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Original Article

Birdlife, a tourist attraction for the southern portion of Bacalar Lagoon, Quintana Roo, Mexico

Birdlife: uma atração turística da porção sul da Lagoa Bacalar, Quintana Roo, México

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Abstract

The Bacalar Lagoon (BL) in Quintana Roo, Mexico; is an area of high interest due to its tourist potential. However, the changes in landuse patterns, urbanization, extensive cattle ranching and rapidly expanding agriculture, have generated negative impacts on areas of adjacent plan communities and wildlife habitats. The objective of this study has to evaluate the level of vegetation conservation in the southern portion of the BL through the avifauna present in sites with contrasting degrees of conservation. Additionally, change "and their habitat preference(s) in the different communities" to and their habitat use preferences in the different communities. To evaluate the level of conservation of the BL, field visits and botanical collections were carried out to identify species. For the counting and identification of birds, monthly surveys were made through coastal tours along the cenote Xul-ha in 2.5 km transects. Four transects were established: two for sites characterized as semi-conserved and two with disturbed sites. A total richness of 40 taxa was observed, which corresponds to 8.1% of the Quintana Roo avifauna and 32% to wetland birds (125 species). The species accumulation curves indicated that semi-conserved and disturbed sites tend to reach asymptotes and with a coverage percentage greater than 90%. In terms of diversity and community structure, no significant differences were observed. However, the semi-conserved and disturbed sites each have 11 unique species and share 18 species. The LB has an intermediate diversity of bird species compared to studies at the Mexican level, the habitat is important for the conservation of birdlife; as it functions as a reservoir of diversity. Strategies has been suggested that promote sustainable tourism, support the restoration of natural vegetation; and facilitate the economic development of the region.

Keywords: Bacalar, bird, tourism impact, vegetation, Xul-Ha Cenote.

Resumo

A Lagoa Bacalar (BL) em Quintana Roo, México, é uma zona de grande interesse devido ao seu potencial turístico. No entanto, as mudanças nos padrões de uso da terra, urbanização, pecuária extensiva e agricultura em rápida expansão geraram impactos negativos nas áreas das comunidades adjacentes do plano e nos habitats da vida selvagem. O objetivo deste estudo foi avaliar o nível de conservação da vegetação na porção sul da BL através da avifauna presente em locais com graus de conservação contrastantes. Além disso, alterar sua(s) preferência(s) de habitat nas diferentes comunidades. Para avaliar o nível de conservação da LB foram realizadas visitas de campo e coletas botânicas para identificação de espécies. Para a contagem e identificação das aves foram realizados levantamentos mensais através de passeios costeiros ao longo do cenote Xul-ha em transectos de 2,5 km. Foram estabelecidos quatro transectos: 2 para locais caracterizados como semiconservados e 2 para locais perturbados. Uma riqueza total de 40 táxons foi observada, o que corresponde a 8,1% da avifauna de Quintana Roo e 32% de aves pantanosas (125 espécies). As curvas de acumulação de espécies indicaram que locais semiconservados e perturbados tendem a atingir assíntotas e com percentual de cobertura superior a 90%. Em termos de diversidade e estrutura comunitária, não foram observadas diferenças significativas. No entanto, os locais semiconservados e perturbados têm, cada um, 11 espécies únicas e partilham 18 espécies. A BL possui uma diversidade intermediária de espécies de aves em comparação com estudos mexicanos, o habitat é importante para a conservação da avifauna; pois funciona como um reservatório de diversidade. Estratégias que promovem o turismo sustentável, apoiam a restauração da vegetação natural e facilitam o desenvolvimento econômico da região foram sugeridas, no presente estudo.

Palavras-chave: Bacalar, ave, impacto turístico, vegetação, Cenote Xul-ha.

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1. Introduction

Rapid urbanization, extensive ranching, and agriculture as well as illegal hunting are the main factors that cause fragmentation and deterioration of natural ecosystems (Marzluff et al., 2001; Fahrig, 2003; Alberti et al., 2003; Villegas and Garitano-Zavala, 2008). They are the factors facilitating the extinction of numerous species in the tropical forests, where most of the global biodiversity concentrates because of the primary food sources, refuge, and reproductive areas wildlife needs (Myers et al., 2000; Brooks et al., 2002).

At present, ornithological studies indicate that the richness and abundance of birds are indicators of the ecosystem health (Cairns and Kerekes, 2000; Figuerola and Green, 2003). However, some species are more sensitive than others due to anthropogenic and/or environmental disturbances, depending on their population density and dispersal capacity (Laurance and Bierregaard, 1997). In this sense, Zurita and Bellocq (2007) reported that raptors are good indicators of conservation; since they require large territorial areas for their movement; despite their low population density. On the other hand, waterfowls are closely linked to waterbodies due to their specific food requirements (*eg*. crustaceans and fishes) (Furness et al., 1993; Hilty and Merenlender, 2000; Zacharias and Roff, 2001).

In Mexico, 1123-1150 species of birds are reported (Navarro et al., 2014). On the other hand, in the Yucatan Peninsula (YP) t509 native bird species are distributed in 62 families representing 44.2% of the total Mexican avifauna (MacKinnon, 1992). For Quintana Roo, Correa-Sandoval and MacKinnon (2005) reported 483 taxa. Out of these, 124 are aquatic and 359 are terrestrial. Ecosystems in Quintana Roo are premier bird habitats. But, they are under extreme anthropogenic pressures due to poorly managed tourism activities that have led to very serious negative impacts on the overall biodiversity of this ecologically sensitive region (Kousis 2000; Williams and Ponsford, 2009).

An area of growing interest due to its high ecotourism potential is the Balacar Lagoon (BL) in Quintana Roo (with an area of 42 km^2), as the southern part of the lagoon has the presence of thrombolites and stromatolites (Siqueiros-Beltrones et al., 2013); that are primary producers of cyanobacteria and benthic diatoms that support abundant populations of gastropods and fishes (Gischler et al., 2008, 2011). This serves as an important food source for the aquatic birds such as the cormorants (Phalacrocoridae) and herons (Ardeidae) (Kerekes et al., 1997; Figuerola and Green, 2003). But these sites are being negatively impacted by rapid expansion of agriculture, urbanization and pooly managed tourist activities that have contaminated surface water resources with high risk fecal bacteria detrimental to both humans and wildlife (McJunkin, 1988; Comisión Nacional del Agua, 2003; Barrera-Escorcia and Namihira-Santillán, 2004).

Birds as a faunal group are considered biological indicators of the state of conservation and trophic relationships in ecosystems; because they respond to the composition and structure of the vegetation (Verea and Solórzano, 2005; Barlow et al., 2006; Verea et al., 2010; Molina and Bohórquez, 2013). In this regard, Lopez-Ornat and Ramo (1992) and Correa-Sandoval and Garcia-Reynoza (2019) mentioned that studies of bird alimentation in the lagoon systems of central and southern Quintana Roo (Sian Ka'an and LB, respectively), are scarce and/or null, despite the importance of these ecosystems for harboring a very rich diversity of avifauna.

Our objective has been to measure the degree of conservation of the surrounding vegetation of the southern portion of the LB, Quintana Roo, Mexico and to analyze if there is an effect on the diversity of birds in sites disturbed by agricultural activities and tourism. It is however expected that there will be some differences in the presence of conservation indicator birds. Furthermore, bird watching is suggested as a strategy to generate new opportunities for ecotourist activities that help reduce impacts of urbanization on the bird diversity and distribution on the different natural communities adjacent to the lagoon.

2. Material and Methods

2.1. Study area

The BL is located between the limits of the municipalities of Bacalar and Othón P. Blanco in Quintana Roo, Mexico, approximately 30 kilometers from the Bay of Chetumal (Oliva-Rivera, 2016) (Figure 1A). The lagoon is a geological crack, known locally as "*the lagoon of the seven colors*", it has a length of 42 km and a width of 2 km; feeds on underground currents from the high areas of the northwest of the YP (Gómez-Pech et al., 2018) (Figure 1B). The BL in its central and southern part has rocky shores that are zones composed of stromatol1ites, the southern part is fed with water by the "*Cenote Xul-Ha*" (C-XH) (adjacent to the homonymous community, Xul-Ha) and the part of the center is fed with water by four cenotes located around the town of Bacalar (Carrillo et al., 2009); where there is a strong current of water to the north of the lagoon, originating from the C-XH which is fed towards the BL by the strait "*the rapids*" (Gischler et al., 2011) (Figure 1C). Due to these waterbodies, the BL has become an area of tourist attraction, for this reason, Bacalar town was decreed in 2006 as a magical town (SECTUR, 2014) and in 2011 as a municipality. Currently, the town of Bacalar has a population of 39,111 inhabitants (INEGI, 2015); while the town of Xul-Ha has a population of 2,200 inhabitants (INEGI, 2010), being an area with less tourist impact, but with high potential for these activities due to its great biological importance and due to the presence of thrombolites and stromatolites (Gischler et al., 2008).

The avifaunal study sites are located in the south-central part of the BL, which ranges from Xul-Ha to the rapids area (Figure 2) with a total length of 5.9 km and width of 0.7 km in its most extensive areas. The southern part of the LB presents different plant communities, such as medium stature tropical forest (Figure1D, site I), mangrove areas with *Rhizophora mangle* L., *Conocarpus erectus* L., *Laguncularia racemose* (L.) C.F. Gaertn. (Figure 1D, sites II and III) and areas of secondary vegetation of medium stature tropical forest (Figure 1D, site IV) (INEGI, 2013). The climate of the area is warm sub-humid, with a rainy regime in summer, the average annual temperature varies from 27-40 °C and a minimum of 14 °C and has an average annual rainfall of 1249 mm (SEMARNAT, 2011; Cálix de Dios, 2014).

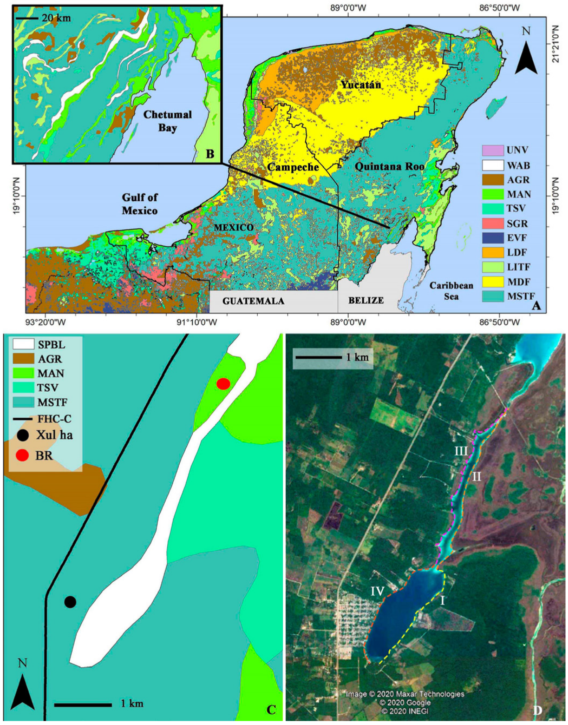

Figure 1. Study area. A. Yucatán peninsula, Mexico. B. Bacalar lagoon in Quintana Roo. C. Southern portion of the Bacalar lagoon and plant communities: AGR = Agriculture, MAN = Mangrove, TSV = Typha-swamp vegetation, MTSF = medium stature tropical forest. D. study sites: I) medium stature tropical forest, II-III) mangrove, IV) secondary vegetation.

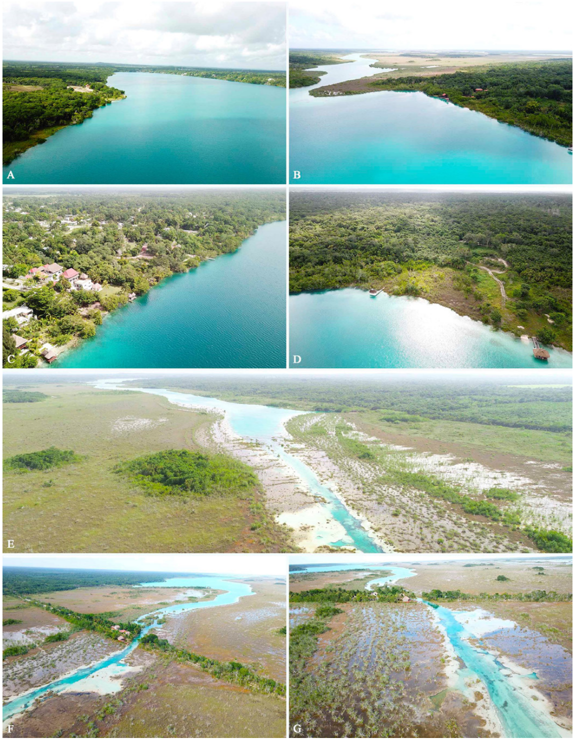

Figure 2. Aerial view of the botanical collection and bird watching sites in the Southern portion of the Bacalar lagoon, Quintana Roo, Mexico. A-B. Medium stature tropical forest. C. Private and tourist settlements. D. Secondary vegetation. E. Rapids with marshy areas and Petenes. F. Tourism in the rapids. G. Riparian vegetation in marsh areas.

2.2. Plant communities

The sites where the linear sighting transects were established in the south-central part of the BL were selected based on the degree of conservation of the plant communities (mangrove, medium sub-evergreen forest, typha-swamp vegetation, secondary forest), previously identified in the vegetation layers of INEGI (2013). We captured satellite images of the study area with Google Earth Pro® 7.3.2.5491 and vegetation images cover taken with drones (Phantom Pro 4® and Mavic Pro®). Furthermore, circular plots with a radius of 17.8 m were established in these sites to identify and corroborate the vascular flora present and degree of conservation (Ibrahim et al., 2004). In these sites, botanical collections were carried out in different seasons of the year to determine the species composition of the vegetation types. No data analysis was performed because only it was only to characterized the vegetation on the plant communities.

2.3. Bird sampling

According to the analysis of the plant communities, the sites of the narrowest part of the BL were classified as semi-conserved sites (sites II and III) and the sites of the widest part (sites I and IV) were considered as disturbed (Figure 1). Between March and October 2018, eight samplings were carried out through coastal routes in a boat, with a speed of 6 km/h (Mangas-Ramírez, 2011; Berumen et al., 2017) in lengths of 2.5 km per transect for each of the sites (Bibby et al., 1992; Buckland et al., 1993; González-García, 2011), which made a total of 10 km of sampling route in the different plant communities bordering the lagoon and a total of 80 km traveled throughout the study (Figure 2). Fixed-radius point sighting samplings were carried out in the transects, with 10 × 42 Vortex binoculars, in addition, photographic records were made with Sony Alpha A58 and Nikon D3400 cameras with 70-200 mm and 70-300 mm telephoto cameras, respectively. The birds were identified using specialized guides from Howell and Webb (1995) and Mackinnon (2017).

2.4. Statistical analysis

To compare and know of the specific alpha diversity of birds in the disturbed and semi-conserved sites of the BL, Shannon and dominance indices were calculated and transformed into effective number of species (Jostand and González-Oreja , 2012). To identify differences in richness, abundance and diversity; we used the Welch's t test (for unequal variances) to identify the significant differences between disturbed and semi-conserved sites with the statistical program R, version 4.2.0, implemented with the RStudio graphical interface (RStudio Team, 2015). A one-way PERMANOVA based on Bray-Curtis distances with 999 permutations was used to analyze differences in the abundance and composition of bird species at the two sites. To compare fairness, abundance rank curves (log) were constructed (Magurran, 2004). In order to identify the relationships between the sites and bird species; the chord diagram was designed with Origin Pro 10.0.5.157 software (Seifert, 2014). With the iNEXT Online program, the accumulation curves, extrapolation and sampling coverage curves by sites were performed (Chao et al., 2016). Diversity analyzes and multivariate tests were performed with the Past® 3.23 program (Hammer et al., 2001).

For the canonical correspondence analysis, the average of the following environmental data were considered: temperature (c°), wind (m/s), humidity (%), precipitation (mm), evapotranspiration (mm). These variables were selected according to Brooks et al. (2001), since they occur at higher levels with greater biodiversity. Similarly, the NDVI data (Normalized Difference Vegetation Index) was also procured that measures the greenness and density of vegetation captured in a satellite image (EOS Data Analytics, 2023), where lower values between 0.2-0.3 represent shrubs and grasslands; while higher values 0.6-0.8 indicate temperate and tropical forests. This is a viable option for the identification and comparison of semi-preserved and disturbed areas that demonstrate changes in the vegetation cover.

3. Results

A total of 40 species of birds belonging to 21 families with a total of 257 individuals were identified in the southern portion of Laguna de Bacalar (SPLB), corresponding to 27 terrestrial species (2 winter residents) and 13 aquatic (2 winter residents) (Figure 3). Regarding richness, abundance and diversity (effective number of species), no significant differences were found between disturbed and semi-conserved sites (Welch's t test, $P > 0.05$, Figure 3, Table 1). In the composition of bird species there were no differences between the two sites based on Bray-Curtis distances (PERMANOVA: F-value = 1.06, P value = 0.38). Finally, the semi-conserved sites got the major abundances value (n = 149 records).

The distribution of abundance did not differ between the disturbed and semi-conserved sites (Figure 4B, 5, 6). The canonical correspondence diagram indicates that there is a difference in the composition of the sites and their species (Figure 7). The variables NDVI and temperature were positively correlated with the families Icteridae and Corvidae; while Jacanidae was found to be positively correlated with precipitation. On the other hand, the families Tyrannidae, Ardeidae and Columbidae, demonstrated a shared composition between the semi-conserved and disturbed sites (Figure 4E). However, according to the Chord diagram, each semi-conserved site has 11 unique bird species; and between them they share 18, hence each site has 29 species (Figure 5A). The five most abundant species were *Eupsittula nana* (38%), *Bubulcus ibis* (32%), *Tyrannus couchii* (25%), *Coragyps atratus* (Figure 3G) (17%) and *Myiozetetes similis* (16%) (Figure 3J) (Table 2). While the best represented families in abundance were Tyrannidae (26.4%), Psittacidae (15.5%), Ardeidae (15.5%), Cathartidae (7%) and Hirundinidae (6.6%). The families with the highest number of species were Tyrannidae (n = 5) and Ardeidae (n = 5). Of the total species, eight were represented by doubletons and 12 by singletons (Table 2).

Figure 3. Bird species representative in the Southern portion of the BL, Quintana Roo, Mexico. A. *Aramus guarauna*. B. *Ardea Herodias*. C. *Bubulcus ibis*. D. B*utorides virescens*. E. *Cairina moschata*. F. *Chloroceryle amazona*. G. *Coragyps atratus*. H. *Jacana spinosa*. I. *Megaceryle torquate*. J. *Myiozetetes similis*. K. *Phalacrocorax auratus*. L. *Phalacrocorax brasilianus*.

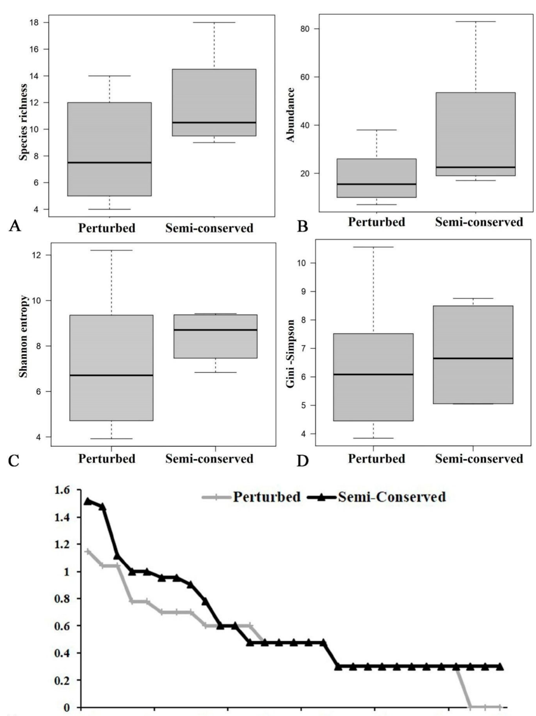

Figure 4. Birdlife diversity and abundance curves in perturbed and semi-conserved sites in the Southern portion of the Bacalar lagoon, Quintana Roo, Mexico. A. Species richness. B. Abundance. C. Shannon entropy. D. Gini-Simpson, the averages were each calculated from 2.5 km-transect. E. Rank abundance curves for birdlife of contrasting environments (perturbed and semi-conserved).

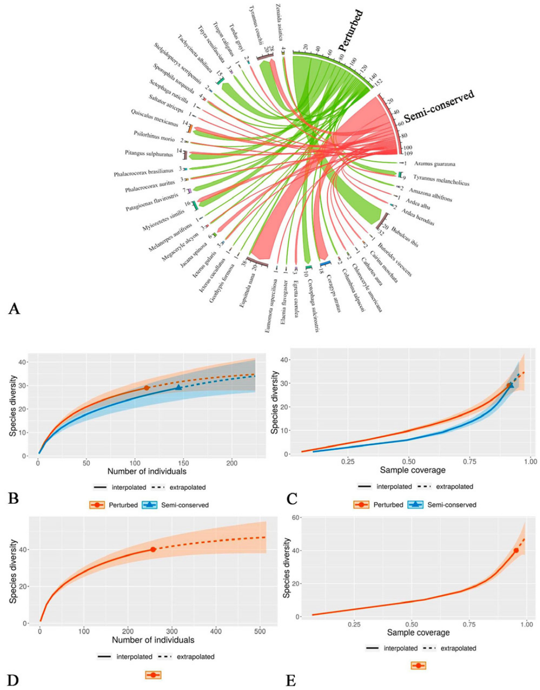

Figure 5. Chord diagram and Rarefaction and extrapolation curve based on sample size and rarefaction curve based on sample coverage at semi-conserved and disturbed sites in the Southern portion of the BL, Quintana Roo, Mexico. A. Chord diagram of abundances of bird species recorded in the Bacalar lagoon and their relationship with the habitats evaluated (perturbed and semi-conserved). B. Rarefaction curve at the sites. C. Rarefaction curve based on site coverage. D. Accumulation and extrapolation curve by sites at the regional level for the micro-basin. E. Sampling coverage curve by sites at the regional level for the micro-basin.

Figure 6. Main tourist activities in the Southern portion of the BL, Quintana Roo, Mexico; (A) Livestock animals; (B) Impact of deforestation on vegetation cover; (C) Tourist settlements; (D) Mangrove vegetation; (E) Tourist activities in the mangrove; (F) Thrombolites and stromatolites; (G) Private property for recreation activities; (H) Restaurant and swimming areas in the rapids.

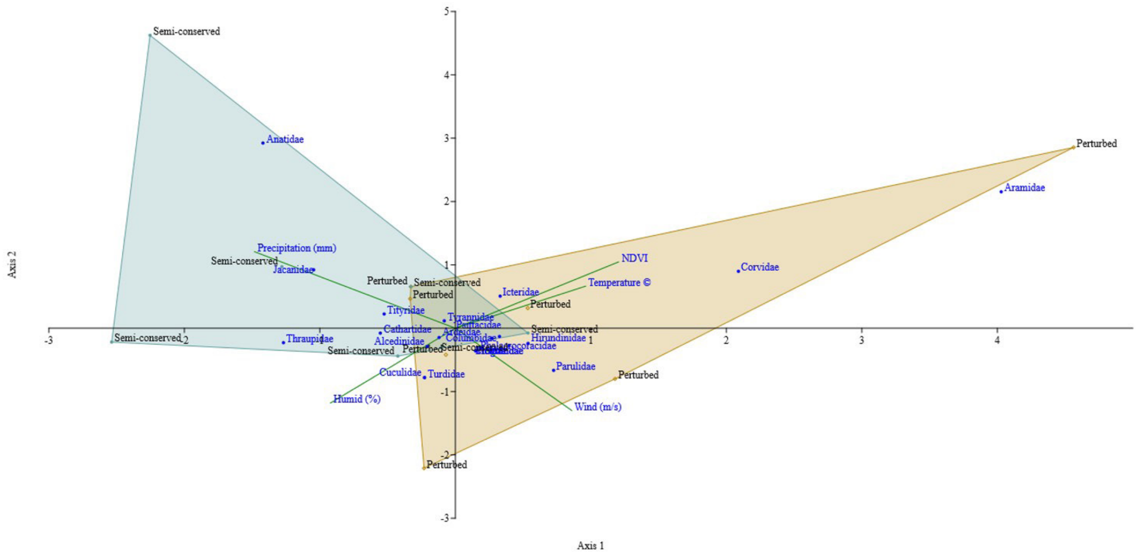

Figure 7. Canonical-correlation analysis (CCA). Preference of bird families with environmental variables in the habitat types evaluated.

Table 1. Value of diversity and richness of bird species in the micro-basins of the southern portion of the BL, Quintana Roo, Mexico. C ^ = Sample coverage.

Indices	Semi-conserved	Disturbed
Richness	12±4	8±4
Abundance	36±31	18±11
Gini Simpson index (D)	6.7±1.9	7.2±3.2
Shannon entropy (H)	8.4±1.2	6.4±2.5
C^	0.92	0.91

Table 2. Diversity, abundance, habitat and conservation categories of the avifauna of the southern portion of the BL, Quintana Roo, Mexico. HA = Habitat: IAE = Inland aquatic environments, CAE = Coastal aquatic environments, SOA = Semi-open areas, OPA = Open areas, CLE = Closed environments. Conservation categories. NOM = Official Mexican Standard (Norma Oficial Mexicana, in Spanish) (NOM-059-SEMARNAT-2010):RE = Risk of Extinction (P, Peligro de extinción, in Spanish), SP = Special Protection (Pr, Protección especial, in Spanish), T = Threatened (A, Amenazada, in Spanish). IUCN =International Union for Conservation of Nature and Natural Resources: LC = Least Concern, NE = Not Evaluated. SB= Seasonality in Birds (according to Mackinnon, 2017): WR = Winter resident, PR = Permanent resident. S-C = Semi-conserved, DI = Disturbed, RA = Relative abundance.

Family/Species	HA	NOM	IUCN	SB	S-C	DI	RA
Alcedinidae	–	–	–	–	–	–	26.5
Chloroceryle americana Gmelin	IAE	–	LC	PR	1	1	–
Anatidae	–	–	–	–	–	–	15.6
Cairina moschata Linnaeus	IAE	RE	LC	PR	2	0	
Aramidae	–	–	–	–	–	–	15.6
Aramus guarauna Linnaeus	IAE	T	LC	PR	0	1	–
Ardeidae	–	–	–	–	–	–	7.0
Ardea alba Linnaeus	CAE	–	LC	PR	1	0	–
Ardea herodias Linnaeus	CAE	–	LC	PR	0	3	–
Bubulcus ibis Linnaeus	OPA	–	LC	PR	32	0	–
Butorides virescens Linnaeus	CAE	–	LC	PR	0	1	–
Egretta caerulea Linnaeus	CAE	–	LC	PR	2	1	–
Cathartidae	–	–	–	–	–	–	6.6

Table 2. Continued...

Family/Species	HA	NOM	IUCN	SB	S-C	DI	RA
Cathartes aura Linnaeus	OPA	–	LC	PR	1	0	–
Coragyps atratus Bechstein	OPA	–	LC	PR	8	9	–
Columbidae	–	–	–	–	–	–	6.2
Columbina talpacoti Temminck	SOA	–	LC	PR	0	2	–
Patagioenas flavirostris Wagler	SOA	–	NE	PR	2	5	–
Zenaida asiatica Linnaeus	SOA	–	LC	PR	1	3	–
Cerylidae	–	–	–	–	–	5.1	–
Megaceryle alcyon Linnaeus	IAE	–	LC	PR	2	1	
Corvidae	–	–	–	–	–	–	3.9
Psilorhinus morio Wagler	SOA	–	LC	PR	1	1	
Cuculidae	–	–	–	–	–	–	2.3
Crotophaga sulcirostris Swainson	OPA	–	LC	PR	0	10	–
Hirundinidae	–	–	–	–	–	–	2.3
Tachycineta bicolor Vieillot	SOA	–	LC	WR	2	0	–
Tachycineta albilinea Lawrence	IAE	–	LC	WR	5	10	–
Icteridae	–	–	–	–	–	–	1.2
Icterus cucullatus Swainson	SOA	–	LC	PR	1	0	–
Icterus gularis Wagler	SOA	–	LC	PR	1	2	–
Quiscalus mexicanus Gmelin	SOA	–	LC	PR	7	5	–
Jacanidae	–	–	–	–	–	–	1.2
Jacana spinosa Linnaeus	IAE	–	LC	PR	3	3	–
Momotidae	–	–	–	–	–	–	1.2
Eumomota superciliosa Sandbach	SOA	–	LC	PR	1	0	–
Parulidae	–	–	–	–	–	–	0.8
Geothlypis formosa Wilson	CLE	–	NE	WR	0	1	–
Setophaga ruticilla Linnaeus	SOA	–	LC	WR	1	0	–
Phalacrocoracidae	–	–	–	–	–	–	0.8
Phalacrocorax auritus Lesson	CAE	–	LC	PR	1	2	–
Phalacrocorax brasilianus Gmelin	CAE	–	LC	PR	2	1	–
Picidae	–	–	–	–	–	–	0.8
Melanerpes aurifrons Wagler	SOA	–	LC	PR	1	0	–
Psittacidae	–	–	–	–	–	–	0.8
Amazona albifrons Sparrman	SOA	SP	LC	PR	0	2	–
Eupsittula nana Vigors	SOA	SP	LC	PR	29	9	–
Thraupidae	–	–	–	–	–	–	0.8
Saltatora triceps Lesson	SOA	–	LC	PR	0	1	–
Sporophila torqueola Bonaparte	OPA	–	LC	PR	0	2	–
Tityridae	–	–	–	–	–	–	0.4
*Tityra semifasciata*von Spix	SOA	–	LC	PR	3	0	–
Trogonidae	–	–	–	–	–	–	0.4
Trogon caligatus Gould	CLE	–	NE	PR	1	0	–
Turdidae	–	–	–	–	–	–	0.4
Turdus grayi Bonaparte	SOA	–	LC	PR	0	2	
Tyrannidae	–	–	–	–	–	–	0.4
Tyrannus melancholicus Viellot	SOA	–	LC	PR	7	5	–
Elaenia flavogaster Thunberg	SOA	–	LC	PR	0	1	–
Myiozetetes similis von Spix	SOA	–	LC	PR	10	6	–
Pitangus sulphuratus Linnaeus	SOA	–	LC	PR	9	5	–
Tyrannus couchii Baird	SOA	–	LC	PR	8	17	–

According to the type of habitat, the semi-open areas had the highest abundance of birds (140 individuals) and the highest number of species (21), followed by open areas with 62 individuals and five species. The inland aquatic environments had a total of 29 individuals and six species and coastal aquatic environments with 14 individuals and six species. Closed environments were the least represented with only two individuals and two species (Table 2).

The highest species richness was found at sites I (n = 23) and II (n = 24), followed by sites IV (n = 16) and III (n = 15). The species accumulation and extrapolation curves show that the semi-conserved and disturbed sites have a coverage greater than 90% with a clear approach to the asymptote and 95% for the entire sampling (Figure 5C). Similarly, the regional level accumulation and extrapolation curve for the micro-basin has an approximate growth to the asymptote, extrapolating between a total of 54 species (Figure 5D).

Of the total of the registered species, four are in some risk category according to NOM-059-SEMARNAT 2010 (SEMARNAT, 2010), *Cairinamostacha* (Figure 3E) is in the danger of extinction (P), *Aramus guarauna* (Figure 3A) as Threatened (A), and *Amazona albifrons* and *Eupsittula nana* needs special protection (Pr). In the list of priority species for Conservation (DOF, 2014) are *Zenaida asiatica* and *Eupsittula nana*.

4. Discussion

4.1. Bird diversity

The present study represents one of the first efforts to assess diversity for the SPBL. Studies in the area are scarce, among these we can cite Chavez-Leon (1988), who obtained 35 new bird records based on observations for the central portion of the Bacalar lagoon (CPLB) and five for the SPBL. Furthermore, López-Ornat et al. (1989) reported five new records for the CPLB. Likewise, other studies have been carried out for BL, on reproductive habits, distribution and feeding on the genera *Psarocolius* (Solorio, 1994), *Aramus* and *Rostrhamus* (Correa-Sandoval and García-Reynoza, 2019).

The diversity reported in this study corresponds to 8.4%, when compared at the state level (Correa-Sandoval and Mackinnon, 2005); at 12.5% (40 versus 328 taxa) when compared to the avifauna of the *Sian Ka'an* Biosphere Reserve, Quintana Roo (Mackinnon, 1992); with the exception of *Cairina moschata*, that includes 39 of the 40 species recorded here. However, the area sampled in the SPBL corresponds to 3.7 sq km (328 ha) *versus* 5,282 sq km (528,148 ha) of the *Sian Ka'an* reserve (Ceballos et al., 2002). Comparing with studies at the YP level, Galvez et al. (2016) reported 42 species, which interact with the red flamingo (*Phoenicopterus ruber*) in wetlands of Yucatán, Mexico; the current study being the most similar in number of species with respect to our work.

Comparing the avifauna in lagoons and micro-basins at the national level, the diversity recorded is more or less similar to that found in this study. It varies depending on the type of vegetation, altitude, latitude and surface area. For example, Hernández-Vázquez (2005) reported 78 species in the "*El Ermitaño*" estuary and the "*Agua Dulce*" lagoon, Jalisco (in low deciduous forest, 1014 ha, 0 m a.s.l.). Zamora-Orozco et al. (2007) enlisted 80 species in *Las Lagunas de Oxidación*, La Paz, Baja California Sur (desert vegetation, 42 ha, 8 ma.s.l.); Zárate-Ovando et al. (2008) reported 67 species in *Bahía Magdalena-Almejas, Baja California Sur* (Mangrove swamps, coastal cliffs and dunes, 1875 km^2, 0-30 m a.s.l.). Studies in the continental and coastal lagoons worldwide report between 29-145 species; for example, Arcos et al. (2008) reported 145 species in Honduras; Bucher and Herrera (1981) 56 species in Argentina; Cruz et al. (2007) 81 species in Lima, Peru; Sillen and Solbreck (1977) 29 species in Stockholm, Sweden; and Hattori and Mae (2001) 25 species in the coastal Lake Biwa, Japan. When comparing with all these studies, it can be pointed out that the species diversity varies depending on the size of the sampled area, geographic area, vegetation type and the climate.

The total sampling coverage curve represented 95% of the expected species (Figure 5E); in agreement with May (1975) and Sillen and Solbreck (1977), suggesting that the accumulation curves tend to be more pronounced when the sampling area is small. Furthermore, the amount of species entry depends on the sampling effort made (Jiménez-Valverde and Hortal, 2003). In this study, 8 of the 40 species were the most common species (*Tyrannus couchii*, *T. melancholicus*, *C. atratus*, *E. nana*, *Tachicyneta albilinea*, *Bubulcus ibis*, *Pitangus sulphuratus* and *Myiozetetes similis*), which were quickly identified due to the size of the sampled area and by the frequency of appearance during the samplings.

4.2. Habitat preferences

Regarding their habitats, 22 taxa were presented in semi-open areas, mostly represented by terrestrial birds. Of the aquatic birds present, six belong to inland aquatic environments, seven to coastal aquatic environments, five to open areas and one to closed areas according to the Mackinnon (2017, Table 2). Sampling along the coast can be an important factor to consider, when the censuses are not carried out within the vegetation areas because the properties are private and it is a limitation for the study. However, a greater number of terrestrial species (26 taxa) was found despite being an area with a greater abundance of favorable ecosystems for waterfowl, in agreement with Luo et al. (2019), suggesting that lakes can be the habitat of terrestrial birds and not only of aquatic birds.

Although the conserved and semi-conserved sites had 11 exclusive species each, only in the conserved sites highly vulnerable species such as *Aramus guarauna* were recorded. According to Mistry et al. (2008), this species can be indicator of conservation of savanna ponds. Similar to trogons in tropical forests (Espinosa de los Monteros Solis, 2001), *A. guarana* belongs to groups of birds highly sensitive to disturbance.

While sites III and IV with the greatest human influence presented the lower diversity. Our results do not agree with the study carried out by González-Martín del Campo et al. (2019), which affirms that the most heterogeneous and fragmented landscapes favor the richness of birds;

where this hypothesis has been debated because few studies have shown high values of diversity in sites with medium disturbance (Fox, 2013). However, homogeneous areas such as marsh areas (III and IV); where there was less diversity of species, there was a dominance of specialist birds such as *Bubulcus ibis*, *Crotophagas ulcirostris*. This coincides with the study by Hanski (2015), who mentioned that the sites with less disturbance and fragmentation favor diversity; agreeing with the data obtained. The sites with greater vegetation cover and less human presence have a greater diversity of taxa, while III and IV have more specialist birds like Anatidae and Jacanidae.

4.3. Tourist impact

Tourist impacts on lakes usually come from certain activities such as swimming, boating, and fishing (Dokulil, 2014). In this sense, the SPBL has these tourist and recreational activities (Figure 6). Tourism is a factor that can cause direct or indirect disturbances through habitat modification and habitat fragmentation resulting from the development of tourism infrastructure (Huhta and Sulkava, 2014), which can cause negative impacts on bird populations (Dokulil, 2014). At the same time, urbanization may favor generalist omnivores (Beissinger and Osborne, 1982; Clergeau et al., 2006; Huhta and Sulkava, 2014) which explains the presence of *Columbina talpacoti* in the SPBL, a species considered as an indicator of disturbance (Rangel-Salazar et al., 2009; González-Jaramillo et al., 2016).

Regarding habitat preferences, species such as *Quiscalus mexicanus* were present in sites of secondary and fragmented vegetation, as well as the presence of *Tyrannus couchii* that built nests with plastic waste. Both species belong to the Passerine order, in which many of their species select areas with relatively open vegetation to feed, because it provides greater accessibility to food and allows predators to be located (Odderskaer et al., 1997; Perkins et al., 2000; Moorcroft et al., 2002; Benton et al., 2003). The above coincides with Laurance and Bierregaard (1997) and Ramírez-Albores (2010) reported that the composition of the avifauna and it's feeding guilds is related to the structure of the vegetation.

Despite the dominance of aquatic ecosystems and marsh areas (Figure 1D), 36% of the species reported in this study were aquatic birds; which suggest that a low percentage of these species when expecting greater abundances due to the lagoon area. In the same way, human presence causes low richness and abundance of birds, observed in both semi-conserved and disturbed sites of the SPBL. They perceive the deteriorated habitat and humans as possible predators (Gill et al., 1996); and agreeing with Bélanger and Bédard (1989), Ebbinge (1991) and Sutherland and Crockford (1993), because birds avoid areas disturbed by anthropogenic activities.

4.4. Conservation plans

The conservation of these sites is essential for the conservation of birds, also due to the presence of four species protected in NOM-059 (SEMARNAT, 2010) such as *Aramus guarauna* (Threatened), *Cairina moschata* (Endangered) and *Amazona albifrons* and *Eupsittula nana* (Subject to special protection). This last species presented abundance and representative presence at the sites during our study. On the other hand, two of these species depend on aquatic ecosystems. For this reason, these ecosystems are important for the conservation of the aquatic species. Therefore, it is necessary developing proper restoration and conservation strategies of critical aquatic bird habitats in the SPBL (Mander et al., 2007; McKinney et al., 2011; Luo et al., 2019).

The protection of these ecosystems is essential and must be compatible with activities that promote conservation such as bird watching, a recreational activity that involve millions of people (Kerlinger, 1993); and is also one of the most important ecological and sustainable hotspots of tourism impacting the conservation of wildlife (Connell, 2009). The tourism activity certainly brings foreign exchanges to the host country; as observers pay significant revenues to spot unusual bird species (Glowinski, 2008; Lee et al., 2009; Edwards et al., 2011). Callaghan et al. (2018) have indicated that an economic benefit of between $213,000-223,000 USD is obtained from bird tourism; just from observing birds like Black-Backed Oriole (*Icterus abeillei*) in Pennsylvania. Meanwhile, Liu et al. (2021) suggest that the per capita recreational value of bird watching is 3.9 times that of general ecotourism; and its per capita economic benefit is 4.5 times that of general ecotourism in China. There are technical differences between ecotourists in versus bird watchers; where the latter present better economic benefits for the local tourism industry.

Although bird watching may serve as an alternative source of income for BL; however, there is currently no organization or group dedicated to bird watching at BL. Hence it is important to promote further research investigations at BL to facilitate the conservation of the wetlands and provide comprehensive information on the local fauna. These ecosystems have great potential to be bird watching areas and can have a high economic value that motivates local people to protect these natural areas, providing education and employment for local guides (Sekercioglu, 2002). Therefore, this is an alternative that can promote sustainable tourism that helps to conserve ecosystems, through ecotourism alternatives based on land use planning that protects the environment and regulates the use of natural resources and the use of ecosystems, which are in danger due to poorly planned development (Figure 6).

5. Conclusion

Due to the large number of private properties, this study could not be carried out in certain areas of interest. However, the first taxonomic list of bird species is presented for the SPLB. The families with the highest abundance were aquatic birds due to the types of ecosystems present in the study area; but, the highest species richness consisted of terrestrial birds. The diversity of species is low compared to other studies, although the accumulation and extrapolation curves indicated that this study represented almost all the diversity of birds expected with the sampling effort carried out in the area. Likewise, this diversity of species is closely related to the types of vegetation and their conservation status, the mangrove and swamp vegetation sites were areas of frequent use for aquatic birds. Despite the fact that there are preserved ecosystems close to the area, birds are in constant risk due to the different tourist activities that cause the change of land use in the different private and urban properties. For this reason, greater avifaunal and biological diversity studies are needed in the different areas (central and north) of the lagoon; better management of the ecosystems, can help in the conservation of the local ecosystems and wildlife; and promote sustainable tourism in the region compatible with tropical ecosystems and associated wetlands.

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