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Management of estuarine beaches on the Amazon coast though the application of recreational carrying capacity indices

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Highlights

- A specific approach based on the RCC model was adopted for estuarine beaches;
- Local human pressures have impacted both the quality of the beaches and their carrying capacity;
- The principal problems are a lack of infrastructure or a public sanitation system;
- Major investments in services are needed to guarantee the recreational experience;
- The specific methodology adopted in this study can be used for other Amazon beach.

1. Introduction

The use of the term carrying capacity in tourism has its origins in the 1960s (Coccossis and Mexa, 2004), to refer to the limits on the numbers of visitors that a tourist attraction can support. Over the past three decades, the growing interest in areas of tourism, such as beaches, has led to the elaboration of the Recreational Capacity Carrying (RCC) conceptual approach to support the development of management plans. Many variables have been used to define the RCC, including the biophysical limits of the environment, its numerical capacity, and the quality of the visitor experience (Saveriades, 2000, Coccossis et al., 2002; Saarinen, 2006). The most widely-used definition of the RCC is the maximum number of people that may visit a tourism destination at the same time without causing the degradation of the physical, economic and socio-cultural environment or any unacceptable decrease in the quality of the satisfaction of visitors (WTO, 1981).

The definition of the carrying capacity of recreational areas has become an essential tool for beach management, as it “enables the preservation of the high quality and quantity of coastal resources whilst meeting not only the current needs, but also securing long-term economic and ecological benefits for future generations” (UNEP/PAP, 1997), leading to an extensive literature in recent years, with a worldwide focus. As the RCC is used to evaluate problems related to overcrowding, these scientists have all been asking the same question – in scientific terms, how many visitors are “too many” for this beach?

In this context, carrying capacity assessment is a technique commonly used in beach management, being applied in different ways and in distinct socio-ecological settings and some recent examples of its application are provided below. De Ruyck et al. (1997) estimated the social carrying capacity from the opinion of users interviewed on King's Beach and Hobie Beach in South Africa. Silva (2002) combined physical and social carrying capacity assessments by using aerial photographs, video images and interviews with beachgoers in Sines (Portugal). Botero et al. (2008) developed a model to calculate carrying capacity based on environmental support, urban infrastructure and tourist services, which was used to assess five Caribbean beaches in Colombia. Jurado et al. (2012) developed an approach to evaluate the growth limits of tourist destinations using a mathematical formula based on integrated RCC indices, which were applied to two scenarios of sustainability, one weak and one strong on the eastern Costa del Sol, Spain.

Studies of the RCC of beaches, based on the fundamental principles of the concept, have been undertaken at a number of sites on the eastern and southern Brazilian coast (e.g., Cordeiro et al., 2012; Polette & Raucci, 2003; Silva et al., 2008), although only limited research has been conducted on Amazon beaches (Silva et al., 2011a; Sousa et al., 2011, 2014; Pessoa et al., 2013), and these studies have focused on oceanic beaches, rather than estuarine ones. Located on the Brazilian Amazon coast, the littoral of Pará state encompasses major estuarine systems and one of the World's largest and best preserved mangrove forests (Souza-Filho et al., 2006). The local landscapes are highly valuable in both ecological and esthetic terms, and both oceanic and estuarine beaches are important recreation areas (Pereira et al., 2014; Sousa et al., 2014). Over the past few decades, the construction of access roads has resulted in the increasing use of the beaches for recreational activities, and tourism has become one of the principal sources of income for the local economy, especially during the vacation periods (Pereira et al., 2007; Szlafsztein, 2009; Szlafsztein & Sterr, 2007).

Unfortunately, almost 30 years after the implementation of federal law number 7661, which established the National Coastal Management Plan, and with many state coastal management plans in force, few practical measures have been taken to minimize, prevent and/or solve the conflicts associated with the use of land along the coast of Pará. As the popularity of the state's beaches has grown exponentially in recent years, the need for coastal zoning and management plans – including the monitoring of RCC indicators – has become increasingly urgent.

An RCC approach is important here because, while these coastal environments are still relatively well-preserved, its beaches already lack sufficient infrastructure and services to satisfy current levels of demand (Pereira et al., 2014). Unplanned and uncontrolled development has resulted in social and economic conflicts, as well as the deterioration of local coastal resources (Oliveira et al., 2011; Pinto et al., 2011; Silva et al., 2011b; Sousa et al., 2013).

In this context, the principal aim of this study was to contribute to the improved management of the beaches in this estuarine environment using the Recreational Carrying Capacity (RCC) concept. To this end, we adapted the standard RCC model to provide a combined assessment of natural and anthropogenic factors considering the unique characteristics of this type of beach. In general terms, it is extremely difficult to determine the "magic number" of tourists because the threshold established by tourists tends to differ from the ecological limits (Jurado et al., 2012), but we adopted a specific approach for these estuarine beaches that can also be used at other Amazon beaches.

2. Amazon estuarine beaches

Estuarine beaches typically have a relatively long shoreline in comparison with those on open coasts, and are affected primarily by tidal currents, with negligible wave action (e.g., Nordstrom, 1992; Vila-Concejo et al., 2010), and are thus considered low energy environments. However, the beaches of the estuaries of the Amazon coast have distinct characteristics, and do not necessarily conform to the classification system adopted by Jackson et al. (2002)[2].

[2]Jackson et al. (2002) proposed four criteria to define low-energy beaches: (i) negligible significant wave heights (H_s<0.25 m) during non-storm conditions, (ii) low significant wave heights (H_s<0.50 m) during strong onshore winds, (iii) narrow beach face width (< 20 m in microtidal environments) and (iv) morphological features that may include those inherited from higher energy events.

Amazon estuarine beaches are located within a mangrove-dominated fluvial-marine ecosystem controlled by meso- and macrotides, waves of moderate energy and strong tidal currents. The climate of the study region is humid equatorial with a mean annual temperature of 26–27°C and annual precipitation generally between 2000 and 3000 mm, with 75–85% of this precipitation falling during the rainy season, between January and May, and a dry season during the second half of the year (INMET, 2015).

The enormous fluvial discharge observed in this area is the result of the region rainfall pattern, which generates a massive input of suspended particulate matter (such as suspended sediments, detritus and organisms) and stained dissolved organic matter (humic substances) from the extensive areas of mangrove. Tide-dominated conditions and strong local tidal currents are responsible for the resuspension of the fine particulate matter contributing to much higher turbidity levels (> 100 NTU) in the coastal waters, including the estuarine beaches. The enormous fluvial discharge from the Amazon River and adjoining estuaries, which represents 20% of the planet's freshwater, results in the typically reduced salinity (near zero) of the region's estuarine beaches, especially during rainy season.

The tidal range reaches a maximum of 11 m at Igarapé do Inferno (Amapá), decreasing northwards along the Amapá coast to 7 m and then 4 m, and 5-6 m to the south on the Pará coast, 3-4 m in Marajó Bay and at Belém, rising eastwards to 7 m in the Gulf of Maranhão, and then declining again to 3 m at the Parnaíba delta (DHN, 2015). Local values of tidal elevation together with estuarine geomorphology determine local tidal current patterns. Strong tidal currents affect the estuarine beaches and can reach velocities of more than 2.0 m s^{-1} (Beardsley et al., 1995). Offshore significant wave heights can reach more than 1.5 m, but the influence of the tides normally prevails over wave action, especially at low tide, when the estuarine waters are sheltered by sandbanks, which reinforce the tidal modulation.

In contrast with other parts of Brazil, the principal recreational period on the Amazon coast coincides with the July school vacation and bank holidays during the second half of the year, given that the January school vacation – the peak period in most other Brazilian regions – coincides with the beginning of the Amazon's long and intense rainy season. Other factors, such as the relative isolation of the beaches due to extensive area of mangrove forest, the difficult access due to presence of countless estuaries, creeks and rivers, and the low quality of the available services and infrastructure, combine to limit the development of the coastal tourism industry.

As a result, only a reduced number of the region's beaches have been used traditionally for leisure activities. However, the human pressure on natural resources, combined with a lack of urban/land-use planning, on these few beaches has increased considerably during the past few decades, generating serious environmental and social issues (Szlafsztein, 2012). These impacts have been affecting the local coast, altering the conditions expected by different interest groups (local residents, business owners, fishermen, beachgoers) for recreational or economic activities.

Beach pollution is the major issue, due to the presence of sewage outfalls located within the intertidal zone (as at Marudá and Murubira beaches). This situation has negative repercussions on the quality of the beach water, especially during the summer vacation period (July). The presence of sewage outfalls have resulted in a number of polluting effects, including unpleasant sights and odors, as well as contamination by bacteria, such as thermotolerant coliforms.

3. Study Area

The study area is located on the Amazon Macrotidal Mangrove coast of the coastal zone of Pará. It comprises three beaches, Colares, Murubira and Marudá (Figure 1). This coastal sector has a highly indented shoreline consisting of bays and associated tidal creeks and their tributaries, which form funnel-shaped estuaries. The bays are filled with mangrove forests, and estuarine beaches are tide-dominated and fronted by extensive intertidal sand- and/or mudflats (Pereira et al., 2016). Colares (mesotidal) and Marudá (macrotidal) beaches are characterized by muddy sediments in the areas not affected by wave action. Located on Colares Island, Colares beach is 96 km far from the state capital, Belém. The island is separated from the continent by the Guajará-Mirim River and the Laura tidal creek, and the beach is located in a sheltered portion of the island. This sandy beach is 561 m long and reaches a width of 400 m during the low spring tides. Due to the influence of the local fluvial conditions, salinity varies between 1 and 5. Marudá beach is 160 km from Belém, at the mouth of the Marapanim estuary. This beach is more exposed to wave action (H_s normally above 1.0 m) and marine waters (salinity 18–28), with a tidal range of up to 5 m. This beach extends for more than 1 km and has a width of around 300 m during the low spring tide.

Murubira beach is located on Mosqueiro Island, 72 km from Belém. This beach is a site of considerable historic and touristic importance for the Brazilian state of Pará. Located on the margin of the Pará River (Marajó Bay), Murubira beach is separated from the continent by the Maguari and Marinhas creeks, and by Sol Bay. The tidal elevation in this beach is of 3.5 m during spring tides (DHN, 2015), and wave height (H_s) may reach 1.5 m (El-Robrini et al., 2006). The beach is 1.4 km long and around 70 m wide during low spring tides.

In spite of being in an area of considerable natural and ecological value, these beaches are used intensively for recreational purposes, resulting in extensive modifications of their original natural status. Currently, Murubira and Marudá can be considered to be semi-urban beaches, with promenades and other infrastructure, while Colares can be classified as a rural beach, with well-preserved natural features, including native vegetation and dunes on the backshore.

Due to the local meso/macrotides, the beach profiles can vary from hundreds of meters (low-tides) to a few meters (high tides). Thus, at the end of the flood tide, high tide and the beginning of the ebb tide, many of the beachgoers frequent bars and restaurants or foreshore areas because the backshore area is negligible.

<Insert Figure 1>

4. Data and Methods

Given the objectives of this study, two main approaches were adopted: (i) the qualitative and quantitative characterization of environmental conditions and services, i.e., the status of the beach, and (ii) the calculation of a recreational carrying capacity index based on an integrated assessment of the physical area of the beach, its natural conditions, and its facilities.

4.1 Recreational Carrying Capacity

The recreational carrying capacity (RCC) of the three study beaches was determined using the basic approach of Cifuentes (1992), as modified by Cifuentes et al. (1999), Segrado et al. (2008), and Zacarias et al. (2011). This approach attempts to establish the maximum number of visitors that can be tolerated in an area based on current physical and natural conditions together with management practices.

Following the approach of Zacarias et al. (2011), we aimed to obtain the recreational carrying capacity (RCC) of the estuarine beaches, based on its physical carrying capacity (PCC), modulated by a series of correction factors which are defined here as a function of the intrinsic characteristics of the study beaches as:

$$RCC = PCC \times WQ \times EnvQ \times EQ \times QS$$

where, *WQ* = water quality, *EnvQ* = environmental quality, *EQ* = ecological quality, and *QS* = quality of services, which are described below.

These four modulation indices cover the main factors that influence the overall quality of the system and they were selected to adjust the PCC (which should represent the maximum capacity of the system) in such a way as to provide an RCC that reflects actual conditions. The range of values of this index was selected in an attempt to establish an equilibrium between the low level of services expected on a beach in a natural environment and the services demanded by beachgoers when using a beach, even in areas dominated by highly natural environments. We have thus established a reduction of 40% in the RCC for beaches on which no services are available, with a much higher value being considered in the case of urban beaches. The range of values should nevertheless be established specifically for each beach, based on an analysis of the demands and requirements of users, even though this may emphasize the need for more services.

4.1.1 Physical Carrying Capacity

The Physical Carrying Capacity (*PCC*) measures the maximum number of visitors that can be supported by the beach. It is obtained by:

$$PCC = A/A_u$$

where, A is the usable area of the study beach, and A_u is the area available per user.

The value of A is obtained for each beach by measuring the area occupied by visitors. Given the local mesotidal (tidal range between 2 and 4 m) or macrotidal (tidal range > 4 m) conditions, the beach mean width was calculated by taking into account the difference between high and low tides (Figure 2). At Colares and Marudá, the lower sector of the intertidal area was not included in the usable area due to presence of muddy sediments which prevented the use of this area by visitors.

<Insert Figure 2>

The available area per user (A_u) was estimated taking the degree of urban development of each beach into account. According to their characteristics, Marudá and Murubira were classified as semi-urban beaches and Colares as a rural beach. To assign the corresponding A_u value we used values reported in the literature for these types of beach (Embratur, 1975; De Ruyck, 1997; Silva, 2002) as well as field data. Based on this, A_u was defined as 10 m²/visitor for the semi-urban beaches and 12 m²/visitor for the rural beach.

4.1.2 Correction factors

The correction factors or the PCC considered in this study were selected to account for the principal factors affecting the recreational use of the beaches in the Amazon region. The relative weight of each factor was scaled taking into account their expected influence based on published studies and the results of local surveys (July 2012 and 2013). These factors are presented below.

(i) Water quality (*WQ*)

This correction factor refers to the water quality of the beach in terms of its potential effects on the health of visitors. Beach water is susceptible to bacteriological contamination which may result in exposure to public health risks during bathing. Thermotolerant coliforms were used to evaluate water quality because these bacteria are considered to be indicators of contamination by sewage, which can cause gastroenteritis, and other health problems, such as respiratory, skin, eye and ear complaints (Fewtrell and Kay, 2015).

The index was divided into four categories, according to the Most Probable Number (MPN) of fecal coliforms per 100 mL: 1.0 (Excellent, <250 MPN 100 mL^{-1}), 0.8 (Very good, 250-500 MPN 100 mL^{-1}), 0.3 (Satisfactory, 500-1000 MPN 100 mL^{-1}) to 0 (Inappropriate, >1100 MPN 100 mL^{-1}) based on the criteria established by Brazilian National Environment Council (CONAMA, 274/2000) for water destined for human bathing.

(ii) Environmental quality (*EnvQ*)

This index reflects the environmental status of the water for bathing, except for the bacteriological component, which is measured by the *WQ* index. The *EnvQ* index has two components, (i) the physicochemical characteristics of the water, and (ii) the aesthetic quality of the sand and water. Each of these components is composed of a number of specific parameters based on the criteria established by CONAMA (357/2005) for bathing water. The final value of the *EnvQ* is given by the mean combined value of these two components. As the effects of this variable on human health are considered negligible, and most affect the beachgoer’s comfort and perceptions, this index was scored between 1.0 (no effect) and 0.6 (maximum effect on users’ perceptions).

Physicochemical variables

The score for this component was calculated by measuring a series of physicochemical variables of the water. To select the critical value for each of these variables, we used the criteria of CONAMA to classify the quality of the water as good or bad. The value of this component was obtained by the simple average of the different variables.

The limits for physicochemical parameters by COMAMA are: pH of 6.5–8.5, dissolved oxygen > 5.0 mg L^{-1}, nitrite < 0.07 mg L^{-1}, nitrate < 0.4 mg L^{-1} and total phosphorus < 0.124 mg L^{-1}. A score of 0.6 was attributed to the upper and/or lower limit values, according to the criteria established by CONAMA, and 1.0 when the limits of tolerance were exceeded. These variables were chosen because they are good indicators of natural and anthropogenic changes in water, and they have been previously used for this purpose (e.g. Praveena et al., 2013; Silva et al., 2013). The parameters are well documented. For example, (i) lower pH levels are known to cause eye and skin irritations, and even a slight change may result in the death of some aquatic organisms; (ii) the excessive input of nutrients through the discharge of sewage leads to eutrophication, which provokes algal blooms, and (iii) the proliferation of algae can lead to the depletion of dissolved oxygen, which is consumed by bacteria during the oxidative decomposition of the organic matter produced by the die-off of the algae.

Visual aspects

The aesthetic quality was based on the absence of oils and fats, floating debris, solid residues in the sand, sand odors, and water turbidity. However, these conditions are rarely found on the Amazon coast where the estuarine and coastal waters are affected by the suspended matter discharged by the many local rivers, which also transport a significant amount of vegetation debris (Pereira et al., 2012, 2013a). Although this does not necessarily imply that water quality will be poor in these environments, we also considered these aspects to be undesirable for beachgoers given that, even in this environment, they have negative attitudes towards these conditions. In this context, the parameters were based on CONAMA, and represent an important indicator of the recreational experience of beachgoers and the visual quality of the beaches.

The score for this component was calculated by integrating the contribution of these five parameters referring to the aesthetic quality of the beach and users' comfort. The CONAMA criteria (357/2005) require negligible water turbidity, no floating debris, and no residues in the sand. All the variables were measured qualitatively (present or absent) and, as in the previous case, the criteria provided by CONAMA were used to establish the corresponding value (0.6, present or 1, absent). The integral value for this component was obtained from the simple average value of each variable.

(iii) Ecological quality (*EQ*)

This indicator measures the status of the natural conditions of the beach that, when affected, may represent the degradation of the resource. In this sense, it implicitly assumes that the RCC represents the maximum potential use of the beach any degradation of its natural conditions. This variable is presented as an index with a score ranging between 1 (no effect on natural conditions) to 0.6 (natural conditions degraded).

According to typical conditions of the study area, three components (degradation of dunes, degradation of mangroves and the risk of coastal erosion) were taken into account through direct observation, and were scored as high (0.6), moderate (0.8) and low (1.0). The overall score of this component was obtained as the simple average of the variables considered.

(iv) Quality of services (*QS*)

In spite of the fact that these beaches are located in a natural environment (semi-urban or rural) they are popular with beachgoers, and regular visitors demand specific services during their stay. Given this, planning the recreational use of the coast where beaches are used intensively must take the quality of the services provided into account, considering that a minimum level of services is required to avoid the collapse of the resource, in recreational terms. Based on the local conditions, a minimum set of services was considered essential for the recreational use of the local beaches – public restrooms, waste bins, parking, accommodation, bar and restaurants, and accessibility. The overall *QS* score for each beach was given by the mean value of the components evaluated, with a final score of between 0.6 and 1.0, with 0.6 referring to the absence of the service, 0.8 for present but unsatisfactory, and 1 when it is adequate. The qualitative assessment was based on visual observations and surveys of beachgoers.

4.2 Beach Status (environmental conditions and services)

The procedures used to assess the qualitative and quantitative features of the environmental conditions and available services for the calculation of the RCC are summarized in Table 1.The services available at each beach were evaluated in situ during the vacation season using a checklist, and photographs were taken of specific features. Environmental conditions were measured in field campaigns during the vacation season. Each beach was surveyed on a Sunday (peak visitation day) during three weeks in July 2012 and July 2013. Surface water samples were collected every three hours between 07:00 h and 19:00 h using 5 L Niskin oceanographic bottle (General Oceanics). These samples were used to determine the pH of the water, dissolved oxygen and nutrient concentrations, and thermotolerant coliform levels. Thermotolerant coliforms were also analyzed in samples of water collected from the Sonrisal stream on Colares beach.

In the laboratory, dissolved oxygen was determined by the Winkler method, as modified by Strickland and Parsons (1968) and pH was measured using a pHmeter (Hanna HI 2221). Thermotolerant coliform levels were determined using the method of the American Public Health Association (APHA, 2012). The water samples were vacuum-filtered through glass-fiber filters (Millipore GF/F 0.7 µm, 47 mm), and then freeze-dried for dissolved nutrient analyses. Dissolved inorganic nutrient (nitrite – NO_2 and nitrate – NO_3)

concentrations were determined by spectrophotometry, following the procedures described by Strickland and Parsons (1977) and Grasshoff et al. (1983). Filtered water samples were also frozen for the subsequent analysis of dissolved total phosphorus (TP) by applying an adaptation of the simultaneous oxidation of nitrogen and phosphorus compounds using an alkaline persulfate oxidizing solution (Grasshoff et al., 1999).

<Insert Table 1>

5. Recreational Carrying Capacity of the Study Beaches

5.1 Physical Carrying Capacity

Table 2 shows the total and usable areas of the three study beaches. The beach with the largest surface area is Marudá, with 123,900 m², adjusted to 93,763 m² by tidal modulation, and further reduced to a final usable area of 67,113 m² (54% of the base value) by the presence of muddy sediments in the intertidal zone. After corrections, the usable area of Colares beach is 27,825 m² (53% of the total surface area), and that of Murubira beach is 16,000 m² (71% of the total area). Murubira is the only one of the three beaches with no muddy sediments in the intertidal area.

To convert these areas into numbers of users, different densities were considered for semi-urban (10 m²/visitor) and rural (12 m²/visitor) beaches. The PCC is thus 6711 visitors for Marudá, 2319 for Colares, and 1600 for Murubira without considering the rotation factor, which takes into account the average length of the stay on the beach, for which, unfortunately, there are no data. However, direct observations made during the study period indicate that the beachgoers usually stay all day long on these beaches, i.e. rotation is very low.

<Insert Table 2>

The spatial distribution of the users on each beach was determined primarily by three main factors, i.e. tidal range, accessibility and the occurrence of cultural events. Thus, the following main characteristics were observed:

(i) Most of the visitors on Colares and Marudá beaches were located at a distance of more than 100 m from the sea and less than 30 m from the main beach access (Figure 3A).

(ii) The distribution of beachgoers at Colares and Marudá and the carrying capacity of the intertidal sector depend on the tidal range (Figure 3B).

(iii) The promenade at Murubira beach was more densely occupied than the other beach sectors (Figure 3C). This sector is occupied primarily by younger beachgoers attending social events (street parties and shows) which are usually organized in this area.

<Insert Figure 3>

5.2 Correction factors

During the survey period, in spite of the large number of people visiting the study beaches, the water quality *WQ* was unsatisfactory at Marudá (0.00), although it was good at Murubira (0.3) and Colares (0.8) beaches (Tables 2 and 3). The highest concentration of thermotolerant coliforms was recorded at Marudá, with more than half of the water samples exceeding the CONAMA limit for human use (> 1100 MPN 100 mL^{-1}). At the opposite extreme, Colares presented the lowest level of microbiological contamination with only 20% of the water samples being contaminated by thermotolerant coliforms (> 1100 MPN 100 mL^{-1}). These levels of bacterial contamination are correlated with the presence of sewage outlets discharging directly on the beach, with 7, 10 and 2 outfalls/km on Marudá, Murubira and Colares beaches, respectively. At Colares, part of the observed contamination may be determined by the discharge of the Sonrisal stream, which had high thermotolerant coliform concentrations (>1100 MPN/100 mL^{-1}).

<Insert Table 3>

All the study beaches obtained satisfactory scores for the environmental quality (*EnvQ*) index (according to CONAMA standards), with values of 0.95 being recorded for Colares, and 0.85 for Marudá and Murubira beaches (Tables 2 and 3). Despite this, a number of aspects of the visual quality of these beaches were evaluated negatively, including sewage outfalls, trash in the water, and turbidity. The accumulation of trash leads to an unpleasant odor, especially at Marudá and Murubira, where social events are frequent. This problem is exacerbated by the lack of public restrooms and infrequent garbage collection.

The ecological quality (*EQ*) of Colares beach was considered to be excellent (0.87), due to the good preservation of its natural environment, dominated by dunes. On the other hand, Marudá (0.67) and Murubira (0.73) were classified as regular (Tables 2 and 4). In the study area, especially Marudá and Murubira beaches, many bars, restaurants and hotels have been constructed on the dunes, affecting 70–80% of the coastline, with major impacts on the local mangroves and coastal restinga vegetation (Figure 4).

<Insert Table 4>
<Insert Figure 4>

When analyzing the quality of services (*QS*), Colares beach obtained the lowest score (0.71) due to its lack of services, while only slightly higher scores (0.80 in each case) were obtained for Murubira and Marudá beaches. Overall, the three study beaches presented severe limitations in terms of the basic services requires for recreational activities (Tables 2 and 5).

Finally, when the correction factors are applied to the PCC scores for the study beaches the *RCC* scores decrease significantly in all cases. The most significant modification was observed in the case of Marudá beach which, despite having the highest *PCC* score, received an *RCC* score of zero, due to the inadequate quality of the water, which was found to be unfit for human use. In this case, the analysis found that the beach should not be used for recreational purposes. In the case of Colares and Murubira beaches, the RCC scores also decreased significantly, reaching values of 1089 visitors at Colares (about 47% of the original score) and 238 at Murubira (15%). These final RCC scores indicate a low carrying capacity, given that most of the necessary infrastructure and services are not provided.

<Insert Table 5>

6. Implications for beach management

The Recreational Capacity Carrying (RCC) is an important tool for beach management when the aim is to enhance the recreational potential of a coastal environment. While the dimensions of the beach – which determine the available space – are a major component of this index, it is also modulated by variables related to the “quality of the visit”, and the “preservation of the resource”. In this study, we adopted an RCC approach to provide management recommendations for Amazonian estuarine beaches. While these environments contain valuable natural resources that must be preserved, they are being used increasingly by local populations for recreational purposes. As a consequence, adequate management is needed to maintain this natural resource, which demands a recreational carrying capacity assessment. The analysis conducted here has shown that, while these rural/semi-urban beaches are still rich in natural resources, increasing and unregulated human pressure has resulted in a significant decrease of the quality of the beaches and, thus, of their carrying capacity.

As mentioned above, the methodological approach used in the present study is an adaptation of a standard RCC assessment protocol, which was modified specifically for the evaluation of estuarine beaches of the Amazon region. To this end, we need to take into account local environmental and social conditions to select adequate indicators for the modulation of the RCC, as well as to define their upper and lower limits. In this study, the proposed scale for the correction factors was based on previous studies of user preferences, together with Brazilian standards of environmental quality (see Methods). The final RCC values obtained by this approach will depend on the scale selected and in this sense, the definition of adequate parameters in essential for a reliable analysis. To apply the same index to other environments, it would be necessary to create a unified scale of correction factors, which would be derived ideally from an extensive study of the requirements and preferences of users.

Of the three study beaches, Colares was the least contaminated, due to its relatively undeveloped and natural conditions, with well-preserved dunes and mangroves. This beach received high scores for all the indices except the quality of services, which are mostly rudimentary or, in some cases, totally absent. This reflects its natural/rural character but emphasizes its inadequate potential for seasonal peaks of visitation.

The much lower carrying capacities estimated for Marudá and Murubira beaches were due primarily to the large number of sewage outfalls and the bacteriological contamination of the water used for recreational activities. Many other factors were also considered unsatisfactory at both beaches, including the undesirable odor of the sand and water, the highly turbid water, the presence of trash on the sand and debris floating in the water, the loss of dunes and mangroves, and the unregulated occupation of the coastline.

The loss of mangroves and dunes has had knock-on effects such as an increase in coastal erosion and the loss of habitat for endangered species. Recreational activities at Murubira are threatened by the low RCC and the lack of investment in the infrastructure needed for the collection and treatment of domestic waste. At Marudá, the situation was critical (RCC = 0), and bathing must be banned due to the high levels of bacteriological contamination. Unfortunately, the local authorities have not taken any measures to mediate this problem.

In Brazil, as in many other parts of the world, the lack of adequate infrastructure and services, and the unregulated occupation of many beaches, has produced an increasingly negative effect on their attractiveness for beachgoers (Mohanty et al., 2008; Olsen, 2003; Pereira et al., 2007; Botero et al., 2008). The results of the present study have demonstrated the need for urgent government intervention (in particular, investments in services and infrastructure) in order to improve the quality of the beaches and guarantee the recreational experience of local beachgoers.

Based on the results of the present study, we can recommend a number of measures that should be taken by local authorities to improve the status of the three estuarine beaches surveyed: (i) the immediate interruption of any sewage outlet that discharges effluents directly onto the beach or into nearby watercourses, (ii) the construction of a public sanitation system and sewage treatment plants, (iii) the establishment of a permanent water quality monitoring system for the beaches used for bathing and other recreational activities, (iv) the installation of a refuse collection system, including an increased number of waste bins and collection points, (v) the immediate prohibition of the construction of buildings on dunes or in areas of mangrove, and (vi) the installation of public restroom facilities, especially during the peak vacation period. These recommendations can be modified for other rural and semi-urban beaches in Brazil, and in other regions of the world.

In addition to these recommendations, the findings of the present study indicate the need for the careful reassessment of many of the standard CONAMA criteria – such as turbidity – used for the evaluation of water quality, given the unique conditions found on the beaches of the Amazon coast. High turbidity, for example, is a typical condition caused by the enormous amount of fluvial discharge and high energy local hydrodynamic conditions (e.g., Pereira et al., 2012a, 2013a, 2013b). Clearly, then, many of the criteria established by CONAMA require revision before being applied to the assessment of water quality in areas of the Amazon coast, where estuaries are dominated by fluvial conditions during the rainy season, and more coastal or marine conditions during the dry season.

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FIGURE CAPTIONS

Figure 1. Study area location. (A) South America and (B-D) part of Pará state, showing Murubira, Colares and Marudá beaches (D), and (E-G) photographs of the study beaches.

Figure 2. Mean difference between the high water level (HWL) and the low water level (LWL) of each study beach during neap tides.

Figure 3. (A) Beachgoers concentrated near the main access road to Marudá beach. (B) Beachgoer distribution depending on the tidal elevation on Colares beach. (C) Promenade at Murubira beach occupied by beachgoers (street party).

Figure 4. Coastlines of the study beaches: (A) Colares (Obtained from: http://www.mapio.cz/a/14390684/); (B) Marudá (Obtained from: http://www.portalturismobrasil.com.br/atracao/6143/Praia-do-Maruda); and (C) Murubira (Obtained from: http://www.ormnews.com.br/noticia.asp?=662130).

Table

Table 1. Summary of the procedures used to compile each index. *Based on CONAMA (274/2000) criteria.

Index	Variable	Data	Frequency	Method
Physical Carrying Capacity	Area/ User density	Field campaigns/ Literature review	Every 1h	Measurement of area/ Counting beachgoers and Literature review
Water Quality	Thermotolerant colifoms*	Water samples	Every 3h	APHA and CONAMA
	Number of sewage outlets*	Direct observation	Once per field campaign	Counting sewage outlets
Environmental Quality				
-Physical-chemical component	Dissolved Oxygen* pH* Nitrite* Nitrate* Total Phosphorus*	Water samples	Every 3 hours	Winkler method (Strickland and Parsons 1968) pHmeter Strickland and Parsons (1972) and Grasshoff et al. (1983) Strickland and Parsons (1972) and Grasshoff et al. (1983) Strickland and Parsons (1972) and Grasshoff et al. (1983; 1999)
- Visual aspects of the beach	Oils/fats Floating debris Solid residues Sand odors Turbidity	Direct observation	Once per field campaign	Check list
Ecological Conditions	Ecological features	Direct observation	Once per field campaign	Check list
Services	Services and infrastructure	Direct observation	Once per field campaign	Check list

Table 2. The RCC calculated for each beach, and the values of the respective PCC and correction factors

	BEACHES		
RCC	**Colares**	**Marudá**	**Murubira**
Total Area (m^2)	52,033	123,900	22,400
Useable Area (m^2)	27,825	67,113	16,000
PCC (persons)	2319	6711	1600
Water Quality	0.8	0.0	0.3
Environmental Quality	0.95	0.85	0.85
Ecological Quality	0.87	0.67	0.73
Quality of Services	0.71	0.8	0.8
RCC (persons)	1089	0	238

Table 3. Water and Environmental quality scores for each study beach.

VARIABLE	BACTERIOLOGICAL SCORE		
	Colares	**Marudá**	**Murubira**
Termotolerant Coliforms	0.8	0	0.3
VARIABLE	**PHYSICAL-CHEMICAL SCORE**		
	Colares	**Marudá**	**Murubira**
Dissolved oxygen	1	1	1
pH	1	1	1
Nitrites	1	1	1
Nitrates	1	1	1
Total Phosphorus	1	1	1
VARIABLE	**VISUAL ASPECT SCORE**		
	Colares	**Marudá**	**Murubira**
Oils and fats	1	1	1
Floating debris	1	0.6	0.6
Solid residues in the sand	0.6	0.6	0.6
Sand odors	1	0.6	0.6
Water turbidity	0.6	0.6	0.6

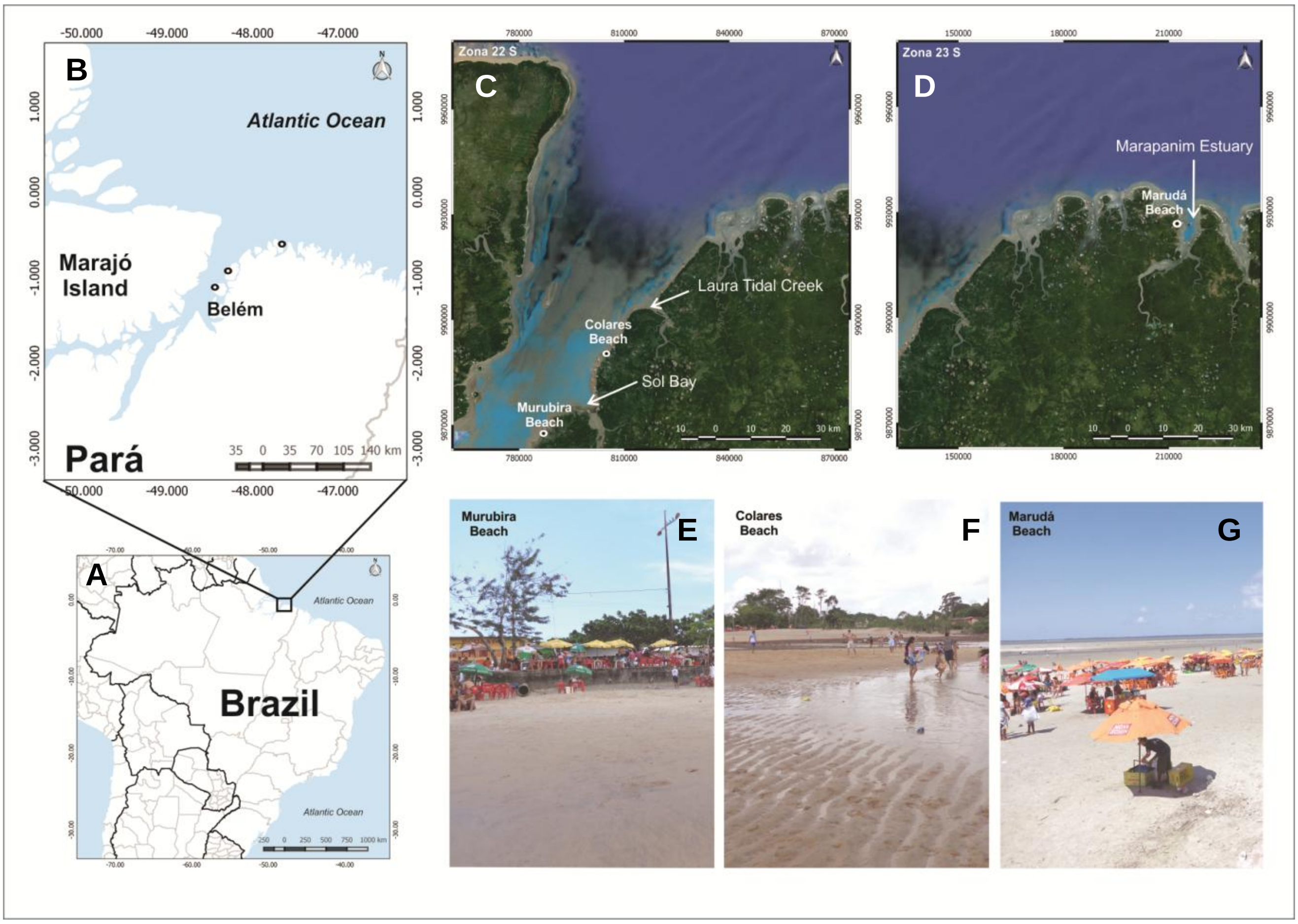
Table 4. Ecological Quality scores for each study beach.

VARIABLE	BEACH		
	Colares	**Marudá**	**Murubira**
Degradation of dunes	1	0.8	0.6
Degradation of mangroves	1	0.6	0.8
Risk of coastal erosion	0.6	0.6	0.8

Table 5. Quality of Services scores for each study beach.

VARIABLE	BEACH		
	Colares	**Marudá**	**Murubira**
Public restrooms	0.6	0.6	0.6
Waste bins	0.6	0.8	0.8
Parking	0.6	0.8	0.8
Safety	1	1	1
Accommodation	0.8	0.8	0.8
Bars and restaurants	0.8	0.8	0.8
Accessibility	0.6	0.8	0.8

Figure (including maps and photographs)



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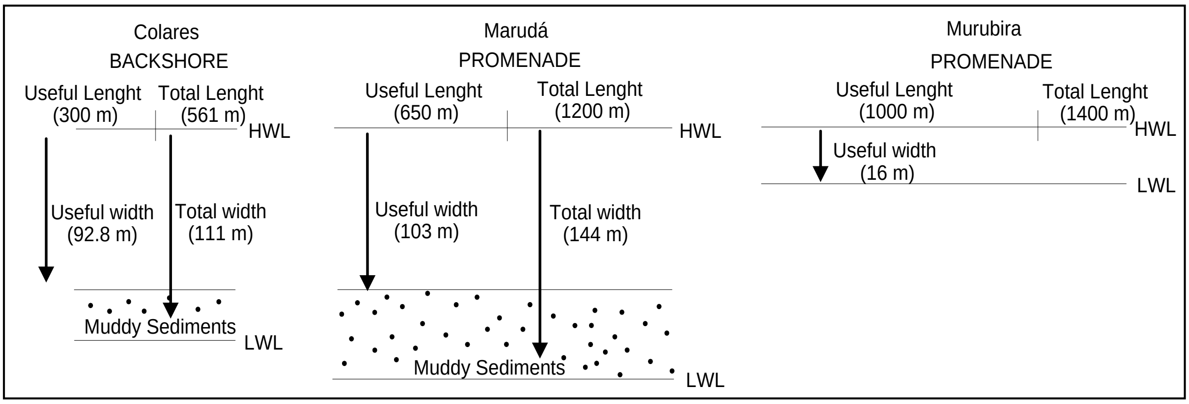

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