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Community and species-specific responses of coastal birds to COVID-19 "anthropause" in the largest hypersaline lagoon of South America

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ABSTRACT

The COVID-19 pandemic led to a reduction in human mobility, known as "anthropause." Few studies have compared birds' community patterns between lockdown and "new normal" periods, especially in extremophile environments. This study presents the first baseline by monitoring coastal birds on 10 beaches along the largest hypersaline lagoon in South America. The birds were counted in September and October 2021 (during a lockdown period) and in October 2022 (after the lockdown – "new normal") during the morning. The continuous route transect methodology was applied by the same observer in all beaches. The Analysis of Covariance (ANCOVA) was used to investigate the response of community abundance to urbanization (raster-based variable) and time of COVID-19 pandemic (lockdown vs. new normal). Rarefaction curve and Permutational Analysis of Variance (PERMANOVA) were used to compare community richness and composition, respectively, between lockdown and new normal periods. Generalized Linear Models (GLM) with negative binomial distribution were applied to test the effect of the same predictors on the three more abundant species. The bird community structure and composition did not change when comparing lockdown and new normal periods, mainly due to dominance of synanthropic species. Among species-specific responses to lockdown, the Southern Lapwing Vanellus chilensis was more abundant during the lockdown on six of the nine beaches where it occurred. Oppositely, the Kelp Gull Larus dominicanus and the Neotropic Cormorant Nannopterum brasilianus were more abundant in new normal period, reinforcing that these species benefit from human subsidies. This may provide a unique opportunity for science-based sustainable ecotourism activities in urban areas with synanthropic species, capitalizing activities such as birdwatching, that would certainly contribute to environmental education actions.

Descriptors: Seabirds, Coronavirus, Coastal lagoon, SARS-CoV-2, Lockdown

To control the spread of COVID-19, many countries enforced lockdowns, causing reduced human mobility known as "anthropause" (Ben-Haddad et al., 2022). This rare situation provided a chance to test hypotheses about human-wildlife interactions (Rutz et al., 2020). Coastal birds' behavior is influenced by humans (Brown et al., 2000; Murchison et al., 2016), and certain species are more likely to be negatively affected by specific factors or conditions than others (Lafferty, 2001). Thus, during local human

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inactivity, bird communities may exhibit different patterns due to changes in dominant species' movement and habitat use (Lewis et al., 2022a). This is particularly true in socio-ecological systems like sandy beaches, where recreational activities rarely cease.

Coastal areas provide highly productive and ecologically significant ecosystems, since they offer crucial functions such as nursery, feeding, and refuge for a diverse range of species (Sheaves et al., 2015). In this regard, coastal lagoons are shallow water bodies located at the boundary between land and sea, being one of the most biologically productive systems of the planet and providing habitats to a vast variety of species, similar to areas that receive contribution by upwelling (Kjerfve et al., 1996; Tavares et al., 2015). These ecosystems are commonly used by birds to forage and rest (Tavares and Siciliano, 2013). Coastal lagoons are also feeding hotspots for several threatened shorebird species in their migration routes (Coleman and Milton, 2012; Jourdan et al., 2021).

Anthropogenic impact can immediately affect individual organisms, leading to changes in habitat use, foraging behavior, and potentially increasing energy expenditure, particularly in highly mobile species like birds (Costa et al., 2017). On the other hand, urban birds are known for their high degree of behavioral flexibility, which allows them to adapt quickly to changes in their environment (Gordo et al., 2020). Gordo et al. (2020) noted that the probability of finding birds during the lockdown had not increased, but detectability by citizens was higher in this period. Such authors suggested that the birds may have been more active or vocal during this period. Regardless of being negative or positive, individual-level impacts can have far-reaching consequences for populations and communities. Thus, bird assemblages have been considered indicators of environmental quality and are promisor tools to assess the collateral effects of COVID-19 on coastal environments (Scarton, 2017).

Studies assessing changes in bird communities during the pandemic, particularly assessing affected species in different ecosystems worldwide, are still scarce. Fors et al. (2022) observed an increase in avian species richness during the COVID-19 lockdown in urban areas of Colombia due to reduced human activity. Meanwhile, Gilby et al. (2021) found that synanthropic birds moved to low-urban beaches in Australia when human-derived food sources became scarce during the lockdown. This study speculates that shifts in synanthropic species could lead to competitive exclusion of scavengers, increased predation on small animals, depredation of eggs and predation on hatchlings from nests of other birds in natural coastlines (Gilby et al., 2021). Given the pandemic emergence, studies exploring the full extent of its impact on natural zones are relatively few, thus comparisons between lockdown and new normal patterns are now imperative.

Gaining insights into species' responses to human influence is pivotal, especially for coastal birds, known for their susceptibility to human presence in coastal areas (Møller et al., 2015; Lewis et al., 2022b). Little is known about human activity's impact on coastal lagoons, especially extreme environments like the largest hypersaline coastal lagoon in South America (Costa et al., 2023). Currently, no research has compared coastal bird community patterns in such lagoons during the global lockdown ("anthropause") and the subsequent "new normal" period, thus, effects like these and their implications for populations are being widely studied to fill this gap (Sol et al., 2018). Therefore, we present the first baseline study by monitoring coastal birds foraging or resting on 10 beaches along a stretch of approximately 15 km in the largest hypersaline lagoon in South America. Our hypothesis is that during the lockdown, human presence reduction benefits the bird community, and thus, we predicted higher species richness and abundance when compared with the new normal period.

We surveyed 10 beach arcs located along a stretch of approximately 15 km around the largest hypersaline lagoon in South America (Supplementary Materials, Figure S1). The Araruama Lagoon (latitude 22°40'–22°57' S and longitude 42°00'–42°23' W) covers an area of 220 km^2 and has an average depth of 2.5 m. It includes extensive shallow areas ranging in depth from 0.5–1.5 m, as well as occasional deep holes up to 17 m deep (Kjerfve et al., 1996). The lagoon receives intermittent inflow from several small streams from the north, resulting in an average discharge of approximately 67 × 10^3 m^3 s^{-1} from the main tributaries (Kjerfve et al., 1996). Only one narrow channel (14-km long) connects the lagoon to the sea, limiting the tidal range to between 0.8 and 1.3 m during spring tide (Kjerfve et al., 1996). Despite being predominantly surrounded by densely populated urban areas and receiving domestic sewage in several areas, this hypersaline lagoon still has some preserved areas (Kjerfve et al., 1996). Thus, the Araruama Lagoon continues to offer appropriate habitats for a variety of migratory and resident coastal bird species (Tavares and Siciliano, 2013). Beaches of the Araruama lagoon are not cleaned and potential food scraps for birds are not removed. Recreational fishing was prohibited during the COVID-19 lockdown periods and artisanal fishing also reduced in the sampled beaches.

The period considered as lockdown had restrictions on the use of beaches in the Araruama Lagoon, including mandatory use of a face mask and minimum distance between people (decree No.128 of August 26, 2021). Thus, typical agglomerations for recreational use were prohibited. The birds were counted and identified by species in September and October 2021 (during a lockdown period – "anthropause") and in October 2022 (after the lockdown – "new normal") during the morning (between 06:00 and 11:00). Each of the 10 beaches was sampled once in each period. The "continuous route transect" methodology was applied by the same observer during lockdown and new normal periods on the same 10 beaches (see Bibby et al., 2000 for details). Thus, each of the 10 beaches (at least 1 km away from each other) was fully sampled. The birds were sighted with the aid of binoculars (Nikon Monarch 8 × 42 mm) and a Canon SL3 camera with a 75-300 mm lens.

Using the "raster" (Hijmans, 2022) and "rgdal" (Bivand et al., 2021) packages in R software (R CORE TEAM, 2022), the level of urbanization of each beach was estimated by the Human Modification Metric (HMc) (Kennedy et al., 2019). The dataset provides a comprehensive evaluation of human influence on terrestrial environments globally, utilizing a 1-km resolution format in GeoTIFF, provided by NASA's Socioeconomic Data and Applications Center (SEDAC) (Kennedy et al., 2019). The HMc quantifies the degree of human modification across lands with geographic coordinates, calculated by multiplying the per-pixel product (HMs) of spatial extent and expected impact intensity, including factors such as human population density, built-up areas, croplands, livestock, roads, mining, oil wells, wind turbines, and night-time lights from satellite imagery with 1,000 m resolution raster data. The final HMc value is calculated as:

$$HMc = 1.00 - \prod_{s=1}^{n}(1-(HMs))$$

The fuzzy sum function operates under the assumption that the impact of a particular factor decreases as other stressors also come into play. The HMc index ranges from 0 to 1 and provides a continuous measure of human modification and a good proxy of urbanization level (Barboza et al., 2021).

Data analysis was based in an adapted before-after-control-impact (BACI) design (Underwood, 1992). The beaches sampled have variability of urbanization levels (HMc), thus showing the spatial representation of impact (control and impact). The temporal resolution of BACI approach was provided by comparing coastal bird community between lockdown and new normal times, representing the periods of almost absence and presence of impact from human agglomeration, respectively. The Analysis of Covariance (ANCOVA) was used to investigate the response of community abundance to urbanization (HMc) and time of COVID-19 pandemic (lockdown vs. new normal) including each beach and period as sampling units (n = 20 bird observations). Abundance values were transformed by square root to ensure linearity, homoscedasticity, and normality of the ANCOVA model. We used graphical inspection of residuals to validate linear models (Zuur et al., 2010). Generalized Linear Models (GLM) with negative binomial distribution were applied to test the effect of urbanization (HMc) and time of COVID-19 pandemic (lockdown vs. new normal) on the three more abundant species. These analyses were performed in R-Studio 12.0.

We used the rarefaction curve with the hill index q = 0 to compare species richness between lockdown and new normal periods. This analysis estimates the number of species as function of the abundance values and sampling effort, allowing to compare data from communities in time and space (Chao et al., 2014). The overlapping of 95% confidence intervals of these curves indicates that differences in species richness among treatments are not statistically supported.

Differences in composition and dominance patterns of coastal bird community during lockdown and new normal periods were tested using non-metric multidimensional scaling analysis (nMDS) and Permutational Analysis of Variance (PERMANOVA) at 95% confidence level. These multivariate analyses were based on the Jaccard and Bray-Curtis indexes calculated from the presence/absence and abundance matrix, respectively. These analyses were performed in PRIMER-PERMANOVA 1.0.1.

A total of 204 birds of 9 species were counted in all beaches, 94 in lockdown and 110 in new normal. We found that community abundance was not affected neither by urbanization (F_{ANCOVA} = 0.386, p = 0.543) nor by lockdown (F_{ANCOVA} = 0.336; p = 0.570) (Supplementary Materials, Figure S2A and S2B). The rarefaction analysis also showed overlapping curves and, therefore, a species richness that did not differ significantly between lockdown and new normal periods (Figure. 1). Finally, community composition (pseudo-$F_{PERMANOVA}$ = 0.816, p_{MC} = 0.515) and dominance patterns (pseudo-$F_{PERMANOVA}$ = 15.333, p_{MC} = 0.225) did not differ between lockdown and new normal periods according to PERMANOVA (Supplementary Materials, Figure S3). Thus, our results indicate no significant effect of lockdown and urbanization in terms of general community composition and structure.

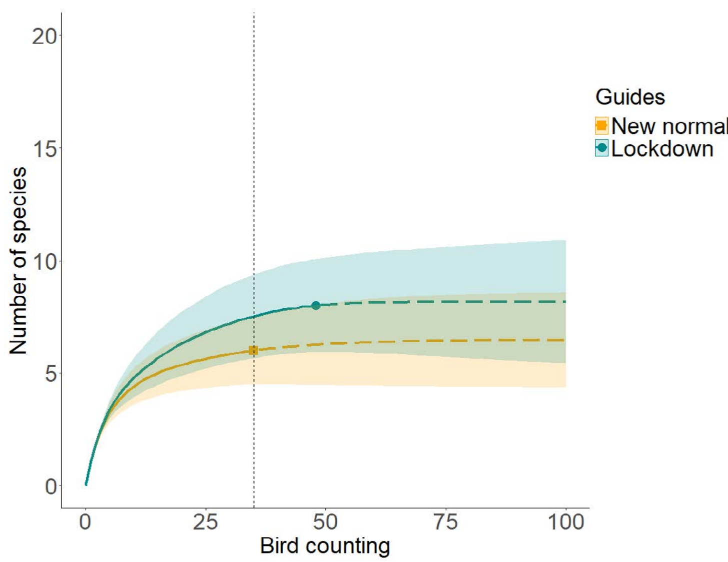

Figure 1. Rarefaction curves comparing the richness of bird species between the lockdown and new normal periods in the largest hypersaline lagoon in South America.

The objective of this study was to compare the shorebird community of Araruama Lagoon before and after the lockdown resulting from the COVID-19 pandemic, also considering the impact of urbanization. A recent study in oceanic sandy beaches showed that the abundance of shorebirds increased during the lockdown (Lewis et al., 2022a). However, with the end of the anthropause and the increased human presence by 34%, a decline of 79.6% in abundance was observed (Lewis et al., 2022a). Opposite to the results of Lewis et al. (2022a), our hypothesis that coastal bird community is richer and more abundant during the lockdown than in new normal period was not corroborated.

Our results demonstrated that the resident bird community of the largest hypersaline lagoon in South America has some resistance to human presence. Indeed, the community is dominated by synanthropic species, such as the Neotropic Cormorant, *Nannopterum brasilianus* (Gmelin, 1789), the Southern Lapwing, *Vanellus chilensis* (Molina, 1782), and the Kelp Gull, *Larus dominicanus* Lichtenstein, 1823 (Ariyama et al., 2019; Je, 2020); together they represented 82% of the total community abundance. This is strong evidence that such species cannot be used as condition indicator species, since they are occurring on urban beaches in the Araruama Lagoon that are typically polluted and overcrowded, mainly during the high tourist season (Costa et al., 2023). Further studies with higher sampling periodicity are necessary to determine if migratory shorebirds, which were absent in our sampling, present a more consistent response to human disturbances during their staying period in Brazil.

Although most species occurred at similar proportions in urban and low-urban beaches in the Araruama lagoon, minor species-specific responses emerged after the COVID-19 lockdown. The Southern Lapwing *V. chilensis* was more abundant during the lockdown on six of the nine beaches where it occurred (Figure 2A), although this difference did not have statistical support according to negative binomial GLM (Chisq = 1.631, p = 0.201). The effect of urbanization was not statistically supported by negative binomial GLM (Chisq = 0.079, p = 0.778) either. This may indicate a tendency of this species using urban areas for resting, nesting, and foraging regardless of human activities. However, the pause of human activities in the lockdown certainly reduced the frequency of agonistic behaviors in the lapwing. Due to its territorial characteristics, the Southern Lapwing displays a diverse range of social and aggressive behaviors that pertain to interactions with other birds and in response to human presence (Delfino and Carlos, 2021). These behaviors represent a negative effect of human presence on the species, increasing energy expenditure and reducing the effort in parental care, potentially leading to reduced chick survival and population sizes (Santos and Macedo, 2011).

Oppositely, the Kelp Gull (*Larus dominicanus*) was more abundant in the new normal period, especially in more urban beaches (Figure 2B). Thus, a statistical support for the interaction between HMc and time of pandemic emerged from the negative binomial GLM (Chisq = 9.639, p = 0.002). The Kelp Gull is a generalist and opportunistic feeder and has benefited from fishing and tourism waste as its main food source in urban areas (Bertucci et al., 2016). Therefore, this species may have been negatively affected by the depleted food scraps during lockdown (Rangel et al., 2020), as suggested by Gilby et al. (2021) for the Torresian crow (*Corvus orru* Bonaparte, 1850). Distinctly, Lewis et al. (2022a) observed a six-fold increase in Kelp Gull abundance during lockdown in Muizenberg Beach on the west coast of South Africa. These markedly different outcomes probably stem from the distinct intensity of human disturbances, which seems to be much greater in Muizenberg Beach than in Araruama lagoon urban beaches. Thus, even tolerant birds do not reach successful metapopulations due to limited space available, noise pollution, and the presence of dogs, and these stressors ceased during lockdown in Muizenberg Beach (Lewis et al., 2022a).

Finally, the Neotropic Cormorant *N. brasilianus* was not affected by urbanization (Chisq = 1.204, p = 0.272), but was more abundant in the new normal in five of the seven beaches where it occurred, although the negative effect of lockdown had no statistical support according to negative binomial GLM (Chisq = 2.831, p = 0.092). This finding indicates that the Neotropic Cormorant is also acclimatized to urban conditions at local scale as expected for a synanthropic species. This species is adapted to feed on various commercial fish (Gil-Weir et al., 2011) that are highly available from artisanal fishing in the Araruama lagoon (Kjerfve et al., 1996). This activity, however, was also interrupted during the lockdown. In contrast, Velando and Munilla (2011), verified that *Phalacrocorax aristotelis* (Linnaeus, 1761) substantially reduced foraging activity as boat use increased, excluding the birds from the best feeding area. This different pattern may result from species-specific responses and variable sensitivity to different stressors. Boats are not as abundant along Araruama Lagoon beaches, thus the benefits provided by human presence probably outweigh disturbances.

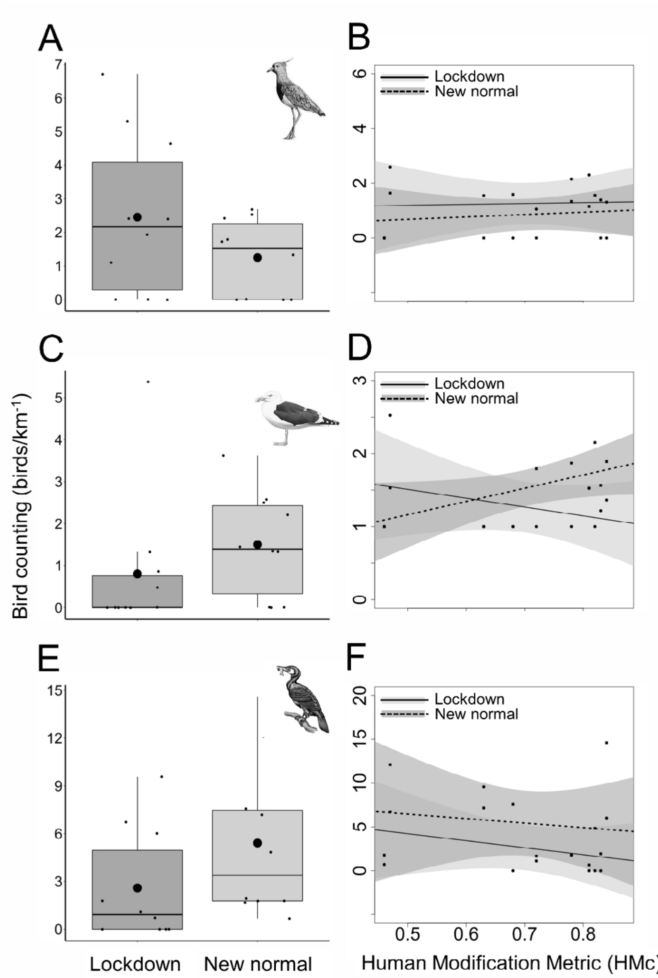

Figure 2. Species-specific responses of coastal birds to urbanization (Hmc – Human modification metric) and lockdown in the largest hypersaline lagoon in South America. A and B: Southern Lapwing, *Vanellus chilensis*; C and D: Kelp Gull, *Larus dominicanus*; E and F: Neotropic Cormorant, *Nannopterum brasilianus*.

Communities from extremophile environments are subjected to strong environmental filters and are usually structured by the individual response of species to physical constraints (as predicted by the Auto-Ecology Hypothesis by (Noy-Meir, 1979). Thus, the ecological implications of our results are likely to be species-specific, mainly since the community has relatively low richness, attenuating the effects of interspecific interactions and possible ecological cascades and regime shifts, including biotic homogenization. Future studies could embrace other taxonomic groups, especially seabird prey, aiming to understand how human activities affect the trophic structure and ecosystem functioning. In this way, the effects of acute and chronic disturbances on ecological processes can be better understood.

Our dataset had relatively limited temporal coverage, but the stabilized rarefaction curve showed that sampling effort was enough to represent the coastal bird community. Thus, our outcomes are valuable and contribute to better describe the anthropogenic impact on coastal environments and the effects of COVID-19 pandemic on biodiversity, especially in extremophile environments inhabited by several bird species such as hypersaline lagoons. In summary, we found minor impact of lockdown on the coastal bird community of the Araruama Lagoon at community level. Some minor specific responses (synanthropic species) emerged, but they did not follow our hypothesis of the anthropause positive effects in general. Our results go against a general pattern of recovery of coastal communities during the COVID-19 lockdown, mainly since the coastal bird assemblage of Araruama Lagoon is dominated by synanthropic species that benefit from interaction with society. This situation presents an opportunity for sustainable urban ecotourism, like birdwatching, to disseminate a biocentric view of the highest hypersaline lagoon in South America and promote environmental education. Effective coastal management should integrate tourism within a broader context and explore innovative funding methods, like "blue bonds" for marine and coastal conservation (Thompson, 2022).

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AUTHOR CONTRIBUTIONS

D.F.R.: Conceptualization; Data curation; Formal analysis; Investigation; Methodology; Project administration; Resources; Validation; Visualization; Writing – original draft; Writing – review & editing.

L.L.C.: Conceptualization; Data curation; Investigation; Methodology; Validation; Visualization; Writing – original draft; Writing – review & editing.

I.B.G: Supervision; Validation; Resources; Writing – original draft; Writing – review & editing.

REFERENCES

Ariyama, N., Moroni, M. & Hernandez, C. 2019. Molecular identification of avian viruses in neotropic cormorants (Phalacrocorax brasilianus) in Chile. *The Journal of Wildlife Diseases*, *55*(1), 105-112. https://doi.org/10.7589/2017-10-256

Barboza, C., Mattos, G., Soares-Gomes, A., Zalmon, I. & Costa, L. 2021. Low Densities of the Ghost Crab Ocypode quadrata Related to Large Scale Human Modification of Sandy Shores. *Frontiers in Marine Science*, *8*. https://doi.org/10.3389/fmars.2021.589542

Ben-Haddad, M., Hajji, S., Abelouah, M., Costa, L., Rangel-Buitrago, N. & Alla, A. 2022. Has the "Covid-19" lockdown an impact on beach faunal communities? The central Atlantic coast of Morocco as a case study. *Marine Pollution Bulletin*. *185*, 114259. DOI: https://doi.org/10.1016/j.marpolbul.2022.114259

Bertucci, T., Silva, E., Marques Jr., A. & Monteiro Neto, C. 2016. Tourism and Urbanization: Environmental Problems of the Araruama Lagoon, State of Rio De Janeiro, Brazil. *Ambiente & Sociedade*, *19*(4), 59-80. https://doi.org/10.1590/1809-4422asoc137111v1942016

Bibby, C., Jones, M. & Marsde, S. (eds.). 2000. *Bird Surveys - Expedition Field Techniques*. London: Expedition Advisory Centre of the Royal Geographical Society.

Bivand, F., Keitt, T. & Rowlingson, B. 2021. rgdal: Bindings for the "Geospatial" Data Abstraction Library.

Brown, S., Hickey, C. & Harrington, B. (eds.). 2000. *United States Shorebird Conservation Plan.* Manomet: Manomet Center for Conservation Sciences.

Chao, A., Gotelli, N. J., Hsieh, T. C., Sander, E. L., Ma, K. H., Colwell, R. K. & Ellison, A. M. 2014. Rarefaction and extrapolation with Hill numbers: a framework for sampling and estimation in species diversity studies. *Ecological Monographs*, *84*(1), 45-67. https://doi.org/10.1890/13-0133.1

Coleman, J. & Milton, D. 2012. Feeding and roost site fidelity of two migratory shorebirds in Moreton Bay, South-Eastern Queensland, Australia. *The Sunbird*, *42*, 41.

Costa, L., Rangel, D. & Zalmon, I. 2023. The presence of COVID-19 face masks in the largest hypersaline lagoon of South America is predicted by urbanization level. *Marine Pollution Bulletin*, *189*, 114746. https://doi.org/10.1016/j.marpolbul.2023.114746

Costa, L., Tavares, D., Suciu, M., Rangel, D. & Zalmon, I. 2017. Human-induced changes in the trophic functioning of sandy beaches. *Ecological Indicators*, *82*, 304-315. https://doi.org/10.1016/j.ecolind.2017.07.016

Delfino, H. C. & Carlos, C. J. 2021. Macro and micro-habitat selection by Vanellus chilensis (Aves: Charadriiformes) in southern Brazil. *El Hornero*, *36*(1), 11-20.

MacGregor-Fors, I., Arbaláez-Cortés, E., Estela, F. A., Ocampo, D., Sánchez-Sarria, C. E., García-Arroyo, M., Aguirre-Samboní, G. K., Cortés-Díaz, D., Franco Morales, J. C., Gaitán-García, C. D., Guerrero-Pelaez, S., Gutiérrez Parodys, Y., Holguín-Ruiz, M., Meza-Angulo, E., Vides, H. A. & Wilches-Vega, J. D. 2022. Increases in avian diversity associated with COVID – 19 lockdowns in urban Colombia. *Animal Biodiversity and Conservation*, *45*(2), 553-572.

Gilby, B. L., Henderson, C. J., Olds, A. D., Ballantyne, J. A., Bingham, E. L., Elliott, B. B., Jones, T. R., Kimber, O., Mosman, J. D. & Schlacher, T. A. 2021. Potentially negative ecological consequences of animal redistribution on beaches during COVID-19 lockdown. *Biological Conservation,* 253, 108926. https://doi.org/10.1016/j.biocon.2020.108926

Gil-Weir, K., Weir, E., Casler, C. L. & Aniyar, S. 2011. Ecological functions and economic value of the Neotropic Cormorant (Phalacrocorax brasilianus) in Los Olivitos Estuary, Venezuela. *Environment and Development Economics*, *16*(5), 553-572.

Gordo, O., Brotons, L., Herrando, S. & Gargallo, G. 2020. Rapid behavioural response of urban birds to COVID-19 lockdown. *Biological Conservation*, *253*, 108926. https://doi.org/10.1101/2020.09.25.313148

Hijmans, R. J. 2022. Geographic Data Analysis and Modeling [R package raster version 3.6-3].

Je, J. 2020. A Review of Avian Influenza A Virus Associations in Synanthropic Birds. *Viruses*. *12*, 1209.

Jourdan, C., Fort, J., Pinaud, D., Delaporte, P., Gernigon, J., Lachaussée, N., Lemesle, J.-C., Pignon-Mussaud, C., Pineau, P., Robin, F., Rousseau, P. & Bocher, P. 2021. Nycthemeral Movements of Wintering Shorebirds Reveal Important Differences in Habitat Uses of Feeding Areas and Roosts. *Estuaries and Coasts*, *44*(5), 1454-1468. https://doi.org/10.1007/s12237-020-00871-5

Kennedy, C. M., Oakleaf, J. R., Theobald, D. M., Baruch-Mordo, S. & Kiesecker, J. 2019. Managing the middle: A shift in conservation priorities based on the global human modification gradient. *Global Change Biology*, *25*(3), 811-826. https://doi.org/10.1111/GCB.14549

Kennedy, C., Oakleaf, J., Theobald, D., Baruch-mordo, S. & Kiesecker, J. 2019. Managing the middle: A shift in conservation priorities based on the global human modification gradient. *Global Change Biology*, 25(3), 811-826. https://doi.org/10.1111/gcb.14549

Kjerfve, B., Schettini, C., Knoppers, B., Lessa, G. & Ferreira, H. O. 1996. Hydrology and salt balance in a large, hypersaline coastal lagoon: Lagoa de Araruama, Brazil. *Estuarine, Coastal and Shelf Science*, 42, 701–725. https://doi.org/10.1006/ecss.1996.0045

Lafferty, K. D. 2001. Birds at a Southern California Beach: Seasonality, Habitat Use and Disturbance by Human Activity. *Biodiversity and Conservation*, *10*, 1949–1962. https://doi.org/10.1023/A:1013195504810

Lewis, J., Collison, J. & Pillay, D. 2022. Effects of COVID-19 lockdowns on shorebird assemblages in an urban South African sandy beach ecosystem. *Scientific Reports*, *12*(1), 5088. https://doi.org/10.1038/s41598-022-09099-8

Møller, A. P., Díaz, M., Flensted-Jensen, E., Grim, T., Ibáñez-Álamo, J. D., Jokimäki, J., Mänd, R., Markó, G. & Tryjanowski, P. 2015. Urbanized birds have superior establishment success in novel environments. *Oecologia*. https://doi.org/10.1007/s00442-015-3268-8

Murchison, C. R., Zharikov, Y. & Nol, E. 2016. Human Activity and Habitat Characteristics Influence Shorebird Habitat Use and Behavior at a Vancouver Island Migratory Stopover Site. *Environmental Management*, 58(3), 386-398. https://doi.org/10.1007/s00267-016-0727-x

Noy-Meir, I. 1979. Structure and function of desert ecosystems. *Israel Journal of Plant Sciences*. *28*(1), 1-19. DOI: https://doi.org/10.1080/0021213X.1979.10676851

R Core Team. 2022. R: A language and Environment for Statistical Computing.

Rangel, D.F., Castro Tavares, D., Zalmon, I.R., 2020. Composição e abundância de aves marinhas costeiras em Arraial do Cabo, Estado do Rio de Janeiro, Brasil. *Ornithologia 11*(1), 1-6

Rutz, C., Loretto, M.C., Bates, A.E., Davidson, S.C., Duarte, C.M., Jetz, W., Johnson, M., Kato, A., Kays, R., Mueller, T., Primack, R.B., Ropert-Coudert, Y., Tucker, M.A., Wikelski, M., Cagnacci, F., 2020. COVID-19 lockdown allows researchers to quantify the effects of human activity on wildlife. *Nature Ecology and Evolution*. *4*, 1156–1159. https://doi.org/10.1038/s41559-020-1237-z

Santos, E. S. & Macedo, R. H. 2011. Load lightening in southern lapwings: group-living mothers lay smaller eggs than pair-living mothers. *Ethology*, *117*(6), 547-555.

Scarton F. 2017. Long-term trend of the waterbird community breeding in a heavily man-modified coastal lagoon: the case of the Important Bird Area “Lagoon of Venice”. *Journal of Coastal Conservation*, *21*, 35-45.

Sheaves, M., Baker, R., Nagelkerken, I. & Connolly, R. M. 2015. True value of estuarine and coastal nurseries for fish: incorporating complexity and dynamics. *Estuaries Coasts, 38*, 401-414.

Tavares, D. C., Guadagnin, D. L., Moura, J. F., Siciliano, S. & Merico, A. 2015. Environmental and anthropogenic factors structuring waterbird habitats of tropical coastal lagoons: Implications for management. *Biological Conservation*, *186*, 12-21. https://doi.org/10.1016/j.biocon.2015.02.027

Tavares, D. C. & Siciliano, S. 2013. An inventory of wetland non-passerine birds along a southeastern Brazilian coastal area. *Journal of Threatened Taxa*, *5*(11), 4586-4597. https://doi.org/10.11609/JoTT.o3424.4586-97

Thompson, B. S. 2022. Blue bonds for marine conservation and a sustainable ocean economy: Status, trends, and insights from green bonds. *Marine Policy*, *144*, 105219.

Underwood, A.J., 1992. Beyond BACI: the detection of environmental impacts on populations in the real, but variable, world. *Journal of Experimental Marine Biology and Ecology*, *161*, 145-178.

Velando, A. & Munilla, I. 2011. Disturbance to a foraging seabird by sea-based tourism: Implications for reserve management in marine protected areas. *Biological Conservation*, *144*(3), 1167-1174.

Zuur, A. F., Ieno, E. N. & Elphick, C. S. 2010. A protocol for data exploration to avoid common statistical problems: data exploration. Methods in Ecology and Evolution, *1*(1), 3-14. https://doi.org/10.1111/j.2041-210X.2009.00001.x