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Correlation between abiotic variables and diversity of birds

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Abstract: The present study was conducted at Saco da Fazenda Estuary, state of Santa Catarina, Brazil. The relationship between the abiotic variables and the diversity of birds at that site was evaluated over a period of ten months (July 2006 – April 2007). The diversity and equitability indices showed similar fluctuations over the study period, with significant differences between sampling months ($F_{11\text{-}132}$ =17,061, p<0.001) and ($F_{11\text{-}132}$= 7,789, p< 0.001). These values were affected by the lower average scores between October and December, in contrast with the higher ones recorded in August, September and July, probably influenced by the dominance of *P. brasilianus* and *L. dominicanus*. The diversity and evenness indices presented similar oscillations over the study months, with significant differences between the sampling months ($F_{11\text{-}132}$=17,061; p<0.001) and ($F_{11\text{-}132}$=7,789; p<0.001) respectively. The Spearman's correlation analysis revealed a significant negative correlation (r = - 0.317, n= 135, p<0.05) between diversity of the aquatic birds and air temperature, but no correlation with wind speed or intensity or height of the tides. In relation to winds, the highest numbers of individuals were recorded in the easterly and east-northeasterly directions and the smallest for the southeasterly winds.

Key words: avifauna, equitability, fluctuations, estuary, Santa Catarina, Brazil.

Resumo: Correlações entre variáveis ambientais e diversidade de aves. O presente estudo foi conduzido no estuário do Saco da Fazenda durante o período de Julho de 2006 a Abril de 2007, totalizando nove meses de amostragem. O objetivo foi avaliar a correlação entre as variáveis abióticas e a diversidade das aves. Neste trabalho os índices de diversidade e equitabilidade apresentaram flutuações semelhantes ao longo do período abrangido pelo estudo, com diferenças significativas entre os meses de amostragem (F11-132 = 17,061, p <0,001) e (F11-132 = 7,789, p <0,001). Estes valores foram afetados pelos valores médios mais baixos entre outubro e dezembro, em contraste com os registrados em agosto, setembro e julho, provavelmente influenciada pela dominância de *P. brasilianus* e *L. dominicanus*. Os índices de diversidade e uniformidade apresentaram oscilações semelhantes ao longo dos meses de estudo, com diferenças significativas entre os meses de amostragem (F11-132 = 17,061; p <0,001) e (F11-132 = 7,789; p <0,001) respectivamente. A análise de correlação de Spearman revelou a existência de uma correlação negativa significativa (r = - 0,317, n = 135, p <0,05) entre a diversidade de aves aquáticas e da temperatura do ar, mas nenhuma correlação foi observada com a velocidade do vento, intensidade ou altura das marés. Em relação aos ventos o maior número de indivíduos foram registrados nas direções leste e leste-nordeste, e o menor para os

ventos de sudeste.

Palavras chave: avifauna, equitabilidade, flutuações, estuário, Santa Catarina, Brasil

Introduction

Estuaries are bodies of calm water that are subjected to a tidal regimen and are open to the sea. As a consequence, temperature and salinity are variable in them, and there is intense exchange of organisms, organic material and nutrients between land and open sea (Odum 1988, Ramaiah *et al*. 1995, Araújo *et al*. 2006).

Due to the high levels of productivity resulting from the mixture of nutrients provided by coastal discharge in the ocean, estuaries are important to various animal species (Barbieri *et al.* 2013). Their physico-chemical characteristics provide abundant nourishment, a nursery and recruiting grounds (Branco *et al.* 2004), where fish and crustaceans of commercial value migrate from the sea to complete their development (Dayton *et al.* 2005).

Birds generally respond to the environmental dynamics and stochastic processes of the systems (Dubowy 1996). Their selection of habitat and decisions are related to foraging seek to optimize temporal events (Barbieri 2009, Ebert *el al*. 2014). The use of the feeding places and the environmental conditions can affect the foraging behavior and the ecology of species – as also their interspecific interactions with potential competitors and predators (Olmos & Silva e Silva 2003). In periods of limited resources this ecological interactions can be more critical (Barbieri & Delchiaro 2009), limiting the abundance of species. Tide regimen and amplitude can affect the availability of food and the abundance of birds in estuarine environments (Mathers & Montgomery 1996, Tiedemann & Nehls 1997). Diversity indices are frequently used in community ecology studies, in an attempt to combine the species richness and relative abundance of individuals among species (Townsend *et al.* 2006).

Brazil has the third greatest diversity of birds in the world (Sick 1997), and many estuaries (Branco *et al*. 2011, Berdardino et al., 2015). Despite this, its aquatic birds and the relationship between aquatic bird diversity and environmental factors such as temperature, wind speed and tidal regimen are still poorly known (Branco 2007, Barbieri & Paes 2008). These environmental factors have been used to evaluate seasonal fluctuations in bird communities of the estuaries of Paraíba (Araujo *et al*. 2006), humid areas and the mangrove forests of Santos-Cubatão (Olmos & Silva e Silva, 2001), the mangrove forests of Paranaguá Bay (Mestre *et al*. 2007) and the coast of Santa Catarina (Branco *et al*. 2004, Branco 2007).

This contribution aims to ascertain the diversity of birds in the estuary of the Itajaí-Açu River, and how it correlates with environmental factors. Two questions have been asked: (1) What is the daily, monthly and seasonal diversity of bird species occurring in this estuary? and (2) What is the correlation between the abundance of birds and the environmental variables temperature, wind speed and height of the tides?

Material and methods

Study Area: Located between the coordinates 26ª 53’33’’ - 26ª 55’06’’ S and 48ª 38’30’’ - 48ª 39’14’’ W, the estuary of the Rio Itajaí-Açu - Saco da Fazenda (Itajaí municipality, Santa Catarina, Brazil) may be characterized as an environment modified by the construction of the sea-walls. These were constructed to contain the channel of the Itajaí-Açu river in 1982. The estuary has a surface area of approximately 63 hectares and is triangular (Schettini 2008) (Figure 1). It presents a low water replacement regimen, a substrate of silt and clay and a maximum depth of 2.0 m (with the exception of the navigation channels which link it to the river, which can reach a depth of up to 9 m), tidal amplitude of less than 1.4 m and average annual rainfall of 1250-1500 mm (Branco 2007, Branco *et al*. 2011).

Methodology: In order to monitor the aquatic birds of the Itajaí-Açu River- Saco da Fazenda River Estuary, fortnightly counts were carried out from a fixed point, from July 2006 to April 2007. All individuals seen on the containing sea-walls of the Itajaí-Açu river as well as those on the rocks at the center of the Saco da Fazenda, in periods of low-tide, were recorded (Figure 1).

Visual contact was aided by binoculars (10X-90X80), and the auditory perception of bird-calls (song and cries) (Branco 2000, 2007). Birds were counted at two-hour intervals, from 08:00 to 20:00h, during which species abundance was registered. In view of the fortnightly sampling plan, the average number of birds per month was adopted as the standard measurement of abundance (Branco 2000).

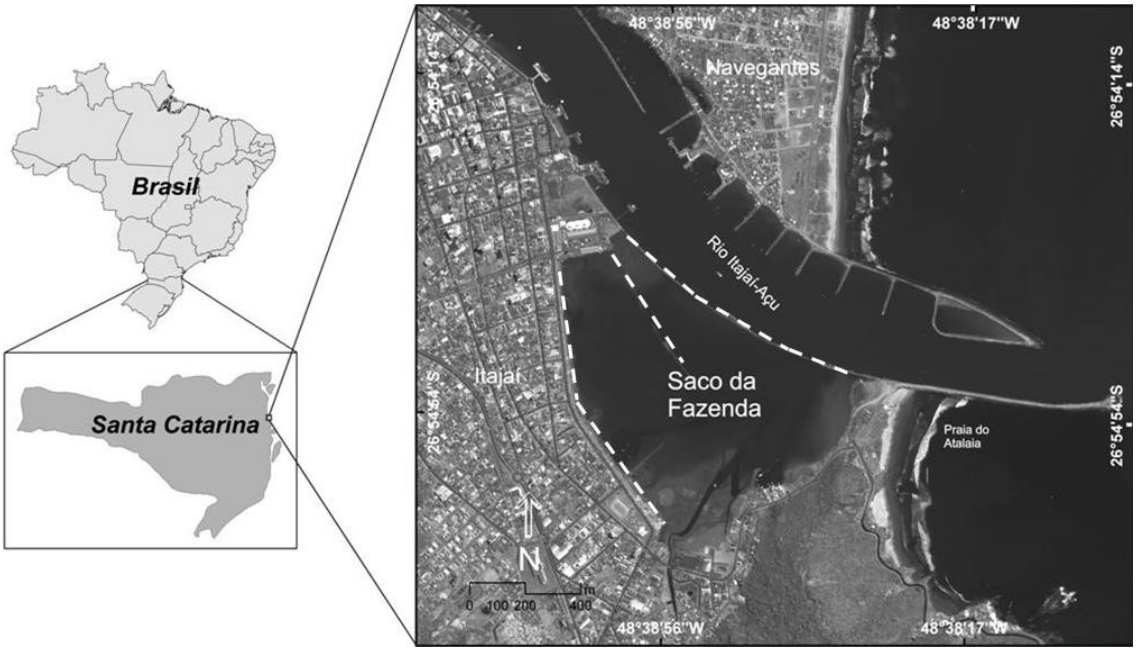

Figure 1. Map of the Rio Itajaí-Açu – Saco da Fazenda Estuary, municipality of Itajaí, SC. Broken lines indicate observation sites.

In this paper the scientific and popular names and the endangered status of birds follow the List of Brazilian Birds (15/01/2014), by the Brazilian Committee of Ornithological Registers (Comitê Brasileiro de Registros Ornitológicos - CBRO, 2014).

The abiotic parameters that interfere with bird abundance were, in each campaign, obtained from both public and private databases and were as follows: height of tides - Banco Nacional de Dados Oceanográficos (BNDO) and temperature of the air, wind speed and wind direction - Banco de Dados Climatológicos/Laboratório de Geoprocessamento e Sensoriamento Remoto - UNIVALI.

Data analysis: To assess the fluctuations in bird abundance, analyses were carried out on daily, monthly and seasonal data. Shannon's diversity (H') and Pielou's evenness (J') indices were calculated using values of average abundance obtained in terms of months, count intervals and seasons of the year, (Ludwing & Reynolds, 1988). Analysis of variance (ANOVA, Zar 1999) was applied to the diversity and evenness indices for the monthly variations that were tested for homogeneity of variance (Bartlett's test) and normality of distribution (Kolmorov-Smirnov's test). Where statistically significant differences were found, the contrast of the averages (Tuckey-Kramer's) test was applied to show which averages were significantly different. The correlation coefficients were determined between the diversity indices of aquatic birds and evenness and abiotic variables. The normality of the distribution of these data was tested by means of Shapiro and Wilk's test (Zar 1999). Since the distribution of the data was not normal, Spearman's correlation analysis (r_s) was applied, with a significance level of $p<0.05$ (Siegel, 1975). Data on wind direction were analyzed descriptively, and the quadrants of greatest frequency and their correlation with abundance were determined.

Results

A total of 29 species, 24 genera and 13 families were observed during 72 counts. Of the species recorded, 93.1% were considered resident species (Table. I). The three families with greatest diversity at the Saco da Fazenda contributed 65.5% of the total species. Ardeidae was represented by nine species, followed by the Laridae with six and the Charadriidae with four. However, two of the resident species, *Phalacrocorax brasilianus* and *Larus dominicanus* contributed with 43.3% and 26.2% of the total number of birds respectively (Table I).

Diversity and evenness indices presented similar oscillations over the study months (Fig. 2), with significant differences between the sampling months ($F_{11\text{-}132}=17{,}061$; $p<0.001$) and ($F_{11\text{-}132}=7{,}789$;$p<0.001$), influenced by the lower average values registered between the counts undertaken in

October and December, in contrast with the values obtained for August, September and July, probably influenced by the dominance of *P. brasilianus* and *L. dominicanus* in the Saco da Fazenda (Table I).

Table I. List of species and total number (N), average number (average N) and diversity and evenness of specimens in the collecting intervals of between 8:00 and 20:00h. Migratory status: resident species (R), seasonal visitor coming from the Northern Hemisphere (VN).

Families / Species/Origin **Collecting times**	08:00 – 10:00		10:00 – 12:00		12:00 – 14:00		14:00 – 16:00		16:00 – 18:00		18:00- 20:00	
	N	N average	N	N	N	N	N	N	N	N	N	N
Anatidae												
Amazonetta brasiliensis (R)	9	0.38	3	0.13	5	0.21	11	0.46	19	0.79	3	0.13
Podicipedidae												
Podilymbus podiceps (R)	-	-	-	-	-	-	-		1	0.04	-	-
Phalacrocoracidae												
Phalacrocorax brasilianus (R)	1880	78.33	2580	107.50	2624	109.33	2569	107.04	2174	90.58	476	19.83
Fregatidae												
Fregata magnificensis (R)	4	0.17	-	-	2	0.08	-	-	1	0.04	-	-
Ardeidae												
Nycticorax nycticorax (R)	-	-	-	-	-	-	-	-	2	0.08	-	-
Nyctanassa violacea (R)	9	0.38	-	-	2	0.08	1	0.04	1	0.04	1	0.04
Butorides striata (R)	4	0.17	-	-	1	0.04	4	0.17	2	0.08	1	0.04
Bubulcus ibis (R)	-	-	-	-	-	-	18	0.75	46	1.92	-	-
Ardea cocoi (R)	6	0.25	3	0.13	7	0.29	2	0.08	3	0.13	-	-
Ardea alba (R)	45	1.88	50	2.08	44	1.83	54	2.25	49	2.04	9	0.38
Syrigma sibilatrix (R)	-	-	-	-	2	0.08	-	-	-	-	-	-
Egretta thula (R)	51	2.13	40	1.67	34	1.42	71	2.96	62	2.58	39	1.63
Egretta caerulea (R)	22	0.92	20	0.83	18	0.75	14	0.58	13	0.54	3	0.13
Threskiornithidae												
Platalea ajaja (R)	6	0.25	1	0.04	-	-	-	-	-	-	-	-
Rallidae												
Gallinula chloropus (R)	72	3.00	76	3.17	59	2.46	46	1.92	45	1.88	26	1.08
Charadriidae												
Vanellus chilensis (R)	203	8.46	192	8.00	259	10.79	177	7.38	154	6.42	57	2.38
Pluvialis dominica (VN)	1	0.04	4	0.17	-	-	1	0.04	-	-	-	-
Charadrius semipalmatus (VN)	85	3.54	25	1.04	32	1.33	-	-	6	0.25	14	0.58
Charadrius collaris (R)	4	0.17	14	0.58	-	-	-	-	-	-	-	-
Haematopodidae												
Haematopus palliatus (R)	78	3.25	97	4.04	9	0.38	71	2.96	8	0.33	2	0.08
Recurvirostridae												
Himantopus melanurus (R)	297	12.38	184	7.67	176	7.33	190	7.92	148	6.17	83	3.46
Laridae												
Larus dominicanus (R)	930	38.75	1203	50.13	1781	74.21	1879	78.29	1076	44.83	577	24.04
Sternula superciliaris (R)	-	-	1	0.04	1	0.04	1	0.04	9	0.38	-	-
Sterna hirundinacea (R)	132	5.50	298	12.42	351	14.63	535	22.29	257	10.71	18	0.75
Sterna trudeaui (R)	135	5.63	185	7.71	151	6.29	116	4.83	82	3.42	13	0.54
Thalasseus sandvicensis (R)	119	4.96	157	6.54	236	9.83	327	13.63	126	5.25	11	0.46
Thalasseus maximus (R)	53	2.21	92	3.83	88	3.67	66	2.75	33	1.38	3	0.13
Rynchopidae												
Rynchops niger (R)	423	17.63	309	12.88	287	11.96	50	2.08	275	11.46	16	0.67
Alcedinidae												
Ceryle torquata (R)	-	-	1	0.04	-	-	-	-	-	-	-	-
Total	**4568**	**190.33**	**5535**	**230.63**	**6169**	**257.04**	**6203**	**258.46**	**4592**	**191.33**	**1352**	**56.33**
Total species	23		22		22		21		24		18	
Diversity IndexH'	1.9596		1,7981		1,7277		1,6949		1,7408		1,5494	
Evenness Index J	0,6249		0,5817		0,5589		0,5567		0,5477		0,5360	

The daily distribution pattern of the species in the ecosystem showed that the greatest average diversity values were registered at the beginning of the morning and the lowest at the end of the afternoon, whereas the evenness presented the opposite tendency, with relatively fewer birds distributed evenly at the end of the afternoon (Fig. 3). Diversity standard deviation were wider at the

end of afternoon, indicated oscillations on avifauna over the day. Equitability standard deviation were high at all monitored times, denoting variations in this metric in study area. These standard deviation results probably were related with significant differences observed in community metrics among daily times.

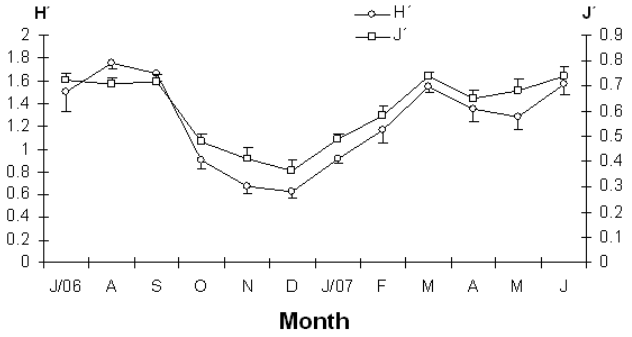

Figure 2. Average monthly variations of Shannon's (H') diversity index and Pielou's (J´) evenness index, in the Rio Itajaí-Açu - Saco da Fazenda Estuary, Itajai municipality, SC.

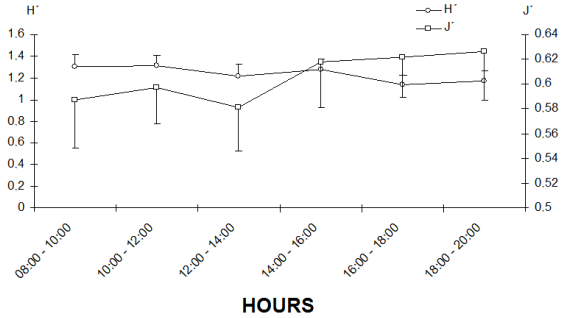

Figure 3. Average daily variations and standard deviation of Shannon's (H') diversity index and Pielou's (J´) evenness index in the Itajaí-Açu River - Saco da Fazenda Estuary, municipality of Itajai, SC.

The analysis of the pattern of variation of the H' and J' indices among the seasons revealed that the winter is responsible for the greatest diversity (1.647) and evenness (0.717), coinciding with the months of lower average abundances of aquatic birds in the studied ecosystem (Fig. 4 and 2), followed by an abrupt fall in the Spring and a gradual increase until the autumn.

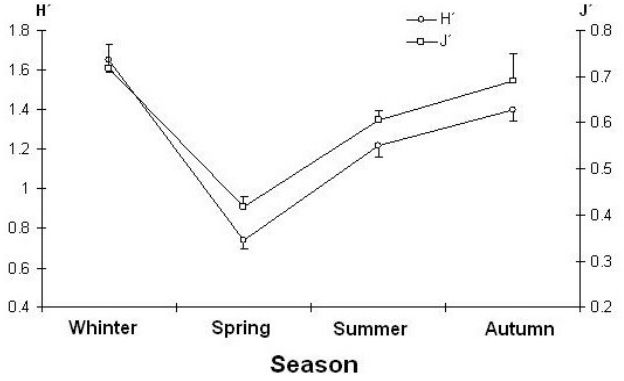

Figure 4. Average seasonal variations of Shannon's (H') diversity index and Pielou's (J') evenness index, in the Itajaí-Açu River- Saco da Fazenda Estuary, Itajai municipality, SC.

Monthly values of Shannon's diversity index (H') varied between 2.16 and 0.77, presenting daily and seasonal fluctuations. Highest values occurred in the winter and the lowest in the summer and spring. Evenness presented daily and seasonal fluctuations, the highest values occurring during the autumn (0.69) and the lowest in the summer (0.47), indicating a less uniform distribution of individuals in the summer. Spearman's correlation revealed a significant negative correlation ($r = -0.317$, $n= 135$, $p<0.05$) between the diversity of aquatic birds and air temperature, but no statistical significant correlation ($p > 0.5$) was observed with wind speed or the intensity or height of the tides (Tab. II).

Table II. Spearman's correlation(r; $p<0.05$) between the diversity of aquatic birds and environmental variables. * = significant p= 0.05; ns = no statistically significant correlation

Diversity	Air temperature	Wind		Height of tide
		Speed	Intensity	
Coefficient de Spearman's	-0.317	-0.051	-0.049	-0.132
Bicaudal value of p	0.0001	0.560	0.570	0.126
Significance	*	ns	Ns	Ns

Wind gusts were registered coming from 13 directions during the period of the study, those of greatest frequency coming from the East-northeast (ENE; n=19), East (E; n=18), Southwest (SW; n=18) and West-southwest (WSW; n=17) (Fig. 5).

Bird abundances in each quadrant were

relatively different, the greatest number of individuals being registered in the directions "E" and "ENE", and the lowest abundance were registered from the Southeast (SE) (Fig. 6). The ANOVA applied to check differences in diversity among most frequent wind directions indicated significant differences ($p<0.05$), being "E" averages significantly different from the "SW" and "WSW".

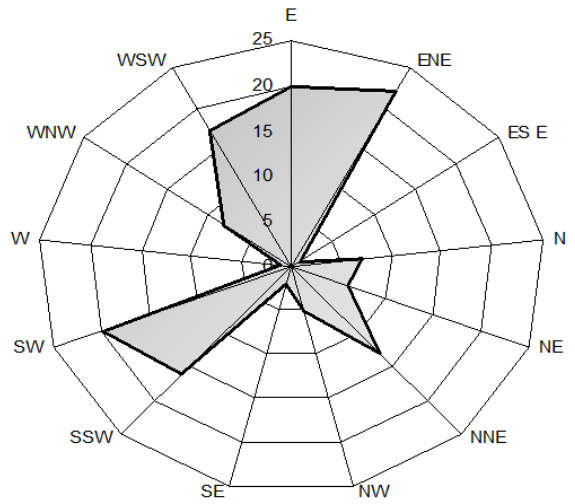

Figure 5. Polar representation of the number of occurrences of winds from the various quadrants on the Itajaí-Açu River - Saco da Fazenda Estuary, municipality of Itajai, SC.

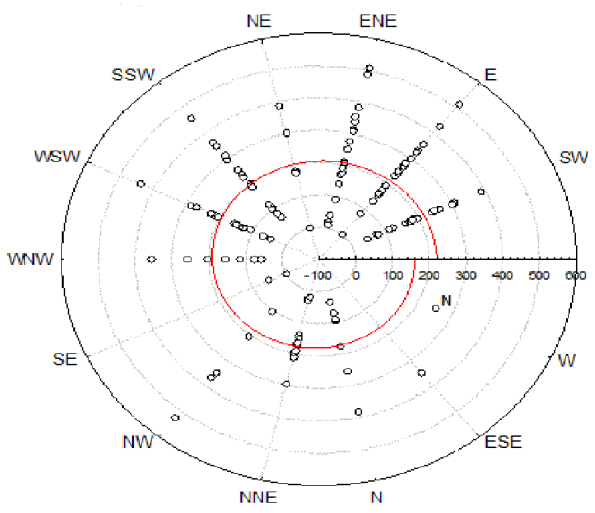

Figure 6. Polar representation of the abundance of birds in the various wind quadrants registered over the study period, in the Itajaí-Açu River - Saco da Fazenda Estuary, municipality of Itajai, SC.

Discussion

Even though South American estuarine environments are very rich in species, bird diversity has not been well studied (Araujo *et al*. 2006). In Argentina, Yorio *et al.* (1994) studied the diversity of marine birds in Patagonia and Gatto *et al.* (2005) studied the Golfo de San Jorge. In Brazil, Branco (2000, 2007) assessed the diversity of the aquatic bird fauna of Saco da Fazenda in Santa Catarina. In the coast of São Paulo, Barbieri and Paes (2008) evaluated the diversity of birds in the Cananéia Estuary and Olmos & Silva e Silva (2001) in Cubatão. However, none of these studies tried to correlate environmental variables such as temperature, wind speed or height of the tides with diversity.

The direct relationship between the distribution of sea, coastal and wading birds and the environmental variables studied in this article is usually expected to affect prey abundance, which is determined by various oceanographic processes (Bakun 1996, Weimerskirch 2001, Ebert *et al.* 2014). In environments that are subjected to marine influence, heterospecific groups of birds are formed when birds of different species have to share resting and/or nesting places. This can turn a considerable advantage of all involved, since the entire group as a whole is more protected. Coastal birds are considered visiting species, and are important surface predators of soft-bottom intertidal fauna (Knox 2001). Try to describe the complex structures of these communities by means a single attribute such as richness or diversity may flaw due to a loss of information (Townsend *et al*. 2006). A more complete picture may be provided by, for example, in a diagram of the relative abundance of species. The seasonal fluctuation pattern reveals that greater abundances are associated with the spring and summer periods. This appears to be related to certain events in the life-cycle of species or to other factors such as reduction in the temperature of the water-surface during the autumn and winter (Branco 2002). Similar patterns were described by Yorio *et al.* (1994) for reproductive colonies of *P. brasilianis*at Punta León, Argentina, and for populations of the same species in the Saco da Fazenda Estuary (Ebert *et al.* 2014.).

The weak but significant negative correlation between diversity and air temperature indicates that, when temperatures are high, species diversity is lower. This confirms the hypothesis that variations in air temperature, and consequently in water temperature, influences bird diversity at Saco da Fazenda Estuary. However, even though birds were observed in the field, the effects of the tide and wind speed, and intensity of foraging activity did not have any statistical influence on the waterbirds in the study area. Average values registered between the

counts undertaken in October and December, in contrast with those values from August, September and July, probably influenced by the dominance of *P. brasilianus* and *L. dominicanus* at Saco da Fazenda.

Various studies have already shown how the number of estuarine birds may vary during the tidal cyle (Nehls & Tiedemann 1993, Mathers & Montgomery 1996, Scheiffarth & Nehls 1996, Tiedemann & Nehls 1997, Zanin *et al.* 2009, Numao & Barbieri 2011). However, our results for Saco da Fazenda differed from those of other studies, demonstrating that the variation in the numbers of birds was not related with tidal cycle. Estuaries that have uniform topography have marked variations in the respective area available for foraging, whereas those with more irregular topography may present adequate areas for foraging during various tidal stages. The variations in the areas available for the feeding of aquatic birds are also clearly marked in the places where the amplitude of the astronomical tide is greater, as is the case of São Luiz, state of Maranhão. In Saco da Fazenda, tide amplitude is small, varying by a maximum of 1.20 m. The small variation in the feeding area available is may be the reason for the lack of correlation between the number of birds and the amplitude of the tides.

Silva Rodríguez *et al.* (2005), studying the ecology of the marine birds that use the littoral of Buenos Aires as a wintering area, declared that climatic variables had some influence on the diet of *Sterna hirundo*. According to these authors, the wind gust has a significant effect on the proportion of fish and insects ingested, as also among marine and estuarine fish. Also, these authors assessed the importance of abiotic variables on *Rynchops niger,* and affirmed that increased ocean agitation caused by strong winds tend to drive individuals of this species to more sheltered estuarine zones. Their study also found a relationship between oscillations in tide height and abundance of *Rynchops niger* individuals, and more intense feeding activity was observed during low tide periods.

Schreiber & Chovan (1986) provided a clear example of the way by which wind influences the activity of *Fregata minor* and *Sula sula*. In their studies demonstrated that the number of birds at rest was greatly affected by the time of the day, seasonality, and mainly by the wind-speed. The number of birds at rest was higher when wind-speed decreased because the energy cost of flying increases in periods of calm weather since birds cannot take advantage of the wind to save energy.

No close relationship was registered in our study between wind and bird diversity. Possibly, differences in foraging at Saco da Fazenda from the type of foraging studied by Schreiber & Chovan (1986) was related with our results of no relationships. The majority of the species recorded in our study feed in the mud, while sea-birds such as the *Sterna sp.* and *Thalasseus sp.* use low-lying areas to rest. Further, in this study, intertidal areas constitute a region where these species maintain their plumage and rest. Thus, further studies should be undertaken in this region, focusing especially on other environmental variables, as wind-speed and also over the abundance of the specific populations and its relations with abiotic variables at ecosystem studied.

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