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COMMUNITY STRUCTURE AND SEASONAL ANALYSIS OF WATERBIRDS IN LENTIC AQUATIC ECOSYSTEMS IN THE MUNICIPALITY OF PETROLINA - PERNAMBUCO

ESTRUTURA DA COMUNIDADE E ANÁLISE SAZONAL DE AVES AQUÁTICAS EM ECOSSISTEMAS AQUÁTICOS LÊNTICOS NO MUNICÍPIO DE PETROLINA - PERNAMBUCO

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ABSTRACT

In order to identify patterns of spatial and temporal occurrences of waterbirds from lentic and hybrid ecosystems, four collection sites were defined, one in the urban area and three in the rural area of the municipality of Petrolina-PE. Observations were made throughout one year and seasonal variation was investigated using circular analyses. Lagoon 2 and the reservoir showed higher species richness and diversity. Regarding occurrence, 7 species were identified as seasonal throughout the study area, 23 showed seasonality in at least one of the ecosystems studied, and another 16 were classified as resident. The formation of peaks of higher clustering for waterfowl communities highlights the use of these lakes and reservoirs as biological corridors, or aquatic stepping stones, highlighting the importance of these ecosystems for the biodiversity of dependent and semi-dependent aquatic avifauna. This information can contribute to the understanding of ecosystem dynamics in lacustrine and hybrid environments of the semi-arid region. This information is useful for understanding these ecological processes, for environmental and health diagnosis, and for investigating potential new bioindicators of these environments.
Keywords: Waterfowl; Avian communities; Circular Statistics; Seasonality; Caatinga.

RESUMO

Com o objetivo de identificar padrões de ocorrência espacial e temporal de aves aquáticas em ecossistemas lênticos e híbridos, foram definidos quatro locais de coleta, um na área urbana e três na área rural do município de Petrolina-PE. As observações foram realizadas ao longo de um ano e a variação sazonal foi investigada por meio de análises circulares. A Lagoa 2 e o reservatório apresentaram maior riqueza e diversidade de espécies. Em relação à

ocorrência, 7 espécies foram identificadas como sazonais em toda a área de estudo, 23 apresentaram sazonalidade em pelo menos um dos ecossistemas estudados e outras 16 foram classificadas como residentes. A formação de picos de maior agrupamento para as comunidades de aves aquáticas destaca o uso desses lagos e reservatórios como corredores biológicos, ou pontos de conexão aquáticos, ressaltando a importância desses ecossistemas para a biodiversidade da avifauna aquática dependente e semidependente. Essas informações podem contribuir para a compreensão da dinâmica ecossistêmica em ambientes lacustres e híbridos da região semiárida. Esses dados são úteis para a compreensão desses processos ecológicos, para o diagnóstico ambiental e de saúde, e para a investigação de potenciais novos bioindicadores desses ambientes.
Palavras-chave: Aves aquáticas; Comunidades de aves; Estatística circular; Sazonalidade; Caatinga.

1. INTRODUCTION

Brazil currently has 1,971 bird species listed by the Brazilian Committee of Ornithological Records (Pacheco *et al.,* 2021). This is the second largest vertebrate group in relation to the number of known species in the country, second only to the ichthyofauna, with 3884 species (Piacentini *et al.,* 2015; Buckup *et al.*, 2007). Of these, about 160 species have aquatic habits, that is, they depend in some way on wetlands for their survival (Branco 2003).

Pacheco (2004), identified 34 species of native water avian in the caatinga. Olmos *et al.*, (2005), pointed out about 45 species of waterbirds in eight areas of caatinga in southern Ceará and western Pernambuco. There was an increase of eleven bird species in just one year, which indicates the incipiency of research on this subject and the potential for identification and occurrence of new species not yet described in the semi-arid region.

Olmos *et al*., (2005), highlight the great wealth of species in the region of Petrolina-PE, due to the large number of temporary ponds, noting the effective population of some species, such as the teals *Dendrocygna viduata* (Linnaeus, 1766), *D. autumnalis* (Linnaeus, 1758), and *Amazonetta brasiliensis* (Gmelin, 1789); the biguá, *Nannopterum brasilianum* (Gmelin, 1789); herons such as *Ardea alba* (Linnaeus, 1758) and *Egretta thula* (Molina, 1782); and the socó *Nycticorax nycticorax* (Leach, 1820).

The term "wetlands" arises in a context of conservation and preservation of areas of international importance as waterfowl habitat. By definition, wetlands are ecosystems at the interface between terrestrial and aquatic environments, continental or coastal, natural or artificial, permanently or periodically flooded or with soaked soils. Their waters can be fresh, brackish or salty and present plant and animal communities with adaptations to water dynamics (Brasil, 2015; Ramsar convention secretariat, 2010). These areas constitute a priority environment for conservation because of their importance for the regularization of water regimes, conservation and preservation of species, and their value as an economic, cultural, scientific, and recreational resource (São Paulo, 1997).

In the Brazilian semiarid region, given its climatic characteristics, the inland wetlands are classified as subject to unpredictable polymodal pulses of short duration, to pluriannual pulses of short duration, and also as wetlands of anthropogenic origin (Peel *et al.,* 2007; Brasil

2015). The latter, more specifically dams and reservoirs, also correspond to hybrid or intermediate ecosystems, classified by Esteves (1998).

In tropical climatic environments, especially in semi-arid ones, reservoirs have multiple uses due to the long periods of water scarcity. Among their uses are energy production, water flow regulation, flood control, fishing, and recreation (WCD, 2000; Gunkel *et al.,* 2015; Gunkel 2009). Moreover, due to the irregularity of rainfall and long periods of drought, these reservoirs play a key role in maintaining human and animal life, especially in the more inland regions of the semiarid region (Júlio-Júnior *et al.,* 2005).

Bozelli *et al.,* (2018) highlights the importance of small wetlands for biodiversity, as their unique environmental conditions enable the development of adaptive responses to changes in these habitats (Blaustein and Schwarz 2001). These temporary wetlands also function as "stepping stones" or "aquatic stepping stones," providing foraging and resting habitats for migratory species (Calhoun *et al.,* 2017).

Thus, understanding the variation in distribution, seasonality, and abundance of aquatic avifauna species can provide subsidies for understanding natural patterns and anthropic impacts that may generate changes in biological communities in ecosystems. The use of circular statistics can be an excellent tool to study seasonal patterns, as species may exhibit behaviors and respond to cyclical phenomena, such as breeding or migration events. Although relatively recent, its use is already applied in studies of plant phenology, contributing to the planning of harvests, recovery of degraded areas and establishment of seedling production schedules

(Drew and Doucet 1991; Tremblay and Castro 2009; Morellato *et al.*, 2010; Silva and Lucena 2023).

Given this perspective, this study aims to identify spatial and temporal patterns of occurrence of waterfowl in lake and reservoir environments in the municipality of Petrolina-PE, Brazil. It was also verified if there is a correlation between bird diversity and accumulated precipitation over the months.

We hypothesize that there is seasonality in species of waterfowl communities in the region and in different ecosystems, modifying their composition, richness and abundance throughout the year. With the predictions: 1.1. There is a difference in composition, richness and diversity among waterfowl communities in the different ecosystems studied. 1.2. There is a positive correlation between bird diversity and accumulated precipitation over the months; 1.3. Waterbird community members show seasonality, with greater richness and abundance during periods of higher precipitation volumes. 1.4. Ecosystems located in rural areas present greater richness, abundance and diversity of species.

2. LITERATURE REVIEW

Continental aquatic ecosystems are classified, according to the dynamics of water flow, into three main categories: lotic, lentic, and hybrid (or intermediate). Lentic ecosystems, which are the focus of this study, are characterized by the absence of significant horizontal water flow and are therefore considered environments of still or standing water. This condition provides greater hydrodynamic stability; however, it also increases vulnerability to environmental degradation processes, such as pollution and eutrophication (Esteves, 1998; Cain *et al.*, 2018).

Eutrophication consists of an increase in primary productivity in aquatic ecosystems, generally associated with the excessive input of nutrients such as phosphorus and nitrogen (Odum and Barrett, 2007). This process promotes significant changes in the ecological structure of these environments, including excessive growth of photosynthetic organisms, reduction in biological diversity, and decreased levels of dissolved oxygen in the water (Esteves, 1998; Van den Bergh *et al.*, 2002; Cain *et al.*, 2018). Such changes directly affect resource availability and habitat conditions, influencing the composition and structure of associated biological communities, including aquatic avifauna.

In the context of the Brazilian semiarid region, these dynamics become even more intense. High average temperatures and low rainfall favor evapotranspiration, increasing nutrient concentration and intensifying the effects of eutrophication, especially during dry periods (Figueiredo *et al.*, 2007). On the other hand, rainy periods promote the expansion of water bodies and the renewal of environmental conditions, generating significant seasonal variations in these ecosystems. These hydrological fluctuations are key factors shaping the dynamics of associated aquatic and terrestrial communities, including waterbirds.

The structure of biological communities in environments subject to disturbances can be understood in light of the Intermediate Disturbance Hypothesis, which suggests that intermediate levels of disturbance favor greater biological diversity (Connell, 1978). However, when these disturbances are intensified by anthropogenic actions, such as effluent discharge, deforestation, and agricultural activities, imbalances may occur, favoring opportunistic species and reducing local diversity.

In this context, the use of bioindicators becomes a fundamental tool for environmental monitoring. Bioindicators are organisms or groups of organisms whose presence, absence, or abundance reflects the environmental conditions of a given ecosystem, allowing the detection of changes and the assessment of environmental quality (Burger, 2006; Markert *et al.*, 2003; Siddig *et al.*, 2016). In aquatic ecosystems, various groups are used for this purpose, such as phytoplankton, periphyton, and fish (Chellappa *et al.*, 2009; Hemraj *et al.*, 2017).

Among bioindicators, waterbirds stand out due to their high sensitivity to environmental changes, diversity of feeding habits, and direct dependence on aquatic habitat conditions for feeding, reproduction, and shelter (Matos, 2011; Frederick *et al.*, 2009). Although still less frequently used in studies of aquatic ecosystem monitoring, they show great potential as indicators of environmental quality, especially in lentic environments.

In semiarid regions, particularly in northeastern Brazil, water bodies such as temporary ponds and reservoirs play a fundamental role in maintaining biodiversity, serving as areas for refuge, feeding, and reproduction for waterbirds, as well as acting as strategic points for migratory species (Olmos *et al.*, 2005; Calhoun *et al.*, 2017). In these environments, there is a strong relationship between bird community dynamics and rainfall, with increased species richness and abundance during rainy periods, when there is greater availability of water and food resources.

Thus, the analysis of the structure of waterbird communities associated with seasonal variations in lentic ecosystems in the semiarid region allows for a better understanding of the ecological responses of these organisms to environmental changes. Furthermore, the combined use of different bioindicator groups, such as periphyton and avifauna, may enhance the interpretation of ecological processes, providing more robust information for the monitoring and management of these ecosystems (Wilson and Bayley, 2012).

3. METHODOLOGY

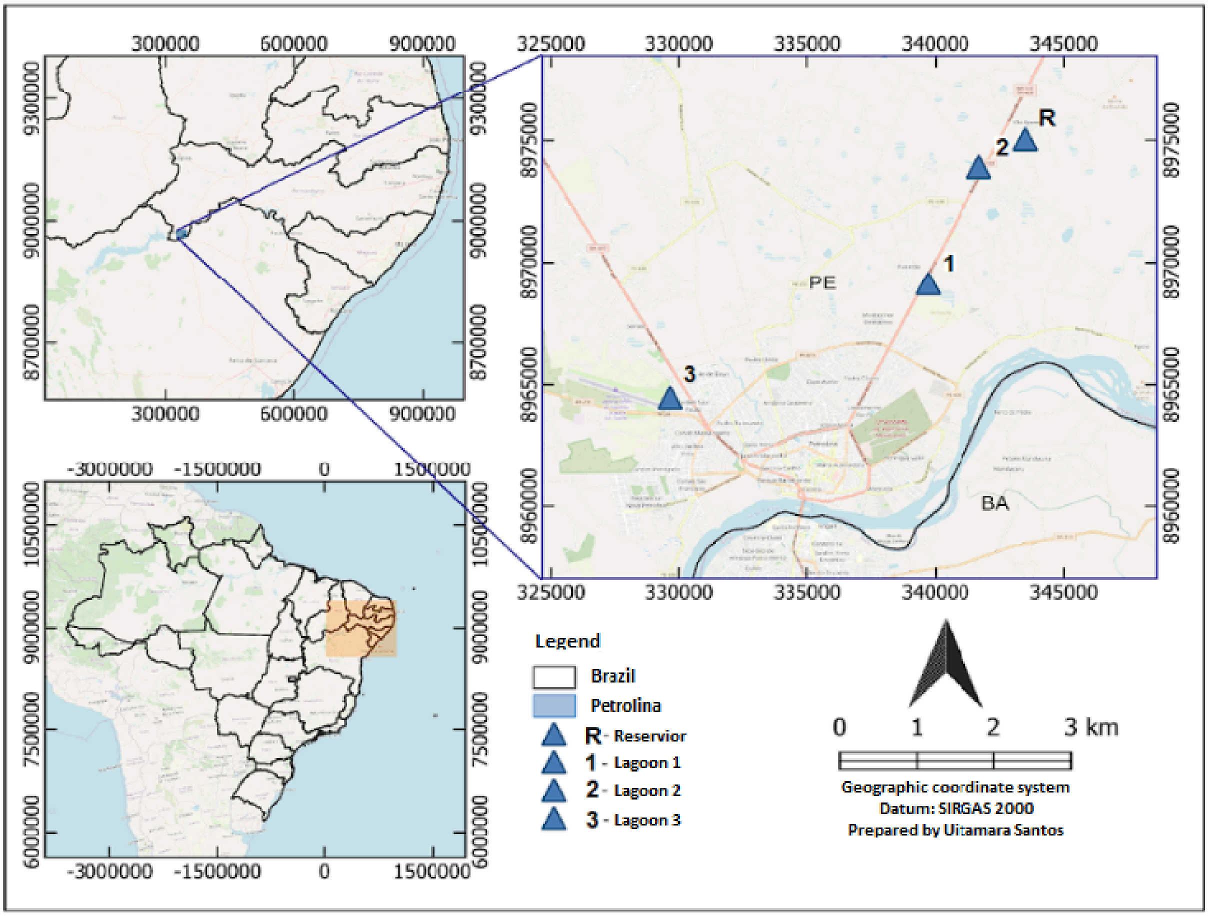
3.1. Study Area

The research was conducted in the municipality of Petrolina, a city located in the semi-arid region, more specifically, in the mesoregion of São Francisco Pernambuco (9°23'39" S, 40°30'35" W). It has a semi-arid climate classification of Bsh type according to the Köppen-Geiger classification updated by Peel *et al.,* (2007), with two well-defined seasons: a dry season from May to October and a rainy season from November to April.

The choice of sites was made according to the following criteria: type of environment, natural or artificial, with the preference of sampling at least one artificial environment; the type of area, rural and urban, with the selection of these two types in the sampling; and accessibility, since some potential ecosystems were located on private land and areas of difficult access.

Three collection points were defined in natural environments (L1, L2 and L3) and one representative of an artificial ecosystem, the reservoir (R). Although there is not only one form of classification for rural and urban areas, the classification adopted here was the one used by the Brazilian Institute of Geography and Statistics (IBGE), where rural areas are those outside the urban perimeter of cities and towns (Cella *et al.*, 2019; IBGE 2017). As well as the Municipal Law of Petrolina No. 2581, of September 20, 2013, which provides for the regulation of the consolidated urban area of the Municipality, in attention to the rules of the New Forest Code, Law No. 12,651, of May 25, 2012. These ecosystems were georeferenced with a GPS (Global Positioning System) receiver and the study sites Lagoon 2 and Reservoir (R) were considered rural for being located in areas of low population density, less than 50 inhabitants per hectare, and the lagoons (L1 and L3) were considered urban (Fig. 1).

Fig. 1: Study sites.



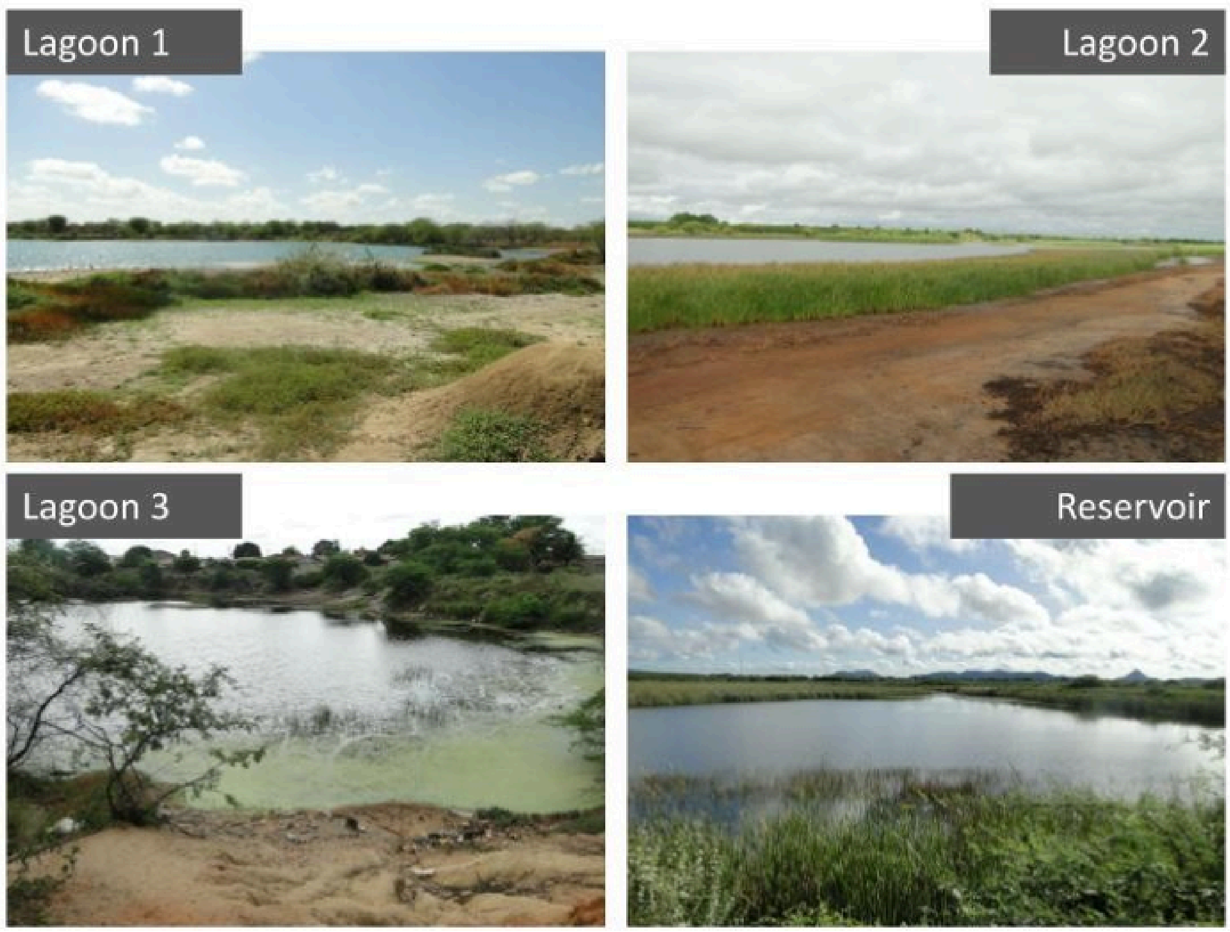
Source: authors, 2022.

Lagoon 1 (L1) is located in the urban area of Petrolina, parallel to the BR 428 highway, near the condominium Campos do Conde, Residencial Vivendas 1 and close to agricultural areas (9°19'22.0 "S 40°27'33.5 "W). This lagoon has debris and garbage accumulation with surrounding vegetation composed of algarobas (*Prosopis juliflora* (Sw) DC), juremas pretas (*Mimosa tenuiflora (Willd.) Poir.)*, faveleiras (*Cnidoscolus quercifolius Pohl.*) and cactaceans *(Cereus jamacaru DC.; Melocactus zehntneri (Britton & Rose) Luetzelb.*; *Pilosocereus sp.)* (Fig. 2). Its water has a moss-green coloration and a fetid odor. Its average depth is 50 cm, and it has an area of approximately 23,489.65 m². In addition, it is possible to notice the presence of salt deposits in the soil and the growth of halophytes (e.g. Sesuvium portulacastrum). This lagoon communicates with other adjacent lagoons by a small stream and receives water from nearby residential complexes, runoff from the surrounding area, and highway 428.

Lagoon 2 (L2) is located next to BR 428, also in the rural area of Petrolina (9°16'48.9 "S, 40°26'26.2 "W) and has only agricultural areas with irrigated fruit culture in its surroundings. Its water has a slightly greenish color and a slightly pungent odor in some periods of the year (dry period), with constant inflow of water and effluents from the surrounding agricultural areas. Its average depth is 89 cm, and it has approximately 87,857.31 m² of total area. Its surroundings are also marked by the presence of algarob trees, juremas and growth of halophytes (e.g.: *Sesuvium portulacastrum*) (Fig. 2). It is also possible to observe the presence of macrophytes, such as Taboa (*Typha* sp.).

Lagoon 3 (L3) is located next to the Cosme and Damião neighborhood (9°21'53.4 "S, 40°33'04.2 "W), in the urban area of Petrolina and presents the smallest size among all analyzed. Its average depth is 138 cm, and it has approximately 9,937.44 m^2 of total area. The surrounding environment presents houses, animal breeding (mainly cattle), as well as a lot of debris and garbage accumulation. Some domestic animals also circulate in the area. The water is slightly greenish in color and has no apparent odor. Despite this, it is possible to observe the presence of macrophyte blooms in the areas closest to the edges of the lagoon. During the analysis period there were no effluent entries, although the lagoon seems to have a communication with another lagoon through a passage. Its vegetation is composed predominantly of *P. juliflora* and *M. tenuiflora* (Fig. 2).

Fig. 2. Study sites. The first three ponds correspond to natural ecosystems and the last one to the reservoir, an artificial ecosystem.



Source: authors, 2022.

The Reservoir (R) is located in Senador Nilo Coelho Project - 11 (9°16'09.9 "S, 40°25'29.1 "W), has slightly greenish water in some points and no apparent odor. Its average depth is 149 cm, and it has a total area of approximately 114,691.93 m^2. This ecosystem receives water through irrigation channels from the São Francisco River. Its surrounding vegetation is constantly pruned or partially removed by the São Francisco and Parnaíba Valley Development Company (CODEVASF), and is composed of juremas (*Acacia spp. Mill.*), algarobas (*Prosopis juliflora (Sw.) DC.*), as well as pteridophytes and aquatic macrophytes (e.g. Typha sp. and Nymphaea sp.).

3.2. Data Collection

The sampling of the bird community was non-probabilistic, with records every two months of the avifauna. Each sampling lasted 3 hours at each study site at fixed times between 5:30 - 9:30 am in the period between January and December 2022. For the counting and identification of dependent and semi-dependent waterfowl species, two observers walked around the lagoons and reservoir, always following the same route, equipped with 40x8 binoculars, field guides for species identification, field notebook, radio communicator and cameras (adapted from Bibby *et al.*, 2000).

These observers walked the paths with pauses for counts in the surroundings of the studied ecosystems, counting only the individuals perched or foraging (in flight) (adapted from Bibby *et al.*, 2000). The count was performed only on the outbound trip, and on the return trip only the species that were not present on the outbound trip were added. The number of species sighted was the average of the individual values measured by each observer on each day of observation.

For identification purposes, the classification and nomenclature of Pacheco *et al.*, (2021) was used. Birds that used the water environment for feeding, resting or breeding were considered dependent and semi-dependent on wetlands (Accordi and Barcellos 2006; Accordi 2003). Meteorological data was collected through the online information portal of the National Institute of Meteorology (INMET) in the period between January and December 2022.

3.3. Statistical Analyses

The monthly frequency for each species was related to the monthly precipitation by means of Spearman's rank correlation test (rs) at a 5% significance level. The first-order Jackknife richness estimator was applied in order to determine the expected number of species through the campaigns carried out.

The variables abundance, richness and diversity were tested for distribution using the Shapiro-Wilk test (1965). When the data accepted the null hypothesis of the Shapiro-Wilk for the normality of the residuals the analysis of variance Anova was used, in cases where the hypothesis was not accepted, the Kruskal-wallis test was used for non-parametric data, testing the alternative hypothesis of difference between the parameters studied according to the zone and study site. Subsequently, Tukey's test was performed in order to identify significant differences between these variables.

Descriptive analyses of circular statistics were performed to analyze the influence of seasonality on the distribution of species and precipitation throughout the year, verifying the month of occurrence of the highest frequency of individuals. The observations were converted into circular data and through the occurrences of species in each observation, the mean angles (μ), angular standard deviation (SD) and length of the mean vector (r) were estimated.

These mean vectors indicated the concentration of data in the circle (year) ranging from 0 (scattered throughout the year, or not seasonal) to 1 (clustered, seasonal). Rayleigh's test was performed to check the reliability limit of the mean vector, at 5% significance level. The null hypothesis that the variables have angular distribution of data satisfactorily described by a von Mises distribution, i.e., they are uniformly distributed around the circle (ZAR, 2014). All analyses were performed in the free software R 4.2.2. using the R Studio environment.

4. RESULTS AND DISCUSSION

Expected species richness through Jackknife estimation indicated that the campaigns yielded approximately 95% of what was expected for the bird community of the study area. According to the observations made, the community of waterbirds, dependent and semi-dependent of the four ecosystems evaluated, is composed of 40 species, arranged in 19 families (Table 1).

Table 1: Dependent or semi-dependent waterfowl species sampled in the study area and their respective descriptive variables analyzed.

Species	n	Local	M	â	month
Accipitridae					
Rostrhamus sociabilis	11	L2, R	0,5	28,76	Jan

(Vieillot, 1817)					
Alcedinidae					

⚠ Esta tabela possui muitas colunas e foi cortada para impressão. Para visualizá-la completa, acesse o artigo original em: https://revistatopicos.com.br/artigos/community-structure-and-seasonal-analysis-of-waterbirds-in-lentic-aquatic-ecosystems-in-the-municipality-of-petrolina-pernambuco?noblockage

Note: "n" corresponds to the abundance, "M" corresponds to the circular average, "â" corresponds to the average angle, "month" is the period of greatest occurrence, "r" is the rho vector that ranges from 0 to 1 and indicates the concentration of individuals around the average date, so when "r" is greater than "0.5" it is an indication that it presents a clustered or seasonal distribution. The "p-value" indicates the significance of the Rayleigh test, which checks the resulting average length of rho. The alternative hypothesis indicates a unimodal distribution and the null hypothesis indicates a uniform distribution.

Source: authors, 2022.

Regarding beta diversity, seven of the species showed a significant concentration (r*) indicating seasonality in the municipality of Petrolina. These species are presented in Table 2.

Table 2: Waterfowl occurrence in ecosystems where seasonality was significant.

Species	Mean	Â (month)	r*	Standard Deviation
Rostrhamus sociabilis	0,5	28,76 (Jan)	0,62	0,97

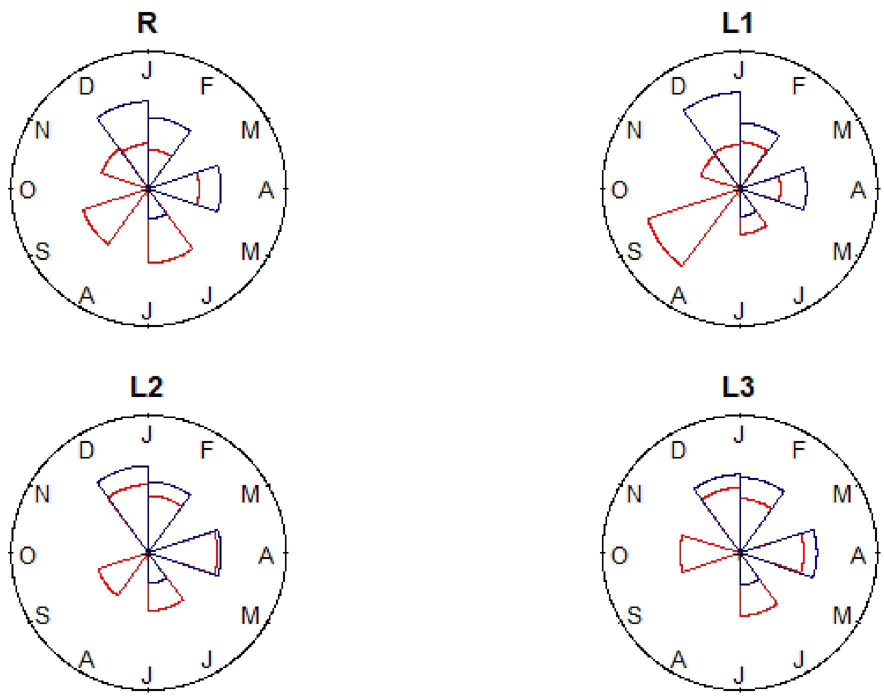
Anas bahamensis	1,02	58,66 (Fev)	0,84	1,49
Dendrocygna autumnalis	2,42	138,70 (Mai)	0,62	0,97
Dendrocygna viduata	2,30	131,88 (Mai)	0,60	1,00
Bubulcus ibis	-0,22	347,1 (Dez)	0,69	0,86
Nannopterum brasilianus	-1,99	246,19 (Set)	0,66	0,90
Fluvicola albiventer	-0,45	334,33 (Dez)	0,54	1,10

Source: authors, 2022.

During the period studied,twenty-three species showed a significant concentration in at least one of the sampled areas, indicating that the occurrence of these species, at least in the ecosystem presented, is aggregated. These were *Amazonetta brasiliensis*, *Anas bahamensis*, *Dendrocygna autumnalis*, *Dendrocygna viduata*, *Tachornis squamata*, *Bubulcus ibis*, *Egretta thula*, *Nycticorax nycticorax*, *Tigrisoma lineatum*, *Vanellus chilensis*, *Certhiaxis cinnamomea*, *Chrysomus ruficapillus*, *Jacana jacana*, *Phaetusa simplex*, *Nannopterum brasilianus*, *Podilymbus podiceps*, *Tachybaptus dominicus*, *Gallinula galeata*, *Tringa flavipes*, *Arundinicola leucocephala*, *Fluvicola albiventer*, *Fluvicola nengeta* and *Phimosus infuscatus.*

The individual sites did not show significant seasonality for community composition throughout the year with results for the rho vector less than 0.5 (Fig. 3).

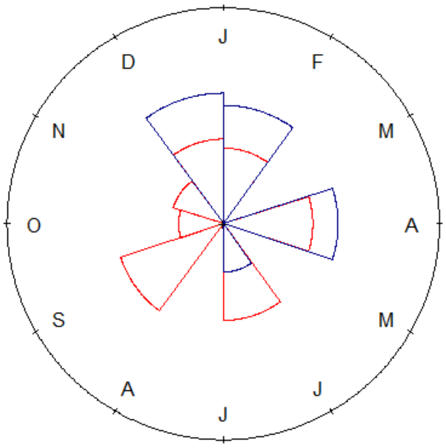
Fig. 3: Distribution of species at the study sites Reservoir, L1, L2, L3 and cumulative monthly precipitation at the study sites.



Source: authors, 2022.

The distribution of species showed variations throughout the period considering the separate areas, being L1 the only medium vector towards September, where 357 individuals of Nannopterum brasilianus were observed in a single campaign, this phenomenon was enough to move the average vector towards September. Considering all occurrences in the sampled areas, there was a period of higher frequency of recording, in September (Fig. 4).

Fig. 4: Species distribution (red) and monthly precipitation (blue) in the study area.

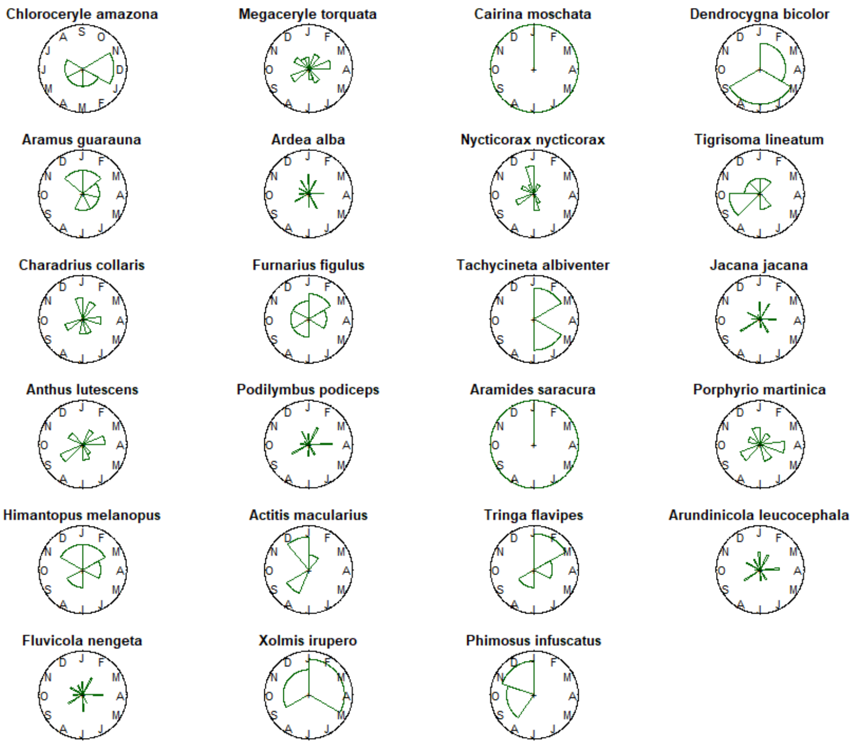


Source: authors, 2022.

This phenomenon may have influenced the regional analysis, if we consider only the other areas (L2, L3 and R), the mean vector pointed to the month of January (â = 2.16; 1.09; 0.36, respectively for the reservoir Sites. In this case, the results for species seasonality in these ecosystems support the hypothesis that the waterfowl community shows seasonality with higher richness and abundance during periods with higher precipitation volumes.

Twenty-three (23), of the forty (40) species, presented a von Mises normal distribution or circular uniform distribution, being these: *Chloroceryle amazona, Megaceryle torquata, Cairina moschata, Dendrocygna bicolor, Aramus guarauna, Ardea alba, Nycticorax nycticorax, Tigrisoma lineatum, Charadrius collaris, Furnarius figulus, Tachycineta albiventer, Jacana jacana, Anthus lutescens, Podilymbus podiceps, Aramides saracura, Porphyrio martinicus, Himantopus melanurus, Actitis macularius, Tringa flavipes, Arundinicola leucocephala, Fluvicola nengeta, Xolmis irupero, Phimosus infuscatus.* Thus, the Rayleigh uniformity test indicates that for these species there is no average angular direction for their distribution, being considered resident or non-seasonal species in the study area. These results can also be seen through the circular graphical analysis (Table 1 and Fig. 5).

Fig. 5: Species with uniform distribution according to Rayleigh's test for uniformity.



Source: authors, 2022.

Some of the results obtained in the test indicate that for some species, *Cairina moschata, Dendrocygna bicolor, Aramus guarauna, Furnarius figulus, Himantopus melanopus* and Xolmis irupero, these results are still inconclusive given the small number of individuals observed.

No correlations were observed between species richness, abundance and diversity variables with monthly precipitation using Spearman's correlation test, respectively (rs = 0.09; -0.14 and 0.15).

Shannon diversity for the waterfowl community for the sampled areas was 2.38. Individually for each of the areas, L2 showed the highest Shannon richness and diversity, L3, in contrast, showed the lowest values for these indices (Table 2).

Table 3: Richness and diversity indices for waterfowl by study site.

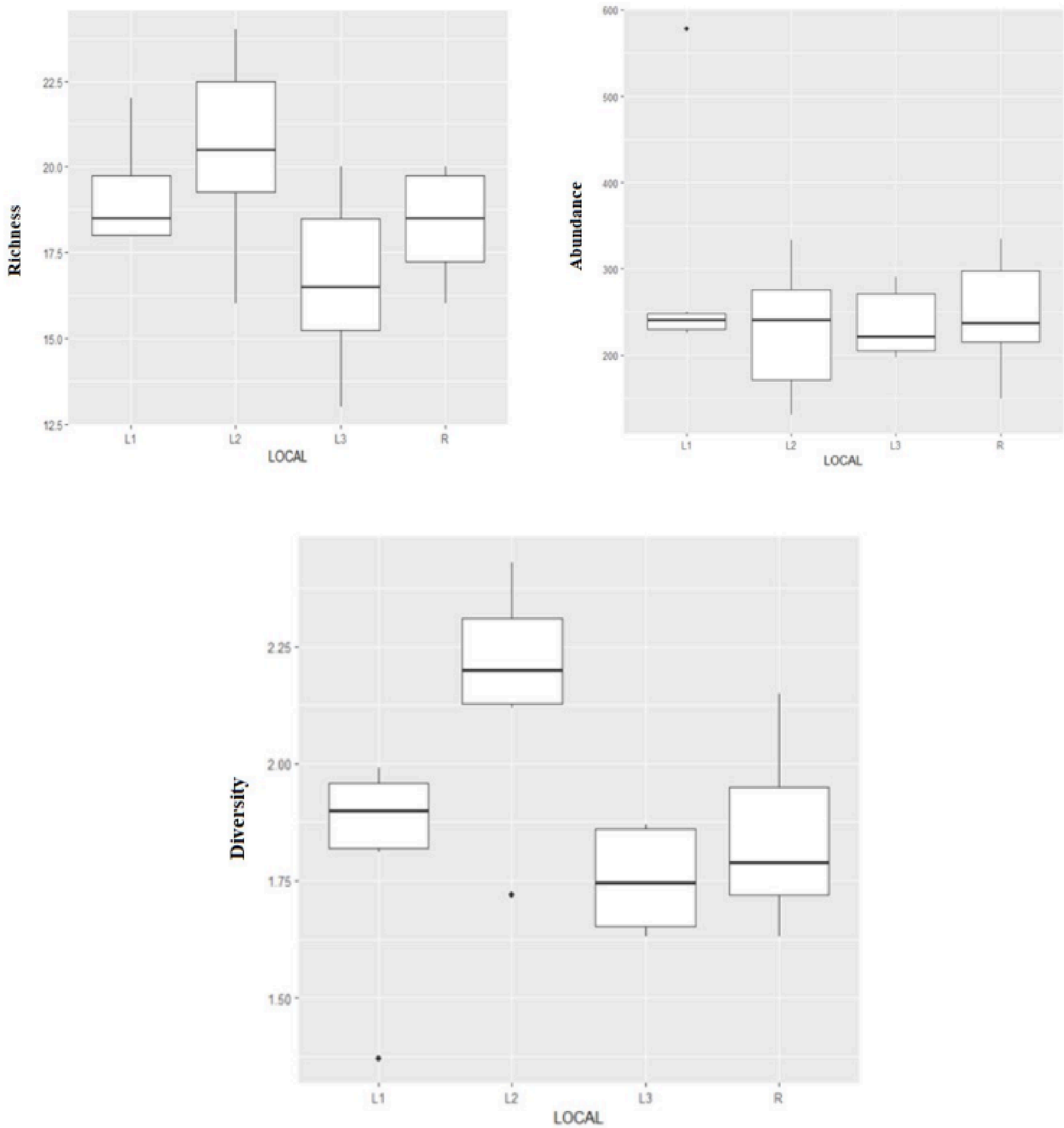
Local	**Observed Richness**	**Estimated Richness**	**Diversity_Shannon**
Lagoon 1 (Urban)	30	35	1,97
Lagoon 2 (Rural)	34	39	2,47
Lagoon 3 (Urban)	29	35	1,95
Reservoir (Rural)	31	37	2,19

Source: authors, 2022.

The beta diversity for the waterfowl community demonstrated an average similarity of 0.64 between sites. L1 achieved the highest similarity with L2 (Jaccard = 0.76), the lowest similarities were obtained between lakes L2 and L3 (Jaccard = 0.59). This result indicates that the regions have similar population characteristics and the similarity between the regions is high.

Significant differences were observed among the sites in relation to richness ($p = 0.05$), where L3 and L2 showed significant differences among themselves, for the others no significant differences were identified using Tukey's test. The species richness of lake 2 was higher and the mean species richness of lake 3 was lower. No significant differences were observed between the reservoir and L1 with the other groups, a result shown in Fig. 6.

Fig. 6: Box-plot of richness, abundance, and diversity, by study site, where R corresponds to Reservoir, L1 to Lagoon 1; L2 to Lagoon 2 and L3 to Lagoon 3.

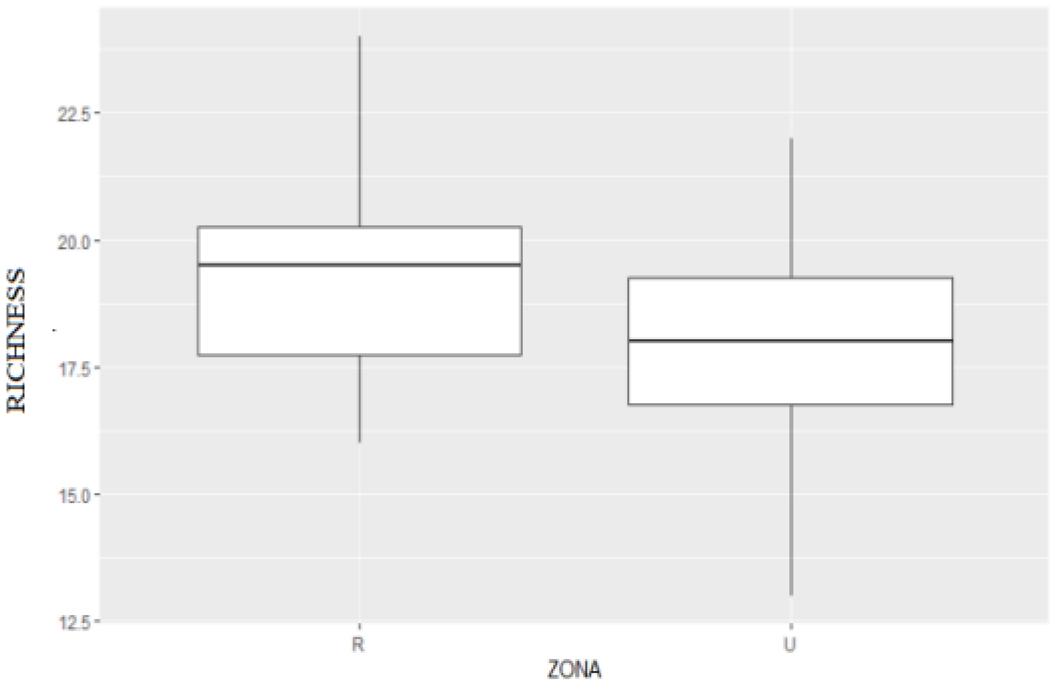


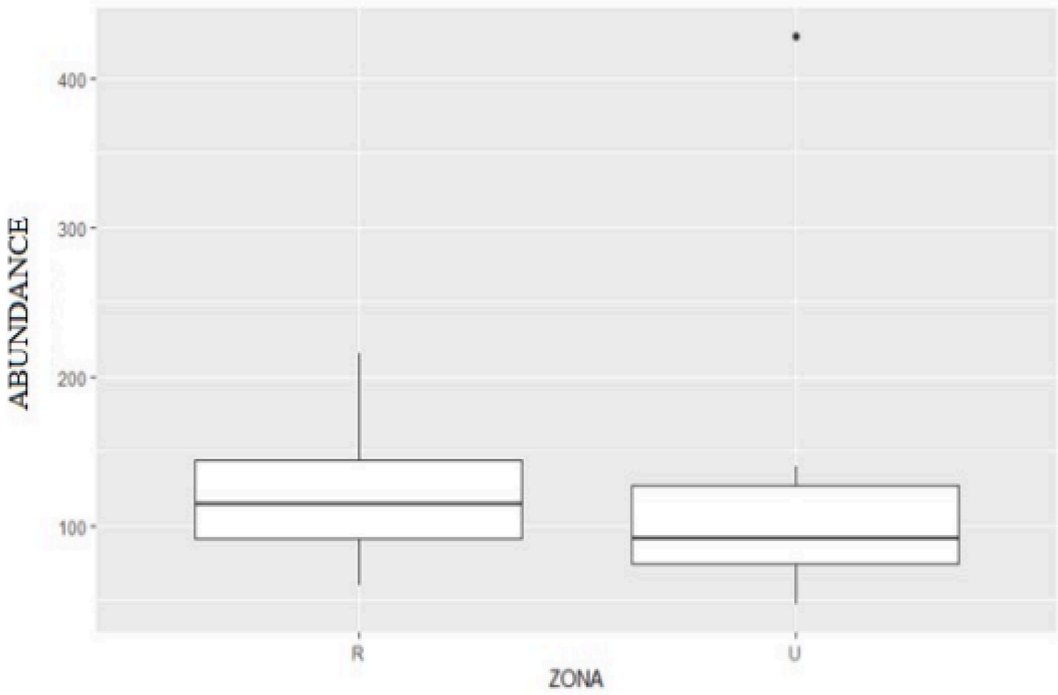
Source: authors, 2022.

The abundance of avians did not present normality of the residuals through the Shapiro-wilk test, thus the Kruskal-wallis test was used for the test of ranks obtaining non-significant values (p=0.46). For this variable, no significant differences were observed between the ecosystems studied in relation to abundance. Regarding bird diversity, significant differences were observed between areas L2 and L1 (p=0.04), L3 and L2 (p=0.01) and the reservoir with lagoon 2 (p=0.05). Therefore, the ecosystems showed significant differences among themselves, with the highest diversity observed at point L2.

Regarding the sampling area, rural and urban, the rural area presented the highest mean species richness (R = 19.41; U = 17.91), however, it was not considered a significant difference in relation to richness through the analysis of variance (Anova) (p=0.15). Regarding abundance, no significant differences were also observed for diversity in the collection zones, the comparison was performed using the Kruskal - Wallis median test (p=0.30). However, regarding diversity, a significant difference was identified between the areas using Anova (p=0.029). The values can be seen in the graphs in Fig. 7 below.

Fig. 7. box-plots of richness, abundance, and diversity by study area.


RICHNESS
22.5
20.0
17.5
15.0
12.5
R
U
ZONA


ABUNDANCE
400
300
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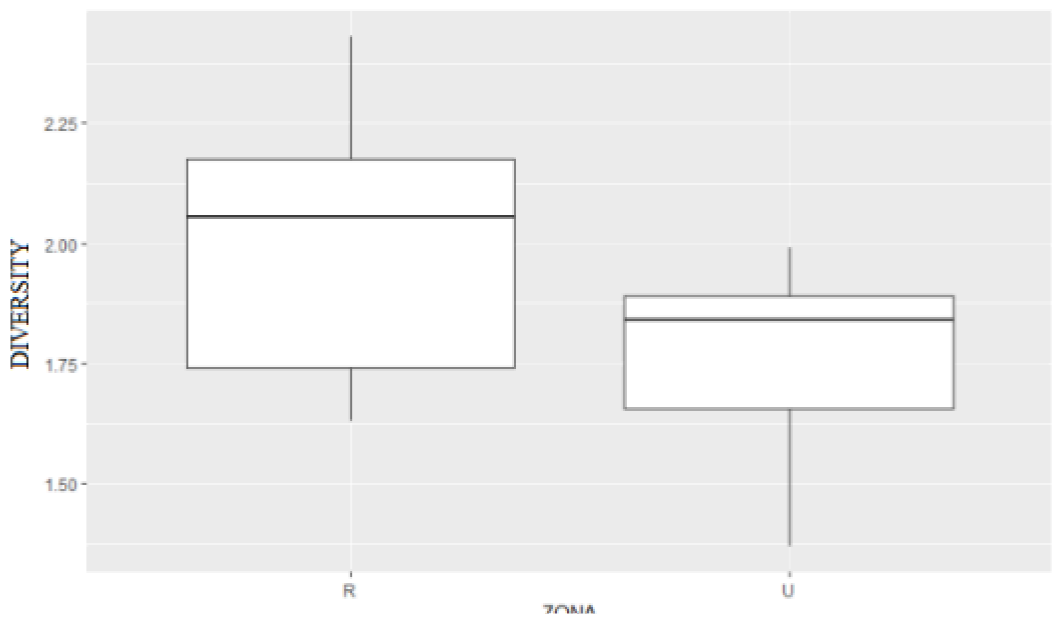
DIVERSITY
2.25
2.00
1.75
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Source: authors, 2022

Thus, we can observe that there was a greater richness, abundance, and diversity in the rural area, of these, only Shannon's diversity presented a significant difference.

The species richness found was higher than the result observed by Pacheco (2004), 34 species. In addition, the estimated richness of this study was 45 species, the same number obtained by Olmos *et al.,* (2005) for waterbirds in areas of Caatinga from southern Ceará and western Pernambuco. Thus, this study obtained satisfactory results regarding the number of species identified, similar to those reported in the literature from similar areas in the Brazilian semi-arid region.

The use of the variable species abundance in isolation may not be sufficient to analyze ecosystems. Therefore, it is important to use it in combination with other variables, such as richness and diversity, since they can provide more sensitive answers about ecological aspects relevant to understanding the dynamics of communities. As shown in this case, abundance showed very close values between each of the communities, however, richness and diversity were essential to reveal the particularities between the areas.

In relation to richness, Lagoon 2 (rural) showed a higher average and amplitude of data according to the observations, especially when compared to L3 (urban). However, when comparing the richness results by area, we noticed that there was no significant difference in the grouping of the areas, which indicates that pond L1 (urban) presents a structure closer to the rural units, which may be related to its proximity, suggesting that these ecosystems function as a metacommunity, while point L3 presents a smaller distribution.

In relation to abundance, the medians were also close, with a greater amplitude at point L2, where there was a greater variation in the number of individuals during the period observed. This characteristic may be related to changes in water volume in the lentic body investigated, during rainy periods the volume increased and the banks were covered by water, the physical characteristics of the terrain limited the foraging area for some species.

The diversity of point L2 was also a highlight in relation to the other areas evaluated, with a significant difference in relation to the other observation points. Regarding the type of environment, there was also a significant difference between rural and urban areas, which may be related to a greater presence of less frequent birds in urban areas, due to the environmental characteristics of these ecosystems, such as greater disturbance from different sources (human and domestic animal traffic, noise and effluent discharge), a visible greater eutrophication and less variability of species in the surrounding vegetation.

The seasonal patterns and distribution of the diver, *Nannopterum brasilianus*, were identified by Manoel *et al.,* (2011) with maximum abundance during the January period in aquatic ecosystems of the southern region of Brazil. In the present study, this species showed seasonality, with a mean occurrence date for the month of September in the municipality of Petrolina-PE. This pattern of seasonality follows the trend of this species in L1. In the other lagoons, no seasonality was observed, indicating that changes in its composition may be related to specific environmental attributes of these different ecosystems, such as depth and trophic state.]

Tavares and Siciliano (2014) in their study in a permanently flooded wetland in the Environmental Protection Area (APA) of Lagoa da Ribeira in Rio de Janeiro, found a high negative correlation between diving species and precipitation, although it was expected that the higher water volume and larger water mirror would contribute to the greater abundance of this species, which did not occur for the study conducted by the authors, as well as for the present study.

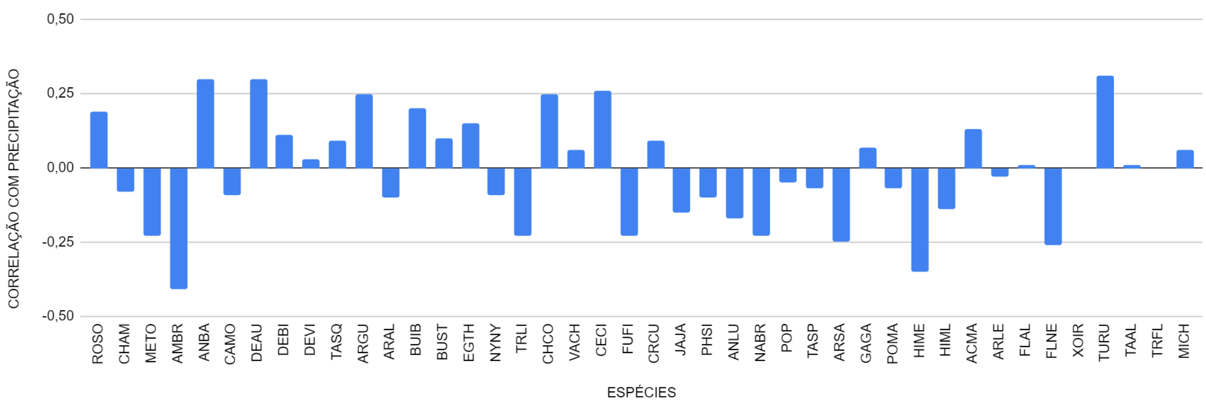
Siqueira and Martins (2019), observed higher species richness in lake environments in Petrolina in July, as well as lower richness in the month of September. The results of the present study do not confirm these observations, since the mean angle for higher concentration of species indicated the month of September (Â= 240,6) thus, presenting a greater possibility of finding different species in this period (Fig. 4).

This result does not corroborate the hypothesis that there would be a higher concentration of species in the rainy season, recorded between the months of January and April (Fig. 4). Our results were contrary to the period indicated for greater bird diversity (Farias 2005; Rodrigues and Michelin 2005; Cruz and Piratelli, 2011). The results presented here also differ from those obtained by Almeida (2019), in an area of Caatinga in the rural area of Mossoró - RN, in which the species richness during the rainy season was twice as high as that obtained during the dry season. Olmos et al. (2005) also observed a greater abundance of aquatic species during July and a reduction in their importance during September in a lentic aquatic ecosystem in the municipality of Petrolina (Lagoa 1). Thus, this study obtained unexpected changes in the seasonality of species, which may have been influenced by climatic abnormalities or changes in the input of water and nutrients in the ecosystems studied.

The relationship between bird diversity and accumulated precipitation over the months was also not observed in this study for the total diversity of the area evaluated. These results, when observed together with the results of the circular analyses, may indicate that other factors may affect the variability of the bird community.

All species showed low correlations with precipitation, lower than 0.5, positive or negative, presented in Fig. 7. Despite this, Pereira *et al.,* (2018), in Rio Grande do Sul, observed greater species clustering during spring, September 23 to December 22, the birds' reproductive period, since during this period the birds are more active, and therefore more visible. Accordi (2003) also found greater richness of birds in the spring and summer, due to the presence of migratory species and those that are exclusive to the above-mentioned seasons. However, the climatic regime of the region analyzed by these authors is different from that of the Caatinga.

Fig. 7. Correlation between species with monthly precipitation in the study area.

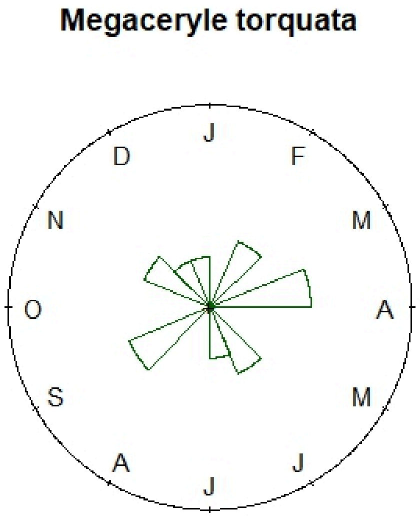


Source: authors, 2022.

The reservoir obtained a single record, for sampling, of *Cairina moschata*. This species is identified as having medium sensitivity to disturbances of anthropic origin according to Stotz *et al.,* (1996), Nunes and Tomaz (2008), Araújo and Silva (2017). Long-term observations are therefore necessary, since their presence in the study area does not provide sufficient evidence to record the seasonal distribution in these ecosystems. Therefore, there is a need for longer observation sample periods in order to obtain more complete results for the distribution of some rare occurrence species.

The fish-eating *Megaceryle torquata*, as an example, presents in its circular graph distribution with two vectors highlighted throughout the year, in April and September, indicating that this species is considered a resident species and there is not only one period of greatest occurrence (Fig. 8). A similar result was observed by Tavares and Siciliano (2014) regarding the occurrence of this species, with constancy in the study area, Lagoa da Ribeira - RJ, greater than 90%. For this species, a negative correlation was also observed with monthly precipitation, with higher occurrence during the dry period. The concentration of individuals during this period may be related to the higher density of fish due to reduced water volume, which would facilitate foraging by piscivorous birds (Macedo-Soares et al. 2010; Tavares and Siciliano, 2014).

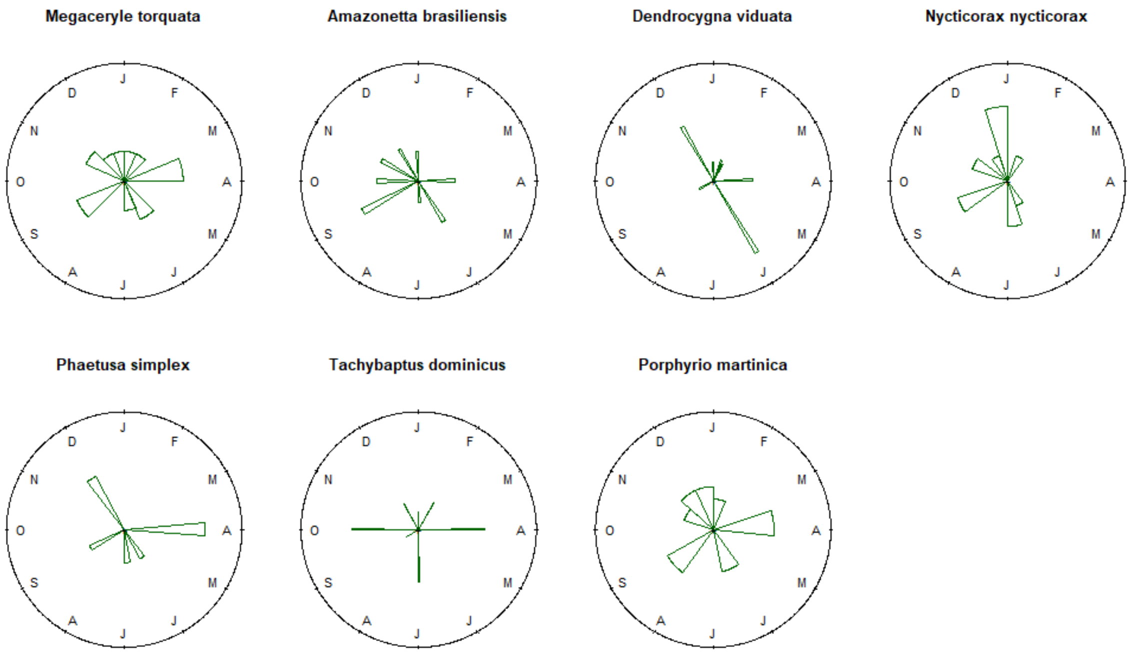
Fig. 8. Temporal distribution and illustration of the species *Megaceryle torquata* in the study area.



Source: authors, 2022.

The species *Amazonetta brasiliensis, Dendrocygna viduata, Nycticorax nycticorax, Phaetusa simplex, Tachybaptus dominicus* and *Porphyrio martinica* also showed distribution with two or more outstanding vectors. This shows that, although these are considered residents, there are one or more peaks of occurrence throughout the year of higher concentration of individuals, except for *N. nycticorax*, all species showed a higher concentration of individuals during periods of lower rainfall, i.e., during the dry season, as seen in Fig. 9.

Fig. 9. Circular plots of occurrence of the species *M. torquata, A. brasiliensis, D. viduata, N. nycticorax, P. simplex, T. dominicus,* and *P. martinica.*



Source: authors, 2022.

Some of the species sampled in the study area, such as *Nycticorax nycticorax, Phaetusa simplex, Tachybaptus dominicus,* were classified as migrants by Nunes and Tomas (2018), which corroborates with the frequencies presented for these species. These may use these ecosystems as aquatic stepping stones for their foraging and resting during migration, as demonstrated by Calhouns *et al.,* (2017), which explains the formation of peaks in the mean vector (r) at certain periods throughout the year.

The presence of migratory waterfowl species in these areas reflects the importance of these ecosystems not only for local biodiversity conservation, but also for regional and international species diversity. The use of these environments as refugia favors local biodiversity and enables the seasonal movement of species through the formation of a wetland corridor (Accordi, 2003).

Also reflects on the connectivity between wetlands as a factor for the conservation of South American waterbirds, pointing out the great importance of these areas for the preservation of endangered species and restoration of ecosystem functions performed by these wetlands (Accordi, 2003).

Although no species classified as endangered have been identified in the environments studied here, the ecosystems themselves are at risk, given the common and constant anthropic disturbances and the low enthusiasm in developing actions for their conservation.

Many of the areas, despite their scenic beauty, are used for the dumping of domestic solid waste, civil engineering debris, animal remains, and agricultural waste dumping. These anthropic changes can cause disturbances in the composition, richness, abundance, and seasonality of species, which has probably already occurred in the environments that were sampled.

Thus, monitoring these areas and the species that use them can provide answers about the environmental health of these ecosystems, as well as enable the identification of possible environmental changes.

CONCLUSIONS

In this study forty-two (40) species of birds dependent or semi-dependent on aquatic environments were identified in three temporary ponds and one reservoir in the municipality of Petrolina-PE. Through circular analyses of the communities, an aggregate temporal behavior was observed in twenty-five (23) bird species in at least one of the analyzed ecosystems. However, for the entire area evaluated, only seven (7) of these species were considered seasonal.

This study is innovative for waterfowl communities in Brazil for using circular statistics to analyze the distribution of these species, which allowed understanding the actual grouping of individuals over a cyclical period through cluster and uniformity analyses, which may bring new contributions to understanding distribution patterns.

In addition, the formation of peaks of higher clustering for waterbird communities highlights the use of these lakes and reservoirs as biological corridors, or aquatic stepping stones, thus highlighting the importance of these ecosystems for the biodiversity of dependent and semi-dependent aquatic avifauna.

This information can contribute to the understanding of the ecosystem dynamics in lacustrine and hybrid environments of the semi-arid region. Information can also be useful for understanding these ecological processes, for environmental and health diagnosis, and for investigating potential new bioindicators of these environments.

It is evident that there is a need for further studies in different observation regions regarding the community structure of waterbirds in the Brazilian semi-arid region, as well as the addition of other parameters that can provide a more comprehensive picture that can help in the understanding of the ecological dynamics of waterbird communities.

Finally, it is evident the need for further studies in different observation regions regarding the community structure of waterbirds in the Brazilian semi-arid region, as well as the addition of other parameters that can provide a more comprehensive picture that can help in the understanding of the ecological dynamics of waterbird communities.

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