearest forest patch was 210 m (±112), while mean distance from sampling unit to the nearest body of water was 98.89 m in straight line (Table 4).

4.1.1 Relationship between avian and herpetofauna communities with landscape metrics

The simple and multiple linear regression conducted in order to identify relationships between bird and herpetofauna richness, abundance and diversity with the landscape metrics calculated utilizing the 4 and 8 neighbour rule, showed that none of the metrics calculated were good predictors of the response variables. This result may be as a consequence of the high degree, and even distribution of fragmentation within the landscape.

Table 4. Mean plus standard deviation, minimum, maximum and coefficient of variance (CV) values by buffer for the landscape metrics calculated. Note: distance to water body was calculated once

Variable	**Buffer**					
	500 m	**1000 m**	**1500 m**	**2000 m**	**2500 m**	**3000 m**
Distance to Water source (m)						
Mean ± SD	98 ± 154	---	---	---	---	---
Minimum	50	---	---	---	---	---
Maximum	800	---	---	---	---	---
Forest cover (%)						
Mean ± SD	14.98 ± 6.7	13.57 ± 3.75	13.46 ± 4.53	14.28 ± 4.61	14.59 ± 4.8	14.79 ± 4.24
CV	44.69	27.61	33.65	32.28	32.94	28.66
Minimum	5.4	7.2	4.7	3.5	4.1	5.1
Maximum	29.5	21.6	26.8	27	30.7	29.1
Forest patch mean area (ha)						
Mean ± SD	2.27 ± 1.4	3.54 ± 1.36	4.73 ± 2.08	5.61 ± 2.23	6.36 ± 2.59	6.92 ± 2.56
CV	61.89	38.42	44.1	39.7	40.71	37.07
Minimum	0.7	1.8	2	2.5	3.5	2.8
Maximum	9.5	8.1	8.8	10.9	14.3	15.2
Distance to nearest forest patch (m)						
Mean ± SD	1497 ± 89	143 ± 60	160 ± 52	154 ± 50	156 ± 40	158 ± 31
CV	59.6	41.7	32.5	32.2	25.7	31.3
Minimum	52	72	74	93	102	108
Maximum	400	372	311	372	321	286

4.2 General description of habitats studied

Out of the 42 sampling units (cacao agroforests: n = 36; secondary forest: n = 6), the cluster analysis differentiated four habitat typologies (Figure 5). The typologies chosen based on the degree of similarity among sampling units of the same cluster were Secondary Forest (n=6); Diversified Cacao agroforests (n=13), Two-Strata Cacao agroforests (n=17) and Cacao-Banana agroforests (n=6). The clusters were statistically different (MANOVA: F = 24.71, p = <0.0001).

The Secondary Forests were characterized by greatest tree richness (22 ± 1.01), abundance (39.5 ± 3.03) and tree basal area (3.23 ± 0.24) along with high vertical structural heterogeneity values (Table 5, Figure 6). These habitats also had low densities of weed cover (19.5 ± 4.17), similar to both Cacao-Banana and Two-Strata Cacao agroforests, as a direct result of having highest shade values (33.5 ± 4.21) (Table 5).

Cacao-Banana agroforests were the least botanically and structurally complex of the three cacao agroforests. These habitats were characterized by having the greatest abundance (39.5 ± 3.47) and basal area (39.5 ± 3.39) of Musaceae, with lowest mean tree richness (3.83 ± 1.01) and abundance (3.83 ± 1.01) (Table 5, Figure 6). Cacao-Banana agroforests were also characterized by having high shade values (27 ± 4.21), this as a consequence of forming a closed lower canopy layer between 2 and 9 m in height (2.6 ± 0.13), as a consequence of the high abundance of Musaceaes (Table 5).

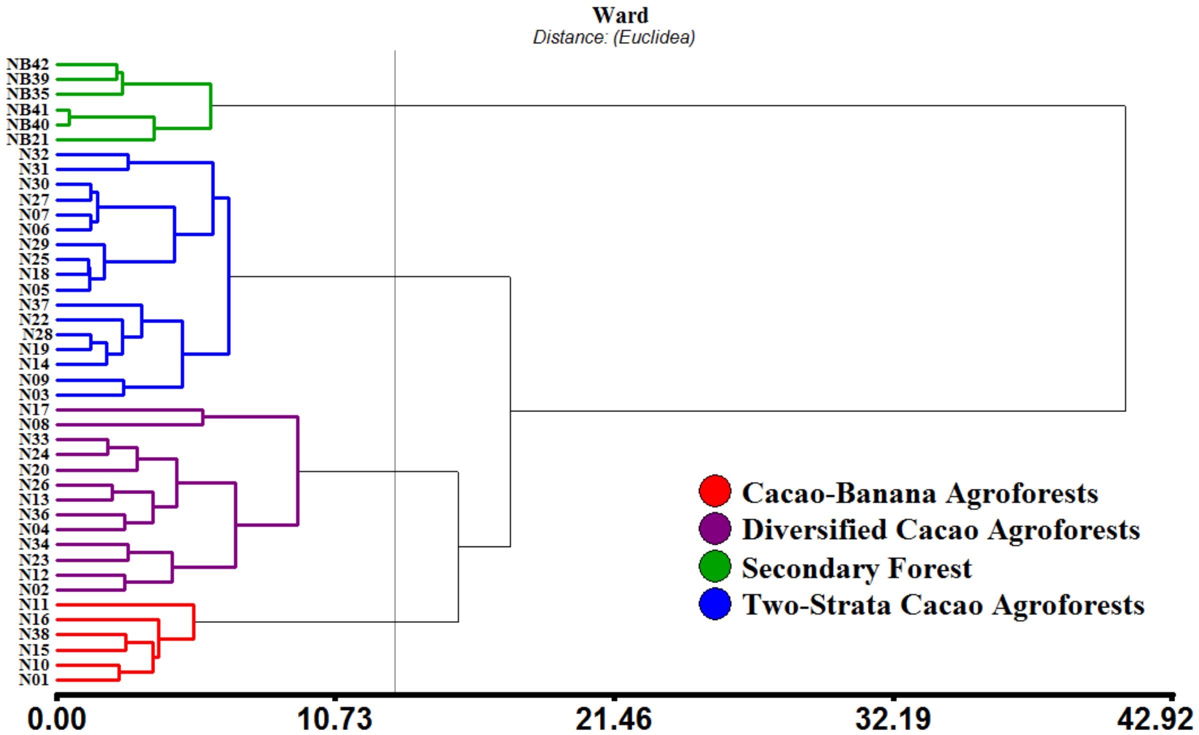

Figure 5. Dendrogram showing the four habitat types obtained through the cluster analysis of habitat structural and compositional variables for the 42 sampling units in Waslala, Nicaragua.

Two-Strata Cacao Agroforests were characterized by having high leaf litter cover (85.22 ± 3.23) and two well-defined vertical strata, these strata were found between 2-9 m and 10-20 m in height. These systems had low tree richness (5.53 ± 0.6) and abundance (15.18 ± 1.8) but not differing from that of Cacao-Banana agroforests (Table 5). The dominant shade trees forming the shade canopy were either *Inga* or *Cordia sp*.

The most botanically and structurally complex of the agroforests were Diversified Cacao agroforests which had higher tree richness (7.46 ± 0.69) and abundance (27.38 ± 2.06) than the other two cacao agroforests, with high weed cover leading to the formation of a well defined “understory” and low Musaceae abundance (Table 5, Figure 6). The canopy layers were formed by a mixture of shade trees dominated by *Cordia*, *Inga*, fruit, palms and forest remnant trees.

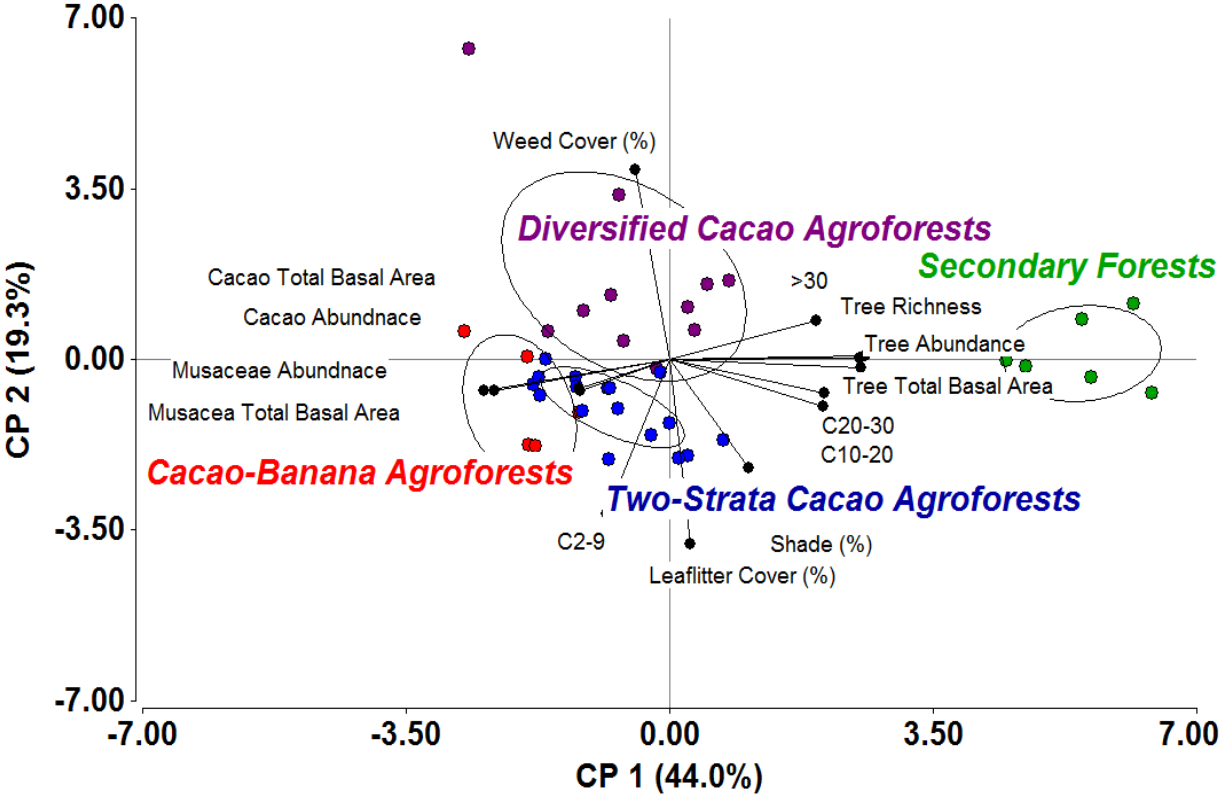

Figure 6. Biplot of the four habitat typologies in association with the habitat structural and compositional variables.

Table 5. Mean comparison of the environmental variables measured in the 42 sampling units utilized to construct the dendrogram. (Cacao-Banana Agroforest (n = 6), Two-Strata Cacao Agroforest (n = 17), Diversified Cacao Agroforest (n = 13), Secondary Forest (n = 6)).

Variable	Habitat				F-Value	P-Value
	Cacao-Banana Agroforest	Two-Strata Cacao Agroforest	Diversified Cacao Agroforest	Secondary Forest		
Weed cover (%)*	18.08 ± 4.17 **a**	15.32 ± 2.48 **a**	32.08 ± 2.83 **b**	19.5 ± 4.17 **a**	7.01	0.0007
Leaf litter (%)	80.63 ± 5.44 **b**	85.22 ± 3.23 **b**	62.98 ± 3.7 **a**	78.95 ± 5.44 **b**	7.14	0.0006
Shade (%)*	27 ± 4.21 **bc**	22.29 ± 2.5 **b**	12.38 ± 2.86 **a**	33.5 ± 4.21 **c**	6.71	0.001
C0-2*	16.83 ± 4.37 **ab**	15.79 ± 2.6 **a**	26.04 ± 2.97 **bc**	32.5 ± 4.37 **c**	4.87	0.0058
C2-9	2.6 ± 0.13 **b**	2.81 ± 0.08 **b**	2.17 ± 0.09 **a**	2.15 ± 0.13 **a**	13.23	<0.0001
C10-20	0.85 ± 0.12 **a**	1.38 ± 0.12 **b**	0.98 ± 0.14 **a**	2.4 ± 0.21 **c**	12.84	<0.0001
C20-30	0.23 ± 0.12 **a**	0.44 ± 0.07 **a**	0.48 ± 0.08 **a**	1.5 ± 0.12 **b**	22.51	<0.0001
C>30*	18.33 ± 2.7 **ab**	16.5 ± 1.6 **a**	21.58 ± 1.84 **b**	38.67 ± 2.7 **c**	17.15	<0.0001
Musaceae abundance*	39.5 ± 3.47 **b**	18.35 ± 2.06 **a**	24.46 ± 2.36 **a**	-----	13.73	<0.0001
Musaceae basal area*	39.5 ± 3.39 **c**	17.85 ± 2.01 **a**	25.12 ± 2.3 **b**	-----	15.23	<0.0001
Cacao abundance	71.17 ± 5.51 **a**	67.88 ± 3.27 **a**	61.08 ± 3.74 **a**	-----	1.47	0.2444
Cacao basal area*	25.92 ± 4.09 **a**	27.97 ± 2.43 **a**	19.31 ± 2.79 **a**	-----	2.82	0.0738
Tree abundance*	8.67 ± 3.03 **a**	15.18 ± 1.8 **a**	27.38 ± 2.06 **b**	39.5 ± 3.03 **c**	24.64	<0.0001
Tree richness	3.83 ± 1.01 **a**	5.53 ± 0.6 **a**	7.46 ± 0.69 **b**	22 ± 1.01 **c**	74.89	<0.0001
Tree basal area	0.63 ± 0.24 **a**	0.8 ± 0.14 **a**	0.87 ± 0.16 **a**	3.23 ± 0.24 **b**	30.42	<0.0001

4.3 Bird, amphibian and reptile community composition

4.3.1 Bird, amphibian and reptile community composition description

We recorded a total of 2,914 birds from 174 species, 195 amphibians from 12 species and 258 reptiles from 19 species were recorded. The five most abundant bird species were *Saltator maximus* (179), *Amazilia tzacatle* (143), *Cyanocorax mor*io (141), *Psarocolius Montezuma* (130) and *Dendroica pensylvanica* (128). The five most abundant amphibians were *Diasporus diastema* (67), *Craugastor bransfordii* (54), *Oophaga pumilio* (32), *Pristimatis ridens* (19) and *Eleutherodactylus biporcatus* (5). *Norops limifrons* (127), *N. humilis* (46), *Ameiva festiva* (21), *Ninia sebae* (13) and *N. lemurinus* (13) were the dominant reptile species observed. Of the 34 bird families Tyrannidae was dominant (Figure 7) while Leptodactylidae and Colubridae where the dominant amphibian and reptile families respectively (Figure 7). Bird mean richness and abundance per plot was 30.45 (±6.89) and 69.38 (±18.11). Observed amphibians mean richness and abundance per plot was 1.75 (±1.13) and 4.88 (±5.1), while for reptiles it was 2.64 (±1.29) and 6.28 (±3.71), respectively.

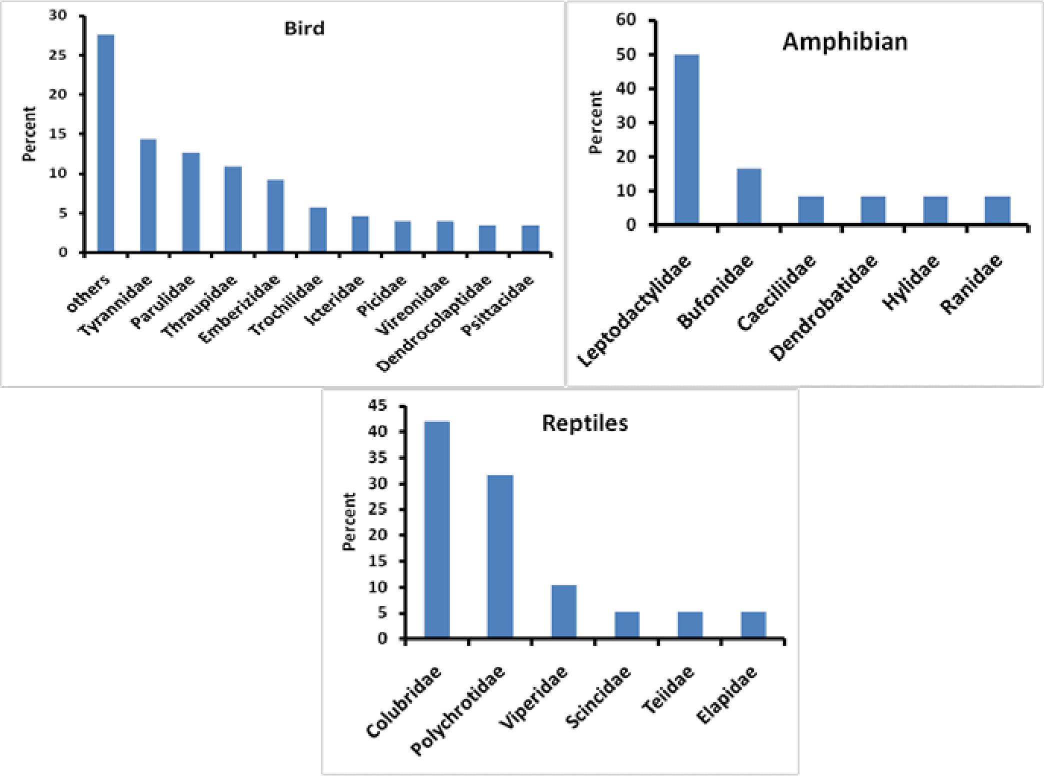

Figure 7. Composition of bird (n = 34), amphibian (n = 6) and reptile (n = 6) families based on the number of species recorded for each, in Waslala, Nicaragua.

Rank-abundance curves for birds, amphibians and reptiles show that there were few dominant species and many rare ones (Figure 8). For birds, the four habitats studied showed similar behaviour in rank abundances except for Secondary Forest remnants that were dominated by *Habia fuscicauda* (12%). The dominant species in Cacao-Banana Agroforests were *Cyanocorax morio* and *Saltator maximus* with a recorded abundance of 26 and 24 individuals respectively. In Two-Strata Cacao Agroforests, *S. maximus* dominanted with 74 individuals, followed by *Amazilia tzacatl* with 68 individuals. In Diversified Cacao Agroforest the same species were dominant but with abundances of 55 and 52 individuals respectively. All of the dominant species in all habitats except for Secondary forests were habitat generalist.

For amphibians Diversified Cacao agroforests showed the most even abundance distribution by species as compared to other habitats, while for reptiles it was Cacao-Banana agroforests

(Figure 8). The dominant amphibian species in Cacao-Banana agroforests were *Diasporus diastema* and *E. ridens* with 19 and 6 individuals respectively, while the least abundant were *Bufo coccifer*, *B. marinus* and *E. fitzingeri*, where each was represented by one individual. *D. diastema* and *E. bransfordii* were dominant in Two-Strata Cacao agroforests, where each species was represented by 40 individuals, while *Gymnopis multiplicata* was the least abundant. In Diversified Cacao agroforests and Secondary Forest remnants *Oophaga pumilio* was dominant (9 and 23 individuals respectively), followed by *E. brandsfordii*, where in each habitat 5 individuals were recorded. *Rana maculata* was least abundant in Diversified Cacao agroforests, while *B. coccifer* was least represented in Secondary Forests; both species were represented by a single individual.

Norops limifrons and *N. humilis* were the dominate reptile species in Cacao-Banana agroforests, each registered 16 and 15 individuals respectively, on the other hand the least abundant species were *Mabuya unimarginata* and *Micrurus nigrocinctus* which were both represented by a single individual. In both Diversified and Two-Strata Cacao agroforests *N. limifrons* was dominant, registering an abundance of 64 and 42 individuals respectively. The least abundant species in Two-strata Cacao agroforests were *Bothrops asper*, *Coniophanes fissidens*, *Drymobius margariferus*, *Hydromorphus concolor* and *Imantodes cenchoa*, all represented by a single individual. *Ninia maculate* and *N. lionotus* were recorded once in Diversified Cacao agroforests, becoming the least abundant species in this habitat. *N. humilis* was dominant (15 individuals) in Secondary Forests while *Atropoides nummifer*, *I. cenchoa*, *N. maculata* and *N. lionotus* were the least abundant.

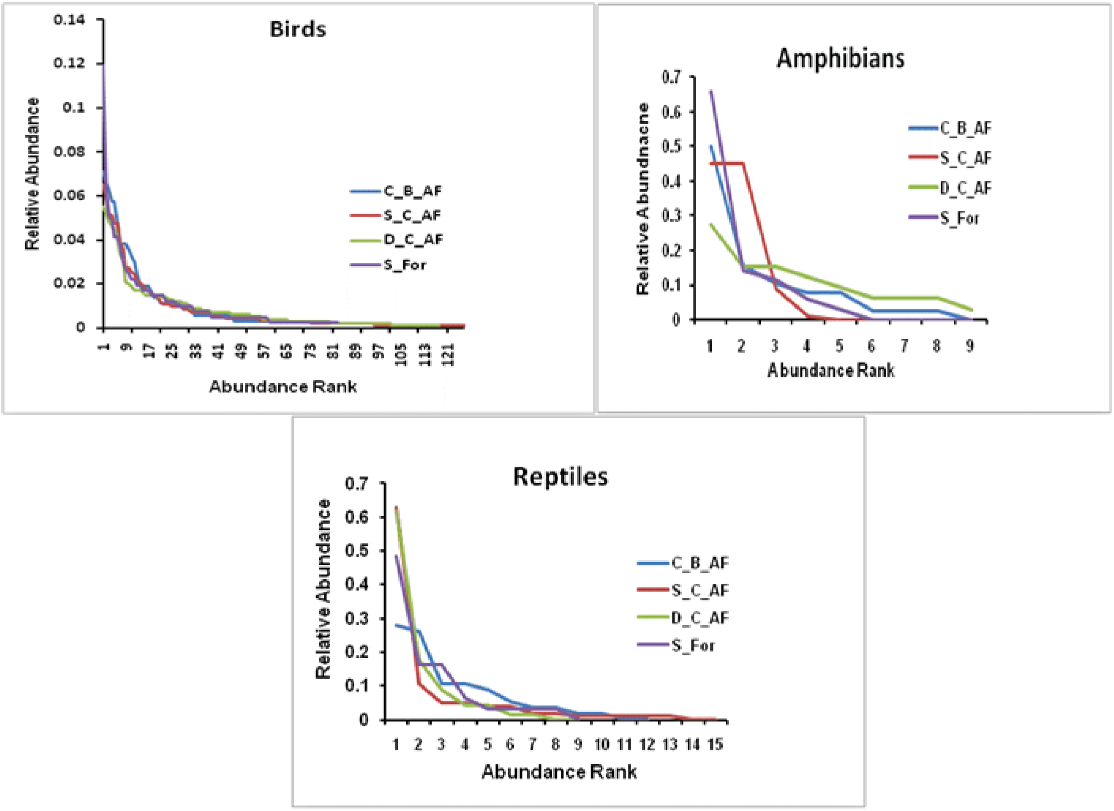

*Figure 8. Bird, amphibian and reptile Rank-Abundance Curves for the four habitats studied in Waslala, Nicaragua (C_B_AF = Cacao-Banana Agroforest (n = 6), S_C_AF = Two-Strata Cacao Agroforest (n = 17), D_C_AF = Diversified Cacao Agroforest (n = 13), S _For (n = 4)). **note for birds S-For, n = 6*

Species rarefaction curves based on individual abundance for birds and reptiles indicate that the sampling effort conducted for Diversified Cacao agroforests was reasonable as the curves show signs of stabilizing (Figure 9 A and C, Table 6). For amphibians an asymptote was reached for Two-Strata Cacao agroforests only, with a 100% sampling efficiency (Table 6). The behaviour of the other curves indicates that recording new species, particularly rare and cryptic ones, would increase with increased effort. Birds species richness recorded by sampling unit did not differ among habitats (Figure 9A), while for amphibians, Two-Strata Cacao agroforests species richness less that of Diversified and Cacao-Banana agroforests but similar to Secondary Forests. Amphibian richness in Secondary Forest was less than that of Diversified Cacao agroforests but not among the other habitats (Figure 9B). In regards to reptiles, species richness recorded in Two-Strata Cacao agroforests did not differ significantly from that of the other habitats, while both Cacao-Banana agroforests and Secondary Forest remnants differed significantly from that of Diversified Cacao agroforests, which have the lowest species richness (Figure 9C).

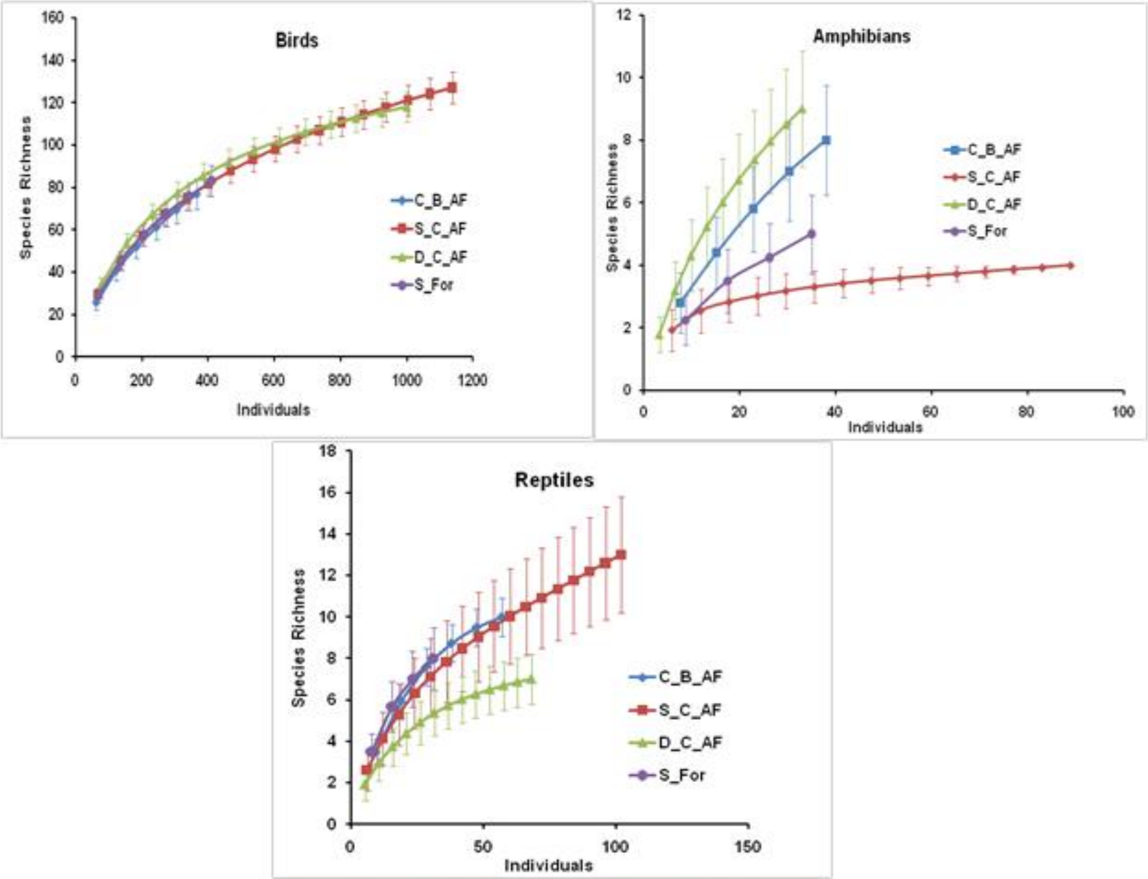

*Figure 9. Birds', amphibians' and reptiles' rarefaction curve and respective confidence intervals for the four habitats studied in Waslala, Nicaragua (C_B_AF = Cacao-Banana Agroforest (n = 6), S_C_AF = Two-strata Cacao Agroforest (n = 17), D_C_AF = Diversified Cacao Agroforest (n = 13), S _For (n = 4)).** note for birds S-For, n = 6.*

The Clench's Model results indicate that greatest estimated bird richness is predicted for Two-Strata Cacao agroforests (173 species). In contrast, the lowest species richness is expected for Cacao-Banana agroforests (133 species). For amphibians greatest estimated richness was expected in both Cacao-Banana and Diversified Cacao agroforests (16 species respectively); while the least was recorded in Two-Strata Cacao agroforests (4 species). For reptiles highest estimated richness was reported for Two-Strata Cacao agroforests (18 species), while the least was recorded for Diversified Cacao agroforests (9 species) (Table 6). Sampling efficiency was reasonable for the three taxa in all habitats studied, as all had a sampling efficiency of more than 57.1% except for amphibians in Cacao-Banana agroforests that reported a sampling efficiency of 50% (Table 6).

*Table 6. Observed and estimated bird, amphibian and reptile richness and sampling efficiency by habitat (Cacao-Banana Agroforest (n = 6), Two-Strata Cacao Agroforest (n = 17), Diversified Cacao Agroforest (n = 13), Secondary Forest (n = 4)). Estimated species richness was calculated using Clench's Model; while percentage sampling efficiency was calculated using observed and estimated richness.**for birds S_For, n=6*

Habitat	Birds			Amphibians			Reptiles		
	Observed Richness	Estimated Richness	Sampling Efficiency	Observed Richness	Estimated Richness	Sampling Efficiency	Observed Richness	Estimated Richness	Sampling Efficiency
Cacao-Banana agroforest	77	133	57.9	8	16	50	10	16	62.5
Two-Strata Cacao agroforest	127	173	73.4	4	4	100	13	18	72.2
Diversified Cacao agroforest	118	151	78.1	9	16	56.25	7	9	77.8
Secondary Forest	83	138	60.1	5	8	62.5	8	14	57.1

4.3.2 Comparison of bird, amphibian and reptile communities among habitats studied

ANOVA show significant difference in mean bird species richness and diversity among the habitats (Table 7). Greater species richness was found in Diversified Cacao agroforests in comparison to both Cacao-Banana and Two-Strata Cacao agroforests. Shannon's Diversity Index was greater for Diversified Cacao agroforests, while Cacao-Banana agroforests was least diverse (Table 7). There was difference with regards to Resident species richness among habitats but not for abundances while for migratories there was difference for both species richness and abundance (Figure 10 A and B). Resident species richness was greater in Diversified Cacao agroforests than in both Cacao-Banana and Two-Strata Cacao agroforests. Migratory species richness and abundance was greater in Diversified and Two-Strata Cacao agroforests than in Cacao-Banana agroforests and Secondary Forest remnants (Figure 10 A and B).

There was no significant difference in amphibian richness and abundance among habitats (F = 1.29, p = 0.2921 and F = 1.73, p = 0.1782 respectively). On the other hand reptile richness did show a significant difference among habitats (F = 3.23, p = 0.0337) but abundance did not differ. Greater reptile richness was found in Secondary forests and Cacao-Banana Agroforests, while Diversified Cacao Agroforests had less richness (14.42 ± 2.9) (Table 7).

*Table 7. Mean species richness, abundance and diversity index for the bird, amphibian and reptile communities recorded in 42 sampling units in Waslala, Nicaragua. (Cacao-Banana Agroforest (n = 6), Two-Strata Cacao Agroforest (n = 17), Diversified Cacao Agroforest (n = 13), Secondary forest (n = 6)). Different letters indicate significant difference (p < 0.05). * = variable was rank transformed.*

	Cacao-Banana agroforest	**Two-Strata Cacao agroforest**	**Diversified Cacao agroforest**	**Secondary forest**	**F-value**	**p-value**
Birds						
Richness	25.5 ± 2.57 **a**	29.18 ± 1.53 **a**	34.92 ± 1.75 **b**	29.33 ± 2.57 **ab**	3.72	**0.0194**
Abundance	61 ± 7.3	66.88 ± 4.34	77 ± 4.96	68.33 ± 7.3	1.34	0.275
Shannon	2.97 ± 0.09 **a**	3.11 ± 0.06 **ab**	3.32 ± 0.06 **b**	3.1 ± 0.09 **ab**	3.96	**0.015**
Simpson*	28.5 ± 4.28 **b**	23 ± 2.54 **b**	12.88 ± 2.91 **a**	28.92 ± 4.28 **b**	4.93	**0.0055**
Amphibians						
Richness	2 ± 0.46	1.78 ± 0.26	1.45 ± 0.30	2.2 ± 0.53	1.29	0.2921
Abundance*	20.22 ± 4.53	23.7 ± 2.55	15.59 ± 2.91	23.27 ± 5.22	1.73	0.1782
Shannon	1.03 ± 0.15	0.68 ± 0.09	0.77 ± 0.13	0.75 ± 0.18	1.25	0.3179
Simpson*	0.42 ± 0.15	0.53 ±0.10	0.43 ± 0.12	0.44 ± 0.20	0.22	0.8795
Reptiles						
Richness	3.5 ± 0.49 **b**	2.65 ± 0.29 **ab**	1.92 ± 0.33 **a**	3.5 ± 0.6 **b**	3.29	**0.0315**
Abundance	9.5 ± 1.43	5.59 ± 0.85	5.23 ± 0.97	7.75 ± 1.76	2.52	0.0735
Shannon*	29.25 ± 4.42 **b**	20.29 ± 2.63 **ab**	14.81 ± 3 **a**	20.29 ± 5.42 **ab**	2.95	**0.0458**
Simpson*	11.42 ± 4.31	20.06 ± 2.64	22.41 ± 3.18	16.75 ± 5.28	1.53	0.2255

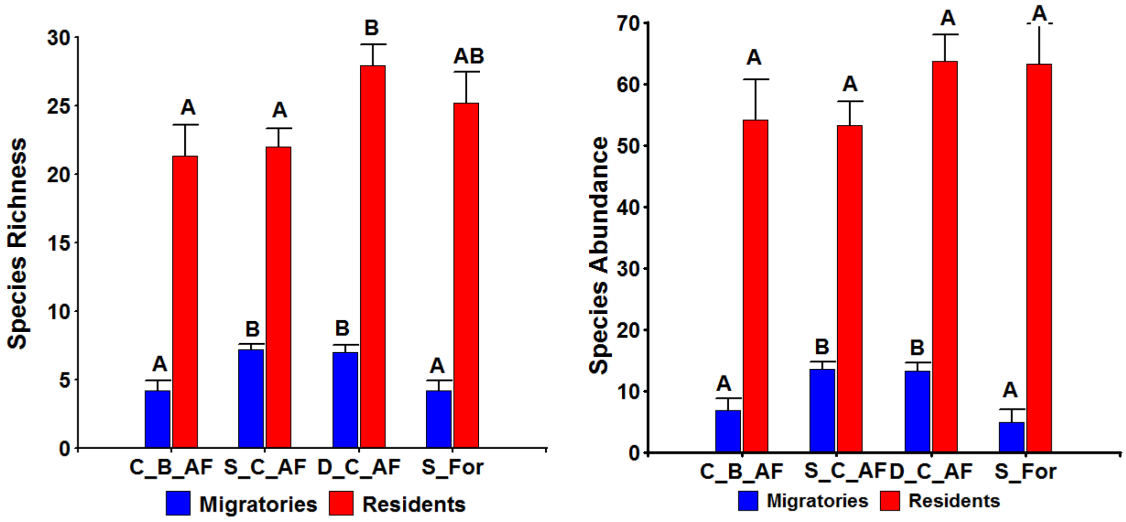

Figure 10. Status for species richness and abundance mean comparisons for bird communities recorded in 42 sampling units in Waslala, Nicaragua. (C_B_AF = Cacao-Banana agroforest (n = 6), S_C_AF = Two-Strata Cacao agroforest (n = 17), D_C_AF = Diversified Cacao agroforest (n = 13), S _For (n = 6)). Different letters indicate significant difference ($p < 0.05$).

The recorded occurrence of bird abundance at the different habitat strata did not differ significantly among habitats studied (ground: F = 1.87, p = 0.1512; Lower Canopy: F = 1.24, p = 0.3101; Middle Canopy: F = 1.45, p = 0.2443; Upper Canopy: F = 1.04, p = 0.3855), except for occurrence in the understory. Bird richness recorded on the understory differed significantly among habitats (F = 9.3, p = 0.0001); Secondary Forests registered the greatest occurrence of birds in the understory (37.67 ± 3.93), followed by Diversified Cacao agroforests (24.81 ± 2.67), while Cacao-Banana and Two-Strata Cacao agroforests did not differ from each other (13.92 ± 3.93 and 15.94 ± 2.33, respectively).

Foraging strata preference for birds showed significant difference among habitats for both species richness and abundance, except for abundance of canopy foragers (F = 2.45, p = 0.0788). Richness and abundance for understory foragers was higher in Secondary Forests than in the cacao agroforests, while canopy foragers' richness was greater in Diversified Cacao agroforests as was the case for species richness and abundance of birds which forage in all strata layers (Table 8).

Table 8. Mean comparison of preferred foraging strata for species richness and abundance of bird recorded in 42 sampling units in Waslala, Nicaragua. (Cacao-Banana agroforest (n = 6), Two-Strata Cacao agroforest (n = 17), Diversified Cacao agroforest (n = 13), Secondary Forest (n = 6). Different letters indicate significant difference (p < 0.05).

Foraging Strata	Cacao-Banana agroforest	Two-Strata Cacao agroforest	Diversified Cacao agroforest	Secondary forest	F-value	P-value
Richness						
Understory Foragers	4.33 ± 0.83 **a**	4.76 ± 0.49 **a**	4.92 ± 0.56 **a**	10 ± 0.83 **b**	1.53	**<0.0001**
Canopy Foragers	12.5 ± 1.88 **a**	14.35 ± 1.12 **a**	17.85 ± 1.28 **b**	11.17 ± 1.88 **a**	3.69	**0.02**
Both Strata Foragers	8.67 ± 1.07 **a**	10.06 ± 0.64 **a**	12.15 ± 0.73 **b**	8.17 ± 1.07 **a**	4.31	**0.0103**
Abundance						
Understory Foragers	8 ± 2.12 **a**	7.94 ± 1.26 **a**	7.54 ± 1.44 **a**	26.5 ± 2.12 **b**	22.26	**<0.0001**
Canopy Foragers	32.5 ± 4.62	36.06 ± 2.75	40 ± 3.14	25.33 ± 4.62	2.45	0.0788
Both Strata Foragers	20.5 ± 3.31 **a**	22.88 ± 1.97 **a**	29.46 ± 2.25 **b**	16.5 ± 3.31 **a**	4.13	**0.0125**

Amphibians occurrence on leaf-litter and branches of trees did not differ significantly among habitats (F = 2.12, p = 0.1146 and F = 1.20, p = 0.3239) (Figure 11). Reptile abundance on leaf litter and branches significantly differ among habitats (F = 3.33, p = 0.0303 and F = 3.07, p = 0.0402, respectively) but not for abundance recorded on the stems of trees (F= 0.42, p = 0.7427) (Figure 11). Greatest reptile abundance was observed on the leaf litter in Cacao-Banana agroforests, while the least occurred in Diversified Cacao agroforests. However the mean abundance did not differ from that of Two-Strata Cacao Agroforests. The greatest abundance of reptiles observed on the branches of trees was reported for Diversified Cacao agroforests, while the least abundance was observed in Two-Strata Cacao agroforests but this difference was only significant compared to Diversified Cacao agroforests (Figure 11).

We found significant and important differences in dietary guild composition by habitat type. Insectivore and gramnivore species richness and abundance differ significantly among habitats (F= 3.39, p = 0.02; F = 4.32, p = 0.01, respectively). Diversified Cacao had greatest mean species richness (12.54 ± 0.91) and abundance (21.92 ± 1.77), as was the case for gramnivores. Nectarivore, frugivore and omnivore species richness and abundance did not differ among habitats studies (Table 9).

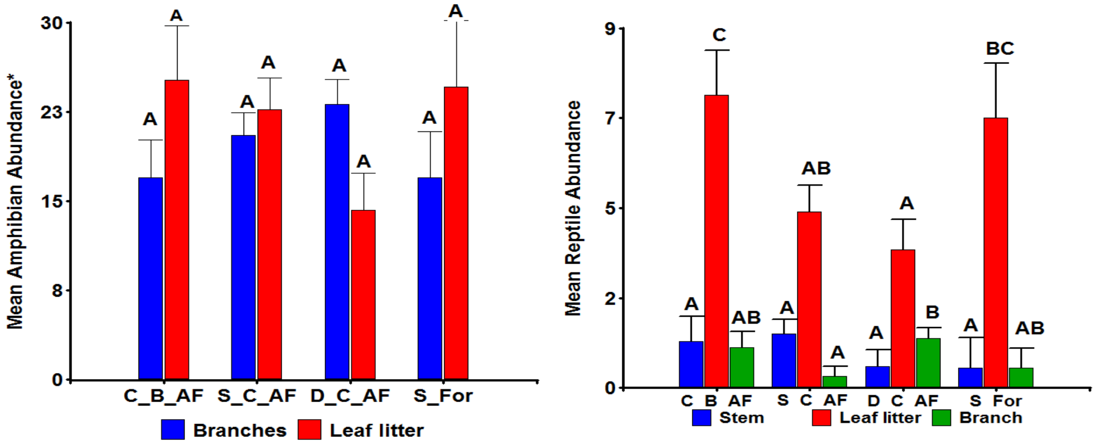

Figure 11. Mean comparison of amphibian and reptile abundance on different habitat strata. (C_B_AF = Cacao-Banana Agroforest (n = 6), S_C_AF = Two-Strata Cacao Agroforest (n = 17), D_C_AF = Diversified Cacao Agroforest (n = 13), S _For (n = 4)). Different letters indicate significant difference (p < 0.05); * *= variables were ranked transformed.*

Table 9. Mean comparison of avian dietary guilds. (C_B_AF = Cacao-Banana Agroforest (n = 6), S_C_AF = Two-Strata Cacao Agroforest (n = 17), D_C_AF = Diversified Cacao Agroforest (n = 13), S _For (n = 4).

	cacao-Banana agroforest	**Two-Strata Cacao agroforest**	**Diversified Cacao agroforest**	**Secondary forest**	**F-value**	**p-value**
Richness						
Insectivores	7.5 ± 1.32 **a**	11.47 ± 0.8 **a**	12.54 ± 0.91 **b**	10.33 ± 1.34 **ab**	3.39	**0.02**
Nectarivores	2.17 ± 0.42	2.06 ± 0.25	2.15 ± 0.29	2.33 ± 0.42	0.11	0.96
Frugivores	3.33 ± 0.81	2.94 ± 0.48	4.85 ± 0.55	3.33 ± 0.81	2.4	0.08
Gramnivores	1 ± 0.46 **a**	0.94 ± 0.27 **a**	2.15 ± 0.31 **b**	0.83 ± 0.46 **a**	3.61	**0.02**
Omnivores	10.83 ± 1.48	11.59 ± 0.88	13.15 ± 1	12 ± 1.48	0.72	0.54
Abundance						
Insectivores	11.17 ± 2.6 **a**	19.82 ± 1.55 **b**	21.92 ± 1.77 **b**	16.5 ± 2.6 **ab**	4.32	**0.01**
Nectarivores	5.5 ± 1.07	5.88 ± 0.63	5.31 ± 0.72	3.67 ± 1.07	1.07	0.37
Frugivores	8.83 ± 2.19	6.65 ± 1.3	11.92 ± 1.49	10.67 ± 2.19	2.55	0.07
Gramnivores	1.67 ± 0.82 **a**	1.12 ± 0.49 **a**	4.08 ± 0.56 **b**	1.17 ± 0.82 **a**	6.09	**0.002**
Omnivores	33 ± 5.03	33.24 ± 2.99	33.69 ± 3.42	35.83 ± 5.03	0.07	0.97

Birds' rarefaction curve based on individual abundance for degree of forest dependence show that Secondary Forests had the greatest richness of forest specialists; on the other hand Cacao-Banana agroforests had the least richness, while Two-Strata and Diversified Cacao Agroforest had an intermediate richness but did not differ from each other (Figure 12 A). For forest generalist birds, Secondary Forests showed the least richness but only differ from Two-Strata Cacao agroforests (Figure 12 B). With respect to generalist birds, all habitats have similar species richness. Secondary Forests reported the highest estimated species richness for forest specialists but the lowest for both forest generalists and generalist species (Table 10). Greatest forest generalists and generalist estimated richness was reported for Two-Strata Cacao agroforests. For all degree of birds' forest dependence highest sampling efficiency was recorded for Two-Strata Cacao agroforests, while lowest sampling efficiency for forest specialist and generalist species was achieved in Secondary Forests, while for forest generalists it was in Cacao-Banana agroforests (Table 10).

Table 10. Observed and estimated richness and sampling efficiency for birds' degree of forest dependence (Cacao-Banana Agroforest (n = 6), Two-strata Cacao Agroforest (n = 17), Diversified Cacao Agroforest (n = 13), Secondary forest (n = 6)). Estimated species richness was calculated using Clench's Model; while percentage sampling efficiency was calculated using observed and estimated richness

Habitat	**Forest Specialists Richness**			**Forest Generalists Richness**			**Generalists Richness**		
	Observed	Estimated	Sampling efficiency	Observed	Estimated	Sampling efficiency	Observed	Estimated	Sampling efficiency
Cacao-Banana agroforest	3	----	---	23	52	43.91	51	78	65.07
Two-Strata Cacao agroforest	9	14	66.32	37	53	69.91	81	103	78.36
Diversified Cacao agroforest	7	12	56.25	34	44	77.41	77	95	80.97
Secondary forest	15	31	48.68	26	38	68.26	42	71	59.05

Mean richness and abundance for degree of forest dependence by birds showed significant difference among habitats studied. Secondary Forests showed greatest occurrence of forest specialist for both species richness and abundance. Forest generalist occurred highest in both Diversified Cacao Agroforests and Secondary Forests in comparison to Cacao-Banana and Two-Strata Cacao Agroforests. Greater species richness of generalist birds was registered in Diversified Cacao Agroforests, while Secondary Forests and Cacao-Banana Agroforests had the least species richness for generalist birds. With respect to generalist species abundance Secondary Forests showed the least, while greater occurrence was registered in the cacao agroforest but there was no significant difference among these (Table 11).

Table 11. Mean comparison for degree of forest dependence for species richness and abundance of bird recorded in 42 sampling units in Waslala, Nicaragua. (Cacao-Banana agroforest (n = 6), Two-Strata Cacao agroforest (n = 17), Diversified Cacao agroforest (n = 13), Secondary forest (n = 6)). Different letters indicate significant difference ($p < 0.05$). = variable values were rank transformed.*

Forest Dependence	Cacao-Banana agroforest	Two-Strata Cacao agroforest	Diversified Cacao agroforest	Secondary forest	F-value	P-value
Richness						
Forest Specialists*	12.25 ± 4.04 **a**	22.91 ± 2.4 **b**	17.04 ± 2.74 **ab**	36.42 ± 4.04 **c**	7.3	**0.0006**
Forest Generalist	6.33 ± 1.12 **a**	6.88 ± 0.67 **a**	9.23 ± 0.76 **b**	10.33 ± 1.12 **b**	3.99	**0.0146**
Generalists	18.67 ± 1.89 **ab**	20.65 ± 1.12 **b**	24.62 ± 1.28 **c**	14.67 ± 1.89 **a**	6.89	**0.0008**
Abundance						
Forest Specialists*	12.17 ± 4.07 **a**	22.26 ± 2.42 **b**	17.62 ± 2.76 **ab**	37.08 ± 4.07 **c**	7.34	**0.0005**
Forest Generalists	13.67 ± 2.99 **a**	12.24 ± 1.78 **a**	15.69 ± 2.03 **a**	29.17 ± 2.99 **b**	8.18	**0.0003**
Generalists	46.67 ± 6.04 **ab**	52.06 ± 3.59 **b**	59.54 ± 4.1 **b**	31.5 ± 6.04 **a**	5.12	**0.0045**

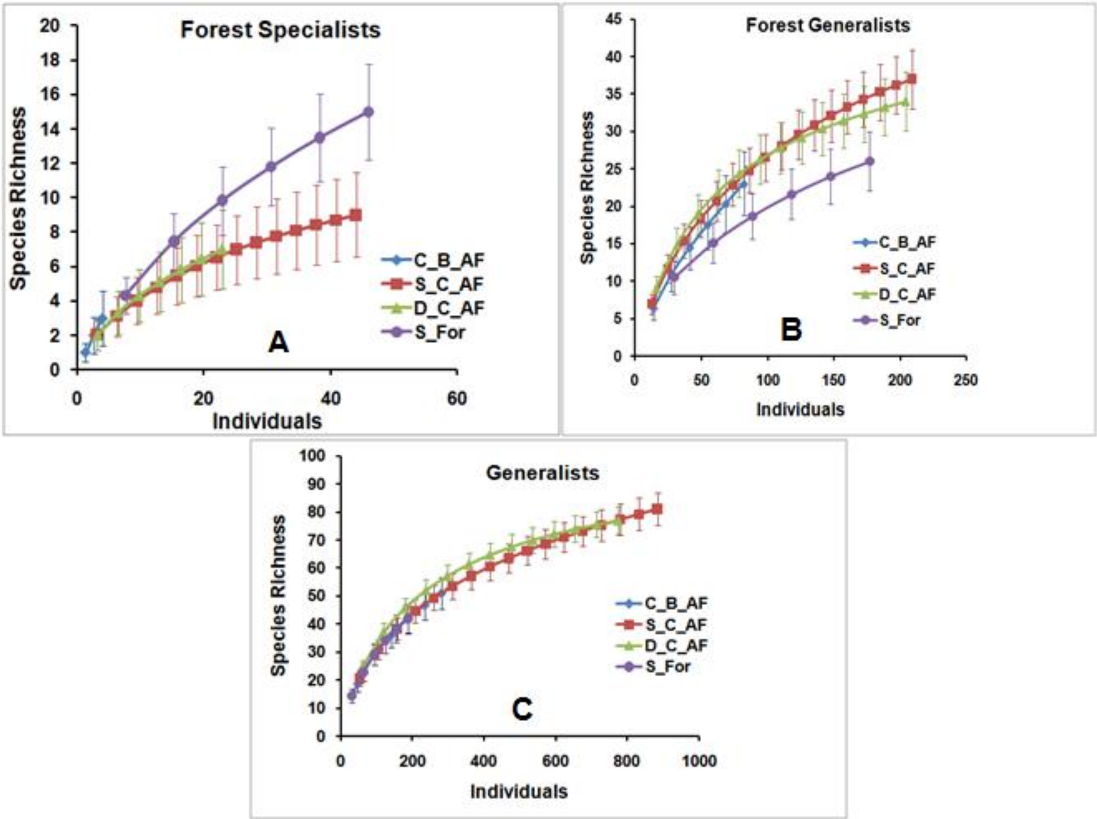

Figure 12. Rarefaction Curves with confidence intervals based on abundance for birds' degree of forest dependence (C_B_AF = Cacao-Banana Agroforest (n = 6), S_C_AF = Two-strata Cacao Agroforest (n = 17), D_C_AF = Diversified Cacao Agroforest (n = 13), S _For = secondary forest (n = 6)).

With the amount of individuals recorded in this study species rarefaction curve based on birds' degree of sensitivity to human disturbances, indicate that there is no significant difference among the four habitats studied for birds with high, medium and low sensitivity to human disturbances (Figure 13). Although there is no statistical difference for both bird richness with high and medium sensitivity to human disturbances, the curve for Secondary Forests indicate the greatest probability of supporting such birds as indicated by the slope of the curve (Figure 13A and B). This result complements our observation that the forest habitat also contained the forest dependent species, which typically are the same species which are sensitive to disturbance. Two-Strata Cacao agroforests, show evidence of stabilizing for high sensitivity species only, while all other habitats indicate that more species can be recorded with an increase in the sampling effort.

The sampling efficiency for all degrees of birds' sensitivity to anthropogenic disturbances appear to be reasonable enough as all habitats had a sampling efficiency of more than 59%, except for Cacao-Banana agroforests for birds with a medium sensitivity (Table 12). Secondary Forests recorded the highest observed and estimated species richness for birds with high and medium sensitivity to human disturbances; on the other hand greatest estimated low sensitivity bird richness was recorded for Two-Strata Cacao agroforests (Table 12).

ANOVA results show that for degree of birds' sensitivity to human disturbances there were significant differences among habitats studied both for species richness and abundance (Table 13). Bird richness and abundance with low sensitivity to human disturbances were higher in Diversified Cacao agroforests than in Cacao-Banana and Two-Strata Cacao agroforests, while Secondary Forests had the least abundance and richness for this category. Secondary Forests reported the highest richness and abundance of birds with medium and high degree of sensitivity to disturbances; on the contrary Cacao-Banana agroforests reported the least occurrence of birds' richness with medium sensitivity to disturbances. Cacao-Banana, Simplified and Diversified Cacao agroforests had no difference in richness and abundance for birds with high degree of sensitivity to anthropogenic disturbances (Table 13).

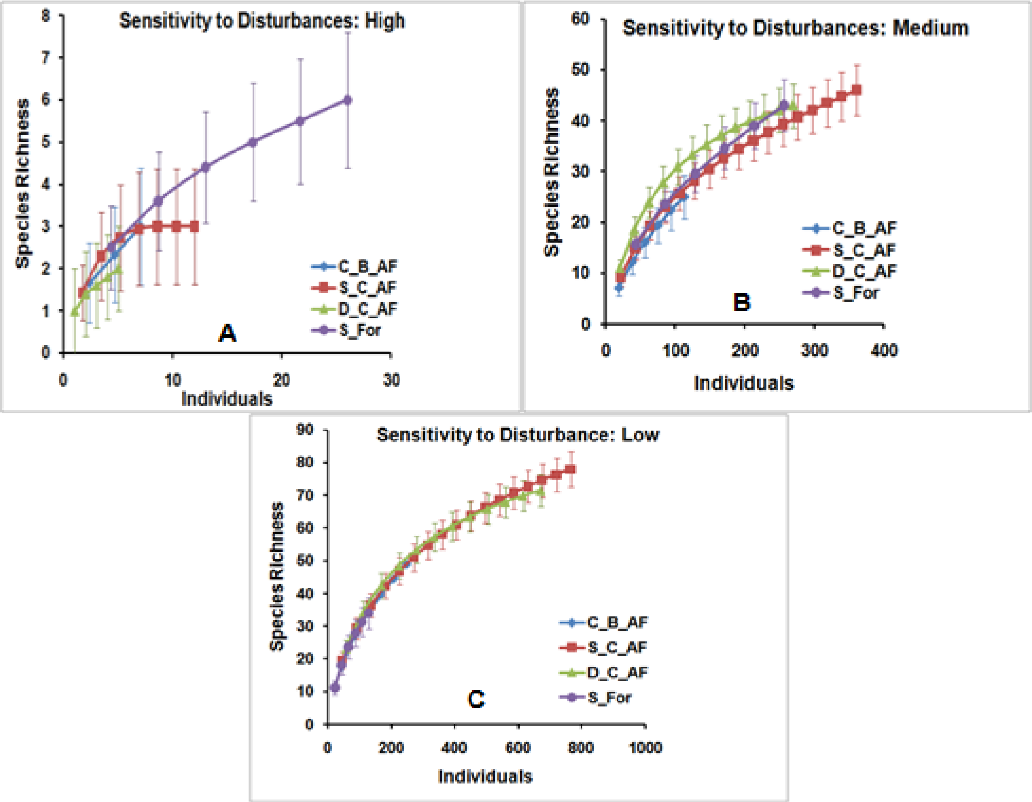

Figure 13. Species rarefaction curve with confidence intervals for birds' degree of sensitivity to human disturbances (C_B_AF = Cacao-Banana Agroforest (n = 6), S_C_AF = Two-Strata Cacao Agroforest (n = 17), D_C_AF = Diversified Cacao Agroforest (n = 13), S _For = Secondary forest (n = 6)).

Table 12. Observed and estimated bird richness and sampling efficiency for degree of sensitivity to human disturbances (Cacao-Banana agroforest (n = 6), Two-Strata Cacao agroforest (n = 17), Diversified Cacao agroforest (n = 13), Secondary forest (n = 6)). Estimated species richness was calculated using Clench's Model; while percentage sampling efficiency was calculated using observed and estimated richness

Habitat	**Disturbance Sensitivity: High**			**Disturbance Sensitivity: Medium**			**Disturbance Sensitivity: Low**		
	Observed	Estimated	Sampling Efficiency	Observed	Estimated	Sampling Efficiency	Observed	Estimated	Sampling Efficiency
Cacao-Banana agroforest	3	5	59.75	25	53	47.41	49	80	61.64
Two-Strata Cacao agroforest	3	4	79.29	46	67	69.05	78	102	76.68
Diversified Cacao agroforest	2	3	76.32	43	57	75.44	73	90	81.38
Secondary forest	6	8	70.81	43	70	61.53	34	58	58.80

*Table 13. Mean comparison of the degree of sensitivity to human disturbances for species richness and abundance of bird recorded in 42 sampling units in Waslala, Nicaragua. (Cacao-Banana agroforest (n = 6), Two-Strata Cacao agroforest (n = 17), Diversified Cacao agroforest (n = 13), Secondary forest (n = 6)). Different letters indicate significant difference (p < 0.05). * = variable was rank transformed.*

Sensitivity to Disturbances	Cacao-Banana agroforest	Two-Strata Cacao agroforest	Diversified Cacao agroforest	Secondary forest	F-value	P-value
Richness						
Low	17.5 ± 1.7 **b**	19.47 ± 1.01 **b**	23.38 ± 1.15 **c**	11 ± 1.7 **a**	2.49	**<0.0001**
Medium	7.17 ± 1.51 **a**	9.12 ± 0.89 **ab**	11.15 ± 1.02 **b**	15.83 ± 1.51 **c**	6.74	**0.0009**
High*	21.33 ± 3.83 **a**	19.03 ± 2.28 **a**	17.35 ± 2.6 **a**	37.67 ± 3.83 **b**	7.17	**0.0006**
Abundance						
Low	41.17 ± 4.76 **b**	44.94 ± 2.83 **b**	55.62 ± 3.24 **c**	21 ± 4.76 **a**	2.21	**<0.0001**
Medium*	17.33 ± 4.33 **a**	18.68 ± 2.57 **a**	19.58 ± 2.94 **a**	37.83 ± 4.33 **b**	5.6	**0.0028**
High*	21.17 ± 3.83 **a**	19.18 ± 2.28 **a**	17.15 ± 2.6 **a**	37.83 ± 3.83 **b**	7.34	**0.0005**

Global ANOSIM results for species composition indicates that bird (r = 0.3111, p = 0.00009990), amphibian (r = 0.1147, p = 0.047395) and reptile (r= 0.157, p = 0.015998) species composition differ among habitats studied. Based on pair wise ANOSIM, the three cacao agroforests do not differ from each other in regards to birds species composition but Secondary Forests did differ from these (Table 14). No habitat that differed from all others for both amphibian and reptile species composition. Diversified and Two-Strata Cacao differed significantly from each other (r = 0.2285, p = 0.000599) based on amphibian composition. For reptile composition there was three pair of habitats that differed significantly, these being: Cacao-Banana and Diversified Cacao agroforests (r = 0.2022, p = 0.059); Two-Strata Cacao agroforests and Secondary Forest remnants (0.3779, p = 0.033) and Diversified and Two-Strata Cacao agroforests (Table 14)

Table 14. Pair wise ANOSIM results for bird, amphibian and reptile species composition based on 10,000 permutations utilizing Bray-Curtis distance.

Habitats	Birds		Amphibians		Reptiles	
	R	p	R	p	R	p
C_B_AF vs. S_C_AF	0.04311	0.356	0.112	0.199	0.2359	**0.057**
C_B_AF vs. S_For	0.4	**0.004**	-0.0139	0.447	-0.0814	0.609
C_B_AF vs. D_C_AF	0.1388	0.134	-0.0568	0.679	0.2022	**0.059**
S_C_AF vs. D_C_AF	0.07307	0.068	0.2285	**<0.0001**	0.06028	0.109
S_C_AF vs. S_For	0.73	**<0.0001**	0.0552	0.361	0.3779	**0.033**
D_C_AF vs. S_For	0.8113	**<0.0001**	-0.1417	0.852	0.1126	0.224

We conducted an Indicator Species Analysis to identify the most characteristic bird species of the four habitat typologies. Species with the highest Importance Value (IV) and P ≤ 0.05 were regarded as characteristic of each habitat. *Phlogothraupis sanguinolenta* (generalist) was the indicator species for Cacao-Banana agroforests while *Dendroica magnolia* (forest generalist) was characteristic of Two-Strata Cacao agroforests. Diversified Cacao agroforests had four indicator species being *Oryzoborus funereus, Cyanerpes cyaneus, Chlorophanes spiza* and *Turdus grayi*. Secondary Forests were represented by a total of 15 indicator species, where *Cyanocompsa cyanoides* was the most characteristic (IV= 100; p 0.001), followed by *Arremon aurantiirostris* (IV = 61.8, p = 0.001) (Table 15).

Table 15. Indicator species analysis based on bird abundance for the four different habitats.

Specie	English Name	Forest Dependence	IV	Mean	p-value
Cacao-Banana Agroforest					
Phlogothraupis sanguinolenta	Crimson-collared Tanager	Generalist	31.9	18.4	0.055
Two-Strata Cacao Agroforest					
Dendroica magnolia	Magnolia Warbler	Forest generalist	33.3	16.9	0.039
Diversified Cacao Agroforest					
Oryzoborus funereus	Thick-billed Seedfinch	Generalist	66.3	17.8	0.001
Cyanerpes cyaneus	Red-legged Honeycreeper	Forest generalist	43.7	18.1	0.011
Chlorophanes spiza	Green Honeycreeper	Forest generalist	38.5	13.3	0.015
Turdus grayi	Clay-colored Thrush	Generalist	35.4	29.1	0.054
Secondary Forest					
Cyanocompsa cyanoides	Blue-black Grosbeak	Forest generalist	100	14.1	0.001
Arremon aurantiirostris	Orange-billed Sparrow	Forest specialist	61.8	13.4	0.001
Phaethornis superciliosus	Long-tailed Hermit	Forest generalist	61.2	21.8	0.001
Habia fuscicauda	Red-throated Ant-tanager	Forest generalist	61.4	27.9	0.003
Microcerculus philomela	Nightingale Wren	Forest specialist	50	11.8	0.005
Ramphastos sulfuratus	Keel-bill Toucan	Forest generalist	54.2	19.5	0.005
Terenotriccus erythrurus	Ruddy-tailed Flycatcher	Forest generalist	42.9	12.4	0.006
Mionectes oleagineus	Ochre-bellied Flycatcher	Forest generalist	50.7	25.5	0.009
Phaethornis longuemareus	Little Hermit	Forest generalist	46.9	18.7	0.009
Momotus momota	Blue-crowned Motmot	Generalist	43.9	22.4	0.018
Manacus candei	White-collared Manakin	Forest generalist	46.4	23.3	0.022
Gymnocichla nudiceps	Bare-crowned Antbird	Forest generalist	33.3	10.8	0.037
Myrmotherula schisticolor	Slaty Antwren	Forest specialist	33.3	10.9	0.037
Trogon rufus	Black-throated Trogon	Forest specialist	33.3	10.9	0.037
Eucometis penicillata	Gray-headed Tanager	Forest specialist	26.6	12.3	0.049

For amphibians, the indicator species analysis, shows that *Diasporus diastema,* was the only characteristic species for Cacao-Banana agroforests (IV = 48.5, p = 0.0322), while there was no significant indicator species for the other habitats (Table 16). For reptiles the analysis indicated that there were three characteristic species (Table 17). *Norops lemurinus* and *Dryadophis melanolomus,* resulted characteristic of Cacao-Banana agroforests, while *N. humilis,* was characteristic of Secondary Forests (IV = 38.0, p = 0.0576.).

Table 16. Indicator species analysis based on amphibian abundance for the four different habitats.

Habitat	Species	IV	p-value
Cacao-Banana Agroforest			
	Diasporus diastema	48.5	**0.0322**
	Bufo marinus	20	0.2583
	Rana maculata	17.4	0.3337
	Pristimatis ridens	21.9	0.4391
Two-Strata Cacao Agroforest			
	Craugastor bransfordii	44.7	0.0648
	Gymnopis multiplicata	6.7	1
Diversified Cacao Agroforest			
	Leptodactylus pentadactylus	9.1	0.5701
	Smilisca phaeota	9.1	0.5749
	Craugastor fitzingeri	10.5	0.6793
Secondary Forest			
	Oophaga pumilio	21.9	0.1066
	Eleutherodactylus biporcatus	11.4	0.7145
	Bufo coccifer	9.9	0.7469

Table 17. Indicator species analysis based on reptile abundance for the four different habitats

Habitat	Specie	IV	p-value
Cacao-Banana Agroforest			
	Norops lemurinus	45.5	**0.0236**
	Dryadophis melanolomus	33.3	**0.0266**
	Geophis hoffmanni	22.2	0.1256
	Micrurus nigrocinctus	16.7	0.237
	Ninia maculata	8.8	0.7618

Two-Strata Cacao Agroforest			
	Ninia sebae	23.3	0.2074
	Mabuya unimarginata	15	0.3531
	Norops limifrons	30.4	0.4419
	Bothrops asper	5.9	1
	Coniophanes fissidens	5.9	1
	Drymobius margariferus	5.9	1
	Hydromorphus concolor	5.9	1
	Norops cupreus	5.9	1
Diversified Cacao Agroforest			
	Norops sp	15.4	0.2901
Secondary Forest			
	Norops humilis	38	**0.0576**
	Atropoides nummifer	25	0.099
	Imantodes cenchoa	20.2	0.1056
	Norops lionotus	19.1	0.1738
	Ameiva festiva	22	0.4399

4.3.3 Relationship between bird and herpetofauna communities with habitat structural and floristic composition.

We conducted simple linear regressions to better understand the relationship between avian communities and habitat structural and floristic composition. Of the many variables that we measured, tree richness and abundance contributed significantly to bird richness, abundance and Shannon's Diversity Index (Table 18); this response was explained by quadratic function. Bird richness was positively affected by an increase in tree richness and abundance within all cacao agroforests (R^2 = 0.25, p = 0.001 and $R^{2\,=}$ 0.26, 0.0007 respectively) but in Secondary Forest the opposite effect was observed. Bird diversity (H') was positively affected by abundance of flowering trees, shade tree richness and abundance (Table 18).

Altitude had a significant positive effect on both amphibian species richness and abundance as did for reptile abundance. Amphibian richness and abundance was negatively affected by percentage of bare ground but most significantly for abundance. On the other hand percentage weed cover and estimated vegetation cover in the upper canopy had a positive effect on amphibian abundance. Temperature had a significant negative effect on reptile abundance (p =

0.002), while both Musaceae abundance and an increase in understory cover had a positive effect (Table 19).

*Table 18. Simple linear regressions for bird richness, abundance, diversity index and evenness with habitat variables, regressor variables shown are those with statistical significance. * = dependant variable was squared root transformed.*

Dependent variable	regressor variable	Slope	R²	R² Aj	T -value	p-valor
Bird Richness	Tree richness	0.2	0.25	0.21	3.54	0.001
	Tree Richness^2	-0.01	---	---	-3.51	0.0012
	Tree abundance	0.08	0.26	0.22	3.71	0.0007
	Tree abundance^2	-0.0013	---	---	-3.59	0.0009
abundance	Tree richness	0.23	0.11	0.06	2.19	0.0347
	Tree richness^2	-0.01	---	---	-2.05	0.0468
	Tree abundance	0.1	0.12	0.07	2.28	0.0285
	Tree abundacne^2	-0.002	---	---	-2.15	0.0382
Shannon	Flowering tree abundance	0.02	0.11	0.09	2.28	0.0283
	Tree richness	0.02	0.23	0.19	3.41	0.0015
	Tree richness^2	-0.001	---	---	-3.41	0.0015
	Tree abundance	0.01	0.25	0.21	3.56	0.001
	Tree abundacne^2	-0.0001	---	---	-3.47	0.0013

Forest specialist bird richness and abundance had a significant positive relationship with Thiollay's Vegetation Index (R^2 = 0.16, p = 0.0094), tree abundance (R^2 = 0.14, p = 0.0142), tree species richness (R^2 = 0.17, p = 0.0059) and tree total basal area (R^2 = 0.15, p = 0.0117) (Table 20). Forest generalist bird richness was positively related with tree richness and abundance, while forest generalist bird abundance was significantly related to Thiollay's Vegetation Index, tree species richness and abundance, as did for tree total basal area. General species richness and abundance was significantly related to tree richness and abundance, but such relationship was best explained by a quadratic function (Table 20).

Birds' degree of sensitivity to human disturbances were highly correlated to birds' degree of forest dependence (forest specialists and birds with high degree of sensitivity to human disturbances: (R^2 = 0.34, p = <0.0001)). For the above reason no regression results are shown between habitat structural and compositional variables with degree of birds' sensitivity to human disturbances as the results were similar to those of degree of forest dependence and plot-scale variables.

Table 19. Habitat variables that had a significant relationship with herpetofauna richness and abundance based on the results obtained from the generalized linear models.

Variable	slope	z-value	p-value
Amphibian Richness			
Altitude	0.001	2.083	0.0372
Bare ground (%)	-0.058	-1.86	0.0629
Amphibian Abundance			
Altitude	0.001	2.652	0.008
Slope	0.012	2.352	0.019
Weed Cover (%)	0.026	4.609	<0.0001
Bare ground (%)	-0.089	-3.682	0.0002
Thiollay’s index (c >30m)	2.05	4.3	<0.0001
Reptile Richness			
----------	----------	----------	----------
Reptile Abundance			
Temperature	-0.16	-3.032	0.002
Altitude	0.0007	1.953	0.05
Thiollay’s index (c0-2)	0.32	2.242	0.03
Musaceae abundance	0.0008	2.936	0.003

*Table 20. Habitat variables that had a significant relationship with degree of forest dependence for bird species richness and abundance based on results obtained from simple linear regression models. * = dependent variable was square root transformed.*

	Forest Specialists*					Forest Generalists*					Generalists*				
Variable	**Slope**	**R²**	**R² Aj**	**T-value**	**p-value**	**Slope**	**R²**	**R² Aj**	**T-value**	**p-value**	**Slope**	**R²**	**R² Aj**	**T-value**	**p-value**
Richness															
Thiollay's Vegetation Index	0.23	0.16	0.14	2.73	0.0094	--	--	--	--	--	--	--	--	--	--
Tree abundance	0.02	0.14	0.12	2.56	0.0142	0.01	0.17	0.15	2.85	0.0069	0.08	0.41	0.38	4.16	0.0002
Tree abundance^2	--	--	--	--	--	--	--	--	--	--	-0.002	--	--	--4.8	<0.0001
Tree richness	0.05	0.17	0.15	2.91	0.0059	0.04	0.19	0.17	3.06	0.004	0.15	0.34	0.31	2.94	0.006
Tree richness^2	--	--	--	--	--	--	--	--	--	--	-0.01	--	--	-3.72	0.001
Tree basal area	0.29	0.15	0.13	2.64	0.0117	--	--	--	--	--	--	--	--	--	--
Abundance															
Thiollay's Vegetation Index	0.23	0.16	0.14	2.73	0.0094	0.33	0.15	0.13	2.68	0.0106	0.47	0.19	0.17	3.06	0.0039
Tree abundance	0.02	0.14	0.12	2.56	0.0142	0.04	0.34	0.32	4.52	0.0001	0.12	0.32	0.29	2.8	0.008
Tree abundance^2	--	--	--	--	--	--	--	--	--	--	-0.001	--	--	-3.51	0.0012
Tree richness	0.05	0.17	0.15	2.91	0.0059	0.12	0.41	0.4	5.29	<0.0001	0.19	0.26	0.23	1.77	0.0841
Tree richness^2	--	--	--	--	--	--	--	--	--	--	-0.01	--	--	-2.56	0.0145
Tree basal area	0.29	0.15	0.13	2.64	0.0117	0.52	0.22	0.2	3.36	0.0017	--	--	--	--	--

Musaceae abundance had a significant negative effect (R^2 = 0.09, p= 0.079) on insectivore bird. Frugivorous bird richness was positively affected by the abundance of fruiting trees (p = 0.0246), while an increase in vegetation between the height of 2-9 m (Thiollay's Index C2-9), negatively affected frugivorous bird richness. The abundance of shade trees had a significant effect on nectarivore richness, but such response by nectarivores was explained by a quadratic function. Flowering tree abundance had a significant positive effect on seed eater richness (R^2 = 0.14, p = 0.0137) (Table 21).

*Table 21. Mulivariate regressions for bird food guilds based on bird richness with habitat variables, regressor variables shown are those with statistical significance. * = dependant variable was squared root transformed.*

Dependent Variable	Regressor variable	slope	R^2	R^2 Aj	T-value	P-value
Insectivorous*	Mucaseae abundance	-0.01	0.09	0.07	-2.04	0.0479
Frugivorous*	# of fruiting trees	0.11	0.21	0.17	2.34	0.0246
	Thiollay's Index (C2-9)	-0.77	0.21	0.17	-2.41	0.0208
Nectarivorous*	Thiollay's Index (C20-30)	0.62	0.27	0.21	2.08	0.0445
	Tree abundance	0.04	0.27	0.21	2.6	0.0132
	Tree abundance^2	0.0005	0.27	0.21	-2.53	0.0157
Gramnivorous*	# of flowering trees	0.21	0.14	0.12	2.58	0.0137
Onmivorous*	Thiollay's Index (C2-9)	-0.63	0.12	0.1	-2.35	0.024

To understand the relationship between avian community composition with habitat structural and compositional variables, we conducted a Multi-dimension Scaling to reduce the dimension of the data into three axes which explained more than 75 of the variance. Results indicate that changes in species composition were mostly correlated to changes in tree richness, abundance and tree total basal area. The formation of a closed canopy at the height of 10-20 m (Thiollay's Index C10-20m) had a positive relationship with avian composition. Cacao abundance, Cacao total basal area and Cacao height had a significant negative association with avian composition, indicating that an increase in cacao density results in greatest degree of change in bird species composition. An increase in Musaceae dbh, had a negative effect on bird composition (Table 22).

Table 22. Spearman Correlation Analysis between bird composition and habitat structural and compositional variables.

Habitat structural variable	**Axis 1**		**Axis 2**		**Axis 3**	
	r	**p**	**r**	**p**	**r**	**p**
Cacao abundance	-0.38	0.01	-0.64	<0.0001	-0.34	0.03
Cacao Total Basal Area (m2)	-0.43	0.004	-0.51	0.001	--	--
Cacao height (m)	-0.4	0.01	-0.63	<0.0001	-0.44	0.003
Tree abundance	0.3	0.05	0.57	<0.0001	--	--
Tree richness	0.34	0.03	0.57	<0.0001	0.35	0.02
Tree Total Basal Area (m2)	--	--	0.53	0.0003	--	--
Musaceae DBH (M)	--	--	-0.35	0.02	-0.38	0.01
Thiollay’s Index (C2-9)	--	--	-0.34	0.03	--	--
Thiollay’s Index (C10-20)	--	-	0.04	0.004	0.43	0.004

We conducted Pearson’s Correlation analysis utilizing species coordinates obtained from the Principal Coordinates Analysis to investigate the association between herpetofauna composition and habitat structural and botanical variables. A total of nine axis were used as these explained 82% of the variance for both amphibians and reptiles. Amphibian species composition had a significant positive association with Musaceae abundance and total basal area, cacao basal area, leaf litter thickness and percentage cover, tree DBH and habitat area. On the other hand there was a significant negative relationship with tree richness and abundance. Amphibian species found in Axis 1 had a negative association with Thiollay’s Vegetation Index and tree basal area but species in Axis 4 were positively associated (Table 23). Reptile species composition was positively associated with Musaceae abundance and total basal area, altitude and distance to water sources but was negatively associated to habitat patch area, temperature and cacao dbh (Table 24).

Table 23. Pearson's Correlation Analysis between amphibian species composition and habitat structural and compositional variables.

Amphibian Composition	**Axis 1**		**Axis 2**		**Axis 3**		**Axis 4**		**Axis 5**		**Axis 6**		**Axis 7**		**Axis 8**		**Axis 9**	
Variable	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**
Thiollay's Vegetation Index	-0.39	0.01	---	---	---	---	0.44	0	---	---	---	---	---	---	---	---	---	---
Musaceae basal area	0.45	0	---	---	---	---	---	---	--	---	---	---	---	---	---	---	---	---
Musaceae abundance	0.41	0.01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Cacao dbh	0.34	0.03	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Cacao total basal area	0.35	0.03	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
slope (%)	---	---	---	---	0.43	0.01	---	---	---	---	---	---	0.37	0.02	---	---	---	---
Leaf litter thickness (cm)	0.41	0.01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Weed Cover (%)	---	---	---	---	---	---	---	---	---	---	---	---	0.32	0.04	---	---	---	---
Tree richness	-0.39	0.01	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Tree abundance	-0.37	0.02	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Tree dbh	0.44	0.0001	---	---	---	---	---	---	0.7	0.0001	---	---	---	---	---	---	---	---
Tree total basal area	-0.35	0.03	---	---	---	---	0.36	0.02	---	---	---	---	---	---	---	---	---	---
Area (ha)	0.36	0.02	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---	---

Table 24. Pearson's Correlation Analysis between reptile species composition and habitat structural and compositional variables.

Reptile species composition	**Axis 1**		**Axis 2**		**Axis 3**		**Axis 4**		**Axis 5**		**Axis 6**		**Axis 7**		**Axis 8**		**Axis 9**	
variable	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**	**r**	**p**
Cacao DBH	---	---	-0.33	0.04	---	---	---	---	---	---	---	---	---	---	---	---	---	---
Musaceae abundance	0.36	0.02	---	---	---	---	---	---	0.36	0.02	---	---	0.47	0.0001	---	---	---	---
Musaceae total basal area	0.33	0.04	---	---	---	---	---	---	0.34	0.03	---	---	0.37	0.02	---	---	---	---
Temperature	-0.47	0.0001	-0.35	0.03	---	---	---	---	---	---	---	---	-0.45	0.0001	---	---	---	---
Altitude (masl)	0.46	0.0001	---	---	---	---	---	---	0.46	0	---	---	---	---	---	---	---	---
Area (ha)	---	---	-0.32	0.04	---	---	---	---	---	---	---	---	---	---	---	---	---	---

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5 DISCUSSION

Our study area was located within an agricultural matrix, dominated by pasture and basic grain fields (corn and beans). Percentage forest cover ranged between 13.46 to 14.98% at all scales (within the 500 m – 3000 m buffers) being classified as highly fragmented under McIntyre and Hobbs (1999) terminology. In this context, cacao agroforests play an essential role in avian and herpetofauna conservation. Of the total 174 bird species recorded, 154 were recorded within cacao agroforests, while the 12 amphibian species and 18 out of the 19 reptile species recorded were found within cacao agroforests. Although appearing to conserve great diversity, most of the species, especially for birds, registered were more generalists in aspects of habitat requirements; stressing the idea that structurally complex cacao agroforests are no substitutes for natural forests (Faria *et al.* 2007; Harvey and Gonzalez Villalobos 2007; Cassano *et al.* 2009) but may be acting as stepping stones favouring species dispersal within an agricultural matrix. This assumption may not be viewed against cacao agroforest biodiversity conservation value but as a consequence of landscape fragmentation.

5.1 The effect of the landscape context on avian and herpetofauna diversity

Contrary to our hypothesis, the continuous landscape variables measured (percentage of forest cover, mean forest patch area, forest patch density) at different scales were not efficient in explaining bird and herpetofauna communities within the habitats studied. This may be as a consequence of the high degree of fragmentation which is distributed homogeneously throughout the landscape. High degree of forest fragmentation, increased isolation between forest patches and decrease forest patch area, additionally explaining why avian and herpetofauna diversity observed was dominated by generalist species. These species are capable of surviving in landscapes with limited natural vegetation cover. Even though forest patches were of limited size, this study shows their capacity to provide food and habitat for some forest specialist species, adding to their conservation value.

Other factors that may have played an important role in determining why landscape variable were not able to explain biodiversity within the different habitats was the resolution and age of the images. Factors that impeded us from doing a detailed and precise land cover classification system. The image having a resolution of 30 m^2 prevented the digitalization of most riparian forest strips and live fences, known to be important factors in explaining diversity (Milder *et al.* 2010) and have lead to an increase in connectivity between remnant forest patches and cacao systems. Images utilized were from 2001 and 2005 and being a dynamic landscape much have change in regards to land covers, which play a role in determining biodiversity in an area. The above reasons, coupled with the fact that land cover classification does not consider land management and level of anthropogenic disturbances significantly affect conservation outcomes (Milder *et al.* 2010) and may have reduced the probability of detecting relationships between forest cover and biodiversity within particular habitats.

Although many authors suggest that habitat fragmentation is perceived differently by species due to difference in dispersal ability, both birds (high dispersal ability) and herpetofauna (low dispersal ability) may be responding to other factors other than the landscape metrics considered. Even though we are not clear on what these factors are, it is possible to assume that the landscape has surpassed its biodiversity conservation threshold. Biodiversity within secondary forest remnants and cacao agroforests are becoming isolated populations with limited exchange of species between source patches. Possible source forest parches were few and more than 4 km in straight line distance from the closest forest patch or cacao system studied.

Distance to remnant forest patches has been reported by many authors as critical in explaining avian community composition (Reitsma *et al.* 2001; Florian 2005; Clough *et al.* 2009) but was otherwise in this study. Species richness of forest specialist, tend to decrease rapidly as one moves away from the forest edge; stressing the idea that forest specialists are unlikely to subsist in cacao agroforests without the immediate proximity of natural forest. Although no relationship was found between avian diversity and distance to forest remnants it suggests the critical role that riparian strips may be playing in forest remnant and cacao agroforests connectivity. It also leads to the assumption that if in Waslala secondary forest remnants were of greater size and with heterogeneous fragmentation there have likely been significant relationships with forest specialists' diversity.

Herpetofauna diversity was neither explained by landscape metrics considered. An important factor to consider here is amphibian mobility capacity; the distance to the nearest forest patch was 210 m, while to the closest water source was 98 m away. Habitats were gaped by cattle pastures or agricultural field, highly affecting migration of species as these are regarded as hostile habitats. This cannot be generalized as many studies indicate that amphibian response to habitat fragmentations and distance to water bodies is species specific due to differences in life history and behavioural characteristics (Cushman 2006), indicating the complexity of analyzing amphibian communities as a whole in determining patterns associated with habitat and landscape variables. Surprisingly distance to water bodies was not a good predictor for neither amphibian species richness nor abundance contradictory to the findings of Russell *et al*. (2002), Loehle *et al.* (2005) and Bell and Donnelly (2006) who suggest that amphibian diversity is more dependent upon the availability of water bodies in the landscape than on intrinsic habitat variables, as a direct response to amphibians' physiological and reproductive requirements. This finding may be as a consequence of the natural history of the dominant family Leptodactylidae (50% of total richness and 77% of total abundance). This amphibian family is least impacted by the presence or absence of water bodies as most of the species recorded were terrestrial who lay their eggs on the leaf litter (Savage 2002).

It is also important to highlight that habitat topographical variables such as altitude and relief helped explain herpetofauna diversity. These results are similar to those of Soares and Brito (2007). Further suggests that explaining species composition is complex as they respond to different variables from habitat complexity, topographic to landscape metrics.

According to Barrett and Guyer (2008), conserving herpetofaunal diversity circles around the conservation and adequate management of suitable habitat and maintaining connectivity among habitat patches. This is highly achieved by conserving riparian forest strips but riparian forest strips by themselves are not enough to conserve viable populations thus the need to develop conservation measures from a landscape focal point of view.

Although secondary forest remnants and cacao agroforests appear to conserve great avian and herpetofauna diversity within this landscape context, their conservation value is dependent on several factors that include distance to primary forest remnants (Ricketts 2001; Tasser *et al.*

2009), percentage of surrounding forest cover (Castelletta *et al.* 2005; Florian 2005; Develey and Metzger 2006), degree of connectivity between forest remnants (Fahrig 2003; Bennett 2004; Faria *et al.* 2006; Schroth and Harvey 2007) and low intensity of anthropogenic disturbances. These factors, critical for biodiversity conservation were absent within the study area, indicating that it has surpass it threshold necessary for biodiversity conservation.

5.2 Habitat comparison

Cacao agroforestry systems in Waslala were previously characterized by having a complex structural and floristic diversity (PCC 2007) but in this study of 36 cacao agroforests, three habitat typologies were identified: Cacao-Banana, Two-Strata and Diversified Cacao agroforests systems. These differ from each other both in floristic and structural complexity indicating a marked habitat gradient within cacao agroforests themselves. These differences are due to changes in habitat structural complexity, moving from agroforestry systems dominated by Musaceae shade, to rustic systems having Musaceae, palms, fruit, legumes and forest remnant trees. These systems are comparable to the indigenous cacao systems identified by Somarriba and Harvey (2003) and Deheuvel *et al*. (2010) in Talamanca, Costa Rica.

5.3 Avian and herpetofauna community comparison in cacao agroforests and secondary forest remnants

Results obtained in this study indicated that agroecological landscapes are capable of supporting great avian and herpetofauna diversity. Within this landscape context, cacao agroforests are critical habitats for both avian and herpetofauna diversity but fall short in providing the necessary resources to support high forest specialist species richness. This may not be directly as a consequence of management practices as all studied systems are managed as organic systems and cacao growers have been trained to employ the same management strategies in their cacao farms but rather as a consequence of the high degree of natural forest fragmentation and to the fact that even the most structurally complex cacao system are highly altered habitats due to marked changes in understory composition and vertical strata complexity as a consequence of shade control (Rice and Greenberg 2000). Remnant forest patches are not of mature forest but classified as secondary forest, highly altered by forest fires, and logging activities for both timber and firewood. These activities have modified the natural habitat structural and floristic composition, directly affecting patch faunal diversity dictating species composition within the landscape. Birds, amphibians and reptiles responded differently within habitat types in respect to mean species richness, abundance and as for species composition; indicating that different taxa and species within each taxa have different habitat requirements and that each fill a specific niche in the ecosystem.

Observed avian assemblage represents 23.4% of the 743 bird species recorded in Nicaragua. An increase in the sampling effort would most likely increase avian richness reported in all habitats as indicated by the species rarefaction curves, increasing the probability of registering rare and cryptic species that may be utilizing the different cacao agroforests. Even though high species richness was reported (174 species, 2914 individuals), a closer look at species composition reveals that of highly alter habitats as the majority were generalists species (100 species, 2125 individuals), while only 20 species were considered to be forest specialists, representing 11.5% of the total bird richness and just 4% of the total recorded abundance (117 individuals) of which 11 species were registered within cacao agroforests (6.3% of the total richness) while 9 species were exclusive to secondary forests. These results reveal that these systems fall short in providing resources required by forest specialists. All but two species were of least conservation concern. *Passerina ciris* and *Vermivora chrysoptera* are listed as near threatened species by IUCN, thus are of great conservation value, as a consequence of showing population declines throughout their range. *P. ciris* (2 individuals) was observed in Diversified Cacao agroforests while *V. chrysoptera* was recorded in all habitats except Cacao-Banana agroforests.

Although we failed to find significant difference in regards to frugivorous and nectarivores, species highly dependent on forest, may indicate that cacao agroforest may offer food resources for these bird guilds. This can further be assumed due to the availability of fruits within the systems (especially ripe bananas), highly favoured by many bird species. Although many shade trees produce fruits eaten by birds (*Inga sp, Citrus spp.*) the diversity of such trees is limited compared to forest remnants (Steffan-Dewenter *et al.* 2007) and food source production is available for part of the year, indicating the dependence of frugivores on neighbouring forest fragments for their survival. On the other hand nectarivores richness was highly associated to secondary forests indicating that the resources offered by cacao agroforests do not appear to sustain nectar feeders.

Amphibian's mean species richness and abundance showed no statistical difference among habitats studied but did showed difference in regards to species composition. Of the 12 amphibian species recorded in the study area all occurred within cacao agroforests and only five species within secondary forests but none were specific to this habitat. This indicates the importance of cacao agroforests in amphibian conservation however all but one species was of least conservation concern. *Eleutherodactylus biporcatus*, is listed as a vulnerable specie by IUCN, as a consequence of showing evident population declines in recent years, this specie was recorded in Secondary Forest (2 individuals) and in Cacao-Banana agroforests (3 individuals).

Cacao-Banana agroforests and Secondary forests were favoured most by reptiles as both had highest mean richness, but no difference among habitats was found for abundance, this may be as a consequence of the available resources provided by these habitats on the leaf litter and by the presence of lower branches, as both habitats reported greatest reptile abundance occurring on the leaf litter and branches.

The almost mirror effect behaviour of the rarefaction curves between amphibians and reptiles may be as a consequence of differences in abundance distribution patterns as a consequence of changes in species dominance at different habitats. These results are similar to those obtained by Urbina-Cardona *et al*. (2006), who state that this could be because of different abundance distribution patterns and hierarchical position of species as a consequence of species affinity to different habitat uses.

Bird, amphibian and reptile species composition responded differently to habitats, indicating that species food and habitat requirements within these taxa are different. ANOSIM results leads to say that secondary forest remnants provide different resources and niches for avian species composition than do cacao agroforests, favouring forest specialist species, while cacao agroforests support more forest generalists and generalist species. Although Secondary Forests reported greatest forest specialist bird richness and abundance in comparison to the cacao agroforests, out of the 83 species reported for this habitat 15 species were forest specialists, this is only 18% of the total richness indicating that forest remnants have been highly disturbed, such human disturbances were evident, creating niches that favor the colonization by generalist species.

For both amphibian and reptiles, ANOSIM results indicate that there was no habitat different for the rest in regards to species composition but there were differences among pair of habitats. The difference between Two-Strata and Diversified Cacao agroforests species composition may be as a consequence that Diversified Cacao had six species not found in Two-Strata cacao agroforests these being *Rana maculata, Smilisca phaeota, Leptodactylus pentadactylus, Oophaga pumilio* and *Bufo coccifer*, while one species found in Two-Strata Cacao systems was not reported in Diversified Cacao agroforests, this being *Gymnopis multiplicata*. These differences in species composition between habitats indicated that different species have different habitat requirements, thus more heterogeneous habitats are capable of providing food and habitat resources for greater diversity as there will be more habitat, food resources and niches that can be exploited by different species. This finding also supports the notion that what is regarded as habitat by one species may not be so for another (Bennett 2004) as a consequence of difference in life history.

High biodiversity richness do not necessarily reflect high quality habitat, however, nor can it be assume that cacao agroforests represent self-sustaining populations (Merola-Zwartjes and DeLong 2005), especially in a highly fragmented landscape as it is the case with the study area, were all cacao agroforests and most remnant forest patches are of limited size. Measures of physiological and reproductive condition will offer an insight to this assumption which were variables not considered in this study.

5.4 Effects of habitat structure and composition on avian and herpetofauna diversity

Birds, amphibians and reptile species richness and abundance responded differently to habitat structural and floristic complexity. The linear regression analysis suggests the importance of shade tree richness and abundance and vertical structural stratification as most influential predictors of avian richness, abundance and diversity in cacao agroforests. These results are similar to other bird studies in agroforestry systems which stress the conservation value of floristic and structurally complex agroforestry systems, which have the potential to offer more food and habitat resources than homogenous and botanically and structurally simplified habitats (Greenberg *et al.* 2000; Rice and Greenberg 2000; Faria *et al.* 2006; Harvey and Gonzalez Villalobos 2007; Greenberg 2008). The relationship between tree richness and abundance with over all bird richness and abundance was explained by a quadratic function indicating that an initial increase in tree richness and abundance leads to an increase in bird richness and abundance but then reaches an asymptote (threshold value), once passing this threshold in tree richness and abundance avian diversity declines. This decline in avian richness and abundance may have been as a consequence of the resources provided by such habitats that favour forest specialist species thus displacing generalist. Bird richness and abundance with respect to degree of forest dependence were greatly explained by botanical and structural complexity. The positive linear relationship found between forest specialist species stress the important role that shade tree richness and abundance play in avian conservation. These findings indicated that an increase in habitat complexity both structurally and floristically have a positive impact on forest specialist species and thus decreasing both richness and abundance of generalist bird species, which are of less conservation concern.

These findings are best explained by the habitat heterogeneity hypothesis (MacArthur and MacArthur 1961). This hypothesis suggests that there exists a positive linear relationship (as was the case in this study) between habitat structural and floristic heterogeneity and species richness and diversity due to an increase in the number of niches that can be filled, favouring specialization and decreasing interspecies competition for available resources (MacArthur and MacArthur 1961; Cramer and Willig 2005; Koh *et al.* 2006). Greenberg *et al.* (2008) suggests that maintaining habitat heterogeneity can be a means of conserving species richness in agricultural landscapes; allowing high species richness conserves both forest dependent and generalist species (Laiolo 2002).

Amphibian richness showed a negative relationship with percentage of bare ground within the habitats. This indicates that an increase in leaf-litter, weed cover and vertical structural heterogeneity has a positive relationship with species richness, although such relationships were not significant in this case but were with abundance. An increase on percentage bare ground makes a habitat more hostile to amphibians due to their unique physiological requirements, as they need a moist environment as a consequence of their moist and permeable skins that may lead to dehydration if exposed to direct sunlight. An increase in leaf litter, weed cover and vertical heterogeneity are likely to offer refuge from direct sunlight and even possible from predators. An increase in vertical habitat complexity has a direct impact on microclimatic conditions, allowing a cooler environment favoured by amphibians due to their physiological requirements.

Reptile richness seems to respond indifferently to habitat floristic and structural heterogeneity, as there was no variable explaining species richness, reflecting the wide range of eco-physiological tolerances within species composition (Urbina-Cardona *et al.* 2006) while abundance was significantly explained by the presence of an understory and by Musaceae abundance. An explanation for this could be as a consequence of species composition and dominance. The dominant species were of the genus *Norops*; comprising 74.8% (193 out of 258 individuals) of the total reptile abundance. Species of this genre tends to be very territorial and strictly diurnal, showing characteristic territorial display, sit-and-wait and active foraging mechanisms (Savage 2002) which may have lead to an increase in the chances of being observed.

Results indicate that different taxa respond differently to habitat heterogeneity as a consequence of the resources (food and habitat types) needed by different organisms, thus in the arena of biological conservation the sustainable management and conservation of heterogeneous landscapes will lead to greater biodiversity conservation.

6 CONCLUSIONS

It is evident that cacao agroforests and remaining secondary forest fragments play a critical role in the conservation of avian and herpetofauna diversity within a highly fragmented landscape; as is the case for the municipality of Waslala. Although these systems conserve high diversity, a closer look at species composition reveals that of generalist species. This may be as a direct consequence that the landscape has surpasses its threshold essential for the conservation of forest specialist species, which are of greater conservation value.

Avian diversity was highest in secondary forest than in all cacao agroforests typologies except for Diversified Cacao agroforests. Diversified Cacao agroforests, being the most floristically and structurally complex of the cacao systems was able to support significantly more avian diversity than did Two-Strata and Cacao-Banana agroforests as was the case for both forest specialists and bird species. Amphibian species richness and abundance did not differ significantly among secondary forests and cacao agroforests. Contrary to avian richness, reptile richness was greater in Cacao-Banana systems than in Diversified and Two-Strata Cacao agroforests.

Although the continuous landscape variables measured at different scales were weak in explaining relationships with avian and herpetofauna diversity, these taxa responded more to plot-scale variables; however additional research is needed to examine in greater detail the effect of landscape structure and composition on avian and herpetofauna diversity. Avian diversity was greatly explained by habitat floristic and structural complexity, indicating that structurally heterogeneous habitat tends to support greater avian diversity, such findings are conclusive with many other biological studies. Amphibian richness responded negatively to percentage of bare ground, while there was a positive relationship with habitat vertical structure heterogeneity. On the other hand, reptile richness did not show a significant relationship with any habitat variable but did abundance.

It is evident that floristically and structurally diverse cacao agroforests have the potential of conserving great avian and herpetofauna diversity within a highly fragmented landscape. And that in this case biodiversity responded mainly to plot-scale variable but it must be emphasize that the surrounding landscape may be playing an important role in determining species composition just that I was unable to detect such relationships.

Predicting species richness requires the consideration of factors other than habitat heterogeneity, even at plot-scales level that include a combination of temporal changes, environmental variations and intra and interspecific competition between organisms(Goetz *et al.* 2007). Both natural and anthropogenic disturbances alter the availability of resources (food and habitat) causing species diversity patterns to vary even within a given habitat.

Even though cacao agroforests supported less forest specialist than did secondary forest remnants, it is essential to acknowledge their conservation value as these agricultural systems provide food and habitat resources for many other species, especially migratory birds, that have been under the conservation lens. Cacao agroforests may be acting as stepping stones within the agricultural matrix contributing to an increase in connectivity between forest remnants thus improving species mobility in an otherwise hostile matrix, especially for herpetofauna where most species posse low mobility rates. Cacao agroforests may be serving as "*biological gas stations*" where species stop to feed and rest in their journey to find suitable habitats.

Although cacao agroforests have the potential of conserving great avian and herpetofauna diversity it is evident that even the most complex of these systems is not a substitute to natural forests as they provide food and habitat resources for more generalized species assemblage but are good alternatives for the conservation of biodiversity within agricultural dominated landscapes and can be promoted as biodiversity friendly agricultural practices especially in or around buffer zones of protected areas and biological corridors.

7 RECOMMENDATIONS FOR THE CONSERVATION AND MANAGEMENT OF AVIAN AND HERPETOFAUNA DIVERSITY

Structurally diverse cacao agroforests have great potential of conserving avian and herpetofauna diversity, therefore it is essential to maintain shade tree richness and abundance within cacao agroforests and to find means of incorporating additional tree species in simplified systems. It is essential to incorporate tree species that not only serve as habitat and food source for biodiversity but provide economic benefits to the farmers, such as the production of fruits (*Magnifera indica, Persea Americans, Citrus spp., Musa spp., Psidium guava, Annona spp)*, timber (*Cedrela odorata, Cordia alliodora)* medicine and firewood.

Many understory species are forest dependent thus finding means of keeping an understory within cacao agroforests will have positive impacts in biodiversity conservation. This can be achieved by incorporating medicinal plants and non-timber species such as *Chamaedorea* palms, which are of high economic value. This provides a win-win situation for farmers.

Forest cover and connectivity between remnants are known to play an important role in determining species composition in agroforestry systems, thus conserving and sustainably managing remaining forest remnants and increasing connectivity by incorporating life fences and maintaining or allowing the natural regeneration of riparian forest stripes within the agricultural matrix will favour forest affiliated species conservation in an otherwise hostile environment.

Given that in rural landscapes, landscape change is as a consequence of landowners' development decisions, it is important to develop agricultural strategies that are beneficial to both biodiversity conservation and productivity. This can be done by educating farmers on the ecological services provided by conserving riparian strips (water supply), implementing the use of life fences around developed plots to enhance connectivity and to incentivize landowner not to develop marginal lands, like those with high relief or found in rocky soils. It is also necessary to develop policies at the national level, which exempt landowners from land taxes if they conserve a percentage of their property under forest cover.

It is also possible to explore the possibility of perusing a “biodiversity-friendly cacao certification scheme” that coupled with the organic and fare-trade premiums already being enjoyed will further incentivize farmers in biodiversity conservation by maintaining or converting their cacao systems into complex agroforests.

It is highly recommended the diffusion and adequate communication of the study’s results to cacao growers and their families on the importance of their cacao agroforests in the conservation of avian and herpetofauna diversity as a means of creating awareness on the diversity of organisms present in their farms and how organism can increase or reduce cacao production.

It is highly recommended to conduct avian and herpetofauna diversity studies in other land uses that form part of the landscapes mosaic in order to develop management and conservation strategies not only based on habitats’ intrinsic features but at different landscape scales and land uses, utilizing a more precise land use classification system than the one utilized in this study. With this in mind it is necessary to develop management and conservation strategies at a landscape level in order to prevent the remaining secondary forest remnants and cacao agroforests to act as sinks but need larger forest patches and increase connectivity from these source points in order to facilitate the movement of organisms between these patches.

Habitat disturbance and landscape modification have great implications on avian and herpetofauna conservation but little research have been conducted in order to evaluate such changes in species composition. It is recommended that further studies are carried in order to investigate this relationship, especially in this highly human modified landscape.

Future research is necessary to gain a deeper understanding on the ecological value of land use heterogeneity at the farm level, and of the relationship between land use heterogeneity and avian and herpetofauna diversity at a farm scale.

The results suggest that an increase in tree richness and abundance has positive impact on birds, amphibian and reptile diversity, indicating that if there is an increase in tree cover within the landscape in the form of diverse agroforestry and silvopastoral systems will not only favor biodiversity conservation but will provide wood resources to farmers lessening their dependence upon forest fragments.

Lastly this study can serve as a baseline data to establish a biodiversity monitoring program to evaluate the effect of habitat fragmentation and the impact of cacao agroforests in biodiversity conservation.

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ANNEXES

Annex 1: List of selected cacao agroforestry systems and secondary forests as sampling units:- proprietor, location, geographical coordinates, altitude and habitat typology, within the Municipality of Waslala, Nicaragua.

Code	Proprietor	Community	Latitude (y axis)	Longitude (x axis)	Altitude (masl)	Habitat Typology
N01	Efraín Gómez Gonzales	Zinica	13.4673056	-85.39233333	657	Cacao-Banana Agroforest
N02	José Víctor Raudez Jarquin	Zinica	13.4676389	-85.39397222	681	Diversified Cacao Agroforest
N03	Rosa Aura López	Ciprés	13.2885278	-85.39341667	481	Two-Strata Cacao Agroforest
N04	Cándido Duarte Mercado	Ciprés	13.2815556	-85.38830556	356	Diversified Cacao Agroforest
N05	Francisco Arostegui Castillo	Ciprés	13.2891389	-85.38566667	413	Two-Strata Cacao Agroforest
N06	Virgilio Herrera	Posolera	13.2940556	-85.41352778	693	Two-Strata Cacao Agroforest
N07	Migdalia Gerónima Rodríguez Lara	Posolera	13.2893889	-85.41266667	689	Two-Strata Cacao Agroforest
N08	Ana Cointa Castro Zamora	Ciprés	13.3090556	-85.39230556	577	Diversified Cacao Agroforest
N09	Oscar Espinoza Ortega	El papayo	13.3078889	-85.34955556	638	Two-Strata Cacao Agroforest
N10	José Ernesto Ortega Orozco	El papayo	13.3070556	-85.34863889	649	Cacao-Banana Agroforest
N11	Sotero Sevilla Castro	Waslalita	13.3399444	-85.39422222	636	Cacao-Banana Agroforest
N12	Eulalio Martínez Ochoa	Ciprés	13.3006667	-85.39294444	556	Diversified Cacao Agroforest
N13	Rosendo Sánchez Hernández	Corozal	13.3563056	-85.36955556	403	Diversified Cacao Agroforest
N14	Isabel Centeno Rodríguez	Caño los Martínez	13.3713056	-85.40138889	537	Two-Strata Cacao Agroforest
N15	Margarito Gómez López	Caño los Martínez	13.3786111	-85.40911111	547	Cacao-Banana Agroforest
N16	Jorge Olivas Ocampo	El papayo	13.3067778	-85.35233333	540	Cacao-Banana Agroforest
N17	Santos Blandón González	Kusuli	13.3944167	-85.32141667	255	Diversified Cacao Agroforest
N18	Crescencio Hernández Páez	Kusuli	13.3929444	-85.31755556	248	Two-Strata Cacao Agroforest
N19	Rogelio Pérez Zamora	Puerto Viejo	13.5085833	-85.25605556	244	Two-Strata Cacao Agroforest
N20	Riman López Martínez	Boca de Piedra	13.4416111	-85.27886111	219	Diversified Cacao Agroforest
NB21	Reynaldo Cantarero	Ocote Tuma	13.2446944	-85.30911111	382	Secondary Forest
N22	Rafael Gómez	Boca de Piedra	13.4455556	-85.27375	220	Two-Strata Cacao Agroforest
N23	José Ramón Orozco González	Ocote Tuma	13.2388889	-85.29747222	256	Diversified Cacao Agroforest

Code	Proprietor	Community	Latitude (y axis)	Longitude (x axis)	Altitude (masl)	Habitat Typology
N24	Orlando Orozco González	Ocote Tuma	13.2379167	-85.2975	251	Diversified Cacao Agroforest
N25	Reynaldo Cantarero	Ocote Tuma	13.2433056	-85.30888889	357	Two-Strata Cacao Agroforest
N26	Noel Suazo Calderón	Caño los Martínez	13.3732222	-85.40013889	487	Diversified Cacao Agroforest
N27	Aurelio Mendoza Rodríguez	San Pablo Kubali	13.4803333	-85.27633333	237	Two-Strata Cacao Agroforest
N28	Sixto Mendoza Hernández	San Pablo Kubali	13.4817222	-85.27886111	233	Two-Strata Cacao Agroforest
N29	Matías Mendoza Hernández	San Pablo Kubali	13.4829167	-85.27633333	217	Two-Strata Cacao Agroforest
N30	Lisandro Flores Luna	Las Jaguas	13.4452778	-85.30769444	235	Two-Strata Cacao Agroforest
N31	Presentacion Hernández	Kusuli	13.4007222	-85.31916667	246	Two-Strata Cacao Agroforest
N32	Benito Díaz Zeledón	Las Jaguas	13.43775	-85.31511111	246	Two-Strata Cacao Agroforest
N33	Estanislao Blandón Montenegro	Boca de Piedra	13.4355	-85.27511111	218	Diversified Cacao Agroforest
N34	Julio Figueroa Díaz	Boca de Piedra	13.4334722	-85.26852778	257	Diversified Cacao Agroforest
NB35	Francisco Cordero	Aserrillo	13.3208056	-85.39927778	595	Secondary Forest
N36	Natividad García Ochoa	San Miguel Dudu	13.31	-85.29638889	242	Diversified Cacao Agroforest
N37	Isidro Granado Montoya	San Miguel Dudu	13.3132778	-85.30041667	263	Two-Strata Cacao Agroforest
N38	María saba García Dávila	San Miguel Dudu	13.3089167	-85.29916667	228	Cacao-Banana Agroforest
NB39	Thomasa Montoya	Posolera	13.29261	-85.4097	350	Secondary Forest
NB40	Margarito Gómez	Caño los Martínez	13.37631	-85.4124	447	Secondary Forest
NB41	Nelson Álvarez Murrillo	Yerba Buena	13.31472	-85.3617	539	Secondary Forest
NB42	Marvin Benito Zeledón	Pejibaye	13.51111	-85.2167	329	Secondary Forest

Annex 2. List of bird species recorded in Waslala, Nicaragua. C_B_AF = Cacao-Banana AFS, S_C_AF = Two-Strata Cacao AFS, D_C_AF = Diversified Cacao AFS, S_For = Secondary Forest; Habitat = preferred habitat based on Stiles (1985): NF = non-forest, FC = forest canopy, FE = forest edge, FI = forest interior; FD = degree of forest dependence based on Stiles (1986):- 1 = generalist, 2 = forest generalist, 3 = forest specialist; sensitivity = degree of birds' sensitivity to human disturbances based on Stotz et al. (1996):- L = Low, M = Medium, H = High; and IUCN Status:- LC = specie of least conservation concern, NT = near threatened species.

Scientific Name	English Name	C_B_AF	S_C_AF	D_C_AF	S_For	Habitat	FD	Sensitivity	IUCN status
Ardeidae									
Bubulcus ibis	Cattle Egret			x		NF	1	L	LC
Accipitridae									
Elanus caeruleus	Black-shouldered Kite		x			NF		L	LC
Ictinia plumbea	Plumbeous Kite		x			FC	2	M	LC
Buteo magnirostris	Roadside Hawk	x	x		x	FE, NF	1	L	LC
Buteo brachyurus	Short-tailed Hawk				x	FC	3	M	LC
Falconidae									
Herpetotheres cachinnans	Laughing Falcon	x				FE, FC	2	L	LC
Cracidae									
Ortalis cinereiceps	Gray-headed Chachalaca		x	x	x	FE, NF	1	L	LC
Columbidae									
Claravis pretiosa	Blue Ground-Dove		x	x		FE, NF	1	L	LC
Leptotila cassinii	Gray-breasted Dove	x	x	x	x	FE, NF	1	M	LC
Columba flavirostris	Red-billed Pigeon	x	x	x	x	NF, FE, FC	1	M	C
Columbina talpacoti	Ruddy Ground-Dove		x			NF	1	L	LC
Geotrygon montana	Ruddy Quail-Dove				x	FI, FE	3	M	LC

Scientific Name	English Name	C_B_AF	S_C_AF	D_C_AF	S_For	Habitat	FD	Sensitivity	IUCN status
Psittacidae									
Aratinga finschi	Crimson-fronted Parakeet	x	x	x	x	FE, NF	1	M	LC
Amazona farinosa	Mealy Parrot			x		FC	3	M	LC
Aratinga nana	Olive-throated Parakeet	x	x			FC, FE, NF	2	L	LC
Brotogeris jugularis	Orange-chinned Parakeet	x	x	x	x	FC, FE, NF	1	L	LC
Amazona autumnalis	Red-lored Parrot				x	FC, FE, NF	1	M	LC
Pionus senilis	White-crowned Parrot	x	x	x		FE, FC	2	M	LC
Cuculidae									
Crothophaga sulcirostris	Groove-billed Ani	x	x	x		NF	1	L	LC
Piaya cayana	Squirrel Cukoo	x	x		x	FE, FC	1	L	LC
Tytonidae									
Tyto alba	Barn Owl			x		FE, NF	1	L	LC
Strigidae									
Ciccaba virgata	Mottled Owl				x	FI, FE, (FC)	2	M	LC
Caprimulgidae									
Nyctidromus albicollis	Common Paraque		x			FE, NF	1	L	LC
Trochilidae									
Threnetes ruckeri	Band-tailed Barbthroat	x				FI, FE	2	H	LC
Hylocharis eliciae	Blue-throated Goldentail	x	x	x	x	FC, FE	2	M	LC
Anthracothorax prevostii	Green-breasted Mango		x			FE, NF	1	L	LC
Phaethornis longuemareus	Little Hermit	x	x	x	x	FI, FE	1	M	LC
Heliomaster longirostris	Long-billed Starthroat		x	x		FC, FE, NF	1	M	LC

Scientific Name	English Name	C_B_AF	S_C_AF	D_C_AF	S_For	Habitat	FD	Sensitivity	IUCN status
Phaethornis superciliosus	Long-tailed Hermit	x	x	x	x	FI, FE	2	H	LC
Archilochus colubris	Ruby-throated Hummingbird			x		FE, NF	1	L	LC
Amazilia tzacatl	Rufous-tailed Hummingbird	x	x	x	x	NF, FE	1	L	LC
Phaeochroa cuvierii	Scaly-breasted Hummingbird		x	x		FE, FC, NF	1	L	LC
Amazilia candida	White-bellied Emerald	x	x	x		FE	2	M	LC
Trogonidae									
Trogon melanocephalus	Black-headed Trogon	x	x	x	x	FC, FE	2	L	LC
Trogon rufus	Black-throated Trogon				x	FI, FE	3	M	LC
Trogon violaceus	Violaceous Trogon	x		x		FE	1	M	LC
Alcedinidae									
Chloroceryle americana	Green Kingfisher	x				FI, FE	2	L	LC
Momotidae									
Momotus momota	Blue-crowned Mot-Mot	x	x	x	x	FE, NF, (FI)	1	M	LC
Electron platyrhynchum	Broad-billed Mot-mot				x	FC, FE	2	M	LC
Eumomota superciliosa	Torquiose-browed Motmot		x			FE, NF	1	L	LC
Galbulidae									
Galbula ruficauda	Rufous-tailed Jacamar		x	x		FE	2	L	LC
Bucconidae									
Malacoptila panamensis	White-wiskered Puffbird			x		FI, FE	3	M	LC
Ramphastidae									
Pteroglossus torquatus	Collared Aracari	x	x	x	x	FC, FE, NF	2	M	LC
Ramphastos sulfuratus	Keel-billed Toucan	x	x	x	x	FC, FE	2	M	LC

Scientific Name	English Name	C_B_AF	S_C_AF	D_C_AF	S_For	Habitat	FD	Sensitivity	IUCN status
Picidae									
Melanerpes pucherani	Black-cheeked Woodpecker	x	x	x		FC, FE	2	M	LC
Melanerpes aurifrons	Golden-fronted Woodpecker	x				FE, NF	1	L	LC
Piculus rubiginosus	Golden-Olive Woodpecker		x	x	x	FC, FE	2	L	LC
Dryocopus lineatus	Lineated Woodpecker		x	x		FE, NF	1	L	LC
Picumnus olivaceus	Olivaceous Piculet		x			FE, NF	1	L	LC
Veniliornis fumigatus	Smokey-brown Woodpecker			x		FC, FE	2	L	LC
Sphyrapicus varius	Yellow-bellied Sap-sucker	x				FE, NF	1	L	LC
Furnariidae									
Xenops minutus	Plain Xenops			x	x	FC, FE	2	M	LC
Anabacerthia variegaticeps	Spectacle-throated Foliage-gleaner				x	FC, FE, FI	3	H	LC
Dendrocolaptidae									
Xiphorhynchus flavigaster	Ivory-billed Woodcreeper		x			FC, FE	2	M	LC
Sittasomus griseicapillus	Olivaceous Woodcreeper		x			FI, FE, FC	2	M	LC
Dendrocincla homochroa	Ruddy Woodcreeper		x			FI, FE	3	H	LC
Lepidocolaptes souleyetii	Streak-headed woodcreeper	x	x	x		FE, NF, FC	1	L	LC
Dendrocincla anabatina	Tawny-winged Woodcreeper		x	x	x	FI, FE	3	H	LC
Glyphorhynchus spirurus	Wedge-billed Woodcreeper		x	x	x	FC, FI, FE	2	M	LC
Formicariidae									
Gymnocichla nudiceps	Bare-crowned Antbird				x	FE, NF, FI	2	M	LC
Thamnophilus doliatus	Barred Antshrike	x		x	x	FI, FE, NF	1	L	LC
Myrmotherula schisticolor	Slaty Antwren				x	FI, FE	3	M	LC

Scientific Name	English Name	C_B_AF	S_C_AF	D_C_AF	S_For	Habitat	FD	Sensitivity	IUCN status
Tyrannidae									
Megarhynchus pitangua	Boat-billed flycatcher	x	x	x	x	FC, FE, NF	1	L	LC
Attila spadiceus	Bright-rumped Attilia		x	x		FC, FE	2	M	LC
Todirostrum cinereum	Common Tody-Flycatcher	x	x	x	x	FE, NF, NF	1	L	LC
Myiarchus tuberculifer	Dusky-capped Flycatcher	x	x	x	x	FC, FE, NF	1	L	LC
Rhynchocyclus brevirostris	Eye-ringed Flatbill				x	FI, FE	3	M	LC
Myiarchus crinitus	Great Crested Flycatcher		x	x		FC, FE,	2	L	LC
Pitangus sulphuratus	Great Kiskadee		x	x		FE, NF	1	L	LC
Myiopagis viridicata	Greenish Elaenia		x		x	FE, FC	2	M	LC
Epidonax minimus	Least Flycatcher		x	x		NF, (FE)	1	L	LC
Zimmerius vilissimus	Mistletoe Tyrannulet	x	x	x	x	FC, FE, NF	2	M	LC
Oncostoma cinereigulare	Northern Bentbill		x	x	x	NF, FE, FI	1	L	LC
Mionectes oleagineus	Ochre-bellied Flycatcher	x	x	x	x	FI, FE	2	M	LC
Legatus leucophaius	Piratic Flycatcher		x			FE, NF	1	L	LC
Terenotriccus erythrurus	Ruddy-tailed Flycatcher	x			x	FE, FI	2	H	LC
Todirostrum sylvia	Slate-headed Tody Flycatcher		x			NF, (FI)	1	L	LC
Myiozetetes similis	Social Flycatcher	x	x	x	x	FE, NF	1	L	LC
Myiodynastes luteiventris	Sulfer-bellied Flycatcher	x		x		FC, FE	1	L	LC
Tyrannus melancholicus	Tropical Kingbird		x	x		NF, FC	1	L	LC
Contopus cinereus	Tropical Pewee	x	x	x		NF	1	L	LC
Elaenia flavogaster	Yellow-bellied Elaenia	x	x	x		NF, FE	1	L	LC
Empidonax flaviventris	Yellow-bellied Flycatcher	x	x	x	x	FI, FE	2	L	LC
Ornithion semiflavum	Yellow-bellied Tyrannulet			x		FE, FC	2	M	LC
Empidonax flavescens	Yellowish Flycatcher	x				FC, FE	2	L	LC
Tolmomyias sulphurescens	Yellow-olive Flycatcher	x	x	x	x	FE, NF, FC	1	M	LC

Scientific Name	English Name	C_B_AF	S_C_AF	D_C_AF	S_For	Habitat	FD	Sensitivity	IUCN status
Pipridae									
Schiffornis turdinus	Thrushlike Schissiforn				x	FI	3	H	LC
Manacus candei	White-collared Manakin	x	x	x	x	FE, FI	2	M	LC
Tityridae									
Tityra inquisitor	Black-crowned Tityra		x	x		FC, FE	2	M	LC
Tityra semifaciata	Masked Tityra	x	x	x	x	FC, FE	1	M	LC
Pachyramphus polychopterus	White-winged Becard		x	x		FE	1	L	LC
Vireonidae									
Vireo solitarius	Blue-headed Vireo		x			FE, FC	2	M	LC
Hylophilus decurtatus	Lesser Greenlet		x		x	FE, FC	2	M	LC
Vireo philadelphicus	Philadelphia vireo	x	x	x	x	FC, FE, NF	1	L	LC
Vireo olivaceus	Red-eyed Vireo		x	x		FE, NF	1	L	LC
Cyclarhis gujanensis	Rufous-browed Peppershrike	x	x			FC, FE, NF	1	L	LC
Vireo gilvus	Warbling Vireo		x			FE, NF	1	L	LC
Vireo flavifrons	Yellow-throated Vireo		x	x		FC, FE	2	L	LC
Corvidae									
Cyanocorax morio	Brown Jay	x	x	x	x	FE, NF	1	L	LC
Trogolodytidae									
Troglodytes aedon	Common House Wren		x	x	x	NF	1	L	LC
Henicorhina leucophrys	Gray-breasted Wood-wren				x	FI, FE	3	M	LC
Microcerculus philomela	Nightingale Wren				x	FI	3	H	LC
Thryothorus rufalbus	Rufous-and-white Wren		x			FI, FE	3	M	LC
Thryothorus maculipectus	Spotted-breasted Wren	x	x	x	x	FE, NF	1	L	LC

Scientific Name	English Name	C_B_AF	S_C_AF	D_C_AF	S_For	Habitat	FD	Sensitivity	IUCN status
Sylviidae									
Ramphocaenus melanurus	Long-billed Gnatwren		x		x	FE, NF, FI	1	M	LC
Polioptila plumbea	Tropical Gnatcatcher		x	x		FC, FE	2	L	LC
Turdidae									
Turdus grayi	Clay-colored Thrush	x	x	x	x	NF, FE	1	L	LC
Hylocichla mustelina	Wood thrush	x	x	x	x	FI, FE	3	M	LC
Thraupidae									
Thraupis episcopus	Blue-gray Tanager	x	x	x		FE, FC, NF	1	L	LC
Phlogothraupis sanguinolenta	Crimson-collared Tanager	x	x	x	x	FE, NF	1	L	LC
Tangara larvata	Golden-hooded Tanager	x	x	x	x	FE, NF, FC	1	L	LC
Eucometis penicillata	Gray-headed Tanager		x	x	x	FI, FE	3	M	LC
Chlorophanes spiza	Green Honeycreeper			x		FC, FE	2	M	LC
Euphonia gouldi	Olive-backed Euphonia			x		FC, FE	2	M	LC
Cyanerpes cyaneus	Red-legged Honeycreeper		x	x		FC, FE	2	L	LC
Habia fuscicauda	Red-throated Ant-Tanager	x	x	x	x	FI, FE	2	M	LC
Tangara lavinia	Rufous-winged Tanager				x	FC, FE, NF	2	M	LC
Ramphocelus passerinii	Scarlet-rumped Tanager	x	x	x	x	NF	1	L	LC
Euphonia affinis	Scrub Euphonia		x			FC, FE	2	L	LC
Piranga rubra	Summer Tanager	x	x	x	x	FC, FE, NF	1	L	LC
Tachyphonus delattrii	Tawny-crested Tanager				x	FC, FE	1	M	LC
Euphonia laniirostris	Thick-billed Euphonia			x		FC, FE, NF	1	L	LC
Piranga ludoviciana	Western Tanager		x	x	x	FE, FC, NF	1	M	LC
Euphonia minuta	White-vented Euphonia		x			FC, FE	2	M	LC
Euphonia luteicapilla	Yellow-crowned Euphonia	x	x	x		FE, NF	1	L	LC
Euphonia hirundinacea	Yellow-throated Euphonia	x	x	x	x	FC, FE, NF	1	L	LC
Thraupis abbas	Yellow-winged Tanager	x	x	x		FE, FC, NF	1	L	LC

Scientific Name	English Name	C_B_AF	S_C_AF	D_C_AF	S_For	Habitat	FD	Sensitivity	IUCN status
Coerebidae									
Coereba flaveola	Bananaquit			x	x	FC, FE, NF	1	L	LC
Emberizidae									
Caryothraustes poliogaster	Black-faced Grosbeak	x	x	x	x	FE, FC	2	M	LC
Saltator atriceps	Black-headed Saltator	x	x	x	x	FE, NF	1	M	LC
Arremonops conirostris	Black-striped Sparrow	x	x	x	x	FI, FE	3	L	LC
Volatinia Jacarina	Blue-black Grassquit	x	x	x		NF	1	L	LC
Cyanocompsa cyanoides	Blue-black Grosbeak				x	FE, FI, NF	2	M	LC
Saltator maximus	Buff-throated Saltator	x	x	x	x	FE, NF	1	L	LC
Atlapetes brunneinucha	Chestnut-capped Brush-finch	x	x			FI	3	L	LC
Passerina cyanea	Indigo Bunting			x		NF	1	M	LC
Arremon aurantiirostris	Orange-billed Sparrow		x		x	FI, FE	3	M	LC
Passerina ciris	Painted Bunting			x		NF	1	L	NT
Pheucticus ludovicianus	Rose-breasted Grosbeak		x	x		FE, NF	1	L	LC
Sporophila schistacea	Slate-colored Seedeater			x		FE, NF	1	M	LC
Oryzoborus funereus	Thick-billed Seed-Finch		x	x		NF	1	L	LC
Sporophila americana	Variable Seedeater	x	x	x		NF	1	L	LC
Sporophila torqueola	White-collared Seedeater			x		NF	1	L	LC
Tiaris olivacea	Yellow-faced Grassquit	x	x	x	x	NF	1	L	LC
Parulidae									
Setophaga ruticilla	American Redstart	x	x	x	x	FC, FE, NF	1	L	LC
Mniotilta varia	Black-and-White Warbler	x	x	x	x	FC, FE	2	L	LC
Dendroica fusca	Blackburnian Warbler			x		FC, FE	2	L	LC
Vermivora pinus	Blue-winged Warbler		x			NF, FE	1	L	LC
Phaeothlypis fulvicauda	Buff-rumped Warbler		x			FE	1	M	LC
Dendroica pensylvanica	Chestnut-sided Warbler	x	x	x	x	FC, FE, NF	1	L	LC

Scientific Name	English Name	C_B_AF	S_C_AF	D_C_AF	S_For	Habitats	FD	Sensitivity	IUCN status
Geothlypis trichas	Common Yellowthroat			x		NF	1	L	LC
Basileuterus culicivorus	Golden-crowned Warbler		x	x	x	FI, FE	3	M	LC
Vermivora chrysoptera	Golden-winged Warbler		x	x	x	FI, FE	2	L	NT
Geothlypis poliocephala	Gray-crowned Yellowthroat				x	NF	1	L	LC
Dendroica occidentalis	Hermit warbler		x			FE, FC, NF	1	M	LC
Wilsonia citrina	Hooded Warbler	x	x	x	x	FI, FE	2	M	LC
Seiurus motacilla	Lousiana Waterthrush		x	x		FE, NF	1	M	LC
Dendroica magnolia	Magnolia Warbler		x	x		FE, FC, NF	1	L	LC
Oporornis philadelphia	Mouring Warbler		x			NF	1	L	LC
Seiurus aurocapillus	Oven Bird			x		FI, FE, (NF)	2	M	LC
Vermivora peregrina	Tennessee Warbler	x	x	x		FE, FC, NF	1	L	LC
Parula pitiayumi	Tropical Parula	x	x	x	x	FC, FE	2	M	LC
Wilsonia pusilla	Wilson's Warbler	x	x	x	x	FC, FE, NF	1	L	LC
Helmitheros vermivorus	Worm-eating Warbler		x			FI, FE	2	M	LC
Dendroica petechia	Yellow Warbler	x	x	x		NF, FE	1	L	LC
Dendroica dominica	Yellow-throated Warbler		x	x		FE, NF	1	L	LC
Icteridae									
Icterus galbula	Baltimore Oriole		x	x		FC, FE, NF	1	M	LC
Icterus dominicensis	Black-cowled Oriole		x	x		FE, NF	1	L	LC
Quiscalus mexicanus	Great-tailed Grackle	x	x	x		NF, FE	1	L	LC
Dives dives	Melodious blackbird	x	x	x		NF	1	L	LC
Psarocolius montezuma	Montezuma Oropendola	x	x	x	x	FE, NF, FC	1	M	LC
Icterus spurius	Orchard Oriole			x		FE, NF	1	L	LC
Amblycercus holosericeus	Yellow-billed Cacique	x	x	x	x	FE, NF	1	M	LC
Icterus mesomelas	Yellow-tailed Oriole		x			FE, NF	1	L	LC

Annex 3: Amphibian species list recorded in Waslala, Nicaragua. C_B_AF = Cacao-Banana AFS, S_C_AF = Two-Strata Cacao AFS, D_C_AF = Diversified Cacao AFS, S_For = Secondary Forest.

Scientific Name	**C_B_AF**	**S_C_AF**	**D_C_AF**	**S_For**
Caeciliidae				
Gymnopis multiplicata		x		
Bufonidae				
Bufo coccifer	x		x	x
Bufo marinus	x			
Dendrobatidae				
Oophaga pumilio			x	x
Leptodactylidae				
Eleutherodactylus biporcatus	x			x
Eleutherodactylus bransfordii	x	x	x	x
Diasporus diastema	x	x	x	x
Eleutherodactylus fitzingeri	x		x	
Eleutherodactylus ridens	x	x	x	
Leptodactylus pentadactylus			x	
Hylidae				
Smilisca phaeota			x	
Ranidae				
Rana maculata	x		x	

Annex 4: Reptile species recorded in Waslala, Nicaragua. C_B_AF = Cacao-Banana AFS, S_C_AF = Two-Strata Cacao AFS, D_C_AF = Diversified Cacao AFS, S_For = Secondary Forest.

Scientific Name	C_B_AF	S_C_AF	D_C_AF	S_For
Polychrotidae				
Norops cupreus		x		
Norops humilis	x	x	x	x
Norops lemurinus	x	x	x	
Norops limifrons	x	x	x	x
Norops lionotus			x	x
Norops sp			x	
Scincidae				
Mabuya unimarginata	x	x		
Teiidae				
Ameiva festiva	x	x	x	x
Viperidae				
Atropoides nummifer				x
Bothrops asper		x		
Elapidae				
Micrurus nigrocinctus	x			
Colubridae				
Coniophanes fissidens		x		
Dryadophis melanolomus	x			
Drymobius margariferus		x		
Geophis hoffmanni	x			x
Hydromorphus concolor		x		
Imantodes cenchoa		x		x
Ninia maculata	x	x	x	x
Ninia sebae	x	x		