

Research Article

How sustainable are recreational practices on Brazilian Amazon beaches?

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ABSTRACT

The present study focused on two beaches on the Amazon coast, located within Conservation Units under distinct management regimes. Within this context, the main aim of this study was to analyze the role of this units as a potential management framework for safety and comfort of local beachgoer. Unplanned territorial occupation, reduced investment in public services, and overcrowding are similar at both beaches, whereas the pressure level is lower on the estuarine beach of Pesqueiro, where the recreational activities are more closely monitored and controlled. Given the different pressures found on Ajuruteua and Pesqueiro beaches, which have a direct influence on the socio-environmental state of these coastal environments, and on the quality of tourist-recreational activities, it will be necessary to adopt appropriate approaches to resolve these problems and guarantee the adequate development of both the local community and tourist activities, in particular with regard to beachgoer safety.

Management implications: The role of Protected Areas (PAs) was studied as a potential management framework for the safety and comfort of beachgoers, where beach tourism practices could be efficiently integrated and managed. Two Brazilian beaches with similar environmental conditions but under different regulatory regimes were studied, focusing on aspects related to beachgoer satisfaction and safety. One of the beaches is not included in the PA and therefore not subject to the PA management plan regulations. Conversely, another beach is located within a PA and is therefore subject to the PA's management plan. This study has shown that PAs are a positive alternative for the management of recreational activities along the Amazonian coast. However, given the specific characteristics of the study area and the limited investment in necessary services, the solutions to the safety problems of the beaches studied include the adoption of specific beach management plans.

1. Introduction

Beaches are one of the most popular recreational destinations, which provide visitors with a variety of experiences, including contact with nature (sea, sun, and sand) and socio-cultural features (landscapes, culture, and traditions), as well as specific facilities, infrastructure, and services (Botero et al., 2015; Marafa & Chau, 2016; Yepes, 2007). Due to this, beach tourism is one of the world's most important economic activities, with the number of beachgoers increasing progressively from 25 million in 1950 to 1.4 billion in 2018, accompanied by a growth in revenue from \$2 billion in 1950 to \$1.5 trillion in 2018 (Dickinson et al., 2016; UNWTO - World Tourism Organization, 2019).

This accelerated growth in tourism nevertheless entails impacts for coastal environments (Burak et al., 2004; Davenport & Davenport, 2006; Hardiman & Burgin, 2010; Papageorgiou, 2016), in particular pristine sites, such as those of the Brazilian Amazon Coast, where tourism has negative effects on the natural environment, as well as undesirable interactions with the local economy, and the welfare of beachgoers (Pessoa et al., 2019; Sousa, Pereira, Trindade, et al., 2017; Sousa, Pereira, Costa, & Jimenez, 2017). While beaches in the Amazon coast have considerable potential for tourism development, the lack of adequate planning has led to a series of problems affecting the activity itself, such as unregulated occupation of land, contamination from sewage outfalls and solid waste, and beachgoers accidents resulting from inadequate

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safety regulations and practices (Pereira et al., 2014, 2018). In addition, the creation of protected areas has become a management tool with a large potential to contribute to the sustainability of local beach tourism (Pessoa et al., 2019).

The Brazilian Amazon coast has a dozen of protected areas, which are responsible for the conservation of nature, sustainable development, scientific research, education, and eco-tourism in delineated areas. These protected areas are divided into two categories, fully-protected and sustainable-use units (Supplementary Material, Table S1). One sustainable-use category is the Extractive Reserve (with the Portuguese acronym RESEX, IUCN category VI), which are territories of common use destined to the conservation of natural resources, culture and means of life of traditional people, playing an important role in the management of areas used to ensure the sustainable use of the area's natural resources by those local traditional populations (Rodrigues & Szlafsztein, 2011). Public visits (such as recreational activities) are allowed within the RESEX, but the recreational activities must be compatible with local interests and the provisions of the local management plan (Federal Law number 9.985/2000).

To verify the role of this protected area on helping to develop sustainable beach tourism practices, the present study focused on beaches located within and adjacent to Federal Marine Extractive Reserves on the coast of the Brazilian state of Pará. In fact, the administrations of the protected areas have little effective control on beach use, so recreational activities may often contradict the policies of sustainability applied within the protected area, resulting in social and environmental conflicts (Pereira et al., 2018; Pessoa et al., 2019). As these conflicts may affect the safety of the beachgoers, effective regulation and planning are required for the whole of the Amazon coast, in order to minimize or mitigate the conditions of hazard and risk derived from inadequate policies on aspects such as land use, public sanitation, and safety measures (Jimenez et al., 2007; Heggie, 2013; Mathews et al., 2014) to guarantee the comfort and well-being of beachgoers (Klein et al., 2003; Lozoya et al., 2011; SLSA 2017). Within this context, one key element to be considered is users' safety which becomes an essential service to be provided in beach management plans for areas devoted to tourism (Mathews et al., 2014; Williams et al., 2018).

To expand coastal tourism in Pará, the private sector has ignored traditional practices (such as artisanal fishing and subsistence agriculture) and overlooked the most effective options for the conservation of local beaches for recreational use (Almeida & Jardim, 2018; Pessoa et al., 2019; Sousa et al., 2016). Unfortunately, this has often resulted in social and environmental conflicts that compromise both, the life quality of the local inhabitants and the comfort and well-being of the beachgoers (Barbosa & Campos, 2017; Pereira et al., 2014). In addition, appropriate regulatory measures are urgently needed in order to guarantee the protection of the environment and the sociocultural sustainability of the local traditional communities, as well as the safety and satisfaction of local beachgoers.

Within this context, the main aim of this work is to analyze the role of extractive reserves as a potential management framework for safety and comfort of the beachgoers, where beach tourism practices could be efficiently integrated and managed. Although the number of elements affecting beach management is very large and diverse (Merino & Prats, 2020), in this work we focus on those aspects related to beachgoers' satisfaction and safety. To this end, we analyze the influence of these protected areas on tourism in two beaches of the Brazilian Amazon Coast with similar environmental conditions, but under distinct regulatory schemes. These are Pesqueiro beach, which is located in the Soure Marine Extractive Reserve, and is controlled by the local population and ICMBio, the Federal Environment Agency "Chico Mendes Institute for

Biodiversity Conservation"; and Ajuruteua beach, which is located within the exclusion polygon¹ of the Caeté-Taperaçu Marine Extractive Reserve. This means that Ajuruteua beach is not included within the Caeté-Taperaçu Marine RESEX and hence is not subject to the management plan regulations of this protected area. On the contrary, Pesqueiro beach is situated within the Soure Marine Extractive Reserve and therefore complies with the management plan regulations of this protected area.

In addition, several studies have established conceptual models for assessing the cause-and-effect relationship between human activities, environmental changes, and their impacts on services and human well-being (Gari et al., 2015; Andrés et al., 2018; Araújo et al., 2021). The DPSWR (Driver-Forces-Pressure-State-Welfare-Responses) conceptual framework (Cooper, 2013) was selected for this study's analysis as it facilitates the identification of the relationships between human activities, environmental changes, and human well-being. The DPSWR framework, derived from DPSIR (Driver-Forces-Pressure-State-Impact-Responses), is an innovative approach that includes a link to human well-being within its structure. It has been employed in the domain of marine environmental management, as evidenced by research conducted by Sardá et al. (2015) on a beach in Catalonia, Spain, and by Ojea et al. (2017) in marine protected areas in the Mediterranean and Black Seas. A distinctive aspect of this model's application in our research is the incorporation of a novel element, namely "natural variability". In this study, we will therefore refer to the conceptual framework as DPSWR_{natvar}. This new component has been added because natural conditions influence the pressure and state components and consequently human welfare.

Given this, the DPSWR_{natvar} was employed to evaluate the social and environmental status of beaches under a scenario of reduced investment in public and private services, a common condition along the entire coast of the Brazilian Amazon region (Pereira et al., 2018; Pessoa et al., 2019; Silva et al., 2013). This assessment will determine how the anthropogenic actions (such as unregulated territorial occupation, and low investment in sanitation and safety measures, etc.) affect the comfort of beachgoers and generate hazards and risks on popular beaches located within or adjacent to protected areas, and then identify the role of protected areas on the observed situation. This study will contribute to the development of future beach management programs adapted to the specific socio-ecological characteristics of Amazonian beaches or beaches around the world that are under distinct regulatory control, such as those located in protected areas.

2. General framework

The DPSWR presents advantages over the DPSIR as it can support multidisciplinary research and facilitate comparability both within and between environmental studies (Cooper, 2012, 2013). However, similar to its predecessor frameworks (e.g., S-RESS by Friend, 1979; PSR by OECD, 1993, 2003; PSIR by Turner, 1999, 2000; DPSIR by EEA, 1999, 2012), the DPSWR abstracts from spatial and temporal analyses of risk factors and the relationships between categories of information. To enhance their utility, socio-ecological accounting frameworks should incorporate the conceptualization of these aspects.

This study proposes the DPSWR_{natvar} conceptual framework that was used as a diagnostic tool for the assessment of the comfort of beachgoers and the specific hazards present on two popular Amazonian beaches. This framework was used for the (i) interpretation of the main *driving force* influencing the welfare of beachgoers, (ii) description of the anthropogenic *pressures* that affect the comfort of beachgoers, or increase the hazards and risks, (iii) description of the actual *state* of the

¹ The Ajuruteua village is located within the Caeté-Taperaçu Marine Extractive Reserve, but the beach zone is part of the Exclusion Polygon in the northern extreme of the reserve (ICMBio 2012).

beaches in terms of human pressures and/or activities, (iv) description of the *welfare* of the beachgoers in relation to changes in this state, and (v) assessment of the implications of and *responses* to the observed discomfort, risks, and hazards (Fig. 1). The variability of natural conditions was incorporated in the analysis as an external factor that intensifies the pressures and affects current conditions and well-being.

In this context, *drivers* have been identified as anthropogenic factors that can be controlled, as they are changes caused by human activities. Anthropogenic factors encompass characteristics related to the lack of planning for specific uses. *Pressures*, on the other hand, were defined as human activities that cause or contribute to a change in the state. To assess these pressures, the selected activities for analysis include those that have the potential to cause discomfort to beach users or increase hazards and risks, as well as factors that could impede effective planning of beach development in terms of comfort and safety.

The *state* is defined as an attribute or a set of attributes of the natural environment that reflects integrity concerning a specified issue. In this study, the state of the beaches was determined based on the evaluation of data collected from questionnaires, checklists, reports from lifeguards, swimming crowds, and satellite images. The methodology used for this analysis is explained in detail in section 4.1.

As *natural variability* also affects the state of the beach, hydrological, microbiological analysis, climatological, and hydrodynamic variables were analyzed in relation to the comfort and safety of beachgoers. The methodology for this analysis is detailed in section 4.2. In addition, the *response* is an initiative intended to reduce at least one impact. In the study area, the response of beachgoers, the tourism sector, and the government was the result of the impacts that affected the well-being of beach visitors and the connections among drivers, pressures, and state.

Indeed, the amalgamation of human activities and environmental conditions highlights the usefulness of DPSWR_{natvar} as a tool for identifying the distinct measures required to prevent particular issues. A range of measures can be implemented to mitigate these problems, and this study has compiled and assessed the management measures considered necessary for the study area, given the low number of actions taken (responses) by local authorities.

3. Study area

3.1. General overview

The study beaches are located in the Brazilian state of Pará (Fig. 2). The coast of Pará extends from the mouth of the Amazon River, in the west, to the Gurupi River, in its eastern extreme, and is divided into five

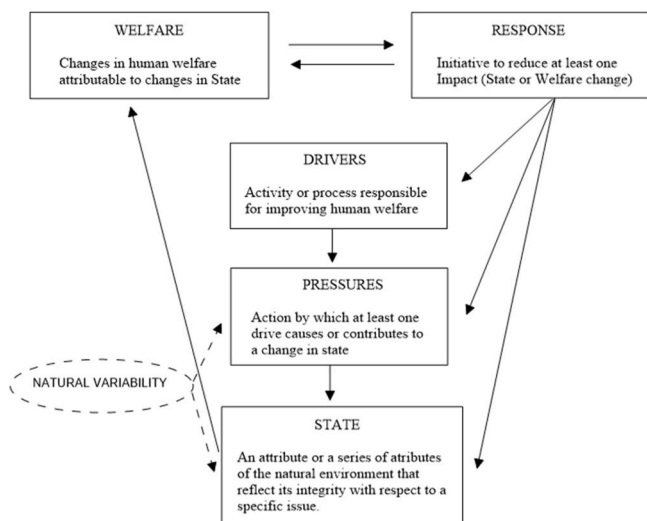


Fig. 1. Summary of DPSWR_{natvar} definitions. (Source: Authors 2023).

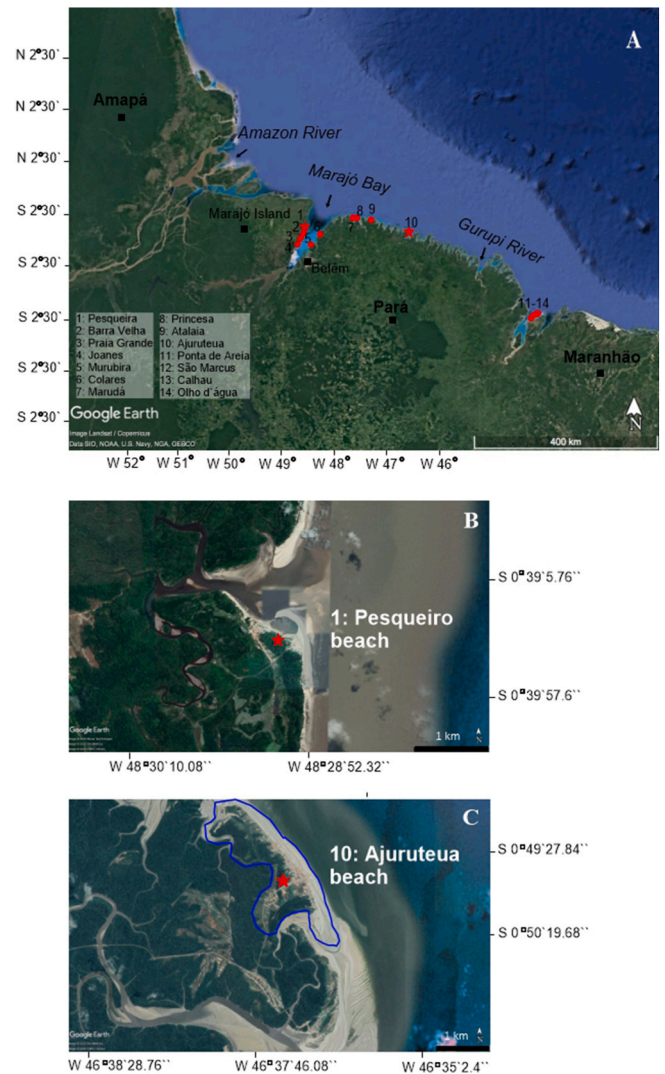


Fig. 2. (A) Amazon coast, showing the Amazon states (Amapá, Pará, Maranhão), Pará coastal sectors and main beaches and rivers. (B) Pesqueiro beach and (C) Ajuruteua beach, detaching the exclusion polygon (blue line) of the Caeté Taperaçú RESEX. Geospatial data on Google Earth (Source: Authors 2022).

sectors: Western Marajó, Eastern Marajó, Continental Estuarine, Fluvial Maritime and Atlantic Coast of Pará (Pereira et al., 2016). The local climate is equatorial humid with well-defined rainy (first semester) and dry (second semester) seasons. Annual precipitation tends to exceed 2500 mm, although 75–90 % of this total is recorded during the rainy season. Air temperatures are high and stable, and generally range between 25 °C and 28 °C, while local winds normally blow from northeast, typically at a speed of 2–4 m s⁻¹, but reaching a maximum of 8.0 m s⁻¹ (Martorano et al., 1993). The whole coast is dominated by mangroves and the enormous fluvial discharge of the Amazon River and numerous local other estuaries. Most of the many sandy beaches are bordered by extensive areas of mangrove forest. Due to the difficulty of access (presence of mangroves and estuaries/rivers) and the long rainy season, the beaches in Pará state are mainly visited in the month of July (school vacation period) and extended holidays, especially in the second semester when precipitation levels are minimal (Pereira et al., 2014; Sousa, Pereira, Trindade, et al., 2017).

Pesqueiro beach is located in the Eastern Marajó sector (Fig. 2B), and Ajuruteua beach, in the Atlantic Coast sector (Fig. 2C). The beaches of the Eastern Marajó sector are located on Marajó Island, along a

relatively straight and continuous shoreline, interrupted only by a number of small estuaries and creeks (Pereira et al., 2016). Most of these beaches are shallow-sloped with recurved spits formed by the local north-south longshore transport. Local hydrodynamics are controlled by the fetch-limited waves generated within Marajó Bay, as well as by the strong tidal currents. This sector attracts a variety of groups of visitors, due primarily to its well-preserved natural environments, but also its unique cultural, gastronomic, and historical heritage. Visitation peaks primarily during school vacation period, with visitors coming mainly from local towns and Belém, the Pará state capital (Pereira et al., 2018; Pessoa et al., 2019). The principal local beaches used for recreational activities are Joanes, Praia Grande, Barra Velha and Pesqueiro (Fig. 2, Szlafsztein, 2009). Pesqueiro beach is located in the Soure Marine Extractive Reserve, which was created by federal decree in November 2001.

The beaches of the Atlantic Coast sector are located within bays or on coastal islands, and are influenced by waves of moderate energy (H_s 1.5–2.0 m, at high tide), macrotides reaching up to 6 m (during spring tides) and strong tidal currents ($\sim 1.5 \text{ m s}^{-1}$). These beaches have a width of 300–400 m (during low spring tides) and are covered with quartz sediments, dominated by fine and very fine sand (Pereira et al., 2016). The principal beaches of this sector are Ajuruteua (located within the “exclusion polygon” in the northern extreme of the Caeté-Taperaçu Marine Extractive Reserve, which was created by federal decree in May 2005), Atalaia (adjacent to the Atalaia Natural Monument, created by Pará state decree no. 2,077, in May 2018), and Princesa (located within the Algodão-Mainandeuva Environmental Protection Area, which was created by Pará state decree no. 5621/90, in November 1990).

3.2. Pesqueiro beach

The municipality of Soure is located on Marajó Island, south of the mouth of the Amazon River. The municipality has an area of 3528 km² and a population of more than 20,000 inhabitants (IBGE 2015). The principal economic activities are cattle ranching, and subsistence fishing and farming (Alves & Santana, 2008; Szlafsztein, 2009). Pesqueiro beach is 8 km from the center of the town of Soure. It is 4 km long and 1 km wide, and surrounded by sand dunes and mangroves. Neap tides are mesotides (2–4 m), while macrotides (up to 4.5 m) predominate during the spring tides (Corrêa & Penafort, 2010; França & Souza Filho, 2006; Silva et al., 2013).

At Pesqueiro beach, the local traditional population depends on extractivism, artisanal fishing, subsistence agriculture, and tourism. Local tourism is based on an ecotourism model, which is dependent on the well-preserved local landscapes and environments (Lobato et al., 2014; Souza, 2008). However, the lack of public services at a local level creates a problematic scenario, and includes inadequate public sanitation and security, reduced education levels and environmental degradation (Lobato & Tavares, 2012; IBGE 2015), although actions taken by the residents of the traditional local populations and the ICMBio have mitigated some major issues (Pessoa et al., 2019). Unfortunately, the management plan of the extractive reserve does not include any specific measures for the regulation of recreational activities on the local beaches (ICMBio 2018).

3.3. Ajuruteua beach

Ajuruteua beach is located in the municipality of Bragança, on the Bragantina Coastal Plain, between the Barca and Chavascal channels. It is approximately 2.5 km long and 300 m wide during the low spring tide (Alves & El-Robrini, 2006). The local hydrodynamics are controlled by macrotides (4–6 m), tidal currents (normally $< 1.0 \text{ m s}^{-1}$), and moderate wave energy (H_s up to 2.0 m), in particular during the flood and high tides (Pereira et al., 2013).

Ajuruteua village has fewer than 300 inhabitants, and the populations depends mainly on subsistence fishing and recreational

activities for its livelihood (Pereira et al., 2007, pp. 210–218). During school vacation period, Ajuruteua beach is visited by thousands of beachgoers, although a number of problems have limited the growth of local tourism (Oliveira et al., 2011; Pessoa et al., 2016). Once again, public services are limited, and there has been little investment in essential areas such as public sanitation and security. In addition, unplanned occupation of land by private interests has caused serious social and environmental conflicts.

4. Methods

This study addressed several social and natural factors to evaluate the role of protected areas on the comfort and safety of beachgoers at popular beaches. The social aspect was focused on through the application of questionnaire and checklists, counts of beachgoers, and the analysis of satellite images and lifeguard reports. Natural variability, that is, climatological (rainfall, air temperature and winds) and oceanographic (hydrodynamic and hydrological) parameters, were also considered in the analysis as external forces affecting pressures and real conditions. The DPSWR_{natvar} conceptual framework was used to organize the relationships between human activities, environmental changes and human well-being, with respect to the comfort of beachgoers and the specific risks and hazards present within this coastal environment. On overview of the measurement, timing, and the variables is presented in Table 1.

4.1. Social aspects

In each survey (Table 1), the variations in the visitation structure were determined by counting the number of beachgoers every hour (from 8 a.m. until 6 p.m.) along two pre-established transects. This data was collected in order to understand the distribution of visitors on a spatial scale (along the pre-established transects and between the two beaches) and a temporal scale (over the course of a day's visit and during the periods studied). The 50-m wide transect was located in the vicinity of beach access points, and were divided into three zones: (1) the promenade and backshore; (2) the intertidal zone between the level of the highest spring tide to that of the lowest neap tide, and (3) the sub-tidal area up to 15 m into the water from the lowest level of the neap/spring tide. Given the tidal cycle, the width of zone 2 was measured every hour.

Beachgoers were interviewed using questionnaires in print format to obtain data on their perceptions on the comfort and security of the beach. The questionnaire covered three aspects – natural (wind and current speeds, wave energy, and water temperature and turbidity), sanitation (trash in the water and on the sand, the odor of the water and the sand, and the presence of dead animals and sewage outfalls), and safety (number of lifeguard and services) with a total of 13 questions. The interviewees were chosen by random sampling in both beaches (316 at Ajuruteua and 55 at Pesqueiro) between 9 a.m. and 5 p.m. (Table 1).

Simultaneously, a checklist was conducted by an expert observer (an academic researcher) to complete the understanding of the sanitation (presence of trash, cesspits or sewage outfalls, dead animals) and safety (lifeguards, tourist information, security services) conditions. At both beaches, a series of photographs were taken to verify whether the lack of adequate planning affects the security of the beachgoers.

Lifeguard reports were also analyzed to determine the principal incidents, accidents, and the application of first aid procedures (Table 1). The lifeguard reports were generated from a standardized statewide database available in SISCOB – CBMPA (2021). This database records all lifeguard activities, distinguishing between preventive, rescue, and other activities. However, each lifeguard unit (Belém for Pesqueiro and Bragança for Ajuruteua) is responsible for providing its reports. These reports are annual and do not account for monthly or weekly periods since the beaches are patrolled during specific timeframes. For instance,

Table 1

Measurement, periods of study and studied variables regarding natural and social conditions.

SOCIAL CONDITION	MEASUREMENTS	STUDIED VARIABLES	TIME
Comfortable and Safety	Application of questionnaires, check list and beachgoer numbers	Questionnaire and check list on physical, sanitation and safety services, number of beachgoers, photos	Pesqueiro: July ^a 2015, 2016, and November ^b 2015 with 10 h (each campaign) Ajuruteua: July ^a 2009, 2010, 2012, 2013, and September ^b 2013 with 10–30 h (each campaign)
Occurrence of Accidents	Lifeguard Reports	Reports	Pesqueiro: 2012 to 2017 Ajuruteua: 2010 to 2014
Microbiological	Field campaigns	Concentration of thermotolerant coliforms	Pesqueiro: July ^a 2015, 2016, November ^b 2015, with 12 h (each campaign) Ajuruteua: July ^a 2010, 2013, 2016, September ^b 2013, 2014, 2016, October ^b 2012, 2013, November ^b 2015, 2016, December ^b 2013, 2014, with 12–60 h (each campaign)
Territorial occupation	Satellite Image of Google Earth	Images	Pesqueiro: 2006, 2014, 2018 Ajuruteua: 2007, 2013, 2019
NATURAL CONDITION	MEASUREMENTS	STUDIED VARIABLES	TIME
Climate	Soure (UTC 82141) station Tracuateua (UTC 82145) station	Rainfall, air temperature and wind speeds from INMET	Pesqueiro: January 2015 to December 2016 Ajuruteua: January 2012 to December 2013
Hydrodynamic and hydrological variables	Field campaigns	Tidal range, significant wave height, current speeds, and water salinity, turbidity and temperature	Pesqueiro: July ^a 2015, 2016, November ^b 2015 with 25 h (each campaign) Ajuruteua: July ^a 2009, 2010, 2012, 2013, September ^b 2013 with 25–72 h (each campaign)

^a Vacation period.

^b Holiday of dry season.

in Ajuruteua, lifeguards are present on weekends, during extended holidays, and the school vacation period (July), while in Pesqueiro, they are only present in July.

Images obtained by Digital globe were extracted using Google Earth (GE) software. These images were used to monitor the coastline and to know the number of buildings in different periods (Table 1). Vegetation, dunes and or edifications were considered as reference line through visual interpretation to define the shoreline at each image.

4.2. Natural aspects

As physical variables can have a temporal effect on the hazards and risks of a specific environment, climate and hydrodynamic data were also compiled and analyzed (Table 1). Rainfall, air temperatures, and wind speeds were obtained from the Tracuateua (UTC 82145) and Soure (UTC 82141) stations of the Brazilian Institute of Meteorology, representing Ajuruteua and Pesqueiro beaches, respectively.

At each study beach, the tidal range, wave heights, and current speeds were measured using wave and tide data loggers (TWR 2050) and a mini-current meter (Sensordata SD 6000) attached to a bottom-mounted mooring at a depth of 1.7 m (during low tides). These data were obtained under spring and neap tide conditions in both equinoctial and non-equinoctial periods. Waves were sampled by taking 512 samples at a burst rate of 4 Hz over a period of 10 min, while water level oscillations were recorded every 2s with mean values being obtained every 10 min, and 10-min means of current intensity and direction were also recorded.

Hydrological variables (Table 1) also have a temporal effect on the real conditions of a specific environment, and thus, the comfort of beachgoers. A bottom-mounted mooring was installed at each beach, to which the CTDs (conductivity, temperature, and depth) were attached. Readings were taken every 10 min over the 25 h sample period (total = 150 readings) by each CTD (RBRmaestro) equipped with turbidity sensors. For temperature, the CTD was accurate to ± 0.002 °C, while for conductivity, it was accurate to ± 0.0003 S m⁻¹.

To determine thermotolerant coliform (microbiological) concentrations, water samples were obtained using Niskin oceanographic bottles from approximately 1.0 m below the surface in bathing areas every hour (Table 1). Once collected, the samples were stored in 250 mL polyethylene containers or glass flasks for laboratory analysis, following the APHA (American Public Health Association) protocol. In the laboratory, the coliform concentrations were determined by the multiple tube fermentation technique (APHA - American Public Health Association, 2004). The quality of the water used for bathing and other recreational activities was evaluated through comparisons with the recommended thresholds established by the Brazilian Ministry of the Environment (CONAMA 2000; 2005).

4.3. Statistical analyzes

Data processing of the responses to the questionnaires given to beachgoers was carried out using the statistical software IBM SPSS v. 26. Each item was evaluated using ordinal scales, with 3 indicating the best condition and 1 indicating the worst condition (e.g., Comfortable-3, Moderate-2 and Uncomfortable-1 for Natural aspects; None/little-3, Moderate-2 and Abundant-1 for Sanitation aspect, and Enough-3, Moderate-2 and None/Insufficient-1 for Safety aspect), and analyzed using the non-parametric statistical test Mann-Whitney *U* to determine the predominant perceptions of beachgoers regarding comfortability and safety aspects in Ajuruteua and Pesqueiro beaches. Due to the discrete nature of the data, tests for normality and homogeneity were omitted for the application of the Mann-Whitney test.

With respect to lifeguard reports, the non-parametric Chi-Square test of Independence (χ^2) was employed to examine whether there was a significant difference in the frequency of accidents between the studied beaches, due to the differences in the types of natural hazards, as well as the number of lifeguards and patrol time, when comparing the two beaches. Additionally, Cramer's *V* coefficient (*qc*) was used to assess the degree of association between the occurrence of these accidents and the study beaches.

The Mann-Whitney test was once again applied to determine if there was a significant difference in the number of beachgoers between the studied beaches and study periods (school vacation or holiday periods). Moreover, in the same section, the ANOVA Welch test was employed to examine the relationship between visiting hours and the number of

visitors for the aforementioned categories.

To assess the hydrodynamic, hydrological, and climatological aspects, the normality of the data was evaluated using the Anderson-Darling test (Stephens, 1974). Additionally, the homogeneity of variances was examined using the Levene test (Levene, 1960). Since the dataset did not meet the assumption of homoscedasticity, the Welch ANOVA test was used as an alternative to the traditional one-way ANOVA. Subsequently, the Games-Howell non-parametric posthoc method was employed to compare the studied groups (i.e., between beaches, between neap and spring tides, and between school vacation and holiday periods) using ranked variables.

5. Results

The results are presented in two parts: the first provides an account of

the social and natural factors that affect the well-being and safety of beachgoers at each of the beaches studied, while the second applies the DPSWR_{natvar} model, which organizes this information by demonstrating each component. In fact, this initial part comprises the indicators delineating the *State* and *Natural Variability* components. With the result of the second part, it was possible to demonstrate the potential of extractive reserves as a managing framework to ensure the safety and comfort of beachgoers.

5.1. Social aspect

5.1.1. Variations in the visitation structure

Both Ajuruteua ($U = 119.00$; $p < 0.001$) and Pesqueiro ($U = 169.50$; $p = 0.005$) beaches experienced a higher influx of beachgoers during the school vacation period (Fig. 3). However, no significant variation in the

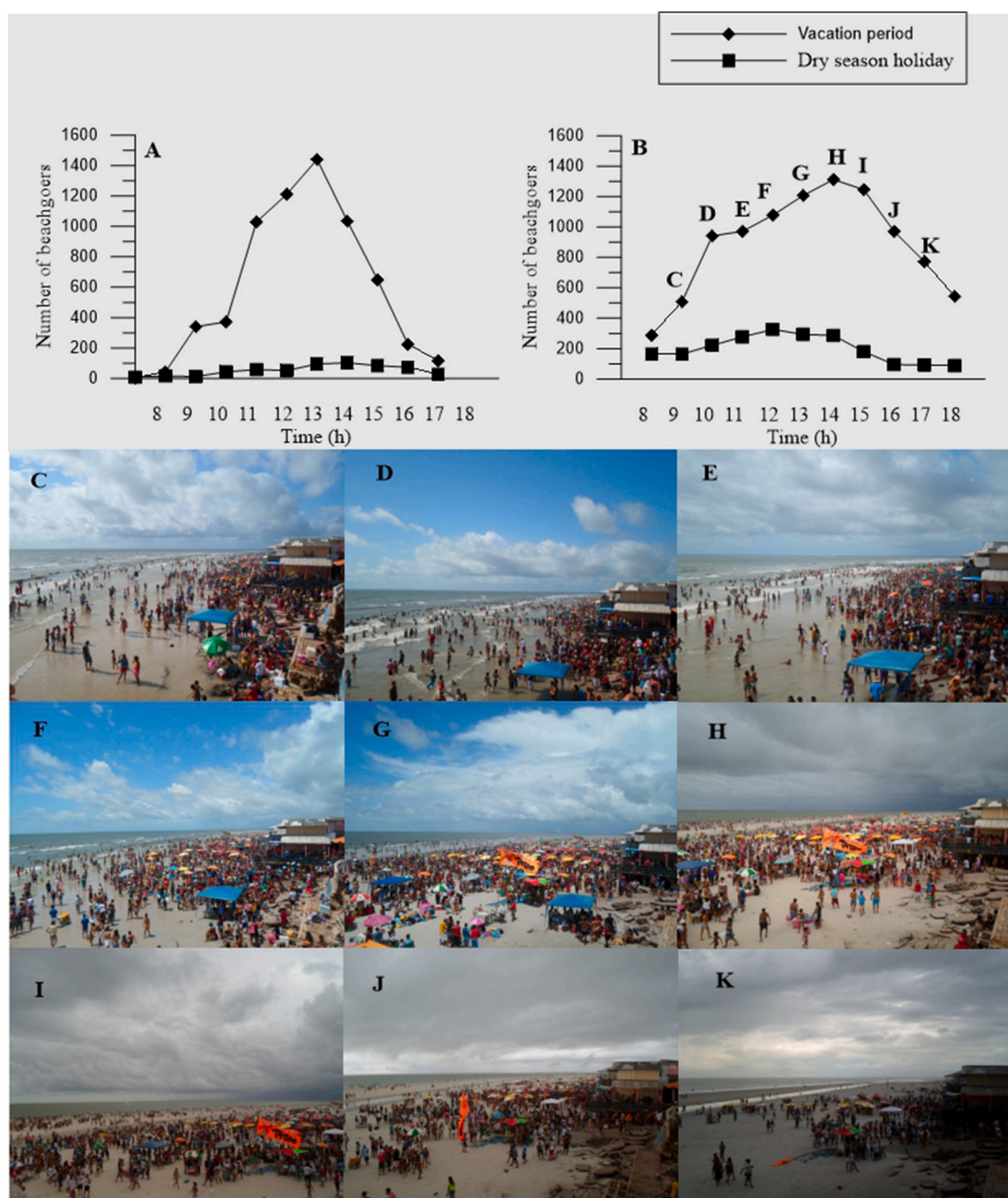


Fig. 3. Number of beachgoers *per* pre-established transects in different periods in Pesqueiro (A) and Ajuruteua (B), and photos showing the dynamic of the beachgoers in different hours (9–17 h) at Ajuruteua. (Source: Authors 2022).

number of visitors was observed between the two beaches during the school vacation period. In addition, a significant difference ($U = 116.00$; $p < 0.001$) was found in the number of beachgoers between the beaches during the holiday period, with Ajuruteua being the most visited beach during this time.

Regarding visiting hours, there were no significant differences between the school vacation and holiday periods at both Ajuruteua and Pesqueiro beaches. However, when comparing the two beaches during the holiday period, significant differences were found ($F = 6.20$; $p = 0.047$) in the number of beachgoers per hour. Ajuruteua had the highest number of visitors in the morning (8 a.m.–11 a.m.) and late afternoon (4 p.m.–6 p.m.) compared to Pesqueiro. Additionally, no significant difference was found when comparing the number of beachgoers during visiting hours between Ajuruteua and Pesqueiro beaches during the holiday period.

5.1.2. Beachgoer' perceptions

According to the questionnaires (Table 2), the beachgoers' perceptions suggest significant differences in almost all responses between the beachgoers of each beach. In terms of natural aspects, most responses ranged from "comfortable" (pleasant conditions) to "moderate" (some discomfort). Significant differences were found for wind speeds ($U = 11.306,500$; $p < 0.001$), current speeds ($U = 10.247,000$; $p = 0.013$), wave energy ($U = 10.564,000$; $p = 0.004$), and water turbidity ($U = 11.134,500$; $p < 0.001$). However, in terms of sanitary aspects, beachgoers at Ajuruteua reported a "moderate" presence of garbage in the sand ($U = 12.489,500$; $p < 0.001$) and water ($U = 12.448,000$; $p < 0.001$). Unpleasant water odor ($U = 10.359,000$; $p = 0.002$) and sewage outfalls ($U = 12.008,000$; $p < 0.001$) were either not observed or observed on a small scale at both beaches. Regarding safety aspects, the majority of the interviewees in Pesqueiro indicated that the number of lifeguards was "insufficient" (78.2 %), while in Ajuruteua, only 37.4 % considered it "enough" ($U = 2.534,000$; $p < 0.001$). Additionally, most of the beachgoers from both groups believed that safety services were not sufficient (Table 2). No significant differences were found between the two beaches regarding the remaining aspects.

5.1.3. Lifeguard reports

The lifeguards at Pesqueiro recorded a total of 158 incidents over a six-year period (Table 3). Most of these involved injuries caused by animals such as stingrays, catfish, and jellyfish (60 cases, i.e., 38 % of the total number of cases in Pesqueiro), as well as other injuries, including fractures and bruising (25 cases, 16 %). There were also two cases of fatal drowning (1 %) and 14 rescues (9 %) of bathers in difficulty, among other incidents.

Table 2

Beachgoers' perceptions with respect to comfort and safety aspects in the study area.

ASPECTS	PESQUEIRO (%)			AJURUTEUA (%)		
	Comfortable	Moderate	Uncomfortable	Comfortable	Moderate	Uncomfortable
Natural						
Wind speeds	74.5	25.5	0.0	45.9	48.4	5.7
Wave energy	52.7	36.4	10.9	29.2	58.8	11.9
Current speeds	41.8	50.9	7.3	24.8	64.5	10.7
Water temperature	40.0	60.0	0.0	31.8	63.5	4.7
Water turbid	30.9	61.8	7.3	16.0	55.7	28.3
Sanitation	None/little	Moderate	Abundant	None/little	Moderate	Abundant
Seawater trash	70.9	23.6	5.5	32.1	40.6	27.4
Sand trash	50.9	41.8	7.3	18.6	45.9	35.5
Water odor	92.7	7.3	0.0	74.2	18.6	7.2
Sand odor	89.1	10.9	0.0	80.2	16.7	3.1
Killed animals	70.9	23.6	5.5	76.7	21.7	1.6
Sewage outfalls	94.5	5.5	0.0	57.2	26.1	16.7
Safety	Enough	Moderate	Insufficient	Enough	Moderate	Insufficient
Lifeguard number	7.3	14.5	78.2	37.4	53.8	8.8
Safety services	0.0	32.7	67.3	7.2	37.1	55.7

Table 3

Main accidents and first aids taken by lifeguards in the study area.

OCCURRENCES	PESQUEIRO	AJURUTEUA
GENERAL		
Non-Fatal Drowning	14	26
Fatal Drowning	2	0
Missing child	10	144
Wounds and injuries	25	346
Animals	60	171
Drunken	0	16
Sudden death	3	48
Cardiorespiratory problem	0	3
Insolation	0	3
Headache	0	4
Others	22	0
FIRST AIDS		
Emergency transport	7	30
Wound dressing	15	223
Total of Occurrence	158	1014
Total of Occurrence/beachgoer numbers	0.0002^a	0.0006^b

^a Pesqueiro received more than 0.7×10^6 beachgoers during weekdays of July months between 2012 and 2017.

^b Ajuruteua more than 1.6×10^6 beachgoers in weekdays of July months and bank holidays between 2010 and 2014. The number of beachgoers was estimated considering only the patrolled period by lifeguards.

In Ajuruteua, the local lifeguards reported significantly higher number of incidents, amounting to 1014 over a five-year period ($\chi^2 = 88.061$; $df = 6$; $p < 0.001$). This indicates a higher frequency of incidents compared to Pesqueiro beach. A moderate correlation was found between the incidents and this particular beach ($\rho_c = 0.280$; $p < 0.001$). The primary types of incidents reported at Ajuruteua included wounds and injuries (346 cases, 34 % of the total number of cases in Ajuruteua), accidents involving animals (171 cases, 17 %), and cases of missing children (144 cases, 14 %), along with instances of sudden death, non-fatal drowning, and other incidents (Table 3).

5.1.4. Checklist

The application of the checklist in Pesqueiro showed that basic sanitation is rudimentary and that cesspits were observed in the dunes, well above the influence of the high tide line (Fig. 4A). They thus do not appear to offer any risk of contamination for the beaches, and this conclusion was supported by the thermotolerant coliform concentrations (see section 5.2).

In Ajuruteua beach there is no public sewage collection system, and cesspits are found on the dunes, intertidal zone, and mangroves (Fig. 4C). In fact, each building has its own cesspit, and during spring



Fig. 4. Main problems found at Pesqueiro and Ajuruteua beaches. Cesspits on dunes area at Pesqueiro (A), unplanned occupation and seawalls at Ajuruteua beach (B), cesspit on the intertidal zone at Ajuruteua beach (C), trash on intertidal zone at Ajuruteua beach (D). (Source: Authors 2022).

tides, the rudimentary cesspits located in the intertidal zone are reached by the water of the high tide, affecting the quality of the water, which becomes contaminated by thermotolerant coliforms (see section 5.2).

With respect to safety condition, in Pesqueiro, the beach was patrolled by lifeguards only during the weekends of the school vacation period when overcrowding was observed. During this period, the beach (~4 km of coastline) was patrolled by three lifeguards. In other scenarios, such as that of the dry season public holidays, no lifeguards were observed on the beach. Safety equipment, and emergency and first aid services were scarce and restricted to the weekends of the school vacation period. In addition, there were no warning signs of dangerous conditions, such as, presence of stingrays anywhere on the beach.

At Ajuruteua, lifeguards were present during the weekends (Saturday and Sunday), when up to six lifeguards are typically on duty, with the number increasing to approximately 10 during extended public holidays, and 15 in the school vacation period (July). This scenario is further accentuated by the lack of any specific beach safety plan for Ajuruteua, and the absence of basic beach management measures, such as the zoning of areas for bathing and swimming, water sports or maritime traffic, or the use of warning signs or alarms to alert beachgoers to physical (hydrodynamics) and biological (animals) hazards, which are important for the reduction of the risk of accidents.

5.1.5. Unregulated occupation

Constructions and infrastructure are minimal at Pesqueiro beach (~150 buildings) when compared to Ajuruteua beach (~500 buildings), and are located in areas of dunes and mangrove. These buildings – mostly houses and bars – are made of timber and built on stilts, following the design recommended by the ICMBio. The analysis of Google Earth images from 2006 to 2018 (Fig. 5A) indicates that the number of buildings in the area increased by more than 30 % during this 12-year period.



Fig. 5. Coastline of Pesqueiro (A) and Ajuruteua (B), showing the unplanned occupation and shoreline retreat in different years. Geospatial data on Google Earth (Source: Authors 2022).

At Ajuruteua beach, unregulated territorial occupation in the intertidal zone, dunes, and mangroves, associated with high local hydrodynamic energy, has resulted in the erosion and degradation of the natural environment and the destruction of infrastructure and buildings (houses, hotels, bars, and restaurants). In 2007, more than 15 unregulated bar/restaurants were visible in the northwestern sector of the beach (Fig. 5B), for example, whereas by 2013, these buildings had disappeared as a result of erosion. Comparing the Google Earth images from 2007 to 2019, the shoreline has retreated by more than 200 m in the northwestern sector and 50 m in the southeastern sector. As a consequence of this process, some of the buildings were moved to the area of dunes and adjacent mangrove, and streets and basic infrastructure (e.g., lampposts, cesspits) were partially or completely destroyed. During the same period, the total number of buildings in the study quadrant increased almost threefold, from ~170 in 2007 to ~500 in 2019. Overall, then, the area of natural beach habitat has been drastically reduced, and to minimize erosive processes, seawalls have been built in many sectors of the Ajuruteua waterfront.

5.2. Natural aspects

The natural variability in physical forces can affect the visitation period and the levels of comfort, hazards, and risks. The intensity of the precipitation during the rainy season limits the visitation period basically to the dry season (Fig. 6A), when rainfall levels decline significantly (only 10 % of the total annual rainfall). Differences in precipitation rates were found between Ajuruteua and Pesqueiro ($F = 14.52$; $p = 0.003$), with slightly higher values recorded in Pesqueiro beach. The air temperature is high and constant (normally, between 25 and 29 °C), being slightly higher during the dry season. Significant differences in temperature were also found when comparing Ajuruteua and Pesqueiro beaches ($F = 7.17$; $p = 0.014$), with higher values recorded in Pesqueiro. In addition, wind intensities vary from 4 to 8 m s⁻¹, reaching high values when the rainfall level is lower (Fig. 6B). Wind

intensity values also exhibited differences between Ajuruteua and Pesqueiro ($F = 16.10$; $p = 0.003$), with higher values observed in Ajuruteua.

At Pesqueiro, the high speed of the local tidal currents was also considered a potential physical hazard, increasing the risk of accidents. Current speeds depend on the tidal range (Fig. 7A), with the highest speeds being recorded when the tidal range (TR) reached 4.0 m (>1.6 m s⁻¹, spring tide) during the spring tides ($F = 24.44$; $p < 0.001$) and the lowest speeds during the neap tides (TR < 2.5 m, less than 1.0 m s⁻¹). The risk of accidents increases during spring tides, in particular 1–3 h after both the low and high tides when tidal current intensities were higher. Significant wave heights (H_s) were normally lower than 0.5 m (low energy waves), and these data are not shown here because waves of this height are not considered to present a risk to beachgoers. In fact, the risk of drowning occurs in areas with high-energy waves (usually over 1.5 m, Morgan et al., 2009; Pereira et al., 2014).

At Ajuruteua, the natural variability of hydrodynamic forces is primarily related to tidal modulation. Fig. 7B shows the impact of tide elevation on wave height at Ajuruteua beach. During the spring tides, the tide elevation reached 6 m, and waves, a height of 1.7 m at high tide (creating a risk of accidents). When the tide decreased to less than 1.0 m at low tide, however, wave heights were less than 0.5 m. Lower energy conditions were recorded during the neap tides ($F = 44.43$; $p < 0.001$), when tides reached around 4.0 m, and wave heights were normally less than 1 m at the high tide. In general, tidal current speeds were usually less than 0.5 m s⁻¹ during neap tides and higher than 0.5 m s⁻¹, during spring tides creating a higher risk of accidents.

With regard to comfort, water temperature and turbidity were measured. The water temperature at both beaches is high and shows low variation (27°–30 °C). However, significant differences were found at Ajuruteua beach ($F = 254.17$; $p < 0.001$) between the school vacation and holiday periods, with higher values observed during the school vacation period. On the other hand, no significant differences were found in turbidity between the periods at both beaches (average of 31 NTU in Pesqueiro and 36 NTU in Ajuruteua).

Based on the CONAMA classification of bathing water in terms of thermotolerant coliform concentrations, Pesqueiro beach showed an

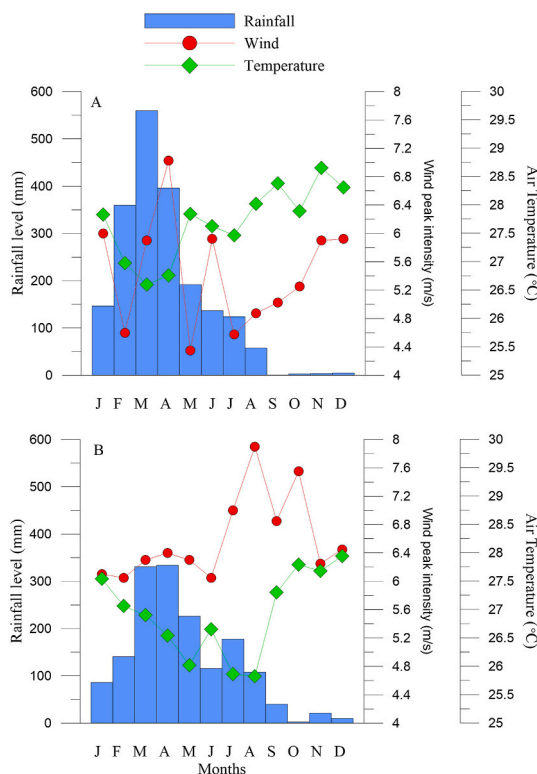


Fig. 6. Rainfall level, maximum wind intensity and air temperature in Pesqueiro (A) and Ajuruteua (B), during the study period. (Source: Authors 2022).

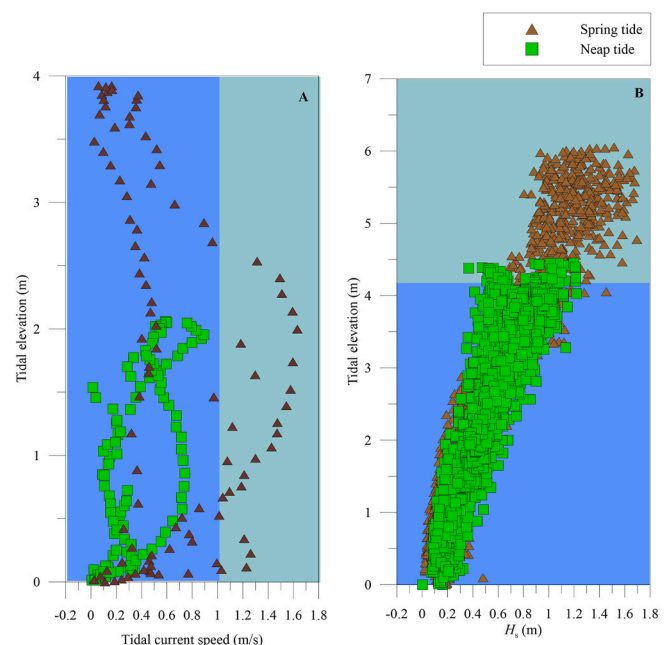


Fig. 7. Hydrodynamic conditions. Relationship between tidal elevation vs tidal currents in Pesqueiro (A), and tidal elevation vs significant height wave in Ajuruteua (B). Green colour means higher hazard (tidal current > 1 m s⁻¹ and TR > 4 m associated to $H_s > 0.8$ m) and blue colour lower hazard, according to Pereira et al. (2016). (Source: Authors 2022).

excellent condition (<250 MPN/100 mL⁻¹, see Table 4). Conversely, in Ajuruteua beach, during the periods when the number of beachgoers is highest (Fig. 3), such as school vacation period and extended public holidays, thermotolerant coliform concentrations were found to exceed 1100 MPN 100 mL⁻¹.

5.3. DPSWR_{navar} application

The six components of the DPSWR (*i.e.*, Driver-Forces-Pressure-State-Welfare-Responses) are described in more detail below and summarized in Table 5. This framework has added the “Natural variability” component to its structure. It was considered here because physical conditions, such as high rainfall levels during the rainy season, stronger winds, a higher tidal range, and stronger tidal currents may all affect the pressure level, the state and the welfare conditions.

5.3.1. Driving forces and pressure

The absence of any specific planning of land use (Driver) is common to both beaches, which are also subject to similar anthropogenic pressures (e.g., low investment in public services such as sanitation and security). However, the pressure level is lower at the estuarine Pesqueiro beach, where territorial occupation and recreational activities are controlled by the local community, according to interviews and field observations, and by ICMBio.

5.3.2. State and natural variability

The state of each beach depends on anthropogenic processes and/or activities. As pressures are also affected by physical aspects, the natural variability of a set of indicators was also considered here in an integrated fashion, to analyze the state condition. The state of each beach and the natural variability of the physical indicators are described in subsections 5.1 and 5.2.

5.3.3. Welfare

The social conditions and natural variability affect the comfort and security, and thus the welfare of the beachgoers in the study area. Welfare is linked to uncontrollable conditions such as climate, hydrodynamics, and hydrology, as well as controllable conditions like sanitation, safety, and unregulated occupations. Based on these conditions and the users' perceptions, welfare was related to:

- **Climate:** The extended rainy season is a negative aspect for beachgoer comfort as it restricts recreational activities. Air temperature, on the other hand, does not limit recreational activities in any way (positive aspect) because it remains consistently high and stable throughout the year. Wind speeds vary from moderate to slightly high but are still considered satisfactory (comfortable) and also do not limit recreational activities.
- **Hydrodynamics:** The high hydrodynamic energy found in the strong currents (mainly during spring tides) at Pesqueiro beach and in the high wave heights at Ajuruteua beach (at the turn of the high tide) can be considered a negative aspect due to the risk of accidents (e.g., drowning). However, the majority of the beachgoers interviewed at Pesqueiro and Ajuruteua still perceive the local hydrodynamics as moderately comfortable and safe.
- **Hydrology:** The water temperature is invariably high during the year and is thus considered to be moderate by the majority of the beachgoers. High turbidity is a result of the natural features of Amazon coast, and it is also considered moderately comfortable by the majority of the beachgoers at Ajuruteua and Pesqueiro beaches.
- **Unregulated occupation:** erosion at Ajuruteua is a combination of unregulated territorial occupation and physical drivers (high hydrodynamic energy and climate). Buildings at risk of collapsing and the rubble left in the intertidal zone as a consequence of erosive processes constitute a risk of accidents for beachgoers. Occupation at

Table 4
Classification of thermotolerant coliforms in Ajuruteua during vacation period*, and dry season holiday**, When asterisk was not used the campaign was taken during a weekday.

	July 10*	Oct 12**	July 13*	Sep 13**	Oct 13	Dec 13**	Sep 14	Nov 14**	Dec 14**	Nov 15**	Jul 16*	Sep 16**	Nov 16**
	Unappropriated	Unappropriated	Unappropriated	Unappropriated	Excellent	Unappropriated	Very good	Excellent	Excellent	Unappropriated	Unappropriated	Unappropriated	Unappropriated
Excellent: 250 MPN.100 mL ⁻¹ , Very Good: 500 MPN mL ⁻¹ , Satisfactory: 1000 MPN mL ⁻¹ (according with CONAMA).													

Table 5DPSWR_{natvar} framework components used in study area.

DRIVERS	PRESSURES	STATE	NATURAL VARIABILITY	WELFARE	RESPONSE
Absence of a specific use planning ^{11,12}	Unregulated territorial occupation ^{11,12}	Erosion enhancement ^{11,12}	Winds, waves, currents, tides	Destruction of infrastructure, streets and edifications. ^{11,12}	Relocation of wooden structures ICMBio control ^a Seawalls ^b
	Low investment in sanitation services ^{11,12}	Microbiological contamination due to presence of sewage outfalls and cesspits ^{11,12} Solid trash contamination ^{11,12}	Low rainfall level (higher beachgoers number)	Degradation of environments (beach, dune, mangrove areas) ^{11,12} Illness Visual and odor pollution ^{11,12}	ICMBio control ^a
	Low investment in safety services ^{11,12}	Insufficient lifeguards ^{a,b} Lack of specific training to different lifesaving skills ^{a,b} Lack of zoning ^{a,b} Lack of safety equipment and first aid services ^{a,b}	Low rainfall level (higher beachgoers number) High hydrodynamics	Occurrence of plagues ^{11,12} Accidents (injuries) ^{11,12} Accidents (drowning and other injuries) ^{11,12}	Lifeguards during the peak bathing period ^{11,12}
	Low Physical Capacity Carrying ^{11,12}	Overcrowding ^{11,12}	Low rainfall level	Discomfort ^{11,12}	No response ^{a,b}

^a Pesqueiro.^b Ajuruteua.

Pesqueiro is controlled by the ICMBio, and therefore is considered a positive aspect here.

- **Sanitation:** Investments in sanitation are minimal, and the discharge of effluents directly onto Ajuruteua beach has resulted in bacteriological contamination, in particular during periods of high spring tides when the number of beachgoers peaks. However, it is worth noting that many beachgoers do not perceive the presence of sewage outfalls, but rather the presence of trash in the sea and on the sand. The perception of the presence of sewage outfalls was positive (none/little) for the majority of beachgoers at Pesqueiro. Sanitation issues are also a consequence of unregulated occupation.
- **Safety:** Investment in beach safety also is minimal, and the number of lifeguards is probably inadequate. This results in an increase in the risk of accidents, especially when hydrodynamic energy and the number of beachgoers is elevated. Beachgoers are unsatisfied with the number of lifeguards at Pesqueiro, and with the available safety services at both beaches.

5.3.4. Responses

The two study beaches presented distinct safety management scenarios for recreational activities. At Pesqueiro beach, which is managed by the ICMBio and the local community, decisions are made within the framework of the management plan of the Soure RESEX. At Ajuruteua beach, which is within an adjacent zone of the Caeté-Taperaçu Marine Extractive Reserve, and is thus excluded from the strict protection of the RESEX, no evidence was found of any practical response in terms of beach safety management or specific measures based on beachgoer comfort, and reduction of risks and hazards. The lack of any effective municipal management initiatives further contributes to the general problem of beach safety and comfort.

Ajuruteua beach presented a range of potential hazards related to public sanitation, although no practical response has been taken. Investments in a sewage treatment system and the removal of all cesspits and other sewage outfalls should ensure the avoidance of the contamination of the water by thermotolerant coliforms. While microbiological contamination was not recorded at Pesqueiro, it would be important to monitor the existing cesspits to avoid eventual leaks and contamination.

The reduced number of lifeguards, the lack of investment in safety services, and the lack of zoning and warning signs are factors that increase the risk of accidents, in particular during periods when the number of beachgoers and the hydrodynamic energy are highest. Beach safety management plans are required on both beaches to ensure the

safety and well-being of beachgoers. These plans should include provisions for an adequate number of lifeguards, the establishment of safety protocols and guidelines, the availability of safety equipment, regular patrols, and education programs for beachgoers about potential hazards and safety precautions.

The combination of the local high hydrodynamic energy and the unregulated occupation on dunes and the intertidal zone is responsible for the erosion processes occurring at Ajuruteua. To avoid the degradation of buildings and coastal features on the waterfront, seawalls have been built by both the private sector and by the government in an attempt to minimize erosion, despite conflicts with local scientists, economic sectors, government authorities, and residents. Even so, the seawalls have not always had positive effects, and a more effective measure would likely be the re-planning of the territorial occupation of the beach, as recommended by the Municipal Coastal Management Working Group (GT-GERCO Bragança) established in 2013 to discuss specific questions related to problems such as erosion and unregulated occupation of land on Ajuruteua beach (Sousa-Felix et al., 2020), and by published studies and official reports (reports approved by the government or by someone with authority). Natural erosive processes were also recorded at Pesqueiro beach, where the increase in the number of buildings requires greater controls by the ICMBio to impede new building and to prevent the future destruction of existing infrastructure.

6. Discussion

Planning is an essential management tool for the success of an organization (whether public or private) and involves three types of plans: strategic, tactical, and operational (Seeley, 1962). These plans have distinct, but interrelated goals, which are necessary to achieve the overall objectives of the organization. In Brazil, the objective of the National Coastal Management Plan (PNGC) is “to plan and manage the socioeconomic activities on the coast in an integrated, decentralized, and participative manner, in order to guarantee the use, control, conservation, protection, preservation, and the recuperation of natural resources and coastal ecosystems” (MMA 2015, p. 181). In this context, the *Orla* Project (an integrated action between the Ministry of the Environment and the Federal Patrimony Secretariat (SPU/MPOG), with the aim of optimizing the planning of coastal areas under Union domain, in this case the waterfront, bringing together environmental, urban and heritage policies), state coastal management programs, and the local (municipal) management plans are essential tools for achieving tactical

and operational objectives of the PNGC (MMA 2015, p. 181). However, the elaboration of state and municipal (Soure and Bragança) management projects is still being debated by the governmental authorities, and none have yet been finalized or implemented. Same time, local tourism is progressively increasing, bringing both natural and social pressures (Pereira et al., 2018; Souza, Rocha, & Sobrinho, 2006). These factors require the urgent implementation of specific management plans.

Beach management plans are necessary to manage common and sensitive resources and to meet community goals, perceptions, and attitudes in order to guarantee long-term sustainability, considering not only tourism itself, but also the conservation of coastal areas (Hanafiah et al., 2021; Yepes, 1999; Zacarias et al., 2011). On the Amazon coast, protected areas, particularly the marine extractive reserves, appear to be a positive alternative for controlling recreational activities. Given this, beach management by protected areas is included in the PNGC as a tactical-operational tool aimed at protecting and conserving beaches and other coastal environments (ICMBio 2012; Barbosa & Campos, 2017). However, as demonstrated by Pessoa et al. (2019), although positive, this management model has limited coverage on the coast of Pará, given that its focus is only on promoting sustainability in traditional local communities, and not the other components (e.g., infrastructure, services, accessibility, safety) commonly found in coastal management plans, especially in the area of beach safety.

Unfortunately, many recreational beaches on the Amazon coast remain outside the sphere of control of the local protected areas, and are thus affected by natural and human pressures due to the multiple interests of both the private and the public sectors. For instance, while Ajuruteua village is located within the Caeté-Taperacú Marine Extractive Reserve, the beach zone is not covered by the management plan of this reserve. This means that the environment loses the potential benefits of sustainable use by local tourism. On the other hand, Pesqueiro beach experiences relatively fewer conflicts compared to Ajuruteua, given the continuous efforts of the community and the government's environmental management agency (ICMBio) in promoting sustainable local development (Pessoa et al., 2019), even though no specific management plan has been elaborated for this beach.

The application of the DPSWR_{natvar} framework in the present study helped to understand the importance of the role of the protected areas in the sustainable use of the recreational beaches based on the evaluation of comfort, hazards and risks. Here, *comfort* was understood as the level of satisfaction of the beachgoers with respect to social and natural variables, *hazards* as the social and natural variables that can expose the beachgoers to injuries, and *risks* as an assessment of these hazards associated with the type and level of usage of the public beaches (Short & Brander, 2013). It is important to emphasize that the understanding how beachgoers perceive and interpret aspects such as water quality (Pereira et al., 2003; Silva et al., 2013) and beach safety (Shibata, 2023; Sotés et al., 2020) have been used as a tool in decision-making processes in coastal management worldwide.

The evaluation of comfort, hazards, and risks will be discussed below, considering the components of the DPSWR_{natvar} framework and analyzing the role of extractive reserves as a potential management framework for the safety and comfort of beachgoers. This analysis will take into account both beachgoers' perceptions and the actual conditions observed during field campaigns. The main aspects to be discussed are:

(i) Sanitation:

The lack of public sanitation and waste collection services, and the presence of cesspits and sewage outfalls are sources of hazard for beachgoers and are linked to health risks (Li & Zhang, 2019). Reduced investment in sanitation services (Pressure) is a serious problem for the entire Amazon coast, and the presence of sewage is the principal source of contamination by thermotolerant coliforms (State) on most recreational beaches, such as Atalaia and Murubira in Pará, and Olho d'Água,

in Maranhão (Pereira et al., 2012; Pinto et al., 2011; Silva et al., 2011, 2013; Sousa, Pereira, Costa, & Jimenez, 2017). While these services are completely absent at both study beaches, the problem is more serious at Ajuruteua, given the larger number of buildings. Unfortunately, the perceptions of some beachgoers at Ajuruteua regarding the lack of sewage outfalls do not correspond to the actual local condition, as cesspits can be found in the intertidal zone and high levels of thermotolerant coliforms make the beach unsuitable for bathing during various periods. In fact, microbiological contamination peaks when the number of beachgoers reaches its maximum level (school vacation period) and coincides with the high spring tides (Natural variability). The presence of thermotolerant coliforms poses a risk of gastrointestinal illness to beachgoers (Welfare) (Cordero et al., 2012; Lamparelli et al., 2015). In contrast, the majority of Pesqueiro beachgoers perceive the local sanitation as being in excellent condition and these findings align with the absence of thermotolerant coliforms.

The lack of an adequate refuse collection service has also resulted in the presence of solid waste (State) on some beaches, and adjacent coastal environments when transported by local tidal currents (Natural variability), as recorded at Colares and Marudá beaches, in Pará (Sousa, Pereira, Trindade, et al., 2017). The accumulation of solid waste tend to be higher during school vacation periods and public holidays, leading to illnesses, injuries, infestations of pests, such as rats and insects, and unpleasant sights and odors (Welfare) (Giusti, 2009). Once again, the situation is more severe in Ajuruteua, and the problem is visually perceived (visual pollution and odors, Welfare) by the beachgoers, as shown in Table 2. In Pesqueiro beach, the ICMBio establishes regulations that ensure a certain level of control over the sanitary situation (Response), although it is not ideal, which is not the case in Ajuruteua. Based on this, a set of measures is proposed for a possible beach management plan for both study beaches.

(ii) Safety services

Beach safety is directly influenced by natural environmental conditions, human activities, and the availability of resources such as lifeguard teams, warning signs, zoning, and first aid equipment (Jimenez et al., 2007; Salterén et al., 2008; UNEP - United Nations Environmental Program, 2009). However, safety services on Amazon beaches have generally received little attention or investment (Pressure). Some popular beaches have few or no lifeguard patrols, and specific training in lifesaving skills is necessary (State). Additionally, safety equipment and first aid services are only found on a limited number of beaches and are typically available only during school vacation and holiday periods (State).

As safety services are virtually non-existent at both beaches, the beachgoers' perceptions were highly negative in both cases. Similar scenarios have been observed on recreational beaches in other parts of the Amazon coast, independently of whether they are contemplated by protected area planning (Sousa, Pereira, Trindade, et al., 2017). At Pesqueiro, three lifeguards appear to be an inadequate number, considering that more than 1400 visitors were recorded in the study transect during peak visitation time (2 p.m.), indicating the need for a larger number of lifeguards. The number of lifeguards in Ajuruteua appears to be adequate during the weekends of the school vacation period, however measures need to be taken to reduce the risk of incidents (Welfare). These measures could include the implementation of warning and information signage as well as safety campaigns. Given this, in general, there is no fixed ideal number of lifeguards, as the required number varies depending on various factors, including the size of the beach, the number of beachgoers, tide and wave conditions, geological risks, etc. However, it is recommended that authorities conduct a proper assessment of risks and specific needs for determine the required number of lifeguards and elaborate safety protocols. For example, Bondi Beach in Australia is approximately 900 m long. During the busy summer months, it has eight lifeguards on duty each day.

Additionally, during weekends and public holidays in the summer period, Bondi is also patrolled by volunteer surf lifesavers (Warton & Brander, 2017). In fact, studies have shown that at beaches patrolled during the bathing season, the risks of accidents are lower, including those caused by dangerous animals (Bordehore et al., 2016), tides (Koonn et al., 2023), rip currents (Woodward, Beaumont, Russell, & MacLeod, 2015), waves (Koon et al., 2018), shore-break wave (de Korte et al., 2021), and other factors.

In the study area, the risks of accidents can increase during (i) school vacation periods, when there is a dramatic increase in beachgoer numbers, and (ii) periods of high hydrodynamic energy (Natural variability) that coincide with public holidays. Despite their similar natural conditions and low levels of investment from the public sector, sustainable practices are relatively well-controlled at Pesqueiro beach (Response). The lack of appropriate zoning (State) for recreational activities (surfing and jet skiing) can be dangerous for other beach users (Welfare). Measures should be implemented, in particular, in Pará, to increase the number of lifeguards and improve their training, zone activities, and provide first-aid equipment (Brito et al., 2016).

(iii) Territorial occupation:

Unregulated occupation and unplanned urbanization (Pressure) have caused serious problems at most recreational beaches on the Amazon coast, where natural features and buildings or other infrastructure have been partially or completely destroyed by erosive processes (State), such as on the beaches of São Luís, in Maranhão state (Silva et al., 2013), and Atalaia (Pereira et al., 2013) and Mosqueiro beaches (Sousa, Pereira, Costa, & Jimenez, 2017), in Pará.

At Ajuruteua beach and these other beaches, both the private and public sectors have erected protective structures (Response) in an attempt to minimize the destruction of local buildings and environmental degradation caused by these erosive processes. However, these measures require complementary actions, such as the removal of structures within the first few meters above the high tide line and projects to restore the dunes (Sigren et al., 2014). It is important to emphasize that these beaches are not part of protected areas, and in Ajuruteua, for example, rudimentary stilted buildings have been built on dunes, in the mangroves, and in the intertidal zone of the beach. This type of land use is prohibited by federal law (Federal Law number 9.605 of February 12, 1998), although this process is not under the control of the local authorities, as it is at Pesqueiro beach, where the number of edifications is controlled by ICMBio.

Conflicts are also minimal in other areas under the control of protected areas, such as Princesa beach, located within the Algodoal-Maiandea Environmental Protection Area, a state sustainable-use protected area (Supplementary Material, Table S1) and Vila dos Pescadores beaches (within the Caeté-Taperaçu Marine RESEX) in Pará. In these beaches, the number of edifications is also controlled by ICMBio, and the relocation of wooden structures further inland (Response) is recorded under erosion scenarios (Pereira et al., 2013; Trindade et al., 2016). Laws and monitoring to prevent unplanned occupation of the beaches and other sensitive areas should be enforced along the entire Amazon coast.

Pressures can intersect and, in this case, unplanned urbanization and unregulated occupation can result in the absence of or low investment in sanitation services as discussed above. Several studies have shown that the presence of cesspits or the illegal dumping of sewage on Amazonian beaches is the result of a combination of these pressures (Silva et al., 2013). On rural beaches located in protected areas, management plans control land use, and any type of sewage dumping and construction of cesspits that could cause a risk to the environment and/or human health are prohibited.

Overall, the problems observed on both beaches were related primarily to the lack of the application of the principal Brazilian coastal management planning tools, both strategic and tactical (PNGC, Orla

Project, GERCO-PA, etc.), the poor performance of state and local governments on local socio-environmental conflicts, urban planning, and the provision of facilities for sustainable community development and tourism. Given the different pressures found on Ajuruteua and Pesqueiro beaches, which have a direct influence on the socio-environmental state of these coastal environments, and on the quality of tourist-recreational activities, it will be necessary to adopt appropriate approaches to resolve these problems and guarantee the adequate development of both the local community and tourist activities, in particular with regard to beachgoer safety.

Finally, beaches located under government environmental management, such as Pesqueiro beach, experience relatively fewer conflicts compared to those that are not under the control of environmental agencies, like Ajuruteua, even though specific management practices may be necessary. In response to the question posed by this study, beaches located within protected areas have more sustainable recreational practices compared to those that are not.

7. Conclusions

This study demonstrated that protected areas are a positive alternative for managing recreational activities along the Amazon coast. However, given the specific characteristics of the study area and the limited investment in necessary services, the solutions to the problems of safety on the studied beaches include the adoption of a beach management plan with specific actions in the areas of territorial occupation planning, sustainable tourism, and infrastructure and services.

This will enhance safety within the beach environment to mediate or avoid the risks associated with the anthropogenic and natural hazards present on the two beaches, thereby providing the beachgoer with a good quality recreation experience and a satisfying visit. The measures indicated here (Table 6) will be essential for the establishment of safe recreational activities and may also be useful for the future development of local tourism and the implementation of projects and for the advancement of the local communities. These measures can also be adopted within the scope of the management plans on each beach.

To be implemented adequately, the management of beach safety conditions requires public actions (at municipal and/or state levels) for the regulation of urban development, the monitoring and control of environmental problems, the promotion of sustainable tourism, and investment in good quality services and infrastructure. Improvements in safety, information, and signposting are also needed, including an increase in the workforce of local public safety agents, as well as investments in services and infrastructure in basic sanitation and refuse collection to eliminate the problems of the contamination of beach and mangrove environments.

Finally, the use of the DPSWR_{natvar} framework in this study has aided in comprehending the significance of protected areas for sustainable recreation on beaches. Including the “Natural variability” element was critical in comprehending uncontrollable factors and how they can impact the pressure level, state, and welfare conditions.

Data availability

All data generated from this study are available from the corresponding author on reasonable request.

CRedit authorship contribution statement

Luci Cajueiro Carneiro Pereira: Writing – review & editing, Writing – original draft, Funding acquisition, Data curation, Conceptualization. **Rubem Manoel Coelho Pessoa:** Formal analysis, Data curation, Conceptualization. **Rosigleyse Correa de Sousa-Felix:** Writing – original draft, Formal analysis, Conceptualization. **Ana Beatriz Brito Dias:** Writing – original draft, Formal analysis, Data curation, Conceptualization. **Brenda Ribeiro Padilha da Silva:** Writing – original draft,

Table 6

Guidelines for the elaboration of a beach management plan for both study beaches.

PRESSURE	GUIDELINE
Unregulated Occupation	- Territorial planning including the removal of buildings from the waterfront^b - Control^{a,b} and prohibition^b of new occupations in the intertidal zone, and mangrove and dune environments - Application of laws and monitoring to prohibit the unregulated occupation of beaches and other sensitive areas^b
Sanitation	- Implementation of a public sanitation system^{a,b} - Elimination of the discharge of effluents and domestic and sanitary waste within the beach environment^b - Investment in measures to promote selective garbage collection^{a,b} - Monitoring of the disposal of garbage and waste in the sand and water^{a,b} - Provision of garbage collection recipients along the shore and in other beach spaces^{a,b} - Creation of awareness campaigns on the need for beach cleaning and the environmental importance of maintaining a clean and litter-free environment^{a,b}
Safety	- Investment in water quality monitoring (thermotolerant coliforms)^b - Provision of an adequate quantity of lifeguards and safety equipment^{a,b} - Inspection of building located in erosive areas with risk of collapse^b - Zoning of recreational activities to avoid or minimize accident risk^{a,b} - Creation of tourist information centers^{a,b} - Implementation of signaling systems (signs, maps) with tourist information, location data, danger and safety zones, tide heights, currents, etc.^{a,b} - Zoning of recreational activities^b - Increased investment in infrastructure and services^{a,b}
Low Physical Capacity Carrying	- Zoning of recreational activities^b - Increased investment in infrastructure and services^{a,b}

^a Pesqueiro.

^b Ajuruteua.

Formal analysis. **Rauquário Marinho da Costa:** Writing – review & editing, Writing – original draft, Funding acquisition, Data curation.

Declaration of competing interest

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

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Appendix A. Supplementary data

Supplementary data to this article can be found online at <https://doi.org/10.1016/j.jort.2024.100741>.

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