ORIGINAL ARTICLE

Habitat fragmentation erodes taxonomic and functional diversity of waterbird communities of the South Pacific coast of Mexico

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Abstract

We characterize the taxonomic and functional diversity of waterbird communities in mangrove forests of 23 coastal lagoons in the southern Mexican Pacific coast, to evaluate the hypothesis of decline of taxonomic and functional richness of waterbird communities in the face of loss of natural habitat cover and increased fragmentation. We quantified patterns of land use cover, considering the heterogeneity of natural and anthropized vegetation cover as a proxy for human-caused fragmentation, and used generalized linear models to explore the relationship between these two covers with the taxonomic richness and functional richness of bird communities. Results show that both aspects of biodiversity positively relate to larger natural habitat areas, while higher fragmentation values have a negative effect on them. Our results suggest that habitat loss and fragmentation of vegetation cover negatively affect the diversity of waterbird communities and can compromise their link to ecosystem functioning processes in coastal lagoons, by decreasing their functional diversity.

Keywords Bird communities · Coastal ecosystems · Functional richness · Functional ecology · Habitat fragmentation · Mangrove forests

Introduction

Coastal ecosystems form a mosaic that links diverse types of terrestrial, marine, and inland water habitats (Sheaves 2009; Buelow and Sheaves 2015). Some of these natural systems are coastal lagoons, which link the mangrove forest habitat with estuaries, where in turn, marine and inland biotas are mixed (Buelow and Sheaves 2015). Coastal lagoons are shallow water bodies separated from the ocean by a barrier and connected to it by canals (Kjerfve 1994). In addition, coastal lagoons are frequently covered by mangrove forests (hereby mangroves), both within these bodies of water and in the periphery (Calderón et al. 2009; Rodríguez-Zúñiga et al. 2013). Though mangroves have low floristic diversity

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they have high structural complexity and harbor a large diversity of animal species (Nagelkerken et al. 2008; Feller et al. 2010). This biological diversity of mangroves contributes to ecosystem functioning mechanisms, like nutrient production and connectivity between inland and marine environments.

Because of their high productivity and the complex structure of the mangrove trees' underwater roots, coastal lagoons act as nurseries for great diversity of fish and crustaceans (Robertson and Duke 1987; Nagelkerken et al. 2008, 2013; Feller et al. 2010). Hence, the aquatic ecosystem of coastal lagoons provides a fundamental source of trophic resources to animals such as waterbirds (Kutt 2007; Buelow and Sheaves 2015). Aquatic birds are one of the most conspicuous animal groups that inhabit coastal lagoons and mangroves. The mangrove forest cover offers resting sites and refuge to these organisms and provides proper nesting sites to diverse species, including several species of cormorants, ibises, herons, pelicans, and seagulls (Pfister et al. 2006; Nagelkerken et al. 2008; McFadden et al. 2016).

Several bird species make use of the mangrove habitat as a place to roost and forage, while also utilizing the tree canopies as nurseries (Pool et al. 1977; Bouillon 2011; Rodríguez-Zúñiga et al. 2013; Buelow and Sheaves 2015). Likewise, specialist bird species can take advantage of mangrove roots, along with the saltpans and creeks they create, as food sources. Indeed, it has been found that the structural complexity of mangrove forests is positively related with bird communities' diversity (Mohd-Azlan et al. 2015). By fulfilling the ecological requirements of their diets, waterbirds become closely tied to regulation mechanisms of ecosystem functioning in coastal lagoons (Hooper et al. 2005; Whelan et al. 2016). They therefore facilitate biochemical processes, provide nutrients to primary producers, prevent eutrophication, and link other environments with the mangrove (Dobrowolski et al. 1993; Smith et al. 1999; Vanni 2002; Ligeza and Smal 2003; Buelow and Sheaves 2015; Fujita and Kameda 2016). Besides, waterbirds regulate the population size of invertebrates, fish, and amphibians and can be involved in trophic cascade phenomena (Wootton 1995; Şekercioğlu 2006). Furthermore, several species from Scolopacidae, Charadriidae, Anatidae, and Rallidae are important seed dispersers of aquatic plants (Green et al. 2016).

Unfortunately, habitat loss and fragmentation due to human impacts threaten coastal lagoons and their mangroves, which have lost 62% of their total world cover up until 2016 (Goldberg et al. 2020). In Mexico, mangrove area loss resulting from human activity has reached 20% since 1980 (CONABIO 2008; Velázquez-Salazar et al. 2021). Some processes correlated with human-mediated habitat loss, like pollution, and even overfishing, threaten mangrove

biodiversity. Altogether, these factors decrease the habitat available to birds inhabiting mangrove forests within coastal lagoons (Polidoro et al. 2014). It has been reported that mangrove loss and fragmentation decrease water quality, as well as populations of crustaceans and fishes (Schaffelke et al. 2005; Tran and Fischer 2017). As a result, trophic resources exploited by waterbirds are compromised (Dobson et al. 2006; Şekercioğlu 2006). Furthermore, habitat loss can decrease the reproductive success of waterbirds by diminishing nesting area, exposing them to introduced predators, or promoting contact between humans and birds (Dolman and Sutherland 1995; Bradbury et al. 2000; Owens and Bennett 2000; Zuberogoitia et al. 2008). Empirical evidence showed that conversion into crop fields and human settlements reduces species richness of bird communities within mangrove forests (Mohd-Taib et al. 2020). Besides, habitat loss is driving a serious threat to bird diversity and their role in the trophic network and ecosystem processes within coastal lagoons and their mangrove forests (CONABIO 2008; Polidoro et al. 2010; Li et al. 2013; Branoff 2017; Mohd-Azlan et al. 2015; Bryan-Brown et al. 2020).

Because of the role of birds in the trophic network and their ecological function within mangrove forests, tracking changes in bird functional diversity is important as an indicator of biodiversity's response to anthropic disturbance (Dobrowolski et al. 1993; Ligeza and Smal 2003; Şekercioğlu 2006). However, most studies analyzing the effects of anthropization on mangrove bird communities are focused on a species abundance-based ecological approach. In addition, it's worth noting that many works analyze bird communities in Asia and Oceania (Li et al. 2013; Mohd-Azlan et al. 2015; Tran and Fischer 2017; Lee et al. 2020; Mohd-Taib et al. 2020; Stiepani et al. 2021), where the most extensive and diverse mangroves are found (Luther and Greenberg 2009). Notably, even though the study of anthropic influence on the relationship between birds and ecological function is a key conservation issue (Şekercioğlu 2006), the application of trait-based ecology to study mangrove bird communities is a barely explored topic (but see De Arruda-Almeida et al. 2018, 2019). Trait-based ecology is focused on assessing the changes in the representation of physiological, morphological, and behavioral characters associated with the success of organisms facing ecological pressure, as well as their effect on ecosystem regulation processes. So, the ecology approach based on functional traits improves our comprehension of biodiversity's response to human activity, as well as the ecological consequences that result from it (Violle et al. 2007; Díaz and Cabido 2001; Suding et al. 2008; Mouillot et al. 2013; Salgado-Negret and Paz 2016).

Here, using a functional trait-based approach to evaluate the effect of mangrove loss and habitat fragmentation

on waterbird communities, we studied bird communities in 23 coastal lagoons of the Mexican South Pacific coast, a territory that is severely threatened by human activity. In Mexico, papers addressing mangrove birds are mainly assessments of species richness without focusing on the effects of human disturbance on functional aspects (e.g., Bojorges-Baños 2011; Serrano et al. 2013; Ruiz Bruce Taylor et al. 2017), despite the severe fragmentation that this ecosystem has suffered as a consequence of human activities (CONABIO 2009). We use observational data to assess the hypothesis that lagoons with smaller natural habitat area, larger anthropic area (urban coverage, agriculture, and no vegetation), and higher mangrove fragmentation would have bird communities that are less taxonomically and functionally diverse.

Methods

Study area

This study included 23 coastal lagoons along the southern Mexican Pacific coast, from the extreme coordinates 20° 40' 18.33" N to the North and 16° 0' 11.23" N to the South. The study area includes the south of Jalisco, the coasts of Colima and Guerrero, and the middle point of Oaxaca (Fig. 1). This zone has a warm sub-humid climate, with summer rainfall and precipitation that ranges from 600 to 1500 mm yearly (García 1998; INEGI 2016). The original plant cover of coastal lagoons is mainly mangrove, predominantly *Rhizophora mangle*, *Laguncularia racemosa*, *Avicennia germinans*, and *Conocarpus erectus* (Rodríguez-Zúñiga et al. 2013).
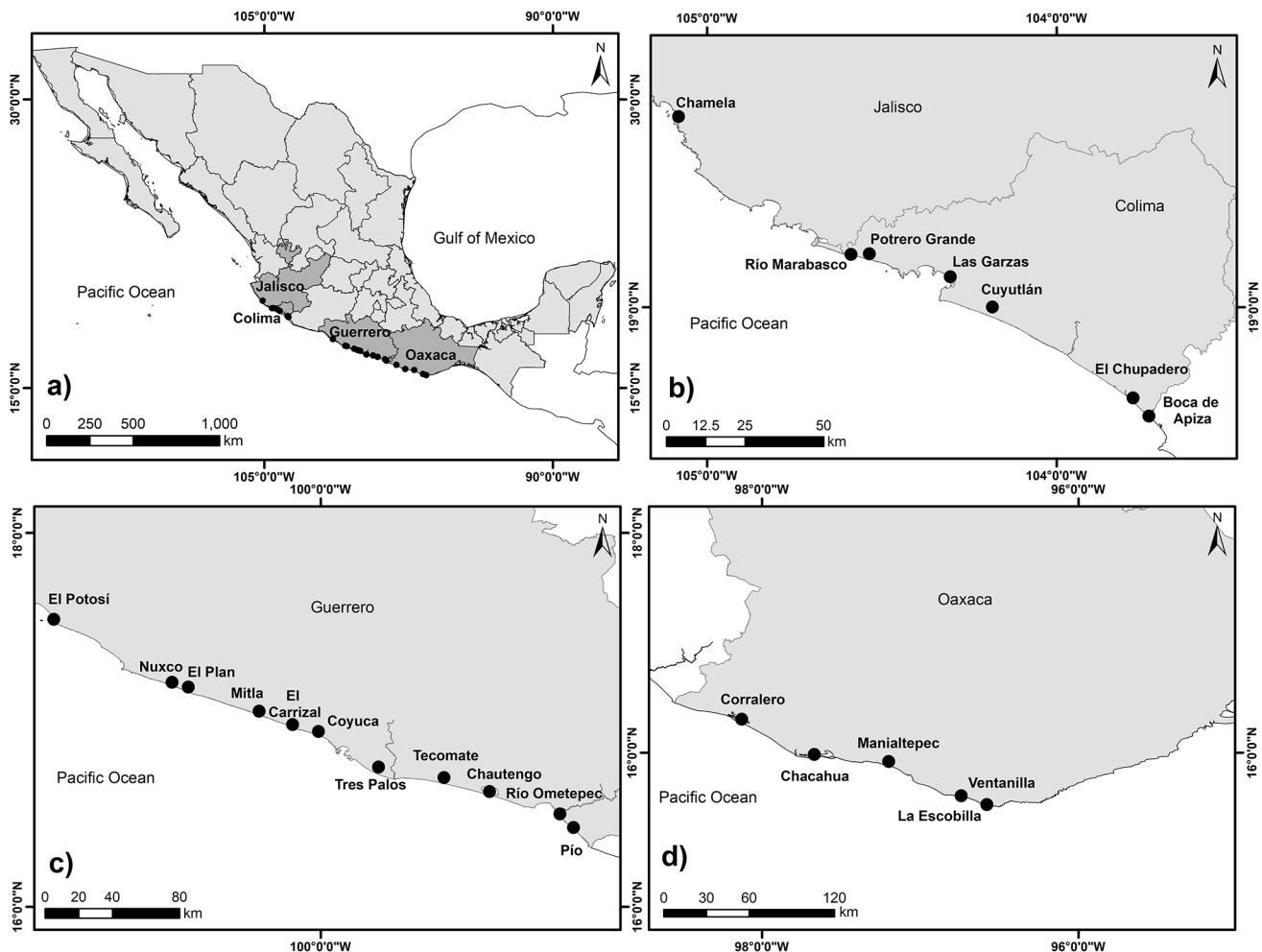

Fig. 1 Study area on the southern Pacific coast of Mexico. **(a)** Location of the states in Mexico (dark gray); **(b)** Location of the sites in the states Jalisco and Colima; **(c)** Guerrero; **(d)** Oaxaca

Bird community composition

Bird records were performed between June 2010 and June 2011, utilizing transects traveled for two to four hours after sunrise, considering birds' peak of diurnal activity, and depending on lagoon size. Transects were traveled at slow speed on a boat, approaching the borders of the lagoon and the central areas. When possible, foot transects of up to 1 km were surveyed, and all-terrain vehicles were used for longer distances. For the analyses, we considered only records of waterbirds (i.e., species that require the aquatic habitat to complete their biological cycle, *sensu* Ramírez-Bastida 2008). Given that the lagoons were visited only twice, it is not feasible to analyze the total of the species' catalogs using conventional methods, such as species accumulation curves or rarefaction analyses. Thus, in order to gauge the effectiveness of the censuses, we followed the proposal of Gómez de Silva and Medellín (2001), which suggests the absence of "omnipresent" taxa as an indicator of incomplete catalogs due to lack of sampling. Therefore, in this study, indicator species were considered common birds on the Mexican Pacific coast and had a frequency record greater than 75%: *Actitis macularius, Fregata magnificens, Nannopterum brasilianum, Ardea herodias, A. alba, Butorides virescens, Egretta thula, E. caerulea* and *E. tricolor*.

Supplementary material 1 shows the species list, according to the AOS taxonomic criteria (Chesser et al. 2021), records by site, and record frequency of waterbird communities in the study.

Bird functional traits

We used specialized databases (Wilman et al. 2014; de Magalhães 2021; Myers et al. 2021; Billerman et al. 2022) to construct a matrix of functional traits for all birds in the study. We considered three continuous life-history traits: body mass, clutch size, and life span. Furthermore, we considered categorical traits related to fulfillment of ecological requirements composed of eight categories related to diet type and eight categories for foraging habitat (Table 1). Finally, for cases in which we lacked specific data, we considered the species with the closest phylogenetic relationship for which information was available. The used trait values are available in Supplementary Material 2.

Habitat characterization

To generate a proxy of the relative cover per habitat type, we traced polygons of the 23 coastal lagoons in kml language using Google Earth Pro (www.earth.google.com),

Table 1 Description of the functional traits considered in this study. The numbers indicate the sources consulted to obtain the data: (1) Wilman et al. 2014; (2) Birds of the World (Billerman et al. 2022); (3) Human Ageing Genomic Resources (de Magalhães 2021); (4) The Animal Diversity Web (Myers et al. 2021)

Category	Trait	Trait description	Ecological significance	References
Life history	Body mass	Mass in grams.	Related to metabolic rate, foraging behavior, life span and territory size.	2,4
	Fecundity	Clutch size	Species with low fecundity may be vulnerable to environmental change.	2
	Life span	Species average lifespan	May be related to mating frequency or ability to recover after disturbances.	2,3,4
Diet	Invertebrates	Invertebrate diet percentage	Affects foraging behavior and flow of matter and energy, species with restricted diets may be vulnerable to environmental change.	1
	Endotherm vertebrates	Endotherm vertebrate diet percentage		
	Ectotherm vertebrates	Ectotherm vertebrate diet percentage		
	Fish	Fish diet percentage		
	Carrion	Scavenger diet percentage		
	Fruits	Frugivorous diet percentage		
	Seeds	Seed diet percentage		
	Plants	Plant diet percentage		
Foraging habitat	Underwater	Forages under the water surface	Affects resource use and flow of matter and energy, species with specific strategies may be vulnerable to environmental change.	1
	Water surface	Forages close to water surface		
	Ground	Forages on the ground		
	Understory	Forages in the understory stratum		
	Mid-high arboreal stratum	Forages in trees at medium or high levels		
	Canopy	Forages in tree canopies		
	Aerial	Forages in the air		
	Pelagic specialist	Forages while flying over the sea		

which were then translated into kmz format. The resolution of the satellite images used did not allow the use of elevation over sea level data to define the area of each lagoon. Thus, we included the adjacent habitat to each lagoon based on the available satellite imaging, aiming to encompass the terrain directly associated with the wetland area. Considering the 23 sites, we included the adjacent habitat up to 693.12 m (+/- 841.75 standard deviation) from the edge of the water cover. Due to the required spatial analyses, we converted the polygons into spatial data archives compatible with ArcGIS (Environmental Systems Research Institute 2015). The resulting polygons were intersected with the land use and vegetation cover in Mexico (Series VI: land use and vegetation, INEGI 2016) using Lambert's conformal conic projection. After the intersection mentioned above, land use categories were simplified into the following categories: (1) water, (2) urban area, (3) agriculture, (4) mangrove, (5) deciduous forest, (6) semideciduous forest, (7) aquatic vegetation, and (8) no vegetation. This step was necessary to simplify data management by reducing vegetation groups, which can be redundant in this kind of analysis. We quantified the area of each lagoon and the area of each type of cover, both in km^2. Using those data, we calculated the area representing natural habitat (mangrove + deciduous forest + semideciduous forest + aquatic vegetation) and the area of anthropized habitat (urban area + agriculture + no vegetation). We used the Shannon-Wiener diversity index (Shannon 1948) as a proxy of habitat fragmentation, which we defined in accordance with Franklin et al. (2002), as a discontinuity in the spatial distribution of resources in such way that it affects species' survival, reproduction, and habitat occupancy. This index reflects the heterogeneity of a data set depending on the number of current categories (here, land use types) and their relative abundance (area in km^2). When the abundance differs greatly among the categories within the data set, the index generates low diversity values. Meanwhile, similar relative abundance among categories results in high diversity values (Shannon 1948). Lagoons with higher habitat fragmentation will have more cover types, with similar areas among them, such that higher habitat fragmentation will result in high Shannon diversity values. As support for this premise, a simple linear regression showed that the number of polygons in each lagoon showed a positive correlation with the estimated Shannon index value ($r = 0.69$, $P < 0.001$). To calculate the index, we did not include the water cover since it represents an area that birds do not utilize for perching, resting, or nesting.

Estimation of biodiversity indicators

We used the recorded species richness value as an approximation of the taxonomic dimension of the bird diversity. To evaluate the representation of the functional dimension of biodiversity, we calculated the functional richness index, Fric (Villéger et al. 2007). This index measures the functional space occupied by the traits represented in a community (Mason et al. 2005; Villéger et al. 2007). High Fric values imply more ecologically resilient and complex communities (Lozanovska et al. 2018; Feng et al. 2020). There is evidence that anthropization causes functional diversity linked to life-history traits to decrease, while functional diversity linked to ecological requirement traits increases (Vázquez-Reyes et al. 2022). Hence, in this study, we calculated the Fric index independently, first considering each trait set (life-history traits and ecological requirement traits) and then using the complete trait set. In order to obtain the Fric value, we calculated the distance between every possible pair of species within the data matrix utilizing Gower distance. With the resulting distance matrix, we calculated a principal coordinate analysis (PCoA). We used the first axes of the PCoA to calculate Fric (Si et al. 2016). These estimates were made with the FD package (Laliberté and Legendre 2010) in RStudio (RStudio Team 2021).

To determine the relationship between bird diversity in coastal lagoons and habitat characteristics, we calculated generalized linear models. The predictive variables for the models were: area of the land use cover categories (water, urban area, agriculture, mangrove, deciduous forest, semideciduous forest, aquatic vegetation, and surface with no vegetation; determined using GIS), total polygon area (in km^2), and forest habitat fragmentation (Shannon diversity). As response variables, we considered: sampled taxonomic richness and the three Fric values mentioned above. Data from all the variables were transformed ($\log 10 + 1$), and we utilized the lowest Akaike Information Criterion, AIC (Akaike 1974) value to determine which model best explained the behavior of the response variable (Burnham and Anderson 1998). We used JMP Pro 14 software (www.jpm.com) to construct the generalized linear models.

Results

Evaluation of species and functional richness

Taxonomic richness values ranged from 15 to 64 species, with a median of 31 species. The lagoons with the highest taxonomic richness were Cuyutlán (64 species), Tres Palos (47 species), and Boca de Apiza (47 species). Fric values varied from 3.236 to 14.082, with a median of 10.022. Cuyutlán (14.082) and Boca de Apiza (13.307) had the highest Fric values. The lagoons with the largest total area were Cuyutlán (148.7 km^2) and Tres Palos (138.6 km^2) were the lagoons with the largest total area. In contrast, Potrero

Table 2 Coastal lagoons on the Southern Pacific coast of Mexico considered in this study. We present environmental variables (total polygon area and habitat fragmentation), and response variables of waterbird communities (species richness and Fric)

State	Lagoon	Total polygon area (km^2)	Habitat fragmentation	Species richness	Fric
Jalisco	Chamela	0.60	0.29	27	6.43
Colima	Río Marabasco	13.65	0.76	17	8.50
Colima	Potrero Grande	5.77	0.88	15	3.24
Colima	Las Garzas	3.52	0.66	25	11.18
Colima	Cuyutlán	138.60	1.01	64	14.08
Colima	El Chupadero	17.10	0.50	24	11.18
Colima	Boca de Apiza	14.64	0.61	47	13.31
Guerrero	El Potosí	30.38	1.12	28	8.68
Guerrero	Nuxco	17.91	0.34	37	9.91
Guerrero	El Plan	54.72	0.70	32	12.91
Guerrero	Mitla	93.02	1.01	37	10.24
Guerrero	El Carrizal	40.28	1.06	17	10.14
Guerrero	Coyuca	62.32	0.92	29	10.07
Guerrero	Tres Palos	148.70	1.15	47	11.77
Guerrero	Tecomate	69.87	1.20	33	9.81
Guerrero	Chautengo	56.03	0.86	43	9.69
Guerrero	Río Ometepec	51.45	0.99	39	12.29
Guerrero	Pío	0.59	0.00	22	8.51
Oaxaca	Corralero	107.50	1.51	33	10.71
Oaxaca	Chacahua	71.84	1.45	30	9.57
Oaxaca	Manialtepec	30.82	0.72	29	10.84
Oaxaca	La Escobilla	0.54	0.00	21	6.72
Oaxaca	Ventanilla	1.98	0.01	28	10.71

Table 3 Generalized linear model results. Predictive variables of the full model: water, urban area, agriculture, mangrove, deciduous forest, semi-deciduous forest, aquatic vegetation, no vegetation, total polygon area (km^2), habitat fragmentation

Response variable	Model predictor variables	AIC	*P* value
Species richness	Full	12.2433	**0.035**
	Total polygon area (km^2), Habitat fragmentation	-28.5851	**< 0.001**
Fric total	Full	0.5232	**0.0183**
	Total polygon area (km^2), Habitat fragmentation	-39.5598	**< 0.001**
Fric ecological requirements	Full	-17.4222	**< 0.001**
	Total polygon area (km^2), Habitat fragmentation	-51.1484	**< 0.0001**
Fric life history	Full	17.8646	0.1405
	Total polygon area (km^2), Habitat fragmentation	-20.6104	**0.016**

Grande, with one of the smallest areas (5.77 km^2), had the lowest values for both taxonomic (15 species) and functional richness (3.236) (Table 2).

Generalized linear models

Models including every habitat cover as predictive variables were all significant, except for the one using life-history traits Fric as the response variable. In all four models, the predictive variables total polygon area and habitat fragmentation, or either, were significant. After readjusting the generalized linear models and contemplating a more reduced model using only total polygon area and habitat fragmentation as environmental variables, we obtained significant models with AIC values expressing better fitness (Table 3). In each of these, the effect of total polygon area was positive and significant. In contrast, the effect of habitat fragmentation on the response variables was negative (Table 4).

Discussion

Consistent with our hypothesis, our results suggest that waterbird taxonomic and functional diversities increased with total polygon area but diminished in response to forest habitat fragmentation.

Generalized linear model results indicated that bird communities' taxonomic and functional diversities increase in larger coastal lagoons. Several studies within Neotropical and European wetlands have documented that available habitat area represents a dominant factor in taxonomic richness increases for waterbirds (de Arruda-Almeida et al.

Table 4 Best fit generalized linear model results. Predictor variables: total polygon area (km^2), habitat fragmentation

Response variable	AIC	*P* value	Model parameters	Effect tests	Parameter estimates
Species richness					
	-28.5851	**0.0005**	Intercept		1.333
			Total area (km^2)	**< 0.001**	**0.287**
			Habitat fragmentation	**0.011**	**-1.003**
Fric total	-37.3252	**0.0008**	Intercept		0.924
			Total area (km^2)	**< 0.001**	**0.238**
			Habitat fragmentation	**0.0049**	**-0.934**
Fric ecological requirements	-50.6149	**< 0.0001**	Intercept		0.905
			Total area (km^2)	**< 0.0001**	**0.204**
			Habitat fragmentation	**< 0.01**	**-0.671**
Fric life history	-20.6104	**0.016**	Intercept		0.899
			Total area (km^2)	**0.0044**	**0.248**
			Habitat fragmentation	**0.021**	**-1.063**

2018; Sebastián-González and Green 2013). This trend is consistent with the theoretical relationship between area size and taxonomic richness (MacArthur and Wilson 1963). Given that a larger size involves a larger quantity and diversity of niches and resources, a greater diversity of species could potentially exploit them (Weisberg et al. 2014; Karadimou et al. 2016; Oliveira et al. 2020). The resource abundance resulting from a larger-sized area likewise explains the positive effect of area size on Fric (Weisberg et al. 2014; Karadimou et al. 2016; Lee and Carroll 2018; Oliveira et al. 2020). Nevertheless, although they respond similarly to area size, the taxonomic and functional aspects of diversity are not mutually related in the same way, particularly in disturbed environments (Mayfield et al. 2010; Biswas and Mallik 2011).

It is worth mentioning that the generalized linear models did not completely explain the variation in the data. This could be because, on a local scale, the specific characteristics of each coastal lagoon determine response patterns that decrease the efficiency of the model. For example, Boca de Apiza and Chacahua had the highest taxonomic and functional diversity values, respectively, yet they are not the lagoons with the highest mangrove cover. This may be because of elements that locally draw higher diversity in bird communities, such as better food availability (Ramírez-Bastida et al. 2018). For example, the structural complexity of mangroves benefits aquatic organisms such as fish and crustaceans, which constitute part of the diet of several waterbirds (Robertson and Duke 1987; Nagelkerken et al. 2008; Buelow and Sheaves 2015). However, these elements were not evaluated in the current study.

In addition, model results showed that, in accordance with our hypothesis, fragmentation of the forest habitat surrounding coastal lagoons negatively affected taxonomic and functional species richness. Because fragmentation negatively affects habitat in terms of continuity and structural and floristic diversity, birds that take advantage of the

mangrove structure and associated aquatic vegetation will be negatively affected (Haddad et al. 2015). The loss of mangrove structural complexity will therefore affect several species, including birds that nest in the arboreal stratum of mangroves, such as frigatebirds, cormorants, and herons, in addition to harming the crustacean and fish populations on which they feed (Robertson and Duke 1987; Pfister et al. 2006; Nagelkerken 2008; McFadden et al. 2016; Tran and Fischer 2017). The mangrove forests surrounding the lagoons are associated to the adjacent land vegetation, which consists mostly of deciduous forest. This represents a continuous habitat with resources that waterbird communities can exploit. In fragmentation scenarios, habitat patches are progressively further isolated, which favors the invasion of foreign species which inhabit the matrix surrounding mangroves (Fahrig 2003; Mohd-Azlan and Lawes 2011). Species movement among fragments is also limited, restricting birds' benefits to habitat connectivity (Buelow and Sheaves 2015; Haddad et al. 2015). On the other hand, the diversity of birds linked to emergent aquatic vegetation associated with mangroves, such as ducks and rails, is directly related to the composition and diversity of plant species (Mohd-Azlan et al. 2015; Bannor and Kiviat 2020; Eitniear et al. 2020; Gauthier 2020; West and Hess 2020). Corralero, Chacahua, Tecomate, Tres Palos, and El Potosí are the five lagoons with the highest habitat fragmentation index in this study, and excluding Tres Palos, they all have intermediate taxonomic richness and Fric values (Table 2). Bird communities in these sites could therefore face a decline which would increase in response to the degree of fragmentation.

The erosion of taxonomic richness and Fric of bird communities in coastal lagoons have potential consequences on the trophic network (Cardinale et al. 2006). The families Charadriidae and Scolopacidae contribute to population control of mollusks and crustaceans (Robert and McNeil 1989), while herons (Ardeidae) feed on many species of invertebrates and fish (Miranda and Collazo 1997). These

groups are well represented in sites with high fragmentation (Chacahua, Tecomate, Tres Palos) and low fragmentation (Ventanilla, La Escobilla), indicating they were not affected by it. On the other hand, ducks (Anatidae) and rails (Rallidae) feed on aquatic plants and contribute to seed dispersal (Şekercioğlu 2006; Green et al. 2016). In this study, these groups had a larger representation in sites with intermediate to low levels of fragmentation (Mitla, Chautengo, La Escobilla) and thus more extensive aquatic vegetation cover. The decline of these taxa could have consequences for the renewal processes of the natural cover of emergent aquatic vegetation (Green et al. 2016). Additionally, birds' role in mineral transport will be lost, leading to impoverishment of water quality and reduced soil nutrients for plants (Vanni 2002; Ligeza and Smal 2003; Şekercioğlu 2006). Given the importance of wetlands as links between land and aquatic habitats and as a hotspot for bird species, their disappearance would represent a severe loss of biodiversity in the region (Li et al. 2021). It is notable that life history traits' functional richness increases with total habitat area but diminishes in response to habitat fragmentation. This pattern could suggest that, besides the loss of several ecological interactions, fragmentation could drive a selective pressure against several life history traits, as has been well documented (Mckinney and Lockwood 1999; Cooke et al. 2019), or even, acting as a filter against birds with specific ecological strategies (Vázquez-Reyes et al. 2022). To answer these issues, it will be necessary to develop detailed assessments of functional traits covariation shifts in response to habitat loss and fragmentation.

Conclusions

Our results suggest that preserving a larger extension of mangrove cover favors the increase of taxonomic and functional diversity of waterbird communities. We also show that stopping and even reversing mangrove fragmentation processes would favor waterbird taxonomical and functional diversity. The conservation of mangrove biodiversity could in turn benefit ecosystem functioning and regulation processes in coastal lagoons. Unfortunately, human activities are involved in the erosion of diversity, compromising ecosystem functioning in coastal lagoons (Thébault and Loreau 2006; Rodríguez-Zúñiga et al. 2013; Mohd-Taib et al. 2020). This problem has been approached from the environmental legal framework since the protection of mangrove coverage in Mexico (CONABIO 2009); however, negative human impact surpasses the protection of mangrove cover, posing a challenge for the conservation of mangroves, their biodiversity and ecosystem functioning (Velázquez-Salazar et al. 2021).

Declarations

Competing interests The authors declare that there is no conflict of interest.

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