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Baseline

Has the “Covid-19” lockdown an impact on beach faunal communities? The central Atlantic coast of Morocco as a case study

Mohamed Ben-Haddad\textsuperscript{a,}\textsuperscript{*}, Sara Hajji\textsuperscript{a}, Mohamed Rida Abelouah\textsuperscript{a}, Leonardo Lopes Costa\textsuperscript{b}, Nelson Rangel-Buitrago\textsuperscript{c,d}, Aicha Ait Alla\textsuperscript{a}

\textsuperscript{a} Laboratory of Aquatic Systems, Marine and Continental Environments (AQUAMAR), Faculty of Sciences, Ibn Zohr University, Agadir, 80000, Morocco
\textsuperscript{b} Laboratório de Ciências Ambientais, Universidade Estadual do Norte Fluminense Darcy Ribeiro, Avenida Alberto Laneiro, 2000, Campos dos Goytacazes CEP, Rio de Janeiro, Brazil
\textsuperscript{c} Programa de Física, Faculdade de Ciências Básicas, Universidade do Atlântico, Barranquilla, Atlântico, Colombia
\textsuperscript{d} Programa de Biologia, Faculdade de Ciências Básicas, Universidade do Atlântico, Barranquilla, Atlântico, Colombia

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\textbf{A B S T R A C T}

The restrictions related to the COVID-19 pandemic have led to a global hiatus in anthropogenic activities; several scientists have utilized this unique opportunity to assess the human impact on biological systems. In this study, the study describes for a period of five years (2018–2022) how the faunal community have been affected by human disturbances, as well as the effect of the “anthropause” period driven by the COVID-19 lockdown. The results confirmed human disturbances on faunal communities related to coastal urbanization. It was found that the “anthropause” period showed the highest values of abundance and biomass, hence the “COVID-19 lockdown” allowed recovery of faunal communities. The findings highlight the impact of human disturbances and that the community showed resilience. Overall, the authorities must perform restrictive measures aiming to mitigate the impact of anthropogenic activities in the study area including the banning of off-road and recreational vehicles, carrying out efficient cleaning and grooming operations, monitoring the severe harvesting of edible species, as well as penalizing the disposal of anthropogenic waste and sewage discharge from the touristic facilities. Likewise, management actions such as the temporal beach closures and the regular surveillance could be advantageous to provide a more sustainable exploitation of sandy beaches.

Sandy beaches are dynamic environments that compose two-thirds of the world’s coastlines (McLachlan and Defeo, 2018). These ecosystems are considered a shelter place where physical, ecological, social, and economic dimensions interact, providing several services for humans (Defeo et al., 2021). Sandy beaches experience continuous stressors such as tourism activities, including trampling, vehicle traffic, pollution, and poor waste management (Costa et al., 2020; Abelouah et al., 2021). The metamorphosis of coastal areas into tourist destinations has caused changes in socio-spatial relationships, leading to the alteration of landscapes and further environmental degradation (Rangel-Buitrago et al., 2018, 2019).

Coastal urbanization is the development associated with the increase of urban population over time in proportion to a region’s rural population (Burt et al., 2019). World human populations are heavily concentrated on sandy beaches, and growing urbanization is putting increasing pressure on beach ecosystems. While the continued growth of coastal cities can provide some economic benefits (UNEP, 2020), these often come at considerable costs to the environment (Duarte et al., 2008). Coastal urbanization is a global phenomenon whose impacts are increasingly pronounced on sandy beaches (Cardoso et al., 2016). It becomes essential to decipher how urban environmental stressors influence faunal abundance, behavior, and physiology (McPhearson et al., 2016). Several coastal species may respond negatively to human disturbances related to urbanization (Costa et al., 2020), thus they can play a key role in the character, functioning and health status of their habitat, acting as ecological disturbance indicators (González et al., 2014, Célentano et al., 2019). The aggregate descriptors of faunal communities are an informative measure that can be useful for many ecosystem-level questions (Rodil et al., 2014).

The target area of the current study is located on the central Atlantic coast of Morocco, which is considered one of the most important coastal areas of the Moroccan coastline (Abelouah et al., 2022a). Thanks to its

\textsuperscript{*} Corresponding author.
E-mail address: mohamed.ben-haddad@edu.uiz.ac.ma (M. Ben-Haddad).

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diverse ecosystems (wetlands, sandy beaches and rocky shores, estuaries, sand dunes, coral reefs and rivers), the marine realm of this part of the country plays a crucial role in its economic development (Ben-Haddad et al., 2022a). Hence, the central Atlantic coast of Morocco is a harbor of a plethora of human activities (tourism, industry, fishing, etc.) that can alter and damage coastal habitats (Lamine et al., 2020; Abe-louah et al., 2022b). The study area has been subjected to high pressures from urban development, mainly related to the construction of tourist facilities such as the “Taghazout Bay”, a 615-ha seaside tourist complex. This complex currently has hotels, tourist villages, restaurants, small shops, a beach club, a medina and golf, tennis, surfing and soccer academies (Ben-Haddad et al., 2022b). These activities attract national and international visitors as well as beachgoers, representing a major source of local disturbances to the faunal communities.

After the declaration of the novel coronavirus disease COVID-19 as a global health emergency in 2020 (Xu et al., 2020), the Moroccan government put in place a series of measures to prevent the transmission of the virus, including the temporary closure of beaches. This "anthropause" caused by the pandemic was utilized to assess the recovery capability of the faunal communities when there was an absence of major human activities on the coast. Several authors found significant impacts of this period on beach quality (Zambrano-Monserrate et al., 2020; Ben-Haddad et al., 2021a, 2021b). No study has assessed the status of all intertidal fauna communities following an urbanization degree during a medium-term period of five years, including the global anthropause. The aim of the study was to fill this gap by conducting a survey from the year 2018 to the year 2022 in central Atlantic coast of Morocco. The authors hypothesize that the sandy beach intertidal community was richer and more abundant during the lockdown (~2020) compared to pre- (2018 and 2019) and post-lockdown periods (2021 and 2022).

The faunal communities inhabiting the intertidal sand were collected each summer season from 2018 to 2022 using a grab (1m$^2$, 50 cm depth) in six sampling sites located along the central Atlantic coast of Morocco (Fig. 1) (Elliott and Decamps, 1973; Fanini and Lowry, 2016). Each sample was sieved through a 1 mm mesh and fixed in formaldehyde (8%), then rinsed in freshwater and preserved in ethanol (70%), following the methodology used by Ben-Haddad et al. (2021b). Species abundance was measured as the number of individuals sampled per square meter (ind/m$^2$) and species richness as the number of species reported in each campaign. To obtain biomass values, the fresh weight of all sampled species was measured, then they were dried at 50 °C for 48 h to obtain the dry weight. Then each sample was heated at 500 °C (5 h) in a furnace, cooled, and ash weight was measured with an analytical scale. The ash-free dry weight was calculated by subtracting the ash weight from the dry weight (Horn and de la Vega, 2016). Biomass was expressed as weight per square meter (g/m$^2$). The total organic matter (TOM) was determined by the mass loss on ignition (LOI) method at a temperature of 500 °C for 24 h (Touch et al., 2017).

An urbanization index was calculated to assess the urbanization level of each year, applying the following equation (Gonzalez et al., 2014; Costa et al., 2017):

$$X = \frac{\sum (X - X_{min})}{(X_{max} - X_{min})}$$

$X$ is the mean value of the urbanization index for each year, $X$ is the score of each category (SI Table 1), $X_{max}$ and $X_{min}$ are values from 0 to 5. The urbanization index categories as described in Gonzalez et al. (2014) are the proximity to urban centers, buildings on the sand, cleaning of the beach, solid waste in the sand, vehicle traffic on the sand, quality of the night sky and frequency of visitors.

Upon the invalidation of the normality assumption (Shapiro-Wilk test), the data were normalized using the natural logarithm transformation. The differences in species abundance and richness between the periods of study were analyzed using one-way ANOVA and the Tukey-Kramer test for multiple comparisons. The differences in biomass and TOM were analyzed using two-way ANOVA and the Tukey-Kramer test for multiple comparisons. The differences in urbanization index were analyzed using the Kruskal-Wallis test and the Dunn’s test for multiple comparisons. All analyses were conducted using the R software (R Core Team, 2019).

Fig. 1. 3D Map of the study area with the sampling points and some photos during the sampling period.
A significant difference (p < 0.05) in community abundance was found between years except for 2018 compared to 2021 and 2019. The lowest mean abundance value was found in 2022 (29.33 ± 5.61 ind/m²) and the highest in 2020, during the lockdown (68.16 ± 8.81 ind/m²) (Fig. 2a).

The highest mean richness was found in 2020 (6.33 ± 0.81 species) during the lockdown, whereas, diversity reported the lowest mean richness in 2022 (1.83 ± 0.75 species) (Fig. 2b; SI Table 2). No significant difference was found between the first three years (p > 0.05), but there was a significant decline of species richness in 2021 and 2022 (p < 0.05). The species reported in the current study are Donax trunculus Linnaeus, 1758, Turritellinella tricarinata (Brocchi, 1814), Cymbium cucumis Röding, 1798, Portunus latipes (Pennant, 1777), Macomangulus tenuis (da Costa, 1778), Natica royi Pin, 1992, Talitrus saltator (Montagu, 1808) and Eurydice pulchra Leach, 1815.

The highest biomass values were also found in the lockdown, representing a mean of 79.66 ± 10.46 g/m². The lowest biomass was recorded in 2022 (25 ± 5.83 g/m²) (Fig. 2c). A significant difference was found between the years except for 2018 compared to 2021, and 2019 compared to 2021 and 2022.

The urbanization index increased from 2018 to 2022, with a decline in 2020 (SI table 1). Before the lockdown, index values were 0.46 in 2018 and 0.77 in 2019. The urbanization degree decreased to 0.31 during the lockdown (2020). In the post-lockdown period, urbanization reached 0.88 in 2021 and 0.91 in 2022. The continuous construction of the tourist resort “Taghazout Bay” and other units (residential blocks, camps, and restaurants) increased the proximity of the coast to urban centers. The proliferation of buildings reached the sand and changed all the coastal scenery. The new infrastructure attracts more visitors, who were nearly absent during 2020 lockdown restrictions. The beach has had various activities related to the high frequency of visitors, such as vehicle traffic on the sand, more solid waste, and further cleaning operations. Light pollution is evident due to the artificial night brightness, while, many hotels and restaurants were closed in the 2020 lockdown, leading to the absence of artificial night light.

Similarly, Fanini et al. (2005) analyzed the impact of trampling and mechanical beach cleaning on Talitrus saltator. They found that the population density was affected by these activities. Then, the T. saltator community recolonized the beach once the peak of the tourist season had passed. Also, Delgado and Silva (2018) highlighted that high levels of anthropogenic pressure could compromise future recruitments and decreases the oocytes production of Donax trunculus. Moreover, Schlacher et al. (2008) confirmed the link between beach traffic and lethal damages caused by vehicles to beach invertebrates, using surf clams Donax deltoides as a bioindicator.

The anthropause provided a unique opportunity to depict the effects of human absence in urban coastal ecosystems (Soto et al., 2021). Existing information show that urbanization has decreased species richness and biomass on sandy beaches worldwide (Orlando et al., 2020; Corte et al., 2022). However, as multiple stressors acting simultaneously affect urban beaches, the relative importance of each has been difficult to reveal. The ceaseless tourist activities spreading on urban beaches worldwide should be taken into account when considering the management of stressors impacting coastal life and ecosystem services they provide (McLachlan and Defeo, 2018). For instance, low biomass on highly urbanized beaches represents low trophic efficiency and prey availability for transient fauna, especially fishes and birds (Costa et al., 2017).

Total organic matter recorded its lowest value during the lockdown period, 2.66 ± 0.90 % (Fig. 3). Whereas, it reached high levels before and after the lockdown peak (9.03 ± 1.13 % in 2019 and 8.41 ± 1.50 %

![Fig. 2. Boxplot graphs displaying in a) community abundance (ind/m²); b) species richness; and c) biomass data (g/m²) during the study period (2018–2022).](image-url)
in 2022). Therefore, the marine litter disposal by the beachgoers in the study (Abelouah et al., 2021) as well as the occasional sewage by the tourist facilities on the beach (Ben-Haddad et al., 2022b) contribute to the elevation of organic matter content in the sediment. Visitors’ absence during the lockdown may have reduced the organic waste on the beach. Pearson and Rosenberg (1978) argued that the organic enrichment of the beach itself contribute to high bacterial decomposition. This may lead to a lowering of oxygen tension available to the fauna and thus low or absent diversity is generated. In contrast, more recent studies have revealed the importance of benthic carbon sources to macrofaunal food webs, and typically find high faunal density and diversity under higher organic matter content (Maria et al., 2011; Bergamino et al., 2012; Aviz et al., 2019). Sibaja-Cordero et al. (2019) showed that differences in faunal richness, abundance, and composition could be explained by environmental differences (grain size composition and total organic matter) in sandy beaches of Costa Rica. This weakens the argument in favor of negative causal effects of organic enrichment in the community descriptors raised in the current study.

However, the LDA vector plot based on the data of abundance, species richness, and biomass (Fig. 4) showed different community patterns before the pandemic (2018 and 2019), during the lockdown period (2020), and after the lockdown peak (2021 and 2022). As higher abundance and biomass values were found during the anthropause, the noticeable reduction in human activities allowed the recruitment, longevity, and reproduction corroborating various studies globally. Costa et al. (2022a) reported that the recovery of the ghost crab metapopulation occurred even in more human-modified beaches during the lockdown. They showed that young metapopulations have thrived on urban beaches when recreational activities ceased.

Microplastic pollution is one example of how anthropogenic activities can affect the faunal communities of sandy beaches besides trampling, cleaning, and vehicle traffic. Indeed, Cho et al. (2021) and Ben-Haddad et al. (2022b) reported that microplastic contamination in the fresh tissue of bivalves living in sandy beaches was relatively high in urbanized areas that attract high and several anthropogenic activities. Significantly, it has been shown that they provoke neurotoxicity and oxidative stress to key species of beach communities (Tlili et al., 2020; Costa et al., 2020). Overall, this may be one of the variables that partially explain the low biomass of species in the most urbanized beach sectors (Costa et al., 2022b). At any rate, some of the eight dominant species reported in the current study are well-known indicator species of ecological disturbance of tourism-related activities (Costa et al., 2020), which ceased temporarily during the lockdown.

On the other hand, the lockdown period revealed a positive effect on shrimp species in the Catalan Sea (Spain), especially the deep-water rose shrimp, when there was reduced fishing (Coll et al., 2021). Similar to the results of the present study, these authors demonstrated that the positive effects gradually disappeared with the relaxation of the lockdown. Likewise, Soto et al. (2021) examined bioindicators from several tourist

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**Fig. 3.** The total organic matter (TOM) of sediment during the study period (2018–2022).

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**Fig. 4.** Linear Discriminant Analysis (LDA) plot displaying groups of similarity between the years.
beaches in Latin American countries in the time of COVID-19 climax, and found positive changes in biological components, clear decrease in human stressors, and high burrow density of ghost crabs along twenty-nine beaches in seven countries of South America. In addition, China et al. (2021) reported that the lockdown elicited a behavioral response that resulted in elevated species richness at designated reef entrances. Researchers also encountered a higher percentage of nesting turtles Dermochelys coriacea during the lockdown (Quesada-Rodriguez et al., 2021).

The negative side of the “COVID-19 anthropause” should be noted, usually related to litter pollution. Meaningfully, the Personal Protective Equipment (PPE) driven by beachgoers is considered as an emergent contaminant of sandy beaches; making benthic organisms and invertebrates vulnerable to adverse interactions (Ben-Haddad et al., 2021a; Dioses-Salinas et al., 2022; Mvovo and Magagula, 2022).

In conclusion, the COVID-19 lockdown permitted recovery of faunal communities in a Moroccan coast recorded an increasing degree of urbanization. The peak of pandemic lockdown has enhanced the awareness regarding the gravity of human activities. Additionally, the paradoxical findings regarding the positive and negative effects of the global “COVID-19 anthropause” oblige the continuous surveillance of sandy beaches, which would be highly recommended to shed light on coastal management as an urgent situation. Unquestionably, management strategies could avoid, prevent, or mitigate environmental, economic, and social losses driven by the negative impacts of urbanization and related problems. Hence, authorities must carry out restrictive measures such as banning off-road and recreational vehicles, providing efficient cleaning and grooming operations, controlling the intense harvesting of edible species (Donacidae), as well as penalizing the irresponsible disposal of anthropogenic waste and the sewage discharge from the touristic facilities. Additionally, temporal beach closures and regular biomonitoring could favor the resilience of fauna to stressors on urban coasts. Thus, zoning strategies and marine reserves could be key tools for biodiversity conservation. These actions must emerge from the concept that beaches represent a vital role in ecology and socioeconomics.

CRediT authorship contribution statement

Mohamed Ben-Haddad: Sampling, Conceptualization, Methodology, Validation, Formal analysis, Writing - Original Draft, Review & Editing.
Sara Hajji: Validation, Formal analysis, Writing - Original Draft, Review & Editing.
Mohamed Rida Abelouah: Validation, Formal analysis, Writing - Original Draft, Review & Editing.
Nelson Rangel-Buitrago: Conceptualization, Methodology, Validation, Formal analysis, Writing - Original Draft, Review & Editing.
Aicha Ait Alla: Conceptualization, Methodology, Validation, Formal analysis, Writing - Original Draft, Review & Editing.

Declaration of competing interest

The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Data availability

Data will be made available on request.

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Appendix A. Supplementary data

Supplementary data to this article can be found at https://doi.org/10.1016/j.marpolbul.2022.114259.

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