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Determining Spatial Relationships between Landscape Structure and Avian Diversity in the Edwards Plateau of Texas

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Abstract

The Edwards Plateau of Texas (USA) is an area of high biological diversity. However, the biodiversity of the Edwards Plateau has been endangered by shifts in the landscape mosaic resulting from continued fragmentation of rural properties. As a contribution to understanding the relationship among landscape structure and biodiversity, the objective of the present study was to investigate specific linkages between landscape structure at two levels (landscape mosaic or cluster of ecosystems and class or types of ecosystems in the landscape), and avian breeding alpha and beta biodiversity (α-diversity and β-diversity) within the Edwards Plateau. The study area was bounded by a circle with a radius of 300 km located at the geographical center point of the Edwards Plateau Ecoregion. Avian data from 31 North American Breeding Bird Survey (BBS) transects were collected from 1990 to 1994. Highly significant positive spatial correlations at the Class level (mean patch size (MN) and α-diversity (abundance and richness) and proximity (PROX) showed that habitats in the Live Oak-Mesquite Savannah sub-region, the less fragmented subecoregion of the Edwards Plateau, were highly suitable for birds. The landscape structure analysis at class level showed that maintaining minimum mean patch size around 8 ha for woodland and 49 ha for scrubland, and a high proximity between patches is important to preserve suitability of habitat for permanent resident species, short-distance migrants, and the woodland and scrubland bird species richness in the Edwards Plateau ecoregion.

Keywords: *Alpha Diversity; Avian Biodiversity; Beta Diversity; Habitat Fragmentation; Landscape Ecology*

1. Introduction

Urban sprawl and its effects have been widely studied since the 1990s. This process generates economic pressure extending well past city limits into the rural landscape, which leads to a reduction in ownership property sizes [1; 2; 3; 4; 5; 6]. Simultaneously, reduction in property sizes leads to changes in landscape structure [7; 8; 9; 10], which can lead to changes in biodiversity [11]; [12; 13; 14; 15; 16; 17; 18; 19]. As Trousdale and Gregory [20] mention, one of the most important and challenging aspects of biodiversity conservation is identifying priority lands for protection from development or other incompatible uses. Between 1982 and 2007, about 11 million acres of agricultural land in the USA were lost to development, essentially an irreversible loss [21]. Since the early 1990's, the Edwards Plateau Texas ecoregion has been among the areas in which the size-class distribution of rural properties has been shifting most rapidly towards smaller parcels [8; 22; 23]. In Texas, the fragmentation of large, family-owned farms and ranches and also (suitable) land loss has been identified as the greatest threat to wildlife habitat within the state [8; 9; 22; 23; 24]. Many rural areas in the 1990s experienced a large increase in residential development; the southern and western portions of the state (the Trans Pecos, Edwards Plateau, South Texas Brush Country, and Coastal Sand Plains ecoregions) have been losing more than 235,000 acres (ac) annually that were in large ownerships (2000 ac), thus dramatically shifting the size-class distribution of farms within these regions [8]. In a case study within a single county (Bastrop), Wilkins et al. [8] found that landscape characteristics such as number of patches per unit area and average patch size of native rangeland were influenced significantly by the subdivision of farms and ranches, that is, by land ownership fragmentation.

As a contribution to understanding the relationship among landscape structure and biodiversity, the objective of the present study was to investigate specific linkages between landscape structure and avian alpha and beta biodiversity within the Edwards Plateau of Texas, using quantitative tools of spatial statistics [25; 26; 27; 28; 29; 30; 31]. The hypothesis tested is that changes in landscape diversity (Richness and SHDI), patch size, and proximity of patches as a measure of wildlife habitat fragmentation are correlated with avian biodiversity changes in the Edwards Plateau of Texas.

1.1. Study Area

The Edwards Plateau of Texas is one of the areas of highest biological diversity in the State [32]. The geological formation of the Plateau and its geographical location between the north-south transition from north plains to the Mexican subtropics, and the east-west transition from humid plains to the southwestern deserts has resulted in a unique landscape mosaic; grassland savannas blend into the Rolling Plains to the north, a fringe of woodlands runs along the Balcones Escarpment to the east, and grasslands are interspersed with scrublands in the western and southern portions of the Plateau (Figure 1). This vegetation mosaic supports a biota that is both locally diverse (high α-diversity) and variable across the landscape (high β-diversity); the Edwards Plateau has been recognized as a biodiversity hotspot at both local [32] and international levels [33]. However, in the 1990s the Edwards Plateau experienced a large increase in residential development [8] and showed an increase in property sizes less than 500 ac which is a “threshold of habitat fragmentation’’ [10].

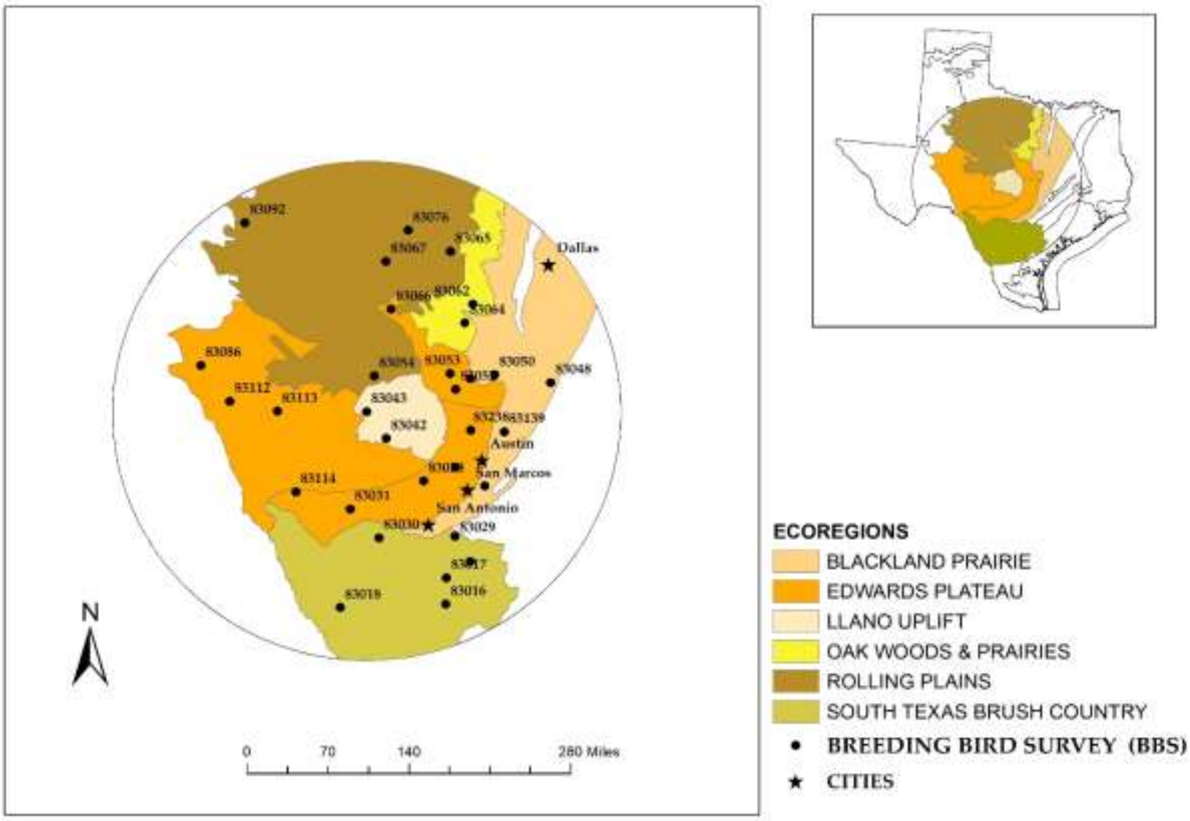

Figure 1. *Geographic location of the study area. Texas ecoregion, locations of the 31 North American Breeding Bird Survey (BBS) transects included in the present study and cities in the study area also are indicated; numbers correspond to the BBS code, of which the first two digits (83) signify Texas, and the final three digits (015-238) correspond to the transect number*

In the present research, the study area was bounded by a circle having a radius of 300 km centered at the geographical center point of the Edwards Plateau Ecoregion, which includes all of the Edwards Plateau and portions of 5 other ecoregions including the following: South Texas Brush, Blackland Prairie, Llano Uplift, Rolling Plains, and Oak Woods. Further, the study area was comprised of 8 Texas ecological subregions, adapted by Wu et al. [34] and Griffith et al. [35], including: Balcones Canyon Lands, Black Land Prairies, Brush Country, Lampasas Cut Plains, Live Oak-Mesquite Savannah, Mesquite Savannah, Mesquite Plains, and Western Cross Timbers (Figure 2).

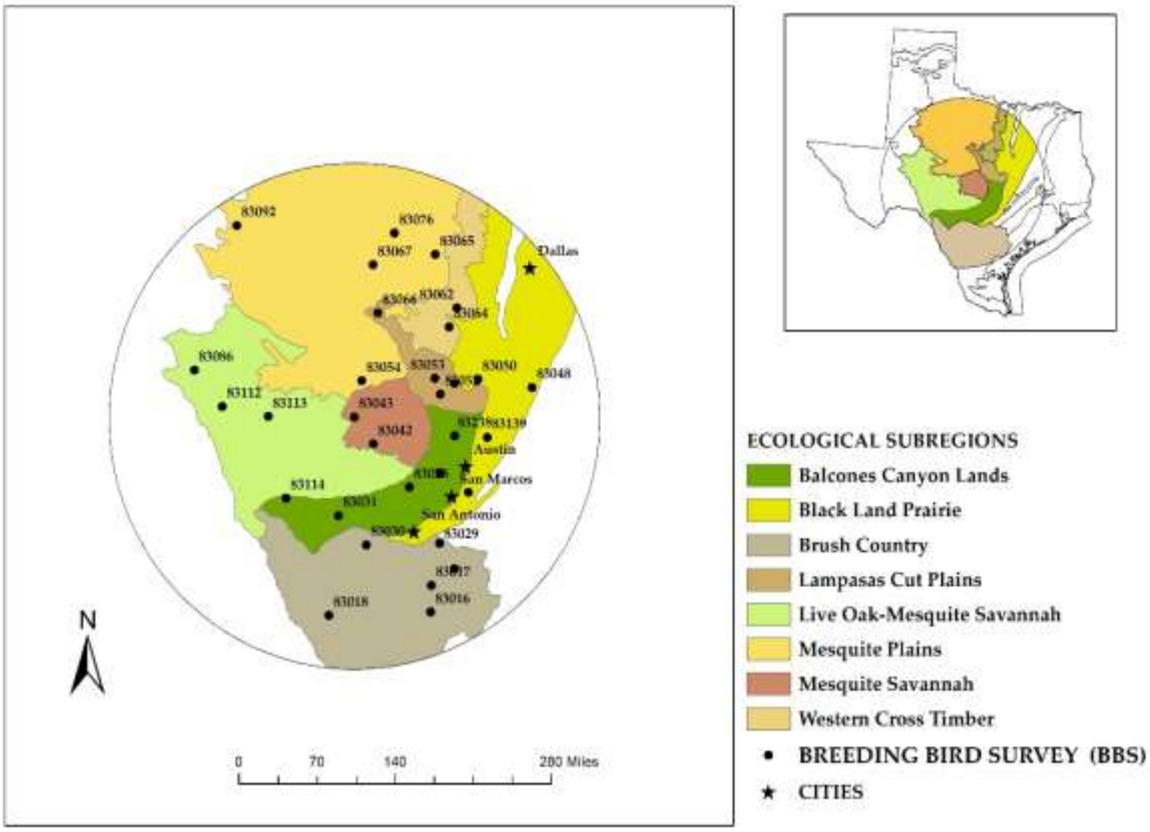

Figure 2. *The study area included the 8 ecological subregions referred to in this research. Locations of the 31 North American Breeding Bird Survey (BBS) transects included in the present study are also indicated. Numbers correspond to the BBS code, of which the first two digits (83) signify Texas, and the final three digits (015-238) correspond to the transect number*

The climate ranges from subtropical steppe to subtropical sub-humid, with mean annual precipitation ranging from 375 mm in the west to 750 mm in the east, about three-fourths of which falls during the growing season (April through mid-November). The mean annual temperature ranges from 21 to 23 $^{\circ}$C. The area is predominantly shrub land grazed by cattle, sheep, and goats, but local tracts are cultivated for domestic pasture and hay; cotton and grain sorghum are grown locally on irrigated land and there are some pecan orchards on flood plains. Landowners commonly lease their land for hunting deer, quail, mourning dove, wild turkey, and/or javelina.

Since the 1990's, many rural areas have been experiencing greatly increased residential development, especially in the eastern portion of the region, due in large part to the influence of large cities such as Dallas-Fort Worth, Houston, San Antonio, and Austin [8; 36]. According to the U. S. Department of Agriculture, more than 2.2 million acres of rural land in Texas was converted to urban uses, and the annual rate of conversion from 1992-97 was nearly 30 percent higher than in the previous 10 years [8]. During this time the population density was around 5000 inhabitants per k^2 in urban areas and 250–500 in surrounding rural areas in the nineties [37]. Conversion from native rangeland to non-native vegetation, e.g., Bermuda grass, has represented a significant loss of important wildlife habitat, especially in the central and eastern portions of Texas. The aforementioned trend is likely to continue according to a study by Martinuzzi et al. [18] which predicted habitat loss within areas of biodiversity significance in the USA for the period 2001–2051, by ecoregions, and under different scenarios of future land use change. Given the recent land fragmentation trends in Texas, some areas of the State's landscape are likely to be even less suitable as wildlife habitat for some species in the near future.

2. Methods

2.1. Bird Survey Data and Methods

Avian data were acquired that had been collected from 31 North American Breeding Bird Survey (BBS), which consists of a set of roadside surveys (over 3,500 transects) conducted each June by experienced birders to provide an index of population change for songbirds [38]. The BBS is a collaborative effort to increase the understanding of North American bird populations and jointly coordinated by the United States Geological Survey, the Canadian Wildlife Service, and, since 2008, the Mexican National Commission for the Knowledge and Use of Biodiversity [39]. Data included the number of bird species and the number of individuals of each species observed on each transect. Each species is also characterized in terms of habitat preferences (e.g., grassland) and migration status (e.g., neotropical migrant), Sauer el al. [39]. Species representing 5 breeding habitats (woodland, scrubland, grassland, wetland and urban) and 3 migration statuses (neotropical migrants, short distance migrants and permanent residents), were reported on virtually all transects. Transects (n=31) (ranging in length from 35.7 to 39.3 km) were selected for the 1990-1994 seasons; 12 located within the three ecological subregions of the Edwards Plateau Ecoregion (Live Oak-Mesquite Savannah, Balcones Canyon Lands, and Lampasas Cut Plains) and the 19 closest transects located in adjacent ecological subregions: 4 in Blackland Prairie, 2 in Mesquite Savannah, 2 in Western Cross Timber, 5 in the Mesquite Plains, and 6 in the Brush Country (Figure 2). No data were available for ecological subregions of the Trans Pecos Ecoregion, or for all four years on some transects. However, each transect had at least 3 consecutive years of data. We chose transects in adjacent ecoregions to represent the Edwards Plateau "ecological border" (Cadenasso et al. [40]). We included data from 1990 to 1994 as the time period of this study based on the important findings of other studies, i.e., Wilkins et al. [8] and Neuman et al. [35], which found that the most important conversion of native rangelands and croplands to non-native ''improved pastures" in Texas occurred from 1992 to 2001.

2.2. Statistical Methods

2.2.1. Avian Diversity

Calculations were performed for each transect pertaining to abundance (total number of individuals of all species per 10 km of transect), two indexes of α-diversity (species richness (number of different species per 10 km of transect) and Shannon's diversity (H'),

Shannon diversity H

$$H' = -\sum\left(\frac{n_i}{N}\right) * \ln\left(\frac{n_i}{N}\right) \quad (1)$$

where n_i represents the number of individuals of the ith species per 10 km of the transect and N represents the total number of individuals of all species per 10 km of the transect, and an index of β-diversity (1 - S') [24; 39],

$$\beta\text{-diversity} = 1 - S' \quad (2)$$

*where S = (2 * pN) / (aN + bN)*

and aN and bN represent the total number of individuals of all species per 10 km of transect in the first and second transects, respectively, and pN represents the sum of the lower of the 2 abundances for each of the species that occur on both transects; for example, if species X, Y, and Z are represented by 2, 4, and 8 individuals, respectively, on the first transect and 3, 5, and 7 individuals, respectively, on the second transect, pN would equal 13 (2 + 4 + 7), each averaged over the period from 1990 to 1994.

The mean and standard deviation of abundance, species richness, H', and β-diversity of transects in each of the 8 ecological subregions were also calculated. Finally, bird species were grouped by breeding habitat and by migration status, as identified in the BBS, with mean abundance and richness calculated for each of the groups for each of the 8 ecological subregions. Avian Abundance and Species Richness for the different ecological subregions were analyzed using one-way ANOVA and Bonferroni Post Hoc tests. Levene and Welch tests were used to determine homogeneity of variance. Avian Species Diversity H' and Beta Diversity were analyzed using the Kruskal-Wallis H and Games-Howell Post Hoc tests. For both parametric and nonparametric statistical tests, ($\alpha = 0.05$)

2.3. Landscape Structure Data and Methods

Land cover data were obtained for the Edwards Plateau Ecoregion for 1992 from the National Land Cover Dataset (1992) of the United States Geological Service (USGS). The spatial resolution of the data was 30 meters, mapped in the Albers Conic Equal Area projection, NAD 83. First, the 21-class land cover classification scheme of the NLCD were regrouped into 5 land cover classes: Woodland, scrubland, grassland, wetland, urban, using the Spatial Analyst tool of Arc 8 GIS (Environmental Systems Research Institute 2000). Next, the more aggregated land cover classes providing habitat for the avian species seen on the BBS transects included in this study were identified. Using the Buffer Wizard tool in Arc 8 GIS (ESRI 2000), buffer scenes of 5, 10, and 20 km around the 31 BBS transects (buffer shape files) were created, then the 20 km buffer was selected as the area representing the landscape pattern. Each buffer shape file was used to "cut" an identical area on the NLCD using the Spatial Analyst tool. The scenes were used to relate landscape structure to avian diversity as described in Donovan and Flather [11]. Within each of the 31 buffer scenes, 6 indexes of landscape structure were calculated at two levels, landscape mosaic or cluster of ecosystems and class or types of ecosystems in the landscape. At the landscape mosaic level, richness of patches (PR) was calculated, i.e., the number of types of land cover classes present in each buffer scene. Shannon Diversity (SHDI) was also calculated using the following formula:

$$SHDI = -\sum_{i=1}^{m} P_i * \ln P_i \qquad (3)$$

where P_i is the proportion of the landscape of each buffer scene occupied by land cover class i.

At the land cover class level, percent of land (PL), patch density (PD) (number of patches / 100 ha), mean patch size (MN) (ha), and the proximity index (PROX), were calculated for each land cover class using FRAGSTATS 2.0 [41; 42]. The formula used for the calculation was the following

$$PROX = \sum_{s=1}^{n} \frac{a_{ijs}}{h_{ijs}^{2}} \qquad (4)$$

where PROX represents the proximity index for focal patch i, a_{ijs} is the area (m^2) of patch ijs within a specified neighborhood (m) of patch ij, and h_{ijs} is the distance (m) between patch ijs and patch ijs, based on patch edge-to-edge distance, computed from cell center to cell center. A 100-meter search radius was selected under the assumption that this was within the daily range of movements of all of the avian species included in this study. Low index values indicate patches that are relatively isolated from other patches within the specified buffer distance, and high values indicate patches that are relatively connected to other patches [43]. PROX was used as an indicator of habitat fragmentation where low index values indicate patches that are relatively isolated from other patches within the specified buffer distance (i.e., more fragmentation), and high values indicate less fragmentation where patches are in closer proximity to other patches [44; 45]. The mean and standard deviation of PR, SHDI, PL, PD, MN, and PROX of the buffer scenes in each of the 5 ecological subregions were also calculated.

2.4. Spatial Autocorrelation of Variables

Tests for spatial autocorrelation were conducted in each of the indexes of avian diversity and landscape structure using Mantel Tests [28]. The Mantel Test (r) is a regression in which the variables themselves are distance, or dissimilarity (ecological distances), matrixes summarizing pair-wise similarities among sample locations:

$$r = \frac{\sum\sum stdA_{ij} * stdB_{ij}}{n-1} \text{ (sum from i to n and sum from j to n, for i} \neq \text{j)} \qquad (5)$$

where n is the number of sample locations, i and j identify the matrix element, B_{ij} is the Euclidian distance matrix of location points, and A_{ij} is the dissimilarity matrix of the variable of interest, in the present case, avian abundance, species richness, H', PR, SHDI, PL, PD, MN, or PROX. For Mantel test calculations, the PASSAGE program was utilized [46].

2.4.1. Spatial Correlations Between Pairs of Avian Diversity and Landscape Structure Indexes

To determine whether the indexes of avian diversity and landscape structure are spatially correlated, a Cross Mantel Test (r) was implemented [28] between each pair of avian diversity and landscape structure indexes. This set of analyses tests for a spatial relationship *per se* between differences of pairs of values of both variables (avian diversity and landscape structure) but does not indicate the degree of correlation between the values of the two variables.

$$r = \frac{\sum\sum stdA_{ij} * stdC_{ij}}{n-1} \quad \text{(sum from i to n and sum from j to n, for i} \neq \text{j)} \qquad (6)$$

where n is the number of sample locations, i and j identify the matrix element, A_{ij} is the dissimilarity matrix of one of the variables of interest, that is, an index of avian diversity (species richness, avian abundance, or species diversity), and C_{ij} is the dissimilarity matrix of the other variable of interest, that is, an index of landscape structure (PR, SHDI, PL, PD, MN, PROX).

2.4.2. Correlation Between Values of Pairs of Avian Diversity and Landscape Structure Indexes

A Pearson's pair-wise correlation (ρ) was conducted for each of the avian diversity and landscape structure indexes. This set of analyses identifies the degree of correlation between the values of the two variables,

$$\rho = \frac{\sum_{i=1}(u_i - m_u)(v_i - m_v)}{S_u S_v} \qquad (7)$$

where u and v are two variables (u is one of the 4 avian diversity indexes and v is one of the 5 landscape structure indexes). m_u and m_v are their respective means, and S_u and S_v are their respective standard deviations. The Modified *t*-test for autocorrelation (CHR), which corrects the degrees of freedom based on the amount of autocorrelation in the data, was used to assess the correlation between each pair of spatially correlated variables [47; 28]. The procedure calculates the amount of spatial autocorrelation of variables to determine how different the effective sample size (n') is from the number of observations.

$$n'(R) = \frac{n^2}{\sum\sum cor(u_i u_j)} \qquad (8)$$

where R is the autocorrelation matrix, n is the number of observations, and u_i, and u_j are the observations of the two variables. Using the PASSAGE program [48], the corrected degrees of freedom (n'-2) were then used to test the significance of the correlation.

3. Results

3.1. Avian Diversity Indexes

Ninety-two different species, including species classified by breeding habitat as woodland (n=24), scrubland (n=36), grassland (n=6), wetland (n=14), and urban (n=12), and by migration status as neotropical migrant (n=41), short-distance migrant (n=19), and permanent resident (n=32), were reported from 1990 to 1994 on the 31 BBS transects (See Tables 1 and 2).

Table 1. *Avian species reported from 1990 to 1994 on the 31 North American Breeding Bird Survey (BBS) transects from which data were drawn for the present study.*

Breeding Habitat	Migration Status	Species
Woodland	Neotropical migrant	Black-and-white Warbler (*Mniotilta varia*)
Woodland	Neotropical migrant	Blue-gray Gnatcatcher (*Polioptila caerulea*)
Woodland	Neotropical migrant	Great Crested Flycatcher (*Myiarchus crinitus*)
Woodland	Neotropical migrant	Red-eyed Vireo (*Vireo olivaceus*)
Woodland	Neotropical migrant	Summer Tanager (*Piranga rubra*)
Woodland	Neotropical migrant	Vermilion Flycatcher (*Pyrocephalus obscurus*)
Woodland	Neotropical migrant	Yellow-throated Vireo (*Vireo flavifrons*)
Woodland	Neotropical migrant	Yellow-throated Warbler (*Setophaga dominica*)
Woodland	Neotropical migrant	Black-chinned Hummingbird (*Archilochus alexandri*)
Woodland	Neotropical migrant	Ruby-throated Hummingbird (*Archilochus colubris*)
Woodland	Neotropical migrant	Black-bellied Whistling-Duck (*Dendrocygna autumnalis*)
Woodland	Neotropical migrant	Chuck-will's-widow (*Antrostomus carolinensis*)
Woodland	Permanent resident	Barred Owl (*Strix varia*)
Woodland	Permanent resident	Eastern Screech-Owl (*Megascops asio*)

Woodland	Permanent resident	Eastern Wood-Pewee (*Contopus virens*)
Woodland	Permanent resident	Carolina Chickadee (*Poecile carolinensis*)
Woodland	Permanent resident	Golden-fronted Woodpecker (*Melanerpes aurifrons*)
Woodland	Permanent resident	Ladder-backed Woodpecker (*Dryobates scalaris*)
Woodland	Permanent resident	Black-crested Titmouse (*Baeolophus atricristatus*)
Woodland	Permanent resident	Red-bellied Woodpecker (*Melanerpes carolinus*)
Woodland	Permanent resident	Wild Turkey (*Meleagris gallopavo*)
Woodland	Short distance migrant	Cooper's Hawk (*Accipiter cooperii*)
Woodland	Short distance migrant	Red-shouldered Hawk (*Buteo lineatus*)
Woodland	Short distance migrant	Brown-crested Flycatcher (*Myiarchus tyrannulus*)
Scrubland	Neotropical migrant	Ash-throated Flycatcher (*Myiarchus cinerascens*)
Scrubland	Neotropical migrant	Bell's Vireo (*Vireo bellii*)
Scrubland	Neotropical migrant	Blue Grosbeak (*Passerina caerulea*)
Scrubland	Neotropical migrant	Golden-cheeked Warbler (*Dendroica chrysoparia*)
Scrubland	Neotropical migrant	Gray Vireo (*Vireo vicinior*)
Scrubland	Neotropical migrant	Indigo Bunting (*Passerina cyanea*)
Scrubland	Neotropical migrant	Lesser Nighthawk (*Chordeiles acutipennis*)
Scrubland	Neotropical migrant	White-eyed Vireo (*Vireo griseus*)
Scrubland	Neotropical migrant	Black-capped Vireo (*Vireo atricapilla*)
Scrubland	Neotropical migrant	Lark Sparrow (*Chondestes grammacus*)
Scrubland	Neotropical migrant	Scott's Oriole (*Icterus parisorum*)
Scrubland	Neotropical migrant	Painted Bunting (*Passerina ciris*)
Scrubland	Permanent resident	Greater Roadrunner (*Geococcyx californianus*)
Scrubland	Permanent resident	Harris's Hawk (*Parabuteo unicinctus*)
Scrubland	Permanent resident	Bushtit (*Psaltriparus minimus*)
Scrubland	Permanent resident	Cactus Wren (*Campylorhynchus brunneicapillus*)
Scrubland	Permanent resident	Carolina Wren (*Thryothorus ludovicianus*)
Scrubland	Permanent resident	Common Pauraque (*Nyctidromus albicollis*)
Scrubland	Permanent resident	Long-billed Thrasher (*Toxostoma longirostre*)
Scrubland	Permanent resident	Olive Sparrow (*Arremonops rufivirgatus*)
Scrubland	Permanent resident	Verdin (*Auriparus flaviceps*)
Scrubland	Permanent resident	Canyon Towhee (*Melozone fusca*)
Scrubland	Permanent resident	Cardinal/Pyrrhuloxia (*Cardinalis cardinalis*/*Cardinalis sinuatus*)
Scrubland	Permanent resident	Common Ground-Dove (*Columbina passerina*)
Scrubland	Permanent resident	Northern Bobwhite (*Colinus virginianus*)
Scrubland	Permanent resident	Northern Cardinal (*Cardinalis cardinalis*)
Scrubland	Permanent resident	Pyrrhuloxia (*Cardinalis sinuatus*)
Scrubland	Permanent resident	Rufous-crowned Sparrow (*Aimophila ruficeps*)
Scrubland	Permanent resident	Scaled Quail (*Callipepla squamata*)
Scrubland	Permanent resident	Western Scrub-Jay (*Aphelocoma californica*)
Scrubland	Short distance migrant	Common Poorwill (*Phalaenoptilus nuttallii*)
Scrubland	Short distance migrant	Black-throated Sparrow (*Amphispiza bilineata*)
Scrubland	Short distance migrant	Groove-billed Ani (*Crotophaga sulcirostris*)
Scrubland	Short distance migrant	Curve-billed Thrasher (*Toxostoma curvirostre*)
Scrubland	Short distance migrant	Field Sparrow (*Spizella pusilla*)
Scrubland	Short distance migrant	Lesser Goldfinch (*Spinus psaltria*)
Grassland	Neotropical migrant	Burrowing Owl (*Athene cunicularia*)
Grassland	Neotropical migrant	Dickcissel (*Spiza americana*)
Grassland	Neotropical migrant	Grasshopper Sparrow (*Ammodramus savannarum*)
Grassland	Short distance migrant	Eastern Meadowlark (*Sturnella magna*)
Grassland	Short distance migrant	Cassin's Sparrow (*Peucaea cassinii*)
Grassland	Short distance migrant	Horned Lark (*Eremophila alpestris*)
Wetland-open water	Neotropical migrant	American Avocet (*Recurvirostra americana*)
Wetland-open water	Neotropical migrant	Belted Kingfisher (*Megaceryle alcyon*)
Wetland-open water	Neotropical migrant	Black-necked Stilt (*Himantopus mexicanus*)
Wetland-open water	Neotropical migrant	Great Blue Heron (*Ardea herodias*)
Wetland-open water	Neotropical migrant	Great Egret (*Ardea alba*)

Wetland-open water	Neotropical migrant	Green Heron (*Butorides virescens*)
Wetland-open water	Neotropical migrant	Pied-billed Grebe (*Podilymbus podiceps*)
Wetland-open water	Short distance migrant	Bewick's Wren (*Thryomanes bewickii*)
Wetland-open water	Neotropical migrant	Cattle Egret (*Bubulcus ibis*)
Wetland-open water	Neotropical migrant	American Coot (*Fulica americana*)
Wetland-open water	Permanent resident	Common Moorhen (*Gallinula chloropus*)
Wetland-open water	Neotropical migrant	Northern Pintail (*Anas acuta*)
Wetland-open water	Neotropical migrant	Northern Shoveler (*Spatula clypeata*)
Wetland-open water	Short distance migrant	Red-winged Blackbird (*Agelaius phoeniceus*)
Urban	Neotropical migrant	Chimney Swift (*Chaetura pelagica*)
Urban	Neotropical migrant	Purple Martin (*Progne subis*)
Urban	Neotropical migrant	Chipping Sparrow (*Spizella passerina*)
Urban	Permanent resident	Northern Mockingbird (*Mimus polyglottos*)
Urban	Permanent resident	House Sparrow (*Passer domesticus*)
Urban	Permanent resident	Inca Dove (*Columbina inca*)
Urban	Permanent resident	Rock Dove (*Columba livia*)
Urban	Short distance migrant	European Starling (*Sturnus vulgaris*)
Urban	Short distance migrant	Blue Jay (*Cyanocitta cristata*)
Urban	Short distance migrant	Common Grackle (*Quiscalus quiscula*)
Urban	Short distance migrant	House Finch (*Haemorhous mexicanus*)
Urban	Short distance migrant	Mourning Dove (*Zenaida macroura*)

Table 2. *Number of birds per breeding habitat and migration status*

Breeding Habitat/ Migration Status	Neotropical migrant	Permanent resident	Short distance migrant	Total general
Grassland	3		3	6
Scrubland	**12**	**18**	**6**	**36**
Urban	3	4	5	12
Wetland-open water	11	1	2	14
Woodland	**12**	**9**	**3**	**24**
Total general	**41**	**32**	**19**	**92**

Scrubland- and Urban-breeding birds were relatively more abundant, whereas grassland breeding birds were relatively less abundant (See Table 3) in all 8 ecological subregions. Migratory birds represented 65% (neotropical migrants 44%, short distance migrant 21%) of birds in the study area (See Figure 3). Birds in this migration status were more abundant than permanent resident birds (See Table 3) in all 8 ecological subregions.

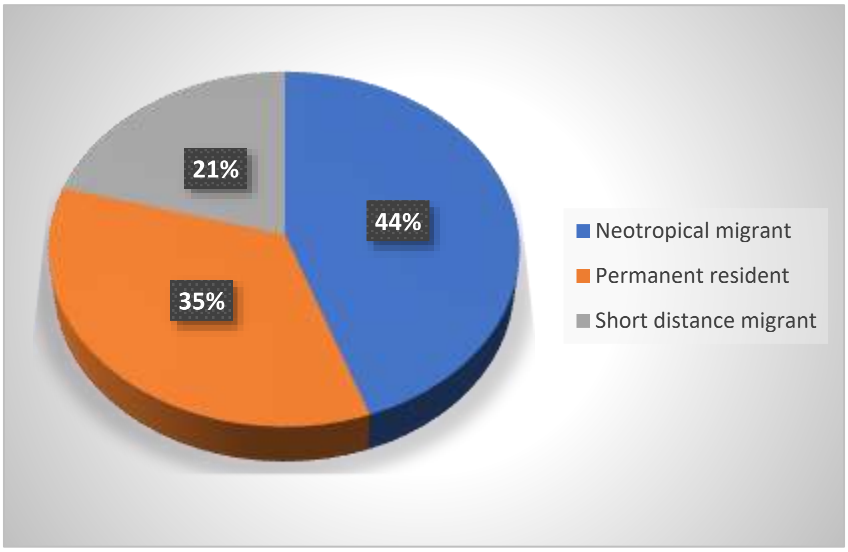

Figure 3. *Percent of birds in three different migratory status classifications in the study area*

The number of species representing these different breeding habitats and migratory status categories generally followed the same patterns as abundance, although the number of woodland-breeding species is essentially as high as the number of scrubland- and urban-breeding species (See Table 3).

Table 3. *Avian abundance (total number of individuals of all species per 10 km of transect (Avian abund.)) and species richness (number of different species per 10 km of transect (Sp. rich.)). Calculation is made for each of the 31 North American Breeding Bird Survey (BBS) transects from which data were drawn for the present study, with species grouped by breeding habitat (woodland, scrubland, grassland, wetland, urban) and migration status (neotropical migrant (Neo. mig.), short distance migrant (S. dist. mig.), permanent resident (Perm. res.).*

			Wood-land		Scrub-land		Grass-land		Wet-land		Urban		Neo. mig.		S. dist. mig.		Perm. res.	
BBS transect code	Ecoregion	Ecological subregion	Avian abund.	Sp. rich.	Avian abund.	Sp. rich.	Avian abund.	Sp. rich.	Avian abund.	Sp. rich.	Avian abund.	Sp. rich.	Avian abund.	Sp. rich.	Avian abund.	Sp. rich.	Avian abund.	Sp. rich.
83015	South Texas Brush	Brush Country	7	10	50	14	38	4	16	4	85	7	108	17	94	15	104	21
83016	South Texas Brush	Brush Country	4	1	20	13	39	4	22	7	73	7	124	16	91	13	60	12
83017	South Texas Brush	Brush Country	9	5	40	14	33	4	20	5	61	8	62	14	76	15	76	17
83018	South Texas Brush	Brush Country	8	4	113	17	16	2	10	5	39	6	34	12	99	15	129	20
83027	Blackland Prairie	Blackland Prairie	4	5	22	7	27	2	56	6	83	7	70	13	91	13	54	11
83028	Edwards Plateau	Balcones Canyon Lands	23	14	47	14	3	3	11	5	47	9	45	22	59	18	74	19
83029	South Texas Brush	Brush Country	10	9	24	13	8	2	19	6	56	9	99	19	54	16	134	19
83030	South Texas Brush	Brush Country	5	4	38	11	10	3	32	4	76	8	56	15	74	13	95	15
83031	Edwards Plateau	Balcones Canyon Lands	20	12	64	19	6	4	14	2	45	9	78	24	64	15	63	23
83042	Llano Uplift	Mesquite Savannah	10	9	50	18	4	3	4	2	54	8	42	19	35	16	62	19
83043	Llano Uplift	Mesquite Savannah	7	9	50	17	10	3	6	1	51	5	37	20	65	15	62	18
83048	Blackland Prairie	Blackland Prairie	5	6	23	7	48	2	16	5	46	9	61	13	61	14	33	11
83050	Edwards Plateau	Lampasas Cut Plains	4	4	24	6	14	3	10	3	52	7	27	12	69	10	31	10
83051	Edwards Plateau	Lampasas Cut Plains	5	5	19	6	7	2	3	2	20	6	17	11	18	11	30	12
83052	Edwards Plateau	Lampasas Cut Plains	5	7	36	10	7	3	5	6	46	10	40	18	53	17	51	14
83053	Edwards Plateau	Lampasas Cut Plains	5	8	28	6	33	3	8	3	61	9	40	16	80	14	57	12
83054	Llano Uplift	Mesquite Savannah	3	5	24	13	16	5	11	3	70	8	50	20	50	13	61	13
83062	Oak Woods	Western Cross Timbers	4	5	38	6	10	2	4	4	50	5	62	12	66	13	59	10
83064	Oak Woods	Western Cross Timbers	6	7	37	6	7	3	3	3	48	7	26	11	48	13	59	11
83065	Rolling Plains	Mesquite Plains	6	7	42	8	19	3	16	5	114	6	79	14	87	14	106	13
83066	Edwards Plateau	Lampasas Cut Plains	9	6	83	7	37	3	25	4	101	7	78	17	164	13	128	12
83067	Rolling Plains	Mesquite Plains	3	4	54	11	33	4	16	3	104	5	68	13	137	15	65	13
83076	Rolling Plains	Mesquite Plains	4	9	51	10	35	5	12	4	82	6	203	21	101	15	77	15
83086	Edwards Plateau	Live Oak-Mesquite Savannah	1	2	46	13	36	3	2	2	39	6	45	12	68	13	50	12
83092	Rolling Plains	Mesquite Plains	1	2	9	7	9	4	5	7	30	8	77	16	29	14	24	9

83112	Edwards Plateau	Live Oak-Mesquite Savannah	4	5	29	15	9	1	0	1	22	3	35	13	33	12	37	13
83113	Edwards Plateau	Live Oak-Mesquite Savannah	5	4	58	16	15	2	6	2	45	6	54	18	69	13	46	14
83114	Edwards Plateau	Balcones Canyon Lands	20	15	67	23	0	1	13	1	13	5	47	27	51	17	47	20
83139	Black Land Prairie	Black Land Prairie	8	8	27	7	54	3	11	7	73	8	71	18	77	14	74	11
83140	Edwards Plateau	Balcones Canyon Lands	24	16	39	16	1	3	12	3	41	12	36	26	27	18	69	23
83238	Edwards Plateau	Balcones Canyon Lands	11	7	40	9	4	2	8	3	79	10	30	16	48	14	87	13

Avian abundance on the 31 transects ranged from 68 to 385 individuals (See Table 4), with higher abundances tending to occur on the northern- and southern-most transects (transect numbers transect numbers 76, 66, 15, and 29). Mean abundance was highest in Mesquite Plains, followed by Brush Country, Black Land Prairie, Lampasas Cut Plains, Balcones Canyon Lands, Western Cross Timber, Mesquite Savannah and Live Oak-Mesquite Savannah, respectively (Table 5).

Species richness ranged from 36 to 71 species, with higher species richness tending to occur along an east-west band of transects lying midway between the northern and southern extremes of the study area (transect numbers 140, 28, 114, and 31, Figure 4). Mean species richness was highest in Balcones Canyon Lands, followed by Brush Country, Mesquite Savannah with Live Oak-Mesquite Savannah, Mesquite Plains, Lampasas Cut Plains and Black Land Prairie having the same, relatively lower, richness (Table 5).

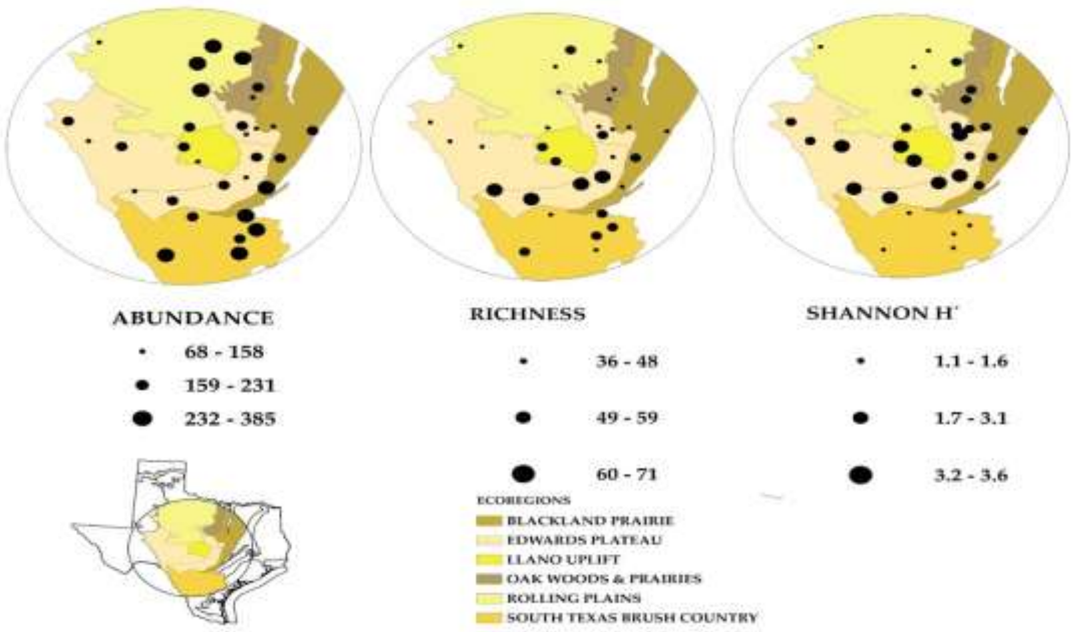

Figure 4. *Avian abundance (total number of individuals of all species per 10 km transect), species richness (number of different species per 10 km transect), and species diversity (H').*

Species diversity, based on values of H', on the 31 transects ranged from 1.1 to 3.6 (Table 4),with no obvious geographical gradients within the study area (Figure 4) Mean species diversity was highest in Balcones Canyon Lands, followed by Mesquite Savannah, Lampasas Cut Plains, Live Oak-Mesquite Savannah, Black Land Prairie, Western Cross Timber, Mesquite Plains, and Brush Country (Table 5). *β-diversity*, based on values of 1-S', on the 31 transects ranged from 1.2 to 2.7 (Table 4). Mean β-diversity was lower in Brush Country, Mesquite Plains, and Balcones Canyon Lands, and higher in Live Oak-Mesquite Savannah and Lampasas Cut Plains. Highest *β*-diversity was found in Live Oak Mesquite Savannah (Table 5, Figure 5).

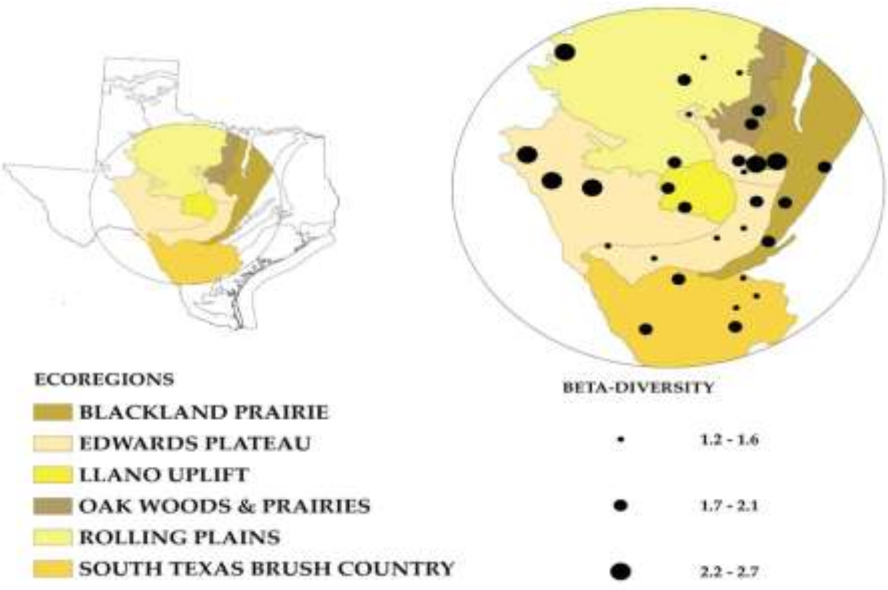

Figure 5. *β-diversity (1-S'), based on Sorensen's similarity index (S) identified in the present study.*

Table 4. *Avian abundance (total number of individuals of all species per 10 km of transect) and two indices α-diversity, species richness (number of different species per 10 km of transect), species diversity (Shannon index, H'), and β -diversity (1-S'). Calculation is made for the 31 North American Breeding Bird Survey (BBS) transects from which data were drawn for the present study. The ecoregion and ecological sub-region (Figs. 1 and 2) to which each transect belongs are also presented.*

BBS transect code	Ecoregion	Ecological subregion	Abundance	Species richness	Species diversity H'	β -diversity (1-Sorensen)
83015	South Texas Brush	Brush Country	311	57	1.5	1.4
83016	South Texas Brush	Brush Country	281	47	1.6	1.7
83017	South Texas Brush	Brush Country	220	51	1.3	1.5
83018	South Texas Brush	Brush Country	274	53	1.1	1.9
83027	Blackland Prairie	Blackland Prairie	261	44	2.9	2.0
83028	Edwards Plateau	Balcones Canyon Lands	189	64	3.5	1.5
83029	South Texas Brush	Brush Country	304	59	1.5	1.3
83030	South Texas Brush	Brush Country	226	46	1.2	1.7
83031	Edwards Plateau	Balcones Canyon Lands	218	63	3.4	1.6
83042	Llano Uplift	Mesquite Savannah	144	55	3.3	1.8
83043	Llano Uplift	Mesquite Savannah	170	54	3.2	1.9
83048	Blackland Prairie	Blackland Prairie	173	45	2.9	1.9
83050	Edwards Plateau	Lampasas Cut Plains	136	36	2.8	2.4
83051	Edwards Plateau	Lampasas Cut Plains	68	36	3.1	2.4
83052	Edwards Plateau	Lampasas Cut Plains	148	54	3.2	1.6
83053	Edwards Plateau	Lampasas Cut Plains	181	44	3.0	2.0
83054	Llano Uplift	Mesquite Savannah	162	48	3.0	2.1
83062	Oak Woods	Western Cross Timbers	189	38	2.8	1.8
83064	Oak Woods	Western Cross Timbers	136	37	2.9	1.8

83065	Rolling Plains	Mesquite Plains	286	45	2.7	1.5
83066	Edwards Plateau	Lampasas Cut Plains	377	47	2.9	1.4
83067	Rolling Plains	Mesquite Plains	274	43	1.2	2.0
83076	Rolling Plains	Mesquite Plains	385	55	1.2	1.2
83086	Edwards Plateau	Live Oak-Mesquite Savannah	164	38	3.1	2.7
83092	Rolling Plains	Mesquite Plains	133	45	1.3	2.2
83112	Edwards Plateau	Live Oak-Mesquite Savannah	104	39	3.0	2.6
83113	Edwards Plateau	Live Oak-Mesquite Savannah	174	46	3.2	2.2
83114	Edwards Plateau	Balcones Canyon Lands	158	65	3.5	1.5
83139	Blackland Prairie	Blackland Prairie	231	52	3.1	1.7
83140	Edwards Plateau	Balcones Canyon Lands	149	71	3.6	1.4
83238	Edwards Plateau	Balcones Canyon Lands	173	46	3.0	2.1

Table 5. *Species diversity. Mean(±1SD) avian abundance (total number of individuals of all species per 10 km of transect), species richness (number of different species per 10 km of transect), species diversity (H'), and β-diversity (1-S'). Indices are calculated in the 8 ecological subregions (Fig. 1) included in the present study.*

Ecological subregion	Abundance	Species richness*	Species diversity*	Beta-diversity
Balcones Canyon Lands	177(±27)	62(±9)	3.4 (±0.2)	1.6 (±0.3)
Black Land Prairie	200 (±56)	44 (±7)	2.9 (±0.1)	2.0 (±0.3)
Brush Country	269 (±38)	52 (±5)	1.4 (±0.2)	1.6 (±0.2)
Lampasas Cut Plains	194 (±131)	45 (±7)	3.1 (±0.1)	1.9 (±0.4)
Live Oak-Mesquite Savannah	147 (±38)	41 (±4)	3.1 (±0.1)	2.5 (±0.3)
Mesquite Plains	270 (±104)	47 (±5)	1.6 (±0.7)	1.7 (±0.5)
Mesquite Savannah	159 (±13)	52 (±4)	3.2 (±0.2)	1.9 (±0.2)
Western Cross Timbers	163 (±37)	38 (±1)	2.9 (±0.1)	1.8 (±0.0)

The * indicates a significant difference was found for the variable (P<0.05).

Table 6. *Mean (±1SD) avian abundance (total number of individuals of all species per 10 km of transect (Avian abund.)) and species richness (number of different species per 10 km of transect (Sp. rich.)). Indices are calculated in the 8 ecological subregions (Figs. 1 and 2) included in the present study, with species grouped by (A) breeding habitat and (B) migration status.*

A. Species grouped by breeding habitat

	Wood-land		**Scrub-land**		**Grass-land**		**Wet-land**		**Urban**	
Ecological subregion	Avian abund.	Sp. rich.	Avian abund.	Sp. rich.	Avian abund.	Sp. rich.	Avian abund.	Sp. rich.	Avian abund.	Sp. rich.
Balcones Canyon Lands	20 (±5)	13 (±4)	51 (±13)	16 (±5)	3 (±2)	3 (±1)	12 (±2)	3 (±1)	45 (±23)	9 (±3)
Blackland Prairie	5 (±2)	6 (±2)	24 (±2)	7 (±1)	36 (±19)	3 (±1)	23 (±22)	5 (±2)	64 (±17)	8 (±1)
Brush Country	7 (±2)	6 (±3)	48 (±34)	14 (±2)	24 (±14)	3 (±1)	20 (±7)	5 (±1)	65 (±16)	8 (±1)
Lampasas Cut Plains	6 (±2)	7 (±1)	42 (±29)	7 (±2)	21 (±16)	3 (±1)	10 (±10)	4 (±2)	57 (±34)	8 (±2)
Live Oak-Mesquite Savannah	3 (±2)	4 (±2)	44 (±15)	15 (±2)	20 (±14)	2 (±1)	3 (±3)	2 (±1)	35 (±12)	5 (±2)
Mesquite Plains	4 (±2)	6 (±3)	39 (±21)	9 (±2)	24 (±12)	4 (±1)	12 (±5)	5 (±2)	83 (±37)	6 (±1)
Mesquite Savannah	7 (±4)	8 (±2)	41 (±15)	16 (±3)	10 (±6)	4 (±1)	7 (±4)	2 (±1)	58 (±10)	7 (±2)
Western Cross Timbers	5 (±1)	6 (±1)	38 (±1)	6 (±0)	9 (±2)	3 (±1)	4 (±1)	4 (±1)	49 (±1)	6 (±1)

B. Species grouped by migration status

	Neotropical migrants		Permanent residents		Short distance migrants	
Ecological subregion	**Avian abundance**	**Species richness**	**Avian abundance**	**Species richness**	**Avian abundance**	**Species richness**
Balcones Canyon Lands	47 (±19)	23 (±4)	68 (±15)	20 (±4)	50 (±14)	16 (±2)
Black Land Prairie	57 (±21)	14 (±3)	48 (±20)	11 (±1)	75 (±13)	13 (±2)
Brush Country	81 (±35)	16 (±2)	100 (±29)	17 (±3)	81 (±17)	15 (±1)
Lampasas Cut Plains	44 (±25)	16 (±3)	16 (±3)	16 (±3)	79 (±62)	14 (±3)
Live Oak-Mesquite Savannah	45 (±10)	14 (±3)	44 (±7)	13 (±1)	57 (±21)	13 (±1)
Mesquite Plains	107 (±64)	16 (±4)	68 (±34)	13 (±3)	89 (±45)	15 (±1)
Mesquite Savannah	43 (±7)	20 (±1)	62 (±1)	17 (±3)	50 (±15)	15 (±2)
Western Cross Timbers	44 (±25)	12 (±1)	59 (±0)	11 (±1)	57 (±13)	13 (±0)

3.2. One-Way Anova

One-way ANOVA results indicated that there was not a statistically significant difference in avian abundance between the Ecological Subregions [$F(7, 21) = 1.874$, $p = 0.125$]. However, one-way ANOVA indicated that there was a statistically significant difference in avian Species Richness between the Ecological Subregions, [$F(7, 21) = 7.416$, $p < 0.0005$]. Specifically, the Bonferroni Post Hoc test results showed statistically significant differences for avian species richness between Ecological Subregions: Blackland Prairie and Balcones Canyon Lands (p=0.018), Balcones Canyon Lands and Lampasas Cut Plains (p=0.001), Balcones Canyon Lands and Live Oak-Mesquite Savannah (p=0.001), Balcones Canyon Lands and Western Cross Timbers (p<0.0005), Balcones Canyon Lands and Brush Country (p=0.009).

Kruskal-Wallis H test results indicated that there was not a statistically significant difference in beta diversity between the Ecological Subregions, $\chi^2(7) = 12.815$, $p = 0.077$, with a mean rank beta diversity score of 17, 7.5, 17.4, 27.17, 18.67, 15, 13.25, and 9 for Blackland Prairie, Balcones Canyon Lands, Lampasas Cut Plains, Live Oak-Mesquite Savannah, Mesquite Savannah, Western Cross Timbers, Mesquite Plains, and Brush Country, respectively. Kruskal-Wallis H test results also indicated that there was a statistically significant difference in Species Diversity H' between the Ecological Subregions, $\chi^2(7) = 24.310$, $p = 0.001$, with a mean rank Species Diversity H' score of 16.7, 28, 17.8, 21, 22.7, 13, 5.4, and 5.6 for Blackland Prairie, Balcones Canyon Lands, Lampasas Cut Plains, Live Oak-Mesquite Savannah, Mesquite Savannah, Western Cross Timbers, Mesquite Plains, and Brush Country, respectively. More specifically, Species Diversity H' between the Ecological Subregions:

Blackland Prairie and Balcones Canyon Lands (p=0.043), Balcones Canyon Lands and Lampasas Cut Plains (p=0.014), Balcones Canyon Lands and Western Cross Timbers (p=0.046), Balcones Canyon Lands and Brush Country (p<0.0005), Blackland Prairie and Brush Country (p<0.0005), Lampasas Cut Plains and Brush Country (p<0.0005), Live Oak-Mesquite Savannah and Brush Country (p<0.0005), Mesquite Savannah and Brush Country (p<0.0005), and Western Cross Timbers and Brush Country (p<0.0005).

3.3. Landscape Structure Indices

Of the 10 land cover classes that resulted from aggregation of the 21 NLCD classes, 5 (woodland, scrubland, grassland, wetland, and urban) provide habitat for the avian species included in this study (Table 7).

Table 7. *The 5 land cover classes used in this study and their relation to the 21 land cover classes identified in the National Land Cover Data (NLCD). We first reclassified the 21 NLCD classes into 5 classes, as described in the text, and then identified those classes that provide habitat for the bird species included in the present study.*

NLCD Code	NLCD Land Cover Class	Reclassification code	Land cover reclassification	Classes providing habitat for birds in this study
11	Water	1	Water	
12	Water	1	Water	
21	Developed	2	Urban	Urban
22	Developed	2	Urban	
23	Developed	2	Urban	
31	Barren	3	Barren	
32	Barren	3	Barren	

33	Barren	3	Barren	
41	Forest upland	4	Woodland	Woodland
42	Forest upland	4	Woodland	
43	Forest upland	4	Woodland	
51	Shrubland	5	Shrubland	Shrubland
61	Non-Natural Woody	6	Non-Natural Woody	
71	Herbaceous Upland Natural/Semi-Natural Vegetation	7	Grassland	Grassland
81	Herbaceous planted/Cultivated	8	Pasture	
82	Herbaceous planted/Cultivated	9	Herbaceous planted/Cultivated	
83	Herbaceous planted/Cultivated	9	Herbaceous planted/Cultivated	
84	Herbaceous planted/Cultivated	9	Herbaceous planted/Cultivated	
85	Herbaceous planted/Cultivated	2	Urban	Urban
91	Wetland	10	Wetland	Wetland
92	Wetland	10	Wetland	

At the landscape mosaic level, richness of patches (PR) ranged from 8 to 10, and Shannon Diversity (SHDI) ranged from 0.5 to 1.7 within the 31 buffer scenes (Table 8).

At the land cover class level, percent of land (PL) in woodland ranged from 1 to 69, patch density (PD) from 0 to 14, mean patch size (MN) from 0 to 20, and the proximity index (PROX) from 0 to 133,109. PL in scrubland ranged from 7 to 87, PD from 1 to 26, MN from 0 to 128, and PROX from 9 to 501,314; PL in grassland ranged from 6 to 64, PD from 4 to 18, MN from 1 to 12, and PROX from 5 to 138,471; PL in wetland ranged from 0 to 1.1, PD from 0 to 2.2, MN from 0.1 to 0.7, and PROX from 0 to 35; and PL in urban ranged from 0 to 6, PD from 0 to 0.9, MN from 0 to 11, and PROX from 2 to 2,160 (Table 8).

Table 8. *Landscape structure indices at the landscape mosaic level (richness of patches, PR; and Shannon Diversity, SHDI) and the land cover class level (percent of land, PL; patch density, PD (number of patches / 100 ha); mean patch size, MN (ha); proximity index, (PROX (PX)). Calculation is made for the buffer scenes around the 31 North American Breeding Bird Survey (BBS) transects (t. code) from which data were drawn for the present study by Ecoregion (Er.) and Ecological subregion (E. sub.).*

		Landscape mosaic indices			Land cover class indices																			
					Woodland				Scrubland				Grassland				Wetland				Urban			
BBS t. code	Er.	E. sub.	PR	SHDI	PL	PD	MN	PX	PL	PD	MN	PX	PL	PD	MN	PX	PL	PD	MN	PX	PL	PD	MN	PX
83015	South Texas Brush	Brush Country	9	1.7	17	11	2	166	24	17	1	222	16	15	1	68	1.1	2.2	0.5	3	1	0.3	3	37
83016	South Texas Brush	Brush Country	9	1.4	13	11	1	88	55	5	11	45153	8	6	1	22	0.6	0.8	0.7	13	1	0.4	1	9
83017	South Texas Brush	Brush Country	9	1.5	16	13	1	74	48	8	6	52866	8	6	1	18	0.9	1.5	0.6	7	0	0.1	2	6
83018	South Texas Brush	Live Oak-Mesquite Savannah	10	1.2	3	4	1	88	60	6	11	1E+05	24	11	2	690	0.2	0.2	0.9	9	0	0.1	1	2
83027	Blackland Prairie	Lampasas Cut Plains	9	1.7	27	8	3	3412	12	18	1	9	23	10	2	103	0.0	0.2	0.1	0	2	0.5	5	118
83028	Edwards Plateau	Balcones Canyon Lands	9	1.2	46	9	5	####	7	26	0	30	40	8	5	4372	0.0	0.2	0.1	0	2	0.5	5	43
83029	South Texas Brush	Brush Country	9	1.7	16	10	2	405	22	15	1	70	14	12	1	27	0.2	0.9	0.3	1	5	0.5	11	2160
83030	South Texas Brush	Brush Country	10	1.5	14	10	1	597	39	7	5	7799	6	6	1	5	0.1	0.2	0.2	0	1	0.2	2	24

83031	Edwards Plateau	Balcones Canyon Lands	10	1.0	69	3	20	1E+05	13	10	1	81	8	8	1	14	0.0	0.1	0.1	0	0	0.2	1	4
83042	Llano Uplift	Live Oak-Mesquite Savannah	9	1.2	37	12	3	3160	43	9	5	31159	16	10	2	80	0.0	0.1	0.1	0	0	0.2	2	7
83043	Llano Uplift	Live Oak-Mesquite Savannah	9	1.2	15	14	1	78	53	6	9	84367	25	9	3	847	0.0	0.1	0.2	0	1	0.3	3	15
83048	Blackland Prairie	Lampasas Cut Plains	10	1.7	24	8	3	621	16	15	1	40	12	14	1	21	0.2	0.7	0.3	1	0	0.4	1	7
83050	Edwards Plateau	Lampasas Cut Plains	9	1.7	29	9	3	1039	13	16	1	17	26	8	4	886	0.1	0.6	0.1	0	3	0.5	6	89
83051	Edwards Plateau	Lampasas Cut Plains	9	1.4	23	10	2	435	19	16	1	453	46	6	8	8356	0.0	0.3	0.1	0	4	0.2	15	511
83052	Edwards Plateau	Lampasas Cut Plains	9	1.3	19	10	2	303	37	13	3	3957	35	10	4	1892	0.0	0.2	0.1	0	2	0.2	8	165
83053	Edwards Plateau	Lampasas Cut Plains	10	1.3	13	12	1	62	46	9	5	44837	30	11	3	269	0.0	0.1	0.1	0	0	0.3	2	12
83054	Llano Uplift	Live Oak-Mesquite Savannah	9	1.3	6	10	1	94	43	5	8	45072	20	10	2	174	0.0	0.2	0.1	0	1	0.3	2	26
83062	Oak Woods	Mesquite Plains	10	1.5	25	8	3	219	12	14	1	588	44	8	6	20418	0.1	0.5	0.1	0	2	1.0	2	16
83064	Oak Woods	Mesquite Plains	10	1.4	18	11	2	100	43	9	5	14981	26	13	2	606	0.0	0.3	0.1	0	1	0.8	2	41
83065	Rolling Plains	Mesquite Plains	9	1.6	28	7	4	847	14	19	1	13	33	8	4	3911	0.1	0.1	1.2	35	1	0.3	2	56
83066	Edwards Plateau	Mesquite Plains	10	1.4	13	10	1	29	40	9	5	29115	32	11	3	2104	0.0	0.1	0.2	0	1	0.9	1	7
83067	Rolling Plains	Lampasas Cut Plains	9	1.1	1	3	1	4	21	12	2	270	64	5	12	138471	0.1	0.6	0.2	0	0	0.1	2	41
83076	Rolling Plains	Mesquite Plains	9	1.5	4	6	1	11	14	14	1	52	43	8	6	28348	0.1	0.5	0.2	0	0	0.0	9	95
83086	Edwards Plateau	Live Oak-Mesquite Savannah	10	0.9	0	0	0	0	52	9	6	73598	42	9	4	18424	0.0	0.0	0.5	1	0	0.7	0	3
83092	Rolling Plains	Live Oak-Mesquite Savannah	9	1.2	0	0	0	0	14	17	1	207	40	4	9	103102	0.1	0.2	0.4	1	0	0.2	1	20
83112	Edwards Plateau	Live Oak-Mesquite Savannah	8	0.7	1	1	1	4	64	6	12	3E+05	35	14	3	3426	0.0	0.0	0.1	0	0	0.5	0	2
83113	Edwards Plateau	Live Oak-Mesquite Savannah	10	0.5	1	2	1	2	87	1	128	5E+05	10	18	1	8	0.0	0.0	0.1	0	0	0.3	1	12
83114	Edwards Plateau	Balcones Canyon Lands	9	1.0	15	7	2	165	64	3	20	2E+05	20	10	2	394	0.0	0.0	0.1	0	0	0.1	3	20
83139	Oak Woods	Lampasas Cut Plains	10	1.6	13	9	1	272	13	16	1	40	19	12	2	172	0.0	0.2	0.1	0	2	0.4	5	91
83140	Edwards Plateau	Balcones Canyon Lands	9	1.1	56	7	8	####	8	25	0	22	31	10	3	360	0.0	0.2	0.1	0	3	0.4	7	72
83238	Edwards Plateau	Balcones Canyon Lands	9	1.4	40	9	4	8122	14	21	1	78	36	9	4	5843	0.1	0.3	0.2	0	6	0.6	9	1265

In the 8 ecological subregions, at the landscape mosaic level, Western Cross Timber, Black Land Prairie and Lampasas Cut Plains had the highest mean PR values, whereas Black Land Prairie had the highest mean value of SHDI (See Table 9). At the land cover class level, Balcones Canyon and Live Oak-

Mesquite Savannah, had almost 95% of area covered by native habitats (woodland, scrubland and grassland). Balcones Canyon Lands had the highest value in woodland cover, and Live Oak–Mesquite Savannah the highest in scrubland. Mesquite Savannah, Lampasas Cut Plains and Western Cross Timber, had almost 85% of area covered in native habitats, especially in scrubland and grassland. Black Land Prairie, Brush Country and Mesquite Plains, had less value in area covered by natural habitats, around 65% (Table 9, Figure 6).

Balcones Canyon Lands were characterized by woodlands (PL = 45), with low PD (7/100 ha), small MN (7.7 ha), and high values of PROX (50323), indicating relatively little fragmentation of woodlands (Tables 9, 10, 11, Figure 6). Live Oak-Mesquite Savannah and Brush Country both were characterized by scrubland, but Live Oak-Mesquite Savannah, had a less-fragmented habitat represented by more than half being covered by scrubland (PL = 67.7), with big patches, MN = 48.6 ha, which are in close proximity to each other, as indicated by a PROX of 301,948 (Tables 9, 10, 11, Figure 6). Mesquite Plains and Lampasas Cut Plains were characterized by grassland (PL = 45 and 35.8, respectively), but the former had the less-fragmented habitat, MN = 7.7 and PROX = 68458, compared with Lampasas Cut Plains, with MN = 4.5 and PROX = 3155 (Tables 9, 10, 11, Figure 6). Balcones Canyon Lands, Lampasas Cut Plains, Black Land Prairie and Brush Country were the most urbanized subregions (PL = 2.2, 1.8, 1.8, and 1.3, respectively). Mean patch size (MN) was 5, 6.5, 4.3, and 3.3 ha, respectively. Proximity index (PROX) was highest in Brush Country (373), followed by Balcones Canyon Lands (281), Lampasas Cut Plains (174), and Black Land Prairie (76), indicating that urban zones were more compact in Brush Country, Balcones Canyon Lands, and Lampasas Cut Plains (Tables 9, 10, 11, Figure 6).

Table 9. *Mean (±1SD) landscape structure indexes at the landscape mosaic level (richness of patches, PR; and Shannon Diversity, SHDI) and the land cover class level (percent of land, PL; patch density, PD (number of patches / 100 ha); mean patch size, MN (ha); proximity index, PROX (PX)). Calculation is made for the buffer scenes in each of the 8 ecological subregions (E. sub.).*

	Land mosaic level		Class level Grassland				Class level Scrubland				Class level Urban				Class level Wetland				Class level Woodland			
E. sub.	PR	SHDI	MN	PD	PL	PX	MN	PD	PL	PX	MN	PD	PL	PX	MN	PD	PL	PX	MN	PD	PL	PX
1	9.2 (0.4)	1.1 (0.2)	3.0 (0.6)	9.0 (1.0)	27 (13)	2196.6 (2711.8)	4.4 (8.7)	17.0 (10.1)	21.2 (24)	47629.6 (106385)	5.0 (3.2)	0.4 (0.2)	2.2 (2.5)	280.8 (550.8)	0.1 (0)	0.2 (0.1)	0 (0)	0 (0)	7.8 (7.2)	7.0 (2.4)	45.2 (20.1)	50323 (57297)
2	9.5 (0.6)	1.7 (0.1)	2.3 (1.3)	11.0 (2.6)	20 (6.1)	295.5 (398.5)	1 (0)	16.3 (1.3)	13.5 (1.7)	26.5 (15.9)	4.3 (2.2)	0.5 (0.1)	1.8 (1.3)	76.3 (48)	0.2 (0.1)	0.4 (0.3)	0.1 (0.1)	0.3 (0.5)	2.5 (1)	8.5 (0.6)	23.3 (7.1)	1336 (1419)
3	9.3 (0.5)	1.5 (0.2)	1.2 (0.4)	9.3 (3.9)	12.7 (6.8)	138.3 (271.1)	5.8 (4.5)	9.7 (5)	41.3 (16)	37505.3 (46037)	3.3 (3.8)	0.3 (0.2)	1.3 (1.9)	373 (875.5)	0.5 (0.3)	1.0 (0.8)	0.5 (0.4)	5.5 (5)	1.3 (0.5)	9.8 (3.1)	13.2 (5.2)	236.3 (216.3)
4	9.5 (0.6)	1.4 (0.1)	4.5 (2.4)	9.5 (2.4)	35.8 (7.1)	3155.3 (3562.7)	3.5 (1.9)	11.8 (3.4)	35.5 (11.6)	19590.5 (21124.6)	6.5 (6.5)	0.4 (0.3)	1.8 (1.7)	173.8 (236.5)	0.1 (0.1)	0.2 (0.1)	0 (0)	0 (0)	1.5 (0.6)	10.5 (1)	17 (4.9)	207.3 (194.9)
5	9.3 (1.2)	0.7 (0.2)	2.7 (1.5)	13.7 (4.5)	29 (16.8)	7286 (9796)	48.7 (68.8)	5.3 (4)	67.7 (17.8)	301947.7 (215326)	0.3 (0.6)	0.5 (0.2)	0 (0)	5.7 (5.5)	0.2 (0.2)	0 (0)	0 (0)	0.3 (0.6)	0.7 (0.6)	1 (0)	0.7 (0.6)	2 (2)
6	9 (0)	1.4 (0.2)	7.8 (3.5)	6.3 (2.1)	45 (13.3)	68458 (62921)	1.3 (0.5)	15.5 (3.1)	15.8 (3.5)	135.5 (122.7)	3.5 (3.7)	0.2 (0.1)	0.3 (0.5)	53 (31.7)	0.5 (0.5)	0.4 (0.2)	0.1 (0)	9.0 (17.3)	1.5 (1.7)	4.0 (3.2)	8.3 (13.3)	215.5 (421)
7	9 (0)	1.2 (0.1)	2.3 (0.6)	9.7 (0.6)	20.3 (4.5)	367 (418.3)	7.3 (2.1)	6.7 (2.1)	46.3 (5.8)	53532.7 (27594.6)	2.3 (0.6)	0.3 (0.1)	0.7 (0.6)	16 (9.5)	0.1 (0.1)	0.1 (0.1)	0 (0)	0 (0)	1.7 (1.2)	12 (2)	19.3 (15.9)	1110.7 (1774.8)
8	10 (0)	1.5 (0.1)	4.0 (2.8)	10.5 (3.5)	35 (12.7)	10512 (14009.2)	3.0 (2.8)	11.5 (3.5)	27.5 (21.9)	7784.5 (10177)	2 (0)	0.9 (0.1)	1.5 (0.7)	28.5 (17.7)	0.1 (0)	0.4 (0.1)	0.1 (0.1)	0 (0)	2.5 (0.7)	9.5 (2.1)	21.5 (4.9)	159.5 (84.1)

Ecological subregions (E. sub.) = 1) Balcones Canyon Lands, 2) Blackland Prairie, 3) Brush Country, 4) Lampasas Cut Plains, 5) Live Oak-Mesquite Savannah, 6) Mesquite Plains, 7) Mesquite Savannah, and 8) Western Cross Timbers.

At the landscape mosaic level, Western Cross Timber, Black Land Prairie and Lampasas Cut Plains had the highest mean PR values, whereas Black Land Prairie had the highest mean value of SHDI (Tables 9, 10,11).

Table 10. *Mean patch size (MN) Ha of land cover classes (woodland, scrubland, grassland and urban) in the ecological subregions.*

Ecological subregions	Grassland	Scrubland	Urban	Wetland	Woodland
Balcones Canyon Lands	2.83	4.45	4.86	0.08	7.69
Blackland Prairie	2.43	0.81	4.45	0.20	2.43
Brush Country	1.21	5.67	3.24	0.49	1.21
Lampasas Cut Plains	4.45	3.64	6.47	0.08	1.62
Live Oak-Mesquite Savannah	2.83	48.56	0.40	0.20	0.81
Mesquite Plains	7.69	1.21	3.64	0.49	1.62
Mesquite Savannah	2.43	7.28	2.43	0.08	1.62
Western Cross Timbers	4.05	2.83	2.02	0.08	2.43

Table 11. *Proximity index of land cover classes (woodland, scrubland, grassland and urban) in the ecological subregions.*

Ecological subregions	Grassland	Scrubland	Urban	Wetland	Woodland
Balcones Canyon Lands	2197	47630	281	0.0	50323
Blackland Prairie	296	27	76	0.3	1336
Brush Country	138	37505	373	5.5	236
Lampasas Cut Plains	3155	19591	174	0.0	207
Live Oak-Mesquite Savannah	7286	301,948	6	0.3	2
Mesquite Plains	68458	136	53	9.0	216
Mesquite Savannah	367	53533	16	0.0	1111
Western Cross Timbers	10512	7785	29	0.0	160

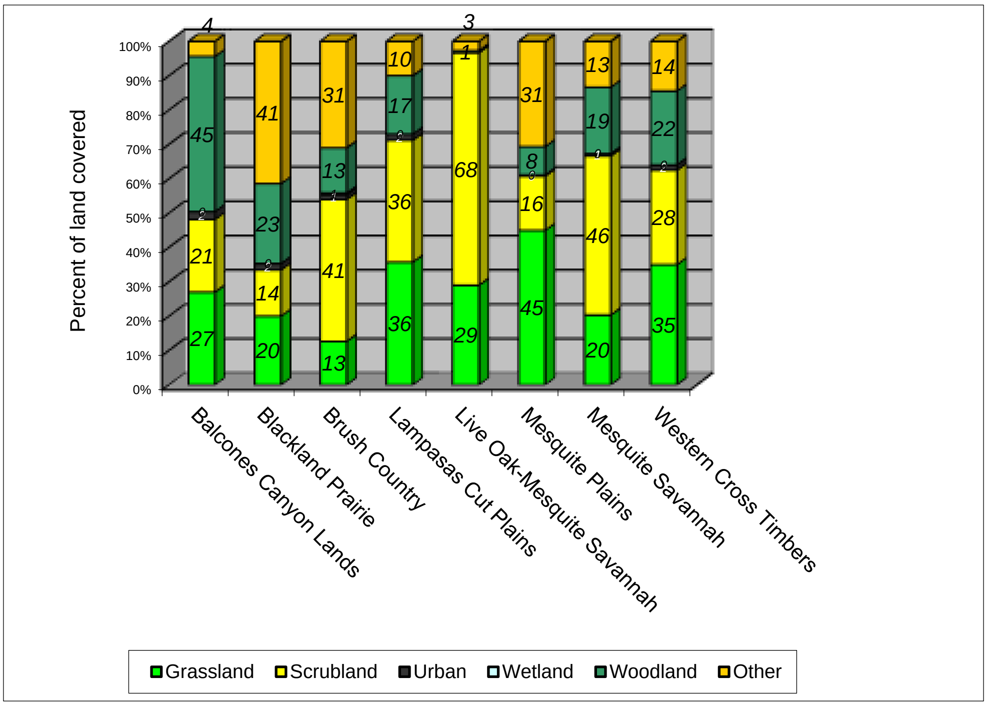

Figure 6. *Mean percent of land in each of the 5 land cover classes in each of the 8 ecological subregions (Figure 2) included in the present study.*

At the land cover class level, Balcones Canyon and Live Oak-Mesquite Savannah, had almost 95% of area covered by native habitats (woodland, scrubland and grassland). Balcones Canyon Lands had the highest value in woodland cover, and Live Oak–Mesquite Savannah the highest in scrubland. Mesquite Savannah, Lampasas Cut Plains and Western Cross Timber, had almost 85% of area covered in native habitats, especially in scrubland and grassland. Black Land Prairie, Brush Country and Mesquite Plains, had lower values in area covered by natural habitats, around 65% (Figure 6).

3.4. Spatial Autocorrelation of Variables

Approximately half of the avian diversity indexes showed significant levels of spatial autocorrelation ($P<0.05$), including avian abundance, H', and (1-S') ($P = 0.0531$, 0.0015, and 0.0141, respectively), but not species richness ($P = 0.4531$).

Landscape structure indexes at the landscape mosaic of SHDI ($P = 0.0072$) showed a significant level of spatial autocorrelation, but not PR ($P = 0.2406$). (Table 12). At the land cover class level all indices were significantly autocorrelated ($P<0.05$) in grassland, PL and PD in woodland and grassland, and MN in grassland and wetland.

Table 12. *Degree of spatial autocorrelation, (α=0.05). Calculation is made for each of 4 indexes of avian diversity (avian abundance, species richness, species diversity (H'), β-diversity (1-S)) and each of 6 indexes of landscape structure (2 at the landscape mosaic level (richness of patches (PR) and Shannon Diversity (SHDI)) and 4 at the land cover class level (percent of land (PL), patch density (PD), mean patch size (MN), proximity (PROX))), as indicated by Mantel's r [28].*

	Indexes	Mantel's r	P
Avian Diversity			
	Avian Abundance	0.1427	0.0531
	Species Richness	0.0051	0.4531
	H'	0.2632	0.0015
	(1-S)	0.2012	0.0141
Landscape Structure			
Landscape Mosaic Level	PR	0.0498	0.2406
	SHDI	0.2643	0.0072
Land Cover Class Level			
Woodland	PL	0.1009	0.1517
	PD	0.4162	0.0001
	MN	-0.0248	0.5400
	PROX	-0.1049	0.8365
Scrubland	PL	0.2216	0.0071
	PD	0.1303	0.0521
	MN	0.0570	0.2952
	PROX	0.1726	0.0884
Grassland	PL	0.3811	0.0001
	PD	0.1742	0.0416
	MN	0.3734	0.0005
	PROX	0.3140	0.0070
Wetland	PL	0.2164	0.0295
	PD	0.1861	0.0603
	MN	0.2970	0.0063
	PROX	0.1889	0.0605
Urban	PL	-0.0770	0.7763
	PD	0.0696	0.1807
	MN	-0.0643	0.7308
	PROX	-0.0859	0.7581

3.5. Spatial Correlations between Pairs of Avian Diversity and Landscape Structure Indexes

Avian abundance, species richness, and H' were not significantly spatially correlated with landscape structure indexes at the landscape mosaic level (PR and SHDI) ($P > 0.28$); (1-S') was not significantly spatially correlated with PR ($P = 0.1220$) but did show a significant positive spatial correlation with SHDI ($P = 0.0253$) (Table 13).

Table 13. *Degree of spatial correlation, (α=0.05). Calculation is made between pairs of avian diversity (avian abundance, species richness, species diversity (H'), β-diversity (1-S)) and landscape structure ((richness of patches (PR), Shannon Diversity (SHDI), percent of land (PL), patch density (PD), mean patch size (MN), proximity (PROX)) indexes, as indicated by Cross Mantel's r [28].*

				Avian Diversity					
Landscape Structure	**Indexes**	**Avian Abundance**		**Species Richness**		**H'**		**(1-S)**	
		Cross Mantel's r	P	Cross Mantel's r	P	Cross Mantel's r	P	Cross Mantel's r	P
Landscape Mosaic Level	*PR*	-0.0095	0.4839	-0.0165	0.5341	-0.0862	0.9736	0.0935	0.1220
	SHDI	0.0033	0.4291	0.0382	0.2831	-0.0236	0.5630	0.2255	0.0253
Land Cover Class Level									
Woodland	PL	0.6042	0.0002	0.4098	0.0025				
	PD	0.0080	0.4143	0.0621	0.2346				
	MN	0.5058	0.0059	0.3185	0.0514				
	PROX	0.6157	0.0027	0.4216	0.0100				
Scrubland	PL	0.1003	0.1006	0.2199	0.0099				
	PD	0.0009	0.3957	0.1627	0.0289				
	MN	0.0445	0.1775	0.0760	0.0967				
	PROX	0.0981	0.1580	0.2073	0.0407				
Grassland	PL	-0.0112	0.4835	0.0345	0.2773				
	PD	-0.0029	0.4408	0.1081	0.1536				
	MN	-0.0536	0.6900	0.0720	0.2210				
	PROX	-0.0323	0.5132	0.1023	0.1957				
Wetland	PL	-0.0036	0.3284	0.0209	0.3683				
	PD	-0.0301	0.4505	-0.0178	0.4959				
	MN	-0.0618	0.6066	0.0567	0.2681				
	PROX	-0.0435	0.5040	0.0359	0.3025				
Urban	PL	-0.0407	0.5917	0.1589	0.1136				
	PD	0.0043	0.4312	-0.0363	0.5887				
	MN	0.0215	0.3579	0.1096	0.1369				
	PROX	-0.0700	0.6222	0.0683	0.2282				

At the land cover class level, both avian abundance and species richness showed a significant positive spatial correlation with PL, MN, and PROX (P < 0.052), but no significant spatial correlation with PD (P > 0.23), in woodlands, and species richness showed a significant positive spatial correlation with PL, PD, and PROX (P < 0.041), but no significant spatial correlation with MN (P = 0.0967), in scrublands. There were no significant spatial correlations (P > 0.11) between any pairs of avian diversity and landscape structure indexes at the land cover class level in grasslands, wetlands, or urban areas.

3.6. Correlation between Values of Pairs of Avian Diversity and Landscape Structure Indexes

After appropriate adjustments for spatial autocorrelation, there were no significant correlations between values of pairs of avian diversity (avian abundance, species richness, H', (1-S')) and landscape structure indexes at the landscape mosaic level (PR, SHDI) (P > 0.068) (Table 14). At the land cover class level, both avian abundance and species richness showed a significant positive correlation with PL, MN, and PROX (P < 0.017), but no significant correlation with PD (P > 0.42), in woodlands, and species richness showed a significant negative correlation with PD (P = 0.0194) in grasslands. There were no significant correlations (P > 0.08) between any pairs of avian diversity and landscape structure indexes at the land cover class level in scrublands, wetlands, or urban areas.

Table 14. *Degree of spatial correlation α=0.05. Calculation is made between values of pairs of avian diversity (avian abundance, species richness, species diversity (H'), β-diversity (1-S)) and landscape structure ((richness of patches (PR), Shannon Diversity (SHDI), percent of land (PL), patch density (PD), mean patch size (MN), proximity (PROX))) indexes, as indicated by the Modified t-Test for autocorrelation (CHR) [28; 40].*

				Avian Diversity					
Landscape Structure	Indexes	Avian Abundance		Species Richness		H'		(1-S)	
		CHR	P	CHR	P	CHR	P	CHR	P
Landscape Mosaic Level	*PR*	0.1413	0.4592	-0.1446	0.3972	0.0577	0.7493	-0.0360	0.8387

	SHDI	0.3785	0.0682	-0.1036	0.7130	-0.3159	0.2763	-0.3829	0.1096
Land Cover Class Level									
Woodland	PL	0.7048	0.0012	0.5987	0.0059				
	PD	0.0761	0.7648	0.1735	0.4248				
	MN	0.6281	0.0009	0.4918	0.0166				
	PROX	0.7050	0.0022	0.6066	0.0035				
Scrubland	PL	0.3474	0.1314	0.4892	0.1399				
	PD	-0.3589	0.1322	-0.4586	0.1592				
	MN	0.1994	0.3378	0.2820	0.2635				
	PROX)	0.3854	0.0801	0.4615	0.1306				
Grassland	PL	-0.0365	0.8345	0.1175	0.5095				
	PD	0.1518	0.4407	-0.4780	0.0194				
	MN	-0.0336	0.8297	0.2662	0.1545				
	PROX	-0.2037	0.1735	-0.0202	0.8991				
Wetland	PL	0.2003	0.4165	0.3112	0.2124				
	PD	0.1969	0.4142	0.3023	0.1894				
	MN	0.0860	0.5976	0.3491	0.1953				
	PROX	0.1184	0.4572	0.2913	0.2035				
Urban	PL	0.0494	0.8401	0.3947	0.1191				
	PD	0.0617	0.7456	-0.0251	0.9069				
	MN	-0.0733	0.7588	0.2947	0.2066				
	PROX	0.0266	0.8816	0.2826	0.1339				

4. DISCUSSION

Avian diversity (α-diversity and β-diversity) and landscape structure were correlated spatially within the Edwards Plateau Ecoregion of Texas. Spatial correlations between β-diversity and SHDI at the landscape mosaic level, showed that β-diversity and turnover of bird communities is positively associated with habitat diversity. The 65% migrant birds (neotropical migrants 44%, short distance migrant 21%) registered in the study area are evidence of that. At the landscape mosaic level, positive significant spatial correlation was found between β-diversity and SHDI (Table 14). Findings at the Live Oak-Mesquite Savannah sub-region concerning less fragmented habitats (highest value of PROXI) and the highest β-diversity values (Table 5) were in agreement with De Jesus Sh.et al. [49], who found that aggregation of forest fragments, had significant effects on beta diversity.

High β-diversity values in (Table 5) the Live Oak-Mesquite Savannah sub-region, the western part of the Edwards Plateau, indicated that in this sub-region, there are high habitat richness and biological differences between patches of different habitats that produce an interchange of species resulting in different bird communities. Noticeably, 97% of the area of this ecological subregion was covered by natural habitat class cover as scrubland and grassland (68% and 29% respectively) and presented high values of landscape richness PR (9.3), (Table 9, Figure 6). This finding is supported by Frutos et al. [50] which compared the bird assemblage structure and composition between heterogeneous agricultural landscapes and homogeneous landscapes and found that environmental heterogeneity increases bird diversity in agricultural areas.

At the class level, Positive spatial correlations found between species richness and scrubland class structure (Pl, PD, and PROX), indicating that spatial arrangement, size, and proximity of patches, are important for conservation in the in Live Oak-Mesquite Savannah. The scrubland-grassland scatter landscape with high number of big scrubland patches MN (48.7 ha) in close proximity to each other, PROX (301,948), mixed with small grassland patches (2.7 ha), can be the key to preserve the appropriate environmental conditions for the 15 scrubland bird species and the 2 grassland bird species that were registered in the Live Oak-Mesquite Savannah (Table 9).

Highly significant positive correlations were found between α-diversity (richness) and class level (mean patch size MN and proximity index PROX) in the Balcones Canyon Lands ecological sub-region, the eastern border of the Plateau. It is in the Balcones Canyon Lands that the highest values of woodland and scrubland bird richness (Table 14) occurred, and where highest values of richness and H’ (Table 5) were observed. Highest alpha biodiversity (species richness and species diversity) in the Balcones Canyon Lands (Table 5), perhaps is mainly due to the addition of urban birds in the area. The aforementioned ecological subregion is one of most urbanized (PL=2.2, MN=5, and PROX=281), and is an ecological transition area or peri-urban ecotone that maybe act as a semi-permeable biological filter [51]. The Balcones Canyon Lands also had a high percentage of land covered by natural habitats (93%), represented by woodland (45%), grassland (27%) and scrubland (21%) (Figure 6). Woodland cover presented the highest values of mean patch size MN (7.8 ha) and PROX (50323), indicating relatively little fragmentation of woodlands (Table 10, 11). However, the woodland habitat of the Balcones Canyon Lands is vulnerable to fragmentation, due to the urban growth of the Austin-San Antonio-San Marcos Metropolitan belt. This expansion will probably produce a decrease in patch size (MN) and an increase in isolation, producing a negative impact on avian α -diversity [11; 51], in agreement with Dale, S. [52] who found weak evidence of isolation effects on bird species diversity and community composition. Population sizes depend on the sizes of and distances among habitat patches. In addition, α -diversity depends on the suitability of the increasing urban habitat separating the favorable patches. As such, colonization of patches to maintain native bird populations can be difficult and can produce local extinctions of native woodland and scrubland species.

Balcones Canyon Lands had the highest number of urban bird richness (9) (Table 6A) and the highest avian abundance of permanent residents (68 (±15, Table 6B), in agreement with Clergeau, P, et al [53], which can be an indication of replacement of natural habitats as woodland and scrubland, by urban zones. On the other hand, 27% of neotropical migrants and 23% of the permanent residents of the eco-region, were registered in this ecological subregion, and therefore it should be a priority to manage the environmental conditions that support highest richness of main habitats within the Balcones Canyon Lands sub-region.

Notably, in the present study multiple spatial correlation analyses were implemented to test the relationships between avian diversity and landscape characteristics. However, perhaps mixed effects models, such as the generalized linear mixed model (GLMM), could be used to analyze landscape change and avian biodiversity relationships. Specifically, one could expand the analytical approach further, for example, analyzing the consequences of fragmentation in terms of area and distance effects, e.g., for those avian species most demanding in terms of area or transitional zones (i.e., edge) and those with lower dispersal capability.

5. Conclusion

This research found highly significant spatial correlations between avian diversity (α -diversity and β -diversity) and landscape structure in the Edwards Plateau Ecoregion of Texas. Significant positive spatial correlation was found between β -diversity with landscape richness and diversity (PR and SHDI) at the landscape mosaic level, and highly significant positive correlations between α -diversity (richness) and mean patch size (MN) and proximity (PROX) at the class level, which confirms our hypothesis that changes in landscape structure are related to changes in avian diversity within the Edwards Plateau of Texas. The results of the present study agree with those from earlier studies, e.g., [8; 9; 10; 11; 12; 17; 23], concerning implications of the relationship between habitat fragmentation and avian biodiversity.

The results at the landscape mosaic level of the present study showed that the western portion of the Edwards Plateau, the Live Oak Mesquite Savanna, had the highest diversity of habitats, low fragmentation (highest value of PROXI), and highest β -diversity. The 65% migrant birds (neotropical migrants 44%, short distance migrant 21%) registered in the study area, showed that there is a high turnover in the Edwards Plateau.

The Balcones Canyon Lands, the eastern portion of the Edwards Plateau, had high significant correlations between α -diversity (richness) and class level indices (mean patch size MN and proximity index PROX. Importantly, the Balcones Canyon Lands ecological subregion is one of most urbanized ecological subregions in the study area. The results showed the highest alpha biodiversity (species richness and species diversity) which may be due to the addition of urban bird species in the area.

At the class level, the importance of preserving all types of land cover (maximum richness) and configurations, in order to preserve the β -diversity, while maintaining mean patch size around 8 ha for woodland and 45 ha in scrubland, and a minimum distance intermediate to that used by permanent resident species and short-distance migrants in breeding movements, in order to preserve the woodland and scrubland bird species richness.

For conservation development, positive spatial correlation at land mosaic level is important for management of Live Oak-Mesquite Savannah, because this sub-ecoregion has high values of β-diversity. Positive spatial correlations at the class level are important to management of the Balcones Canyon Lands because it is the sub-ecoregion with high values of α-diversity (richness and Shannon H'). By identifying which areas are most likely to be at highest risk of future habitat fragmentation and greatest loss of biodiversity, one may more efficiently target these locations and allocate the limited resources to protect the habitat and/or wildlife most at risk.

The present study was an extension of Gonzalez et al. [10] and can serve as a model of the spatial analysis technique with important implications for conservation planning, providing a template that may be used with more recent datasets in future studies. Nevertheless, we are aware that other statistical methods do exist for conducting avian abundance and landscape change analyses similar to those of the present study. In future research, it would also be interesting to analyze the data using GLMM with regard to functional trait classifications of avian species, e.g., Sreekar et al. (2015) and Kawamura et al. (2019), such as breeding and niche habitats, behavioral characteristics (e.g., solitary versus social), and migration status.

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7. Author Contributions

Both authors have made substantial contributions to the conception or design of the work; the acquisition, analysis, or interpretation of data; and have drafted the work or substantively revised it; and have approved the submitted version.

8. Conflicts of Interest

The authors declare no conflicts of interest.

References

[1] Costanza, R.; d-Àrge, R.; de Groot, R.; Farber, S.; Grasso, M.; Hannon, B.; Limburg, K.; Naeem, S.; O"Neill, R.; Paruelo, J.; Raskin, R.; Sutton, P.; Marjan B. The value of the world's ecosystems services and natural capital. *Nature*, 1997, *387*, 253-260.

[2] Adger, N.; Luttrel, C. The values of wetlands: Landscape and institutional perspectives. Property rights and the utilization of wetlands. *Ecol Econ* 2000, *35*, 75-89.

[3] Antrop M. Changing patterns in the urbanized countryside of Western Europe. *Landscape Ecology* 2000, *15*, 713-730.

[4] Swenson, J.; Franklin J. The effects of future urban development on habitat fragmentation in the Santa Monica Mountains. *Landscape Ecology* 2000, *15*, 713-730.

[5] Luck, M.; Wu, J. A gradient analysis of urban landscape pattern: A case study from the Phoenix metropolitan region, Arizona, USA. *Landscape Ecology* 2002, *17*, 327-339.

[6] Radeloff, V.C.; Hammer, R.B.; Stewart, S.I.; Fried, J.S.; Holcomb, S.S.; McKeefry JF. The wildland-urban interface in the United States. *Ecological Applications* 2005, *15(3)*, 799-805.

[7] Stanfield, B.; Bliss, J.; Spies, T. Land ownership and landscape structure: A spatial analysis of sixty-six Oregon (USA) Coast Range watersheds. *Landscape Ecology* 2002, *17*, 685-697.

[8] Wilkins N.; Hays A.; Kubenka D.; Steinbach D.; Grant W.; González E Kjelland M, Shakelford J. Texas Rural Lands. Trends and Conservation Implications for the 21st Century. Texas Cooperative Extension, Texas A&M University System, College Station, 2003.

[9] Kjelland, M.; Kreuter, U.; Clendenin, G.; Wilkins, N.; Wu, B.; Gonzalez, E.; Grant, W. Factors related to spatial patterns of rural land fragmentation in Texas. *Environ Manage* 2007, *40*, 231-244.

[10] González Afanador, E.; Kjelland, M.E.; Wu, X.B.; Wilkins, N.; Grant, W.E. Ownership property size, landscape structure, and spatial relationships in the Edwards Plateau of Texas (USA): landscape scale habitat management implications. *Environ Syst Decis* 2016, *36(3)*, 310-328.

[11] Donovan, T.; Flather, C. Relationship among North American songbirds trends, habitat fragmentation, and landscape occupancy. *Ecological Applications* 2002, *12*, 364-374.

[12] Lovett-Doust, J.; Biernacki, M.; Page, R.; Chan, M.; Natgunarajah, R.; Timis, G. Effects of land ownership and landscape-level factors on rare-species richness in natural areas of southern Ontario, Canada. *Landscape Ecology* 2003, *18*, 621-63.

[13] Gavier-Pizarro, G.I.; Radeloff, V.C.; Stewart, S.I.; Huebner, C.D.; Keuler, N.S. Rural housing is related to plant invasions in forests of southern Wisconsin, USA. *Landsc Ecol* 2010, *25*, 1505–1518.

[14] Shochat, E.; Lerman, S.; Anderies, J.; Warren, P.; Faeth, S.; Nilon, C. Invasion, competition, and biodiversity loss in urban ecosystems. *Bioscience* 2010, *60*(3), 199–208.

[15] Kowarik, I. Novel urban ecosystems, biodiversity, and conservation. *Environ Pollut* 2011, 159(8–9), 1974–1983.

[16] Fontana, S.; Sattler, T.; Bontadinac, F.; Moretti, M. How to manage the urban green to improve bird diversity and community structure Simone. *Landsc Urban Plan* 2011, *101*, 278–285.

[17] Hamilton, C.M.; Martinuzzi, S.; Plantinga, A.J.; Radeloff, V.C.; Lewis, D.J.; Thogmartin, WE. Current and future land use around a nationwide protected area network. *PLoS One* 2013, *8*(1), e55737.

[18] Martinuzzi, S.; Radeloff, V.C.; Higgins, J.V.; Helmers, D.P.; Plantinga, A.J.; Lewis, D.J. Key areas for conserving United States' biodiversity likely threatened by future land use change. *Ecosphere* 2013, *4*(5), 58.

[19] Campos, P.R.A.; Rosas, A.; de Oliveira, V.M.; Gomes, M.A.F. Effect of Landscape Structure on Species Diversity. *PLoS ONE* 2013, *8*(6), e66495.

[20] Trousdale, W.; Gregory, R. Property evaluation and biodiversity conservation – Decision support for making hard choices. *Ecological Economics* 2004, *48*, 279-291.

[21] National Resources Conservation Service (NRIS) (2013) 2007 National Resources Inventory – Land use status and trends. 50 p.

[22] González, E. Urban influence on diversity of avifauna in the Edwards Plateau of Texas: effect of property sizes on rural landscape structure. Doctoral dissertation, Texas A&M University. Texas A&M University, 2005.

[23] López, R. In the Texas Land Trends, *publication of the Texas A&M Institute of Renewable Natural Resources* 2014, *1(1)*, 1-6.

[24] Shackelford, J.; Shackelford, C. Fragments of a Texas Landscape. Texas Partners in Flight – Flyway Newsletter, *Texas Parks and Wildlife* 2003, *10*, 16-18.

[25] Ludwig J.A., Reynolds J.F. Statistical Ecology: A primer on Methods and Computing. John Wiley and Sons, Inc: New York, NY, 1988.

[26] Isaaks, E.; Srivastava, M. Applied Geostatistics. Oxford University Press: New York, 1989

[27] Legendre, P.; Fortin, M.J. Spatial pattern and ecological analysis. *Vegetatio* 1989 *80*, 107-138.

[28] Fortin, M.J.; Gurevitch, J. Mantel tests: Spatial structure in field experiments. In: Scheiner, S.M.; Gurevitch, J. (Eds.), Design and Ecological Experiments. Chapman & Hall New York, 1993, pp. 343-359.

[29] Dutilleul, P.; Clifford, P.; Richardson, S.; Hemmon, D. Modifying the t-Test for assessing the correlation between two spatial processes. *Biometrics* 1993, *49(1)*, 305-314.

[30] Dale, M.R.T.; Fortin, M.J. Spatial autocorrelation and statistical test in ecology. *Ecoscience* 2002, *9*, 162-167.

[31] Fortin, M.J.; Payette, S. How to test the significance of the relation between spatially autocorrelated data at the landscape scale: A case study using fire and forest maps. *Ecoscience* 2002, *9(2)*, 213-218.

[32] Hillis, D. 2000. Hotspot of Biodiversity: Unique and Endangered Animals of Central Texas. http://www.esi.utexas.edu/outreach/ols/lectures/Hillis/ (Date Accessed: 06/28/04).

[33] Ricketts, T.; Imhoff, M. Biodiversity, urban areas, and agriculture: locating priority ecoregions for conservation. Conservation Ecology 2003, *8(2)*:1. [online] URL: https://www.researchgate.net/publication/42763175_Biodiversity_Urban_Areas_and_Agriculture_Locating_Priority_Ecoregions_for_Conservation (accessed on 08/ 12/ 2020).

[34] Wu, B.; Smeins, F.; Slack, D. Funadamentals of Ecology. Laboratory manual. Kendall/Hunt Publishing Company, 2002.

[35] Griffith, G.; S. Bryce, J.; Omernik.; Rogers, A. Ecoregions of Texas. Project report to 4 Texas Commission on Environmental Quality, Austin, TX. 2007.

[36] Neuman, M., Bright, E. 2008. Texas Urban Triangle: Framework for Future Growth. System Research Report SWUTC/08/167166-1 Southwest Region University Transportation Center Texas Transportation Institute Texas A&M University System College Station, Texas. https://www.census.gov/history/www/through_the_decades/overview/1990.html .

[37] Sauer, J.R.; Hines, J.E.; Fallon, J. The North American Breeding Bird Survey, 2003.

[38] Sauer, J.; Pardieck, K.; Ziolkowski, D.; Smith, A.; Hudson, MA.; Rodriguez, V.; Berlanga H.; Niven, D.; Link, W. The first 50 years of the North American Breeding Bird Survey. *The Condor. Ornithological applications* 2017, *119*, 576–593.

[39] Cadenasso, M.; Pikett, S.; Weathers, K.; Jones, C. Framework for a Theory of Ecological Boundarie. BioScience 2003, 53, 750-758.

[40] Calderón-Patrón, J.; Moreno, C.; Zuria, I. Beta diversity: half a century of advances. *Revista Mexicana de Biodiversidad* 2012, *83*, 879-891.

[41] McGarigal, K.; Marks, B. FRAGSTATS: Spatial pattern analysis program for quantifying landscape structure. Gen. Tech. Rep. PNW-GTR-351: Portland, OR: United States Department of Agriculture, Forest Service. Pacific Northwest Research Station, 1995.

[42] Stanfield, B.; Bliss, J.; Spies T. Land ownership and landscape structure: a spatial analysis of sixty-six Oregon (USA) Coast Range watersheds. *Landsc Ecol* 2002, *17*, 685–697.

[43] Turner, M. G., Gardner, R., O'Neill R., 2001. Landscape Ecology in Theory and Practice: Pattern and Process. Springer, New York.

[44] Brooks, J.; Stanfield, J.; Spies, T. Land ownership and landscape structure: A spatial analysis of sixty-six Oregon (USA) Coast Range watersheds. *Landscape Ecology* 2002, *17*, 685-697.

[45] Mörtberg, U.M.; Balfors, B.; Knol W.C. Landscape ecological assessment: A tool for integrating biodiversity issues in strategic environmental assessment and planning. *Journal of Environmental Management* 2007, *82*(4), 457-470.

[46] Rosenberg M.S. (2005) Pattern analysis, spatial statistics, and geographic exegesis. PASSAGE Program Results and Analysis 1966 - 2002. Version 2003.1.

[47] Clifford, P.; Richardson, S.; Hemmon D. Assessing the significance of the correlation between two spatial processes. *Biometrics* 1989, *45(1)*, 123-134.

[48] Rosenberg, M.S.; Anderson, C.D. PASSaGE: pattern analysis, spatial statistics and geographic exegesis. version 2. *Methods Ecol Evol* 2011, *2(3)*, 229–232.

[49] De Jesus, Sh.; Wagner, P.; Bispo, A. Bird diversity along a gradient of fragmented habitats of the Cerrado. An. Acad. Bras. Ciênc. . 2018 vol.90 no.1 Rio de Janeiro MarEpub Dec 11, 2017https://doi.org/10.1590/0001-3765201720160383

[50] Frutos, A.E.; Reales, C.F.; Lorenzón, R.E.; Ronchi-Virgolini, A.L. Spatial variation in bird assemblages are linked to environmental heterogeneity in agricultural landscapes in the province of Entre Ríos, Argentina. *Avian Biology Research* 2016, *9(4)*, 273-281.

[51] Winter, M.; Johnson, H.; Douglas,_H.; Shaffer, A.; Donovan, T.; Daniel, W. Patch Size and Landscape Effects on Density and Nesting Success of Grassland Birds. *The Journal of Wildlife Management* 2006 *70(1)*, 158-172.

[52] Dale, S. Islands in the forest: effects of patch size and isolation on farmland bird species richness and community composition of farmland patches in forest landscapes. 2019, *Landscape Ecol* 34, 2823–2836 (2019). https://doi.org/10.1007/s10980-019-00920-w

[53] Clergeau, P., Savard, J., Mennechez, G., & Falardeau, G. (1998). Bird Abundance and Diversity along an Urban-Rural Gradient: A Comparative Study between Two Cities on Different Continents. *The Condor, 100*(3), 413-425. doi:10.2307/1369707

[54] Sreekar, R., Srinivasan, U., Mammides, C. et al. 2015. The effect of land-use on the diversity and mass-abundance relationships of understory avian insectivores in Sri Lanka and southern India. Sci Rep 5, 11569.

[55] Kawamura K, Yamaura Y, Senzaki M, Ueta M, Nakamura F. Seasonality in spatial distribution: Climate and land use have contrasting effects on the species richness of breeding and wintering birds. Ecol Evol. 2019;9: 7549–7561.

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