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Impacts of the COVID-19 pandemic restrictions on solid waste pollution in the worldwide iconic Copacabana Beach (Rio de Janeiro, Brazil)

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ABSTRACT

Total and partial restrictions to beach access during COVID-19 pandemic created an opportunity to evaluate its effect on coastal pollution. We aimed to determine the impact of access restrictions on solid waste pollution at Copacabana beach, Brazil. Solid waste amount was analyzed considering beach access restrictions: unrestricted, total closure, partial restriction, new normal. Relationships of atmospheric temperature and precipitation with access restrictions were assessed and confounding effects controlled for further analyses. Beach access restrictions significantly reduced solid waste pollution at Copacabana beach, beach closure reduced waste amount in 72 %. Partial restrictions and new normal periods have significantly reduced solid wastes amount on the beach in 60 % and 36.88 %, respectively. Qualitative data revealed that most of solid wastes were single-use plastics recently disposed at Copacabana beach, reflecting beachgoer's effects on waste left on the beach. A positive impact of COVID-19 pandemic restrictions was detected on solid waste pollution at Copacabana beach.

Litter accumulation in coastal ecosystems has become a global growing problem and challenge (Schneider et al., 2018). Marine litter (i.e., “any anthropogenic, manufactured, or processed solid material regardless of size” discarded, disposed of, or abandoned that ends up in the marine environment”; UNEP and NOOA, 2012) represents a threat to animals, biodiversity, and public health (Fossi et al., 2018; Schneider et al., 2018; Shen et al., 2019; Takada and Karapanagioti, 2019). The presence of marine litter on coastal areas has also an economic and social cost, since litter pollution reduces the tourism and recreational activities, and increase the municipal costs for litter management (Newmann et al., 2015). Different amounts and types of litter have been found along Brazilian coast, where plastics represent the main item on sandy beaches (Andrades et al., 2020), similarly to other coastal systems worldwide (Schneider et al., 2018).

Sandy shores provide a wide range of ecosystem services (e.g., coastal protection, water catchment and purification, wildlife maintenance, aesthetic and recreational value), and many of them are essential to support human uses of coastal areas (Barbier et al., 2011). The intrinsic ecological values and functions provided by beaches are often perceived as secondary to their economic and social value (Schlacher et al., 2007). Therefore, beaches are attractive areas subjected to multiple disturbances, especially the urban ones located at large coastal cities (Cabioch and Robert, 2022). These anthropogenic impacts are leading to losses in biodiversity, productivity, and habitats, as well as modifications of the subtidal zone that is important for the recruitment of many species (Schlacher et al., 2007). Sandy beaches are also considered sinking areas of marine litter (Mclachlan and Defeo, 2018), where these debris can alter the physical properties of sediments (e.g., heat transfer, grain compaction, and permeability; Caron et al., 2011), reduce beach aesthetic value, and harm marine fauna (Fossi et al., 2018, 2020).

The disease that started as an outbreak of unknown origin pneumonia reported in Wuhan (China) was declared as COVID-19 pandemic on 11th March 2020 by the World Health Organization (WHO), following the coronavirus (SARS-CoV-2) spread in 114 countries (WHO, 2020). Since the beginning of COVID-19 pandemic, humanity has paid a high price in terms of human lives lost, mental and health injuries, sudden changes in society behavior, economic costs, and increased poverty (e.g., Daniel, 2020; Pfefferbaum and North, 2020). In Brazil, a greater spread of the coronavirus began just after the carnival holiday in...
March 2020. At that time, >10 million people were agglomerated just at the Rio de Janeiro city, among them 2.1 million of tourists (Rio City Hall, 2020). So far, the global spread of coronavirus has infected >290 million people in the world, leading to >5 million human deaths (WHO, 2022).

The persistence of this global pandemic has shifted the priority to people’s health, with little focus on how the human behavioral changes and social restrictions imposed by coronavirus spread would impact the urban coastal ecosystems. The battle against coronavirus has elicited negative indirect environmental effects. The applied measures attempting to prevent the virus spreading have reduced recycling, stimulated consumption of single-use plastics for safety and hygiene reasons that were inadvertently disposed in urban beaches, and promoted the mixing of medical waste (e.g. contaminated masks, gloves, used or expired medications) with domestic waste, leading to a worst scenario of soil contamination (Zambrano-Monserrate et al., 2020; Okuku et al., 2021; Robin et al., 2021; Silva et al., 2021; Yang et al., 2021). However, beach closures and low frequency of beachgoers have also led to a reduction in litter amount and foam pollution, improvement of water quality, fauna enhancement, and recovery of coastal ecosystem health and processes (Zambrano-Monserrate et al., 2020; Edward et al., 2021; Okuku et al., 2021; Soto et al., 2021).

Total and partial restrictions to urban beach access imposed by COVID-19 pandemic created a great opportunity to evaluate the magnitude of beachgoers effect on waste pollution at these coastal systems. Therefore, this study aimed to determine the impact of COVID-19 pandemic restrictions on solid waste pollution at Copacabana beach, one of the most iconic beaches worldwide. For that, we have analyzed and compared the amount of solid waste collected at four different periods of human access restrictions to Copacabana beach. Moreover, we have also assessed the relationships of atmospheric temperature and precipitation with beach restriction periods to control for their effects from subsequent analysis. Copacabana beach, located in the south zone of the Rio de Janeiro city - Brazil, is an urban tourist sandy beach easily accessed by multiple public transport options. It is an oceanic beach, with a wide strip of sand and a surf region, as well as 4.2 km of shoreline oriented to SW-NE. The beach arc is delimited by two rocky shores from the eastern end of Leme beach (22° 57′ 46″ S; 43° 09′ 52″ W) to the Copacabana Fort (22° 59′ 09″ S; 43° 11′ 16″ W) (Ivan et al., 2009), protecting Copacabana beach from the action of winds and waves. Morphodynamic beach state varies from intermediate to reflective, with an intertidal slope (1/m) of 23.56 and 13.79, and medium sand (Veloso et al., 2006). In terms of population, the Copacabana neighborhood is the most populous in the South zone of Rio de Janeiro city, with >140,000 inhabitants (IBGE, 2010). It is also the beach that attracts more daily visitors and tourists (166.66–323.50 persons/50 m²; Veloso et al., 2006), having >80 hotels that frequently reach their full capacity during summer vacation and holidays. The most famous sandy beach in Brazil, Copacabana has become a symbol of Rio de Janeiro city (Ivan et al., 2009). Thus, considering its high cultural, socio-ecological, and economic importance, this beach was chosen as model in this pioneer study to determine the impacts of beach access restrictions on solid waste pollution.

Quantitative data of solid waste (t) daily collected twice a day on the sand of all beach extension were provided by Municipal Urban Cleaning Company of Rio de Janeiro (COMLURB) from January 2019 to June 2021, in addition data of accumulated solid waste were provided for the month of May 2021. The beach consists of north and south, where the kiosks are located (supratidal) to the portion where the wave interacts with the coastline (intertidal), covering the entire length of the Copacabana coastline. Litter sampling on the beach was carried out by trained collectors from the urban cleaning company (>370 persons/shift) in two shifts: from 7:00 am to 3:00 pm, and from 4:00 pm to 0:00 am. In the first shift, the collectors were separated into beach sectors to simultaneously perform the cleaning in the entire beach extension and the most visible solid wastes were collected in the sand strip using forks and then bagged. In the second shift, small tractors performed the mechanized cleaning after the manual cleaning and removal of litter by the trained collectors along the entire length of the beach. Mechanized cleaning was performed in the two shifts at New Year’s Eve holiday that is traditionally celebrated at Copacabana beach attracting thousands of people. All the collected solid waste was weighed at the end of the day and sent to a landfill with the help of tractors with trailers to remove the litter bags (Teixeira, 2010). Qualitative analysis was only performed with solid waste collected before pandemic restrictions (2018–2019) following social restrictions and recommendations from local health agency. All solid wastes found in delimited areas (250 m of extension) from the supratidal to the intertidal were manually collected at four independent periods before quantitative sampling. Data of accumulated precipitation (mm) and mean atmospheric temperature (°C) acquired by the meteorological station at Copacabana (22° 59′11″S; 43° 11′21″W) were compiled for the whole period analyzed (2018–2021). Meteorological data are online available at the public database Rio Alert System (https://alertario.rio.rj.gov.br/).

Information related to access restrictions to the beaches during the COVID-19 pandemic was compiled from the official journal of Rio de Janeiro municipality (https://doweb.rio.rj.gov.br/). Strict restrictions were applied by local government using municipal guards to supervise and control beach access, and violations resulted in fines. Additional information was searched on Google using the keywords “access to Rio de Janeiro beaches” and “COVID-19 beaches”, in Portuguese. Due to the social restrictions imposed by the COVID-19 pandemic, the access to Copacabana beach was free and “unrestricted” (n = 64 weeks from January 1, 2019 to March 14, 2020). During lockdown due to the COVID-19 pandemic, there was a total restriction to beach access - “beach closure” (n = 16 weeks from March 15 to May 30, 2020 and from March 21 to April 24, 2021). After that, “partial restriction” to beach access consisted in periods that staying in the sand for sunbathing was prohibited, but people were allowed to access the beach for sport activities (n = 24 weeks from May 31 to October 31, 2020 and from April 25 to May 08, 2021). When beach access was completely free, even with social restrictions (e.g., people agglomeration was not allowed) imposed by the pandemic, the period was classified as “new normal” (n = 29 weeks from November 01, 2020 to March 20, 2021 and from May 09 to June 30, 2021). Data availability (i.e., n = number of weeks) by beach access category was determined by the official restrictions due to COVID-19 pandemic.

Variations of meteorological variables -mean atmospheric temperature and accumulated precipitation per week- were tested among beach restriction periods through multivariate permutation analysis (PERMANOVA). When the effect was significant, generalized additive models (GAMs; normal distribution; Gaussian identity as linkage function) followed by Akaike’s information criterion (AIC) were applied to identify the relationship between the meteorological variable and solid waste on the beach. In addition, the meteorological variables were applied as covariates in subsequent analyses to control for their effects on dependent data, considering the potential effect of meteorological variables on beach users’ frequency. A constrained multivariate analysis of redundancy (RDA) was applied using the data of solid waste collected on Copacabana beach and periods of beach access restriction. RDA axes significance was assessed through Monte Carlo permutation tests. The impact of access restrictions (i.e., independent variable) on the amount of solid waste (i.e., dependent variable; accumulated tons per week as replicate) was tested by applying a PERMANOVA with meteorological variables as covariates using 9999 permutations of reduced model residuals. Data were Log x+1 transformed and Euclidean distance was applied in all PERMANOVA analyses. Post-hoc pairwise comparisons were applied to identify significant differences on the amount of solid waste between periods of access restriction to Copacabana beach. RDA and GAMs (followed by AIC) were performed using the CANOCO 4.56 software (ter Braak, 1995), while PERMANOVA was performed using...
the Primer software (PRIMER-e). Graphs were developed in CanoDraw (RDA and GAM) and GraphPad Prism 5.0 (StatSoft).

The patterns of precipitation (PERMANOVA, $F_{1,132} = 4.92, p = 0.03$) and atmospheric temperature (PERMANOVA, $F_{1,132} = 73.29, p = 0.0001$) differed significantly among the restriction periods of Copacabana beach. Values of accumulated precipitation and atmospheric temperature (means ± SE) by periods were, respectively: 38.21 ± 7.7 mm and 24.84 ± 0.31 °C (unrestricted); 30.02 ± 6.94 mm and 24.66 ± 0.44 °C (beach closure); 34.53 ± 10.07 mm and 23.14 ± 0.29 °C (partial restrictions); 32.54 ± 7.69 mm and 24.68 ± 0.48 °C (new normal). However, AIC did not select any relationship than null model for the association between precipitation and solid waste. A significant non-linear relationship between solid waste amount and atmospheric temperature (GAM, $F = 14.04, p = 0.0003$) was selected (AIC = 9.46 × 10^5) (Fig. 1). This significant relationship indicated that, irrespectively of beach restriction periods, lower amounts of solid waste were collected on the beach at lower temperatures (19–22 °C), followed by an increase on solid waste amount with increased temperatures (above 24 °C; Fig. 1). Higher amounts of solid waste collected on the Copacabana beach during the weeks with higher temperatures indicate a raise in visitation frequency with greater production of wastes left on the beach. Our findings indicate that visitors were more impactful than rainfall transportation, especially during sunny and warm weeks, for solid waste pollution in one of the most touristic urban beaches in the world. Unfortunately, significant effects of tourist's presence and urbanization level on litter and solid waste abundances have been found at other Brazilian sandy beaches (e.g., Sucu et al., 2017; Araijo et al., 2018; Abude et al., 2021; Nobre et al., 2021), as well as touristic sandy beaches worldwide (e.g., Ariza et al., 2008; García-Ordóñez et al., 2020; Pervez et al., 2020).

Cyclic seasonal variations were clearly found for atmospheric temperature (Fig. 2b). Precipitation was more intense between February and April 2019, followed by February and March 2020, but it remained oscillating without marked variations in the other periods (Fig. 2c). During the pre-pandemic period of unrestricted access to Copacabana beach (i.e., from January 2018 to February 2020), the amount of solid wastes exhibited a similar pattern of seasonal variation shown by atmospheric temperature data (Fig. 2a), as previously evidenced by GAM results. Well-marked peaks of solid waste amount were evidenced in January between 2018 and 2020 (pre-pandemic period; Fig. 2a), which seems to reflect the influence of New Year's Eve celebration and summer vacation (that also affects the high solid waste amount in February). The huge punctual impact of this traditional celebration can be expressed by the 32,250 and 29,555 tons of solid wastes collected on Copacabana beach only on 1st January 2019 and 2020, respectively. The New Year's Eve of 2020 showed a record of nearly three million people celebrating on Copacabana beach (G1, 2020). The abrupt drop in the amount of solid wastes since March 2020, compared to the same period in previous years (Fig. 2a), can be explained by the first cases of COVID-19 in Brazil and, consequently, the beginning of total restriction to beach access. From August 2020, the amount of solid wastes gradually increased on the beach, but it was still lower than in the previous years. A punctual increase in the amount of solid wastes on Copacabana beach was detected in January 2021 (new normal period), probably due to an increase in beach users’ frequency during summer vacation and New Year's Eve holiday. Although no official New Year's Eve celebration has occurred in 2021 at Rio de Janeiro city, the total amount of 11,700 tons of solid wastes was collected on Copacabana beach on 1st January 2021. Although the amount of solid wastes followed a similar seasonal pattern along the studied years, the levels of waste collected in Copacabana beach were 2–3 time lower during the pandemic period than those in the previous non-pandemic years.

RDA revealed that periods of beach access restriction (i.e., explanatory variable) imposed by the COVID-19 pandemic could explain the trends evidenced by solid wastes data (i.e., response variable). Only the first eigenvalue reported was canonical (RDA1 eigenvalue = 0.389); thus, only data distribution on this axis was interpreted. RDA1 was statistically significant (Monte Carlo, F-ratio = 141.57, $p = 0.0001$) and showed a correlation value of 0.726, accounting for 52.7 % of total data variation explicability. RDA1 evidenced a gradient in the distribution of solid waste data by the restrictions in beach access from unrestricted access (pre-pandemic) to total restriction (beach closure) during the COVID-19 pandemic (Fig. 3a). The highest amount of solid wastes collected on Copacabana beach corresponded exclusively to data from the pre-pandemic period of unrestricted beach access ($\bullet$), located on the left side of RDA1, and these data were positively related to the vector “solid waste”. In contrast, the lower amount of solid wastes was collected during the COVID-19 pandemic – beach closure (i.e., samples located at the right side of RDA1; $\circ$). Intermediate amounts of solid wastes were recorded during partial restrictions of beach access ($\bigcirc$) and new normal period post-pandemic ($\times$), as evidenced by the sample location of these data in the middle portion of ordination diagram. Data from these two periods showed a close distribution with some level of data overlap in the ordination axis, that indicate more similarity between samples from these periods (Fig. 3a).

Restrictions to beach access imposed by the COVID-19 pandemic and its prevention measures (e.g., social restrictions) significantly reduced the solid waste pollution on Copacabana beach (PERMANOVA, $F_{3,132} = 60.965, p = 0.0001$). The pairwise comparisons showed significant differences between all the restriction periods ($p \leq 0.0167$). The amount of solid waste on Copacabana beach during free and unrestricted access was significantly higher than in the other periods, followed by the periods of new normal, partial restriction, and beach closure (Fig. 3b). On the average, beach closure during COVID-19 pandemic resulted in 72 % of reduction in solid wastes on Copacabana beach. Partial access restrictions to beach users resulted in 60 % of reduction in solid waste compared to pre-pandemic period (unrestricted). Even during the new normal period (i.e., unrestricted access to the beach, but with measures of social restrictions post-pandemic), the amount of solid waste left on the beach was significantly lower (36.88 %) compared to the pre-pandemic period (Fig. 3b). Access restrictions to Copacabana beach
Fig. 2. Monthly data of solid wastes and meteorological variables at the Copacabana beach (Rio de Janeiro, Brazil) from January 2018 to June 2021. a) Amount of solid wastes (kt = 10³ tons) collected on the beach; b) mean atmospheric temperature (°C); c) accumulated precipitation (mm). Distinct colors indicate different years: yellow = 2018, green = 2019, orange = 2020, and pink = 2021. The COVID-19 pandemic restrictions have begun at Rio de Janeiro city on 15th March 2020. (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
directly reduced the visitation rates, leading thus to decreases on the anthropogenic pressures arising from this (e.g., noise, pollution, unnatural odors, human trampling). As evidenced by our study, beach access restrictions have significantly and expressively reduced solid waste pollution at this urban tourist beach. Moreover, notable positive changes in biological components and reductions in human pressures were detected in other 29 urban beaches of Latin-American countries during COVID-19 pandemic (Soto et al., 2021). In coastal ecosystems, COVID-19 lockdown has also reduced macroplastics concentration in the Gulf of Mannar, India (Edward et al., 2021) and the overall amount of litter along the Kenyan coast (Okuku et al., 2021). However, consequences of social changes driven by the COVID-19 pandemic (e.g., extensive use of personal protective equipment) may become a problem to coastal ecosystems due to irregular waste disposal (Rakib et al., 2021).

At Brazilian beaches, marine litter pollution is mainly related to river drainages and estuarine run-offs, seasons, tourism and recreational activities, fishing, and people flow as land-based sources (e.g., Suciu et al., 2017; Araújo et al., 2018; Andrades et al., 2020; Abude et al., 2021; Nobre et al., 2021). We have detected a seasonal pattern of solid waste disposal on Copacabana beach, even with no access of beach users during the lockdown (~22,810 t week⁻¹) and after controlling for the potential confounding effects of atmospheric temperature and precipitation. In spite of regular cleaning, solid wastes may be related to buried litter from recreational activities accumulated on sandy beach, marine debris or terrestrial wastes that could reach this urban beach. Most of the solid wastes found on easy-access urban beaches at Rio de Janeiro city (including Copacabana beach) are composed by items commonly related to local disposal (e.g., plastic, cigarette butt, metal, and paper; Abude et al., 2021). Similarly, our qualitative analysis of solid wastes (n = 937) sampled before access restrictions evidenced that most of the items found (~97%) at Copacabana beach were single-use plastics recently disposed by beachgoers (food containers, straws, bottles, bottle caps; Supplementary material; Fig. S1). All the types of litter found (plastics and cigarette butt) came from recreational and touristic activities. Local litter sources have been estimated to be highly relevant to the total budget of floating plastics that enter into coastal systems (~60–90% at Scottish coast; Turrell, 2020). Litter input to Brazilian beaches seems to be influenced by people environmental awareness and socio-economic characteristics of beachgoers (Santos et al., 2005). At Southern Brazilian beaches, higher litter inputs occurred in areas frequented by people with lower annual income and educational level, tourism was the main source of marine debris, and litter level showed a strong correlation with beachgoers density (Santos et al., 2005). Since beach restrictions associated with pandemics are an exception and transient condition, despite the regular cleaning on Copacabana beach, management practices are suggested to improve social perceptions about inadequate waste disposal to effectively engage local society and tourists to reduce litter pollution and improve beach quality.

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CRediT authorship contribution statement

Raquel A.F. Neves: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Resources, Writing – original draft, Writing – review & editing, Funding acquisition. Júlia T.C. Seixas: Conceptualization, Methodology, Investigation, Writing – original draft. Nathália Rodrigues: Methodology. Luciano N. Santos: Conceptualization, Methodology, Validation, Formal analysis, Investigation, Writing – review & editing, Funding acquisition.

Declaration of competing interest

Authors declare no financial and personal relationship with other people or organizations that could inappropriately influence the study entitled “Impacts of the COVID-19 pandemic restrictions on solid waste pollution in the worldwide iconic Copacabana Beach (Rio de Janeiro, Brazil)” submitted for the appreciation of Marine Pollution Bulletin as a Baseline Research.

Data availability

The authors do not have permission to share data.

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![Graph](https://example.com/graph.png)

Fig. 3. Amount of solid wastes collected on Copacabana beach during different periods of beach access restriction. Restriction periods are indicated by different colors: unrestricted (n = 64, *), new normal (n = 29, *), partial restrictions (n = 24, *), and beach closure (n = 16, *). a) Biplot ordination diagram of redundancy analysis (RDA) with the vector (arrow) corresponding to the amount of solid wastes (t) and black crosses representing the centroids of each data group (i.e., multivariate means of sample groups for a given period); b) Mean (±standard deviation) of the total amount of solid wastes (kt = 10³ t) collected by restriction period. Distinct letters mean statistically significant differences among periods (pairwise comparisons, p < 0.0167). (For interpretation of the references to color in this figure legend, the reader is referred to the web version of this article.)
References

Abude, R.R.S., Augusto, M., Cardoso, R.S., Cabrinha, T.M.B., 2021. Spatiotemporal variability of solid waste on sandy beaches with different access restrictions. Mar. Pollut. Bull. 171, 112743 https://doi.org/10.1016/j.marpolbul.2021.112743.

Andrades, R., Pegado, T., Godoy, B.S., Reis-Filho, J.A., Nunes, J.L.S., Grillo, A.C., Machado, R.C., Santos, R.G., Dalcin, R.H., Freitas, M.O., Kuhnhe, V.B., Barbosa, N. D., Adelir-Alves, J., Albuquerque, T., Bentos, B., Giarizzo, T., 2020. Anthropogenic litter on brazilian beaches: baseline, trends and recommendations for future approaches. Mar. Pollut. Bull. 151, 110842 https://doi.org/10.1016/j.marpolbul.2019.110842.

Araújo, M.C.B., Câncalo-Cavalcanti, J.S., Costa, M.F., 2018. Anthropogenic litter on beaches with different levels of development and use: a snapshot of a coast in Pernambuco (Brazil). Front. Mar. Sci. 5, 1–10. https://doi.org/10.3389/fmars.2018.00233.

Ariza, E., Jiménez, J.A., Sárs, R., 2008. Seasonal evolution of beach waste and litter during the beach season on a contaminated coast. Waste Manag. 28, 2604–2613. https://doi.org/10.1016/j.wasman.2007.11.012.

Barbier, E.B., Hacker, S.D., Kennedy, C., Koch, E.W., Stier, A.C., Silliman, B.R., 2011. The value of estuarine and coastal ecosystem services. Ecol. Monogr. 81, 169–193. https://doi.org/10.1890/10.1510.1.

Cai, B., Robert, S., 2022. Integrated beach management in large coastal cities. A review. Ocean Coast. Manag. 217, 106019 https://doi.org/10.1016/j.ocecoaman.2021.106019.

Carson, H.S., Colbert, S.L., Kaylor, M.J., McDermid, K.J., 2011. Small plastic debris changes water movement and heat transfer through beach sediments. Mar. Pollut. Bull. 62, 1708–1713. https://doi.org/10.1016/j.marpolbul.2011.05.032.

Daniel, S.J., 2020. Education and the COVID-19 pandemic. Prospects 49, 91–96. https://doi.org/10.1007/s12536-019-00363-x.

Edward, J.K.P., Jayanthi, M., Malleshappa, H., Immaculate Jeyasanta, K., Laju, R.L., 2021. Personal protective equipment (PPE) pollutive plastic waste in Cox’s bazar, the longest natural beach in the world. Mar. Pollut. Bull. 116, 112497 https://doi.org/10.1016/j.marpolbul.2021.112497.

City Hall, 2020. Better carnivals of all times at the Rio: mais de 10 milhoes de foliões e alto índice de aprovação por turistas. Available online at https://prefeitura.rio/rio-acontece/melhor-carnaval-de-todos-os-tempos-no-rio-mais-de-10-milhoes-de-folioes-e-alto-indice-de-aprovaaco-por-turistas/, accessed on September 15, 2021.

Robin, R.S., Purvaja, R., Ganguly, D., Hariharan, G., Paneerselvam, A., Sundari, R.T., Karthik, R., Neethu, C.S., Saravanakumar, C., Semanti, P., Prasad, M.H.K., Mugilaranan, R., Rohan, S., Arumugam, K., Samuel, V.D., Ramesh, R., 2021. COVID-19 restrictions and their influences on ambient air, surface water and plastic waste in a coastal megacity, Chennai, India. Mar. Pollut. Bull. 171, 112739 https://doi.org/10.1016/j.marpolbul.2021.112739.

Santos, L.R., Friedrich, A.C., Wallner-Kerschnach, M., Fillmann, G., 2005. Influence of socio-economic characteristics of beach users on litter generation. Ocean Coast. Manag. 48, 742–752. https://doi.org/10.1016/j.ocecoaman.2005.08.006.

Schlacher, T.A., Dugan, J., Schoeman, D.S., Lastra, M., Jones, A., Scapini, F., McLachlan, A., Delfo, O., 2007. Sandy beaches at the brink. Divers. Distr. 13, 956–560. https://doi.org/10.1111/j.1472-6463.2007.00363.x.

Schneider, F., Parsons, S., Gift, S., Stolte, A., McManus, M.C., 2018. Collected marine litter—a growing waste challenge. Mar. Pollut. Bull. 128, 162–174. https://doi.org/10.1016/j.marpolbul.2018.01.011.

Shen, M., Mao, D., Xie, H., Li, C., 2019. The social costs of marine litter along the east china sea: evidence from ten coastal scenic spots of Zhejiang Province, China. Sustainability 11, 1807. https://doi.org/10.3390/su11061807.

Silva, A.L.P., Prata, J.C., Walker, T.R., Duarte, A.C., Ouyang, W., Barcelo, D., Rocha-Santos, T., 2021. Increased plastic pollution due to COVID-19 pandemic: challenges and recommendations. Chem. Eng. J. 405, 126683 https://doi.org/10.1016/j.cej.2020.126683.

Soto, E.H., Botero, C.M., Milanis, C.B., Rodriguez-Santiago, A., Palacios-Moreno, M., Díaz-Ferguson, E., Velanquez, Y.R., Abbehussen, A., Guerra-Castro, E., Simsone, N., Muñoz-Remes, F., Milho, J.R.S., 2021. How does the beach ecosystem change without tourists during COVID-19 lockdown? Biol. Conserv. 255, 108972 https://doi.org/10.1016/j.biocon.2021.108972.

Suruco, M.C., Tavares, D.C., Costa, L.L., Silva, M.C.L., Zalmon, L.R., 2017. Evaluation of environmental quality of sandy beaches in southeastern Brazil. Mar. Pollut. Bull. 119, 133–142. https://doi.org/10.1016/j.marpolbul.2017.04.045.

Takada, H., Karasapaglou, H.K., 2019. Hazardous chemicals associated with plastics in the marine environment. In: The Handbook of Environmental Chemistry. Springer Nature. https://doi.org/10.1007/978-3-319-95568-1_315.

teer Braak, C.J.F., 1995. Ordination. In: Jongman, R.H.G., van Tongeren, O.F.R., teer Braak, C.J.F. (Eds.), Data Analysis in Community and Landscape Ecology. Cambridge University Press, Cambridge, pp. 91–173, 315.

Teixeira, C.A., 2010. Limpeza das praias do Rio. Prefeitura do Rio, Companhia Municipal de Limpeza Urbana – COMELURB. Rio de Janeiro, Brazil. Available online at https://rio.parme.rj.gov.br/web/comlurb/escrinocartorio/articulo/id=120173, accessed on September 12, 2021.

Turrell, W.R., 2020. Estimating a regional budget of marine plastic litter in order to advise on marine management measures. Mar. Pollut. Bull. 150, 110725 https://doi.org/10.1016/j.marpolbul.2019.110725.

UNEPA, NOOA, 2012. The Honololu Strategy – A Global Framework for Prevention and Management of Marine Debris, 50 https://doi.org/10.1016/CB2007110101423e.

Veloso, V.G., Silva, E.S., Parente, C., Estevam, M., Suche, A.C., 2018. The Ecology of Sandy Shores, 3 ed. Springer Nature. https://doi.org/10.1007/978-3-319-16510-3_142. https://doi.org/10.1007/978-3-319-16510-3_142. https://doi.org/10.1007/978-3-319-16510-3_142. https://doi.org/10.1007/978-3-319-16510-3_142.