

**AVALIAÇÃO DA QUALIDADE TURÍSTICA DE PRAIAS
ARENOSAS NO SUDESTE DO BRASIL: UMA ABORDAGEM
MULTI-INTEGRADA**

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CAMPOS DOS GOYTACAZES – RJ

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Tese apresentada ao Centro de
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LISTA DE ABREVIACÕES

ACC – Avaliação do cenário costeiro

CAPES – Coordenação de Aperfeiçoamento de Pessoal de Nível

CBB – Centro de Biociências e Biotecnologia

CCF – Capacidade de carga física

CCR – Capacidade de carga real

CCT – Capacidade de carga turística

CM – Capacidade de manejo

COS – Praia da Costa Azul

ES – Estado do Espírito Santo

FAR – Praia do Farol de São Thomé

FER – Praia de João Fernandes

GRA – Praia Grande

GRU – Praia de Grussaí

GUA – Praia de Guaxindiba

IPGP – Índice de prioridade de gestão de praias

LCA – Laboratório de Ciências Ambientais

MMA – Ministério do Meio Ambiente

MOR – Praia do Morro

P – Probabilidade da hipótese nula (H_0) de um teste estatístico ser verdadeira

PER – Praia do Perú

RJ – Estado do Rio de Janeiro

SER – Praia da Sereia

UENF – Universidade Estadual do Norte Fluminense Darcy Ribeiro

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RESUMO

Este estudo investigou os impactos da superexploração turística e das lacunas de gestão na integridade ecológica e na atratividade de praias arenosas, propondo um arcabouço metodológico integrado que combina a Capacidade de Carga Turística (CCT), a avaliação técnica da qualidade cênica, a percepção dos visitantes e o Índice de Prioridade de Gestão de Praias (IPGP). Uma revisão sistemática de 143 artigos (2000–2023) sobre CCT evidenciou um crescimento nas publicações pós-2012, com predominância de estudos na Europa (45%), Ásia (34%) e Américas (19%). Embora 80% dos estudos estejam alinhados aos Objetivos do Desenvolvimento Sustentável (ODS), apenas 36% propuseram soluções mitigadoras para a superlotação, enquanto 54% detectaram cenários de *overtourism*, adotando a referência de 10 m²/usuário como o padrão ideal de conforto. A CCT foi aplicada a nove praias do sudeste brasileiro sob cenários de uso de 5 m² e 10 m², utilizando 69 indicadores (Bandeira Azul e Projeto Orla). No Rio de Janeiro, o limite de conforto (10 m²) foi excedido apenas em áreas turísticas centrais, enquanto no Espírito Santo, a sobrecarga foi registrada em todas as praias analisadas da região centro-sul. Praias certificadas com a Bandeira Azul (Peró-RJ, Sereia-ES) demonstraram índices superiores de gestão, contrastando com áreas menos urbanizadas que carecem prioritariamente de serviços e infraestrutura. A análise da percepção dos usuários (n=540) revelou uma superestimação de 30% na qualidade cênica em comparação à avaliação técnica, fenômeno acentuado em destinos populares como Praia Grande e João Fernandes. Observou-se alta tolerância à aglomeração, com 51% dos visitantes dispostos a permanecer na praia mesmo no cenário crítico de densidade (5 m²/pessoa). Em contrapartida, houve baixa tolerância à poluição: 70% deixariam o local no pior cenário de degradação por resíduos sólidos (15 itens/m²). Economicamente, projeta-se que a perda da qualidade ambiental possa gerar prejuízos de até US\$ 52 milhões por verão, impactando diretamente a receita local devido à evasão de turistas. O turismo via redes sociais apresenta-se como uma ferramenta potencial de alavancagem, desde que vinculado à conservação e educação ambiental. O IPGP proposto, ao integrar as dimensões social, ambiental e econômica, indicou que a prioridade de gestão está fortemente associada à pressão de uso e déficits infraestruturais. Conclui-se que o IPGP constitui uma ferramenta de baixo custo para a gestão pública, favorecendo o monitoramento, a prevenção e a comunicação social, oferecendo um roteiro prático para conciliar a sustentabilidade e a rentabilidade do turismo costeiro.

Palavras-chave: Praias arenosas; superlotação turística; qualidade cênica; gestão costeira; percepção ambiental; prioridade de gestão.

ABSTRACT

This study investigated the impacts of overtourism and management gaps on the ecological integrity and attractiveness of sandy beaches, proposing an integrated methodological framework that combines Tourism Carrying Capacity (TCC), technical assessment of coastal scenic quality, visitor perception, and a Beach Management Priority Index (BMPI). A systematic review of 143 articles (2000–2023) on TCC revealed an increase in publications post-2012, with a predominance of studies in Europe (45%), Asia (34%), and the Americas (19%). Although 80% of the studies aligned with the Sustainable Development Goals (SDGs), only 36% proposed mitigating solutions for overcrowding, while 54% detected overtourism scenarios, adopting the reference of 10 m²/user as the optimal comfort standard. The TCC was applied to nine beaches in Southeastern Brazil under use scenarios of 5 m² and 10 m², utilizing 69 indicators (Blue Flag and Projeto Orla). In Rio de Janeiro, the comfort threshold (10 m²) was exceeded only in central tourist areas, whereas in Espírito Santo, overload was recorded in all analyzed beaches in the south-central region. Beaches certified with the Blue Flag (Peró-RJ, Sereia-ES) demonstrated superior management performance, contrasting with less urbanized areas that primarily require services and infrastructure. User perception analysis (n=540) revealed a 30% overestimation of scenic quality compared to the technical assessment, a phenomenon accentuated in popular destinations such as Praia Grande and João Fernandes. High tolerance for crowding was observed, with 51% of visitors willing to remain on the beach even in the critical density scenario (5 m²/person). In contrast, there was low tolerance for pollution: 70% would leave the site in the worst-case scenario of solid waste degradation (15 items/m²). From an economic perspective, it is projected that the loss of environmental quality could generate losses of up to US\$ 52 million per summer, directly impacting local revenue due to tourist avoidance. Tourism promotion via social media appears as a potential leverage tool, provided it is linked to conservation and environmental education. The proposed BMPI, by integrating social, environmental, and economic dimensions, indicated that management priority is strongly associated with use pressure and infrastructural deficits. It is concluded that the BMPI constitutes a low-cost tool for public management, favoring monitoring, prevention, and social communication, offering a practical roadmap to reconcile the sustainability and profitability of coastal tourism.

Keywords: Sandy beaches; tourist overcrowding; coastal scenic quality; environmental perception; management priority.

ESTRUTURA DA TESE

Introdução geral: Contextualiza o tema, apresenta a problemática central e oferece uma visão sintética dos conteúdos desenvolvidos nos Capítulos 1–4, destacando a relevância científica e aplicada do estudo.

Capítulo 1: Realiza uma revisão global sobre capacidade de carga turística (CCT), mapeando métodos e dimensões empregadas (física, ambiental, sociocultural e econômica) e os instrumentos de política voltados ao enfrentamento da sobrecarga, alinhados à Agenda 2030. Identifica inconsistências conceituais e baixa padronização de monitoramento/validação. Como contribuição, propõe diretrizes e caminhos decisórios para gestores adotarem avaliações comparáveis e efetivas (Anexo 1).

Capítulo 2: Propõe e aplica uma ferramenta integrada que combina capacidade de carga turística com a avaliação da qualidade do cenário costeiro, utilizando indicadores do Programa Bandeira Azul e diretrizes do Projeto Orla (infraestrutura, serviços, educação/informação e balneabilidade) em praias arenosas do Sudeste do Brasil (Anexo 2).

Capítulo 3: Analisa como a poluição por lixo, aglomeração humana e baixa qualidade na infraestrutura/serviços influenciam a percepção de frequentadores de praia, interferindo na permanência/evasão e gasto turístico. Compara avaliações técnicas por especialistas e perceptivas de visitantes de praia para identificar convergências e vieses, e estima perdas econômicas potenciais associadas a cenários de degradação. Os resultados orientam intervenções focalizadas para mitigar a evasão e preservar a atratividade da praia.

Capítulo 4: Desenvolve uma ferramenta multi-integrada de priorização de gestão para praias com potencial local, regional e nacional/internacional, combinando capacidade de carga turística, indicadores ambientais do cenário costeiro e percepção dos visitantes. A abordagem gera um ranqueamento de urgência de intervenção e apoia a alocação eficiente de recursos, oferecendo base objetiva para decisões em contextos turísticos heterogêneos.

Considerações finais: Síntese das principais informações obtidas considerando os múltiplos capítulos dessa tese.

Introdução geral

As praias arenosas reúnem biodiversidade singular e serviços ecossistêmicos com forte lastro no turismo, mas enfrentam um paradoxo: os mesmos atributos que atraem visitantes vêm sendo degradados por urbanização costeira sem planejamento e pela intensificação do turismo de massa, comprometendo a integridade da Zona Litorânea Ativa, faixa entremarés, bancos de areia e dunas (Fanini et al., 2021; Harris e Defeo, 2022; Defeo e Elliott, 2020). Impactos crônicos, como trânsito de veículos, pisoteio, supressão de vegetação, espécies exóticas e poluição luminosa/sonora, somam-se a pressões sazonais de superlotação e à presença de resíduos sólidos, que deterioram a estética e a funcionalidade do cenário costeiro (Botero et al., 2013; Rêgo et al., 2018; Aguilera e González, 2023). Diante desse cenário, a gestão costeira requer abordagens integradas e adaptativas, capazes de traduzir diagnóstico em decisões e resultados práticos (Marchese et al., 2021).

Entre as ferramentas de planejamento ambiental turístico, a capacidade de carga turística destaca-se por avaliar os limites de uso das praias diante da pressão turística, estabelecendo limites de uso com base em condicionantes ambientais e sociais, estimando o número máximo de usuários que uma praia pode acomodar sem comprometer os recursos naturais ou a qualidade da experiência recreativa (Cifuentes, 1992; Morales et al., 2018; Rodella et al., 2020). A capacidade de carga turística não é um atributo fixo do destino, varia no tempo e no espaço e, em praias arenosas, incide sobretudo sobre a faixa de areia, área principal de uso recreativo (Saveriades, 2000). Por isso, “limitar números” não basta: a capacidade de carga turística funciona como indicador de proximidade do limite, acionando medidas preventivas quando infraestrutura e condições naturais tornam-se insuficientes (Fernández-Villarán et al., 2020; Leka et al., 2022).

Paralelamente aos estudos de capacidade de carga turística, foram desenvolvidos métodos para avaliar o valor do cenário costeiro. Esta avaliação mensura como impactos antrópicos, aglomeração, erosão, resíduos sólidos, esgoto e urbanização, afetam a integridade ecológica e o valor cênico, oferecendo suporte direto ao planejamento (Cristiano et al., 2016; Ergin, 2019). Índices e protocolos, como *Integrated Beach Value Index* (Cervantes e Espejel, 2008), *Beach Quality Index* (Ariza et al., 2010), *Índice de Calidad Ambiental en*

Playas Turísticas (Botero et al., 2014) e *Bathing Area Registration and Evaluation* (Micallef et al., 2011), organizam evidências para decisões de gestão. O Bandeira Azul, certificação anual focada em qualidade ambiental, água, serviços e educação, é especialmente relevante em países em desenvolvimento, onde pode catalisar proteção, reputação internacional e aprendizagem em gestão, apesar de limitações (Klein e Dodds, 2017; Dodds e Holmes, 2020; Botero e Zielinski, 2020). Na América Latina, a aplicação ainda é incipiente e há críticas quanto à incorporação sistemática de perspectivas locais e à não consideração de sobrecarga turística e conflitos de uso (Lozoya et al., 2014; Lucrezi et al., 2016).

A qualidade cênica influenciada por lixo, densidade de público e infraestrutura é determinante para escolha de destino, satisfação e rentabilidade (Jarvis et al., 2016; Corraini et al., 2018; Basterretxea-Iribar et al., 2019). Resíduos reduzem a estética, a percepção de qualidade e desencorajam a visita, figurando entre os principais indicadores para usuários em diferentes regiões e compondo critérios de certificação (Cervantes e Espejel, 2008; Rangel-Buitrago et al., 2019). Percepções variam por perfil socioeconômico e tipo de usuário: residentes tendem a valorizar mais atributos naturais; turistas mostram menor lealdade e maior propensão à evasão quando expectativas não são atendidas (Stedman, 2006; Hiltunen, 2007; Krelling et al., 2017). Ainda há lacunas sobre o grau de convergência entre avaliações técnicas por especialistas e percepções de visitantes, embora a literatura recomende monitoramento integrado para gestão mais efetiva (Roca e Villares, 2009; Defeo et al., 2009; Botero et al., 2015). Torna-se, assim, fundamental investigar como percepção (residentes e turistas) e qualidade cênica explicam permanência/evasão e gasto turístico, estimando impactos econômicos de resíduos e aglomeração.

A manutenção da qualidade de praias depende de avaliações integradas e periódicas, alinhadas às normas legais, políticas ambientais e melhoria contínua (Lucrezi et al., 2016; Chen e Teng, 2016). Uma ferramenta de priorização que combina as principais ferramentas de gestão, a avaliação da capacidade de carga turística, avaliação do cenário costeiro e a percepção de frequentadores de praia é essencial para identificar prioridades de intervenção de gestão em praias com potenciais turísticos distintos (local, regional e

nacional/internacional), reconhecendo limites e potencialidades de certificações e orientando alocação de recursos e mitigação de sobrecarga.

Apesar do avanço conceitual e metodológico, persistem lacunas operacionais na gestão de praias arenosas. A capacidade de carga turística, isoladamente, não assegura sustentabilidade nem lida com conflitos sociais gerados pela sobrecarga (Fernández-Villarán et al., 2020). As avaliações de cenário e certificações ainda carecem, sobretudo na América Latina, de integração sistemática de percepções locais e de uma abordagem explícita da sobrecarga turística (Nelson et al., 2000; Roca e Villares, 2008; Lozoya et al., 2014). Ao mesmo tempo, mudanças climáticas e pressões de uso convergem para reduzir a área de uso recreativo, elevando a urgência de ferramentas integradas e adaptativas (Valdemoro e Jiménez, 2006).

Essa tese responde diretamente as lacunas supracitadas ao: (i) avaliar a capacidade de carga turística com projeções prospectivas; (ii) aplicar e integrar capacidade de carga turística e a avaliação do cenário costeiro com base no Bandeira Azul e Projeto Orla em nove praias do Sudeste do Brasil; (iii) quantificar como a qualidade cênica e a percepção de usuários se traduzem em rentabilidade (gasto, permanência, evasão); e (iv) operacionalizar uma ferramenta multi-integrada para priorizar necessidades de gestão em praias com diferentes potenciais turísticos.

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CAPÍTULO 1

Evaluation of tourist carrying capacity on sandy beaches: a global review

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Evaluation of tourist carrying capacity on sandy beaches: A global review

Abstract

Overexploitation of sandy beaches by tourism, coupled with inadequate management, compromises their ecological integrity and ecosystem services.

The Tourism Carrying Capacity (TCC) Assessment is a promising tool for effective coastal management and governance, offering key information for environmental planning. This study reviewed 143 articles published in English between 2000 and 2023, revealing a steady increase in publications, particularly from 2012 onward. European beaches (45 %) were most studied, followed by Asian (34 %) and American (19 %) beaches. About 80 % of the articles aligned with at least one of the Sustainable Development Goals (SDGs), yet only 36 % proposed solutions for TCC overload, which was identified on 54 % of beaches using a 10 m² per visitor threshold. Proposed solutions included enforcement, ecosystem monitoring, and partnerships with private companies, civil society organizations (CSOs), and universities, all critical for addressing current and future coastal squeeze. Under a scenario where visitor numbers remain constant, the TCC Overload Index could increase by 129 %. The study highlights the need for standardized measurement criteria for TCC and further debate over restricting visitor numbers. This global dataset provides strategies for mitigating tourism overexploitation and offers guidelines for coastal managers and scientists to implement practical actions in coastal ecosystems.

Keywords: Coastal management; Tourism; Environmental quality; Sustainable development; Systematic review

1. Introduction

Sandy beaches are rich in biodiversity and provide many ecosystem services, but they are suffering from inadequate conservation efforts. Human activities such as unplanned coastal urban development and the intensification of mass tourism have historically impacted the ecological integrity of these environments. All the social-ecological dimensions in the habitats of the Littoral Active Zone (LAZ), such as sandbanks, intertidal zones, and dunes, are now threatened (Mendoza-González et al., 2018; Fanini et al., 2021; Harris and Defeo, 2022). The lack of effective coastal management strategies, combined with the intensification of mass tourism, threatens the ecological integrity and coastal resources that attract tourists to beaches, creating a tourism paradox (Fanini et al., 2020; Defeo and Elliott, 2020).

In addition to long-standing issues like vehicle traffic (Schlacher and Thompson, 2007), trampling (Machado et al., 2017), vegetation suppression (Rêgo et al., 2018), and light and noise pollution negatively impact the LAZ (Longcore and Rich, 2004; Aguilera and Gonzalez, 2023). For instance, visitors react negatively to the presence of solid waste, despite the fact that beach users themselves are significant sources of pollution (Botero et al., 2013; Krelling et al.,

2017). Another issue is overcrowding, which has led to increased tourist avoidance and sub-national economic losses (Zacarias et al., 2011; Krelling et al., 2017).

These pre-existing coastal challenges are now being compounded by the effects of climate change, which adds a new and increasingly urgent dimension to beach management. The physical dimensions of beaches determine the surface area available to users and the services provided, while morphodynamic processes will influence coastal use and exploration (Valdemoro and Jim'enez, 2006). Climate change is affecting ocean dynamics in several ways, including warming waters, changes in average wave height (Casas-Prat and Sierra, 2013; O'Grady et al., 2021), rising sea levels and coastal squeeze (Nicholls and Cazenave, 2010; Palmer et al., 2021). As a result, the available surface area for recreation and ecosystem functioning is shrinking, increasing the urgency of applying integrated and adaptive management approaches.

The establishment of optimal management tools provides a scientific basis for enhancing beach ecosystem management across social, environmental, and economic dimensions (Marchese et al., 2021). One such tool is the study of tourist carrying capacity (TCC) (Cifuentes, 1992; Morales et al., 2018; Rodella et al., 2020), which determines, based on environmental and social factors, the maximum number of users a beach can support without compromising the sustainability of natural resources or the recreational experience (Cifuentes et al., 1990; Rodella et al., 2020; Silva et al., 2020). However, limiting the number of users alone does not ensure beach sustainability (Fernandez-Villar et al., 2020), and additional strategies are needed to mitigate the impacts of tourism.

Therefore, TCC assessments should consider other factors, such as infrastructure and tourist behavior patterns, and can focus on specific dimensions monitored in each geographic context, including physical, environmental, sociocultural, and economic aspects (Zelenka and Kacetl, 2014). Furthermore, TCC is not an intrinsic attribute of a destination, nor is it uniformly applied to all of its spatial components (Saveriades, 2000). In the context of sandy beach environments, for instance, TCC calculations typically focus on the sand strip, which represents the primary area used for recreational purposes. The results are dynamic and should be monitored over time due to spatio-temporal changes arising from different pressures exerted on a destination (Simón et al., 2004).

TCC is an essential strategy for assisting coastal managers in developing appropriate plans, promoting sustainable development, and mitigating the socio-environmental impacts exacerbated by uncontrolled tourism (Botero et al., 2018; Diniz et al., 2022, 2024). Thus, TCC studies should focus on proposing, evaluating, and implementing solutions to the challenges of tourism overload and overexploitation, rather than merely calculating the number of users that a beach can accommodate. The aim of these studies should be to seek effective solutions for coastal management (Zekan et al., 2022).

Previous literature reviews have investigated TCC from various perspectives and scenarios, including its application in caves (Santos and Brilha, 2023), mountains (Sgroi, 2020), urban tourist destinations (Wang et al., 2020), and as a strategy to minimize the impacts of recreational diving (Giglio et al., 2020). While these reviews contribute to the advancement of TCC, there remains a gap in understanding its application to beach ecosystems. TCC assessment methods have been adapted for recreational beaches (Melo et al., 2006; Maciel et al., 2008) and are primarily applied at a regional scale (Sousa et al., 2014; Rodella et al., 2020; Bustos et al., 2021; Diniz et al., 2024). However, international organizations such as the UN (United Nations) and the UNWTO (World Tourism Organization) have integrated tourism sustainability into their strategies (European Commission, 2017; Cooper et al., 2018). Organized and conscious tourism is a global demand, and management tools such as TCC help achieve the Sustainable Development Goals of the 2030 Agenda, a commitment made by leaders of 193 countries and coordinated by the United Nations (Colglazier, 2015).

In this context, the objective of this study was to conduct a review to assess the implementation of the tourist carrying capacity (TCC) method on beaches and propose future management guidelines to promote sustainable development. Specifically, this study aims to: 1) Characterize the main methods employed in assessing the tourist carrying capacity of beaches; 2) Investigate assessments that integrate social, economic, and environmental aspects into the tourist carrying capacity in accordance with the sustainable development objectives of the 2030 Agenda; 3) Identify the geographical distribution of the studies; 4) Examine national policies addressing tourist overload; 5) Analyze the strategies proposed to mitigate or resolve the impacts of tourist overload; 6) Propose measures for short-, medium-, and long-term coastal management. Finally, we

conducted a meta-analysis that predicts TCC overload under erosion and accretion scenarios for 2050.

2. Material and methods

2.1. Systematic literature review

A systematic review was conducted using four scientific databases: Scopus, Web of Science (WoS), SciELO, and Google Scholar. The search was restricted to peer-reviewed articles published in English between 2000 and 2023. This time frame was selected based on the development of tourist carrying capacity (TCC) studies in beach ecosystems, which started after 2000. Initial publications focused on conceptual frameworks, followed by a gradual shift toward more theoretical and applied research (Mexa and Coccossis, 2017; Long et al., 2022). Thus, the 2000–2023 period reflects the specific evolution and maturation of TCC approaches in coastal and beach settings.

The search was performed using a set of terms (in the title, abstract, and keywords): “tourism AND carrying AND capacity AND beach” (n = 105); “tourism AND carrying AND capacity AND coastal” (n = 32); “tourist AND overload AND beach” (n = 2); and “tourist AND overload AND coastal” (n = 4). In Google Scholar, the search was segmented into custom publication year ranges (2000–2004, 2005–2009, 2010–2014, 2015–2019, 2020–2023) due to the high number of total search results (>18,000 results). For each interval, the 100 most relevant results were considered, as determined by pre-established database criteria, such as the number of citations and the direct relationship with the topic of interest (Li et al., 2010). For the other databases, all results published between 2000 and 2023 were included in the analysis.

Through the database search, 1573 documents were found (Fig. 1). The studies were then selected based on exclusion criteria inspired by Moher et al. (2009), which propose systematic procedures for improving the transparency of review processes. Although we did not apply the full PRISMA checklist or register a formal systematic review protocol, we adopted its structure as a methodological reference to enhance clarity and rigor in our document selection. The first exclusion criterion removed non-indexed articles, books, theses, dissertations, and technical reports. The second criterion excluded duplicate indexed articles, counting each as only one document. The third criterion excluded articles if the

full document was not available online or if, after reading the abstract, the article did not address tourist carrying capacity as its main subject.

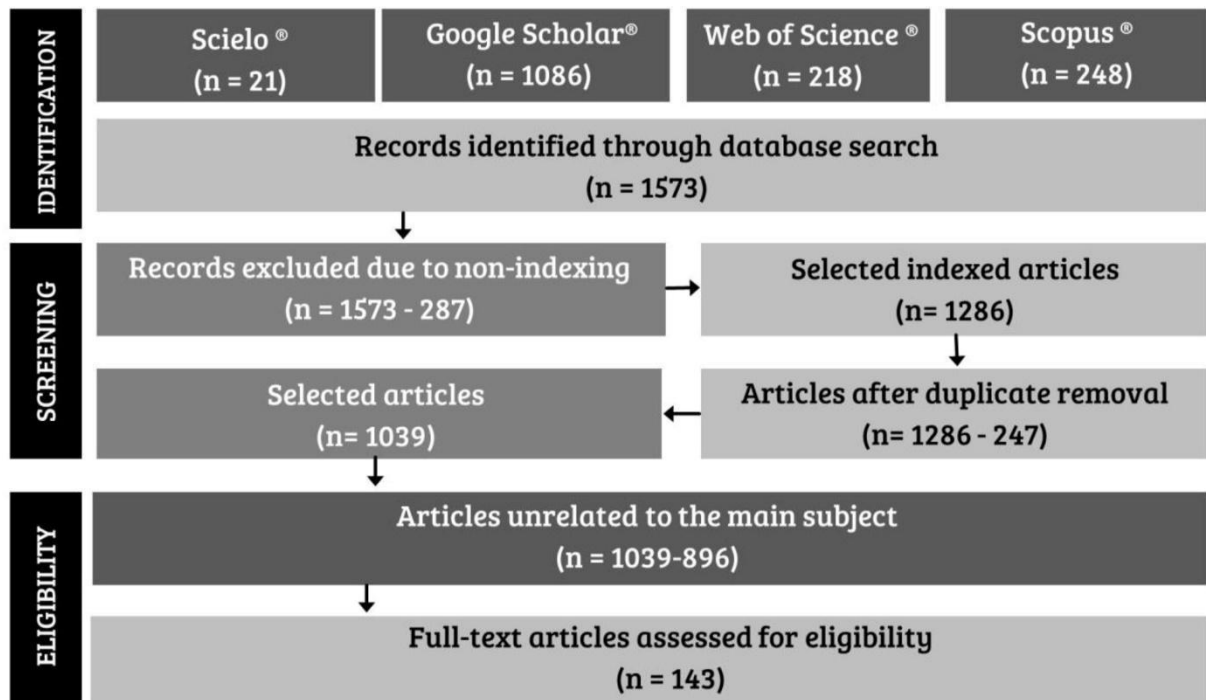


Fig. 1. Flowchart illustrating the search protocol for documents included in the systematic review.

2.2. Literature analysis

The following data were extracted from each selected reference: 1) Year of publication; 2) Impact factor of the scientific journal; 3) Country of the study area; 4) Scale of coverage, categorized as local, regional (covering more than one municipality), national (covering more than one state), or international (covering more than one country); 5) Type of research, classified as quantitative, conceptual, literature review, or meta-analysis; 6) Methods used in the assessment of tourist carrying capacity; 7) Proposals for mitigating or resolving the impacts of tourist overload.

All selected TCC articles were categorized into either the “solution” or “problem” approaches related to tourist overload. Studies classified as “solution” were those that presented proposals or measures aimed at mitigating or resolving the impacts associated with intense tourism. Articles classified as “problem” described patterns, processes, and mechanisms of anthropogenic impacts on ecological ecosystems, biodiversity loss, and tourism revenue, without advancing towards solutions (Heller and Zavaleta, 2009). Articles that addressed both

problems and solutions with similar emphasis were classified as belonging to the “solution” category (Fonseca et al., 2021).

Measures aimed at mitigating or resolving the impacts associated with tourist overload, as found in articles classified as “solution,” were analyzed and grouped into the following categories: 1) engineering works to contain coastal erosion and expand the sand strip, including techniques such as rock fill, artificial landfill and the construction of breakwaters; 2) monitoring of species and ecosystems sensitive to anthropogenic disturbances, aiming the mitigation of tourism negative impacts; 3) suggestions for new scientific research to advance knowledge in the area of tourist carrying capacity and identify effective management strategies; 4) collaborative partnerships between universities, private companies and non-governmental organizations; 5) recommendations for local coastal managers to improve environmental monitoring, zoning of the primary uses of the beach, professional training, and the application of new technologies, with the aim of adequately planning infrastructure to meet visitor demands while considering both tourism needs and the preservation of the beach ecosystem.

The methods used to assess tourist carrying capacity were categorized into different types based on their approaches. “Physical carrying capacity” was assigned to studies that considered physical aspects, such as beach width or length and the number of visitors. “Management capacity” was applied when the assessment methods included indicators related to the services and infrastructure available on the beaches, such as security, recreation, and accommodation (Box 1). To categorize the methods related to “social carrying capacity,” “ecological carrying capacity,” and “economic carrying capacity,” the social, environmental, and economic dimensions of the United Nations Sustainable Development Goals (SDGs) were used as a reference. Among the 17 established goals, eight address social issues (SDGs 1, 2, 3, 4, 5, 7, 11, and 16), four relate to the economic dimension (SDGs 8, 9, 10, and 12), and four focus on the environmental dimension (SDGs 6, 13, 14, and 15) (United Nations, 2018; Nilson et al., 2016).

Box 1. Definitions and terminologies for assessing Tourist Carrying Capacity.

Tourist Carrying Capacity	Number of visitors that can be accommodated in a given leisure area without causing unacceptable social consequences and
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	without negatively impacting natural resources (Cifuentes, 1992; WTO, 1997).
Minimum Area per User	The ideal space available on the beach sand surface should be 10 m ² per user so as not to compromise the recreational experience. However, depending on the type of beach and the intensity of use, 5 m ² per visitor is considered an acceptable minimum space (Yepes, 2002).
Physical Carrying Capacity	Maximum number of users that can be accommodated on a beach based on its physical dimensions and the duration of their visit (Cifuentes, 1992).
Management Capacity	Management Capacity assesses the adequacy of available facilities and services, such as toilets, showers, lifeguards, parking, and accessibility for individuals with reduced mobility, using both qualitative and measurable indicators. It also evaluates the efficiency of current management by examining policies and conservation programs implemented on the beach, including emergency response capabilities, law enforcement, monitoring of illegal behavior, and maintenance of facilities (Cifuentes, 1992).
Social Carrying Capacity	Assessment of local community satisfaction with tourism development and tourists' recreational experience, considering infrastructure accessibility, preservation of local culture, and the adequacy of public services such as health, transport, and security (Cifuentes, 1992; Saveriades, 2000).
Ecological Carrying Capacity	Limit at which sensitive ecosystems, such as coral reefs, mangroves, dunes, and sandbanks, can support human activities without experiencing degradation. This concept also includes restrictions on visitation during critical periods such as species reproduction, turtle egg laying, and the presence of migratory birds and mammals, ensuring that tourist activities do not compromise the ecological integrity of these environments (Seidl and Tisdell, 1999; Clayton, 2002).
Economic carrying capacity	It assesses the economic potential of coastal resources for ecotourism, considering benefits to the local community such as job creation, increased income, and investment in public infrastructure. The analysis includes the economic impacts of activities related to travel services, hotels, and food establishments. For instance, preserving a marine area vital for fishing may be more valuable than several lower-value activities, such as sand mining. Conversely, a private beach at a luxury hotel may seem valuable, but its value might be less compared to the aggregate benefits of general recreational activities enjoyed by a larger number of visitors (Clayton, 2002; Jennings, 2004).
Sustainable Development Goals (SDGs) focusing on the social dimension	SDG 1: No Poverty
	SDG 2: Zero Hunger
	SDG 3: Good Health and Well-being
	SDG 4: Quality Education
	SDG 5: Gender Equality
	SDG 7: Affordable and Clean Energy

	SDG 11: Sustainable Cities and Communities
	SDG 16: Peace, Justice, and Strong Institutions
Sustainable Development Goals focusing on the economic dimension	SDG 8: Decent Work and Economic Growth
	SDG 9: Industry, Innovation, and Infrastructure
	SDG 10: Reduced Inequalities
	SDG 12: Responsible Consumption and Production
Sustainable Development Goals focusing on the environmental dimension	SDG 6: Clean Water and Sanitation
	SDG 13: Climate Action
	SDG 14: Life Below Water
	SDG 15: Life on Land

Box 2. Strategies for beach management based on global suggestions to mitigate the impacts of tourist overload. The classification of strategies is based on previous studies on beach and coastal management (Micallef & Williams, 2002; Chen & Teng, 2016; Diniz et al., 2024).

Environmental awareness
• Provision of recent information on beach occupancy rates and the latest results of bathing suitability analyses via a website; • Electronic panels, or electronic applications; • Monitoring visitor satisfaction with sandy beaches regarding the quality of coastal scenery, including aspects such as safety, comfort, services, and infrastructure, through an official application or website that provides a complaints channel; • Investment in the ecotourism sector, including tourist guides and activities focused on disseminating environmental information, such as observing marine animals (whales, dolphins, birds, etc.), boat trips, diving, and interpretive trails; • Carrying out regular environmental education and information activities during the high tourist season for tourists and throughout the year in schools or local communities for residents, in partnership with universities, non-governmental organizations, and private educational institutions; • Information signs indicating the locations of accommodation and food services, lifeguard stations, police stations, and bathrooms, along with the dissemination of a code of conduct for beach behavior.
Partnerships with private companies, non-governmental organizations, and universities
• Formation of a management committee with representation from all stakeholders in coastal decisions, including non-governmental organizations, private companies, marine environment research groups, and owners of accommodation and food establishments; • Professional training for coastal managers and technicians through participation in workshops, courses, and national and international forums on environmental protection and impact assessment on beaches.

Engineering and Infrastructure Works
● Implementation of video cameras to monitor the safety of beach visitors, integrated with a real-time information system that includes automatic people counting, using the tourist carrying capacity method; ● Regulation of beach cleaning services, including daily manual waste removal, sufficient waste containers, and partnerships with recycling facilities and local waste pickers; ● Implement an entry fee system for marine protected areas to encourage tourists to visit during off-peak times through reduced rates. Fees should be adjusted based on tourist demand, with higher charges during peak times, weekends, peak seasons, and in more sensitive marine areas. This model aims to balance visitor numbers throughout the year, alleviating tourism overload on marine resources. Additionally, the revenue generated can enhance beach monitoring and management; ● Map urban areas vulnerable to coastal erosion by monitoring coastline retreat in collaboration with geographers, engineers, and other specialists. This process aims to establish building regulations and facilitate the removal of unauthorized structures in prohibited areas or those posing a safety risk to the population; ● Implement domestic and industrial wastewater treatment systems; ● Develop a work plan for coastal erosion control, using engineering techniques such as building breakwaters, rockfill, and groynes to protect the coast from wave impact; ● Develop beach nourishment projects as needed, involving continuous sand replenishment to counteract coastal erosion and restore beach width; ● Monitor critical erosion points and assess morphological and sedimentary changes along the coastline, focusing on factors such as rising sea levels, wave movement, dune removal, suppression of native vegetation, and irregular urban construction.
Species and ecosystem monitoring
● Zoning in the coastal ecosystem to regulate the primary uses of beaches, such as fishing, industrial, and recreational activities; ● Designate protected areas for the conservation of marine biodiversity; ● Program for the restoration of native vegetation and sensitive environments, such as dunes and mangroves, in degraded areas, established in collaboration with research groups from educational institutions; ● Comprehensive database on fauna and flora species present in sensitive ecosystems associated with the beach, such as sandbanks, coral reefs, mangroves, and dunes; ● Monitoring of water quality in collaboration with private companies or research groups specialized in water resources.
Scientific Research

• Long-term estimation of tourist carrying capacity using a standardized method to minimize the influence of local political interests and/or economically biased decisions in selecting management capacity indicators; • Advances over classical approaches to tourist carrying capacity to enable global monitoring applicable to any type of beach, using measurable metrics obtained through advanced statistical analyses; • Marketing strategies to promote the sustainable use of beaches by the tourist community, encouraging participation in environmental education events and favoring the use of local services and establishments to boost the economy; • Integration of techniques into the tourist carrying capacity method to define ecological limits for recreational use in coastal ecosystems, considering factors such as species' reproductive seasons, turtle nesting sites, and areas of environmental sensitivity.
Oversight
• Monitoring illegal practices, such as vehicle traffic on the beach, improper access to protected sensitive areas, loud noise, and entry into zones with warnings of danger due to rip currents or high waves; • Establishing environmental standards for owners of resorts, restaurants, and hotels, emphasizing their responsibility for cleaning the areas surrounding their establishments and adhering to proper waste disposal practices; • Participating in environmental certification processes aimed at preserving beach quality, which require adherence to criteria for solid waste removal in the coastal zone, water quality for bathing, and accessible infrastructure for the elderly and people with special needs.

To enable global comparisons, the beach studies that employed the concept of tourism carrying capacity (TCC), defined by the available space per visitor (in m²), were standardized based on a generic reference value of 10 m² per person, as proposed by Yepes (2000). This standardization was necessary to provide a consistent baseline for comparing beaches with diverse characteristics and methodological approaches. It allowed us to estimate the degree of overcrowding or underutilization across different sites regardless of their local TCC criteria. Based on this, we calculated the Tourism Overload Index (TOI) (Diniz et al., 2024), using the natural logarithm of the ratio between the available space per visitor and the reference value of 10 m². After multiplying the TOI by -1, the positive values indicate beaches that are overcrowded, while a negative index signals beaches that can accommodate more visitors. The beaches were categorized into three groups: (a) environmentally protected areas, (b) areas with environmental quality certification, such as the Blue Flag, and (c) areas without any form of environmental management. To evaluate the future tourism carrying

capacity of the selected beaches, global shoreline change projections were used, accounting for three main factors: (1) alterations due to long-term environmental factors, (2) retreat from sea-level rise, and (3) erosion from extreme storms. These projections were made for the year 2050, under Representative Concentration Pathways (RCP) 4.5 (moderate emissions) and 8.5 (high emissions) (Vousdoukas, 2020).

A linear regression analysis using R was conducted to examine the variation in the number of articles published from 2000 to 2023. Additionally, a comparison was made to determine whether there were significant differences between the number of publications that addressed sustainable development objectives in TCC assessments and those that focused solely on problems or presented solutions to tourism overload. To assess the relevance of countries' scientific publications in the field of TCC, the average impact factor of the journals in which the articles were published was calculated. Other quantitative data were presented as percentage values and graphs, while qualitative data (e.g., proposals for mitigating the impacts of tourism overload) were analyzed descriptively.

3. Results and discussion

3.1. Global trends in tourism carrying capacity research

A compilation of articles on tourist carrying capacity (TCC) on beaches indexed by the four databases ($n = 143$ documents, appendix A) indicates a linear increase in the number of publications over the past 23 years (Fig. 2). The results show a significant increase ($p < 0.05$) in the average number of articles from the period 2000–2011 to 2012–2023. A bibliographic review on research trends in sandy beaches, covering the period from 1950 to 2013, revealed the underrepresentation of beach science in the scientific literature. However, the exponential increase in the number of publications during this period suggests that this is a relatively recent and emerging research field. This growth is linked to the formal recognition of beaches as ecosystems in the 1970s. Furthermore, environmental management, including studies on tourism carrying capacity, became evident in the early 1990s (Nel et al., 2014).

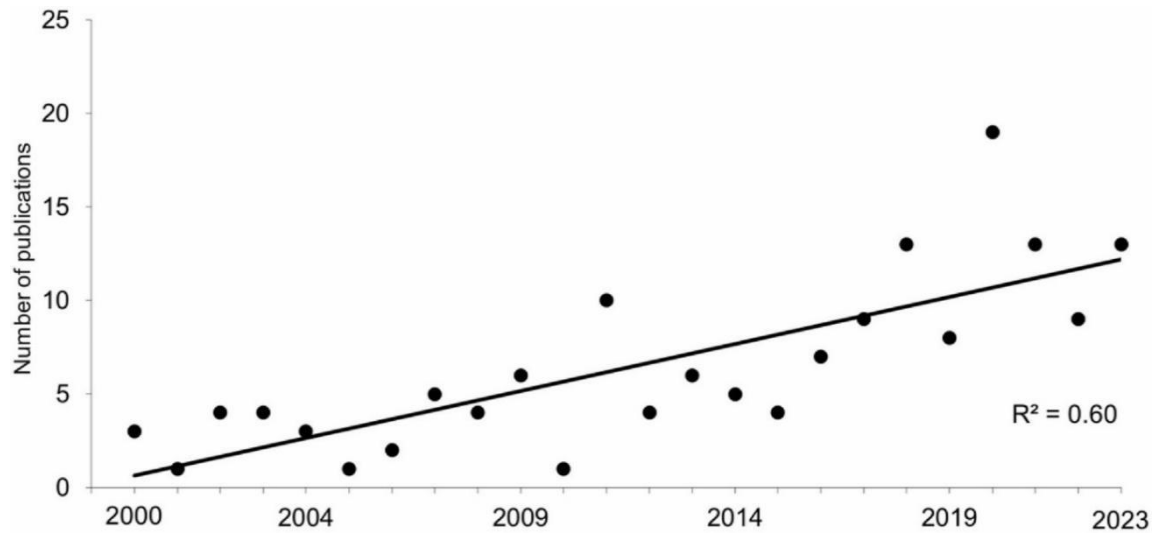


Fig. 2. Number of annual publications on tourist carrying capacity from 2000 to 2023. Black dots indicate the temporal trend of the studies.

The analysis also aimed to determine the global scope of TCC research by examining the geographic distribution of the main study centers (Fig. 3). The investigation, by continent, revealed that European beaches are the most studied globally (45 %, $n = 64$), followed by Asia (34 %, $n = 48$), America (19 %, $n = 27$), and Oceania (3 %, $n = 4$). No publications were identified for the African continent, despite its considerable coastal tourism potential and its extensive coastline.

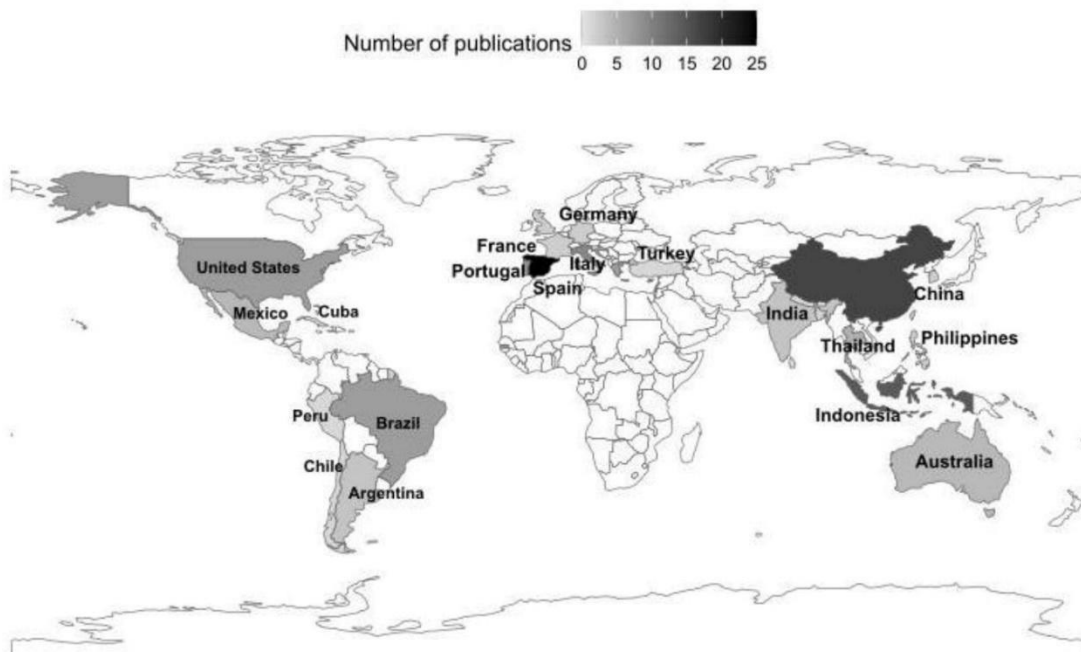


Fig. 3. Number of publications on Tourist Carrying Capacity (TCC) by country.

It is important to highlight that this review considered only articles published in English, which may have influenced the representation of some regions. For instance, in the case of Brazil, a country with vast coastal areas and strong tourism activity, the limited number of studies identified may reflect a specific underrepresentation of tourism carrying capacity (TCC) research, rather than an overall lack of beach-related studies. In contrast, the analysis of beach ecosystem studies conducted by Nel et al. (2014), covering the period from 1950 to 2013, revealed that most of the literature are predominantly from the United States, South Africa, Brazil, and Italy. These publications were mostly produced by small research teams (fewer than four authors), often affiliated with a single institution. According to the authors, the field still faced the challenge of forming large multidisciplinary teams, which are essential for advancing robust experimental science and contributing to broader ecological theory (Nel et al., 2014).

The number of publications (n) and the impact factor (IF) showed a relevant publications on TCC primarily concentrated in Spain and China ([Fig. 4](#)). In Spain (17 %, n = 25, IF_avg = 5.6), the intense tourist flow is mainly attributed to coastal tourism, with popular destinations such as Benidorm and Marbella. Additionally, culturally significant cities like Madrid and Barcelona attract many tourists (Albaladejo and González-Martínez, 2019). According to the United Nations World Tourism Organization, Spain is the second most popular tourist destination globally (UNWTO, 2019). In 2019, the country received 83,509 foreign tourists, with an annual growth rate of 2.6 % (INE, 2020). In China (12 %, n = 17, IF_avg = 4.3), the government has been implementing measures to address environmental overload since 2013. In 2017, the General Office of the Chinese Communist Party established a long-term management plan to monitor and restrict the use of water resources, land, and marine areas (Li et al., 2018).

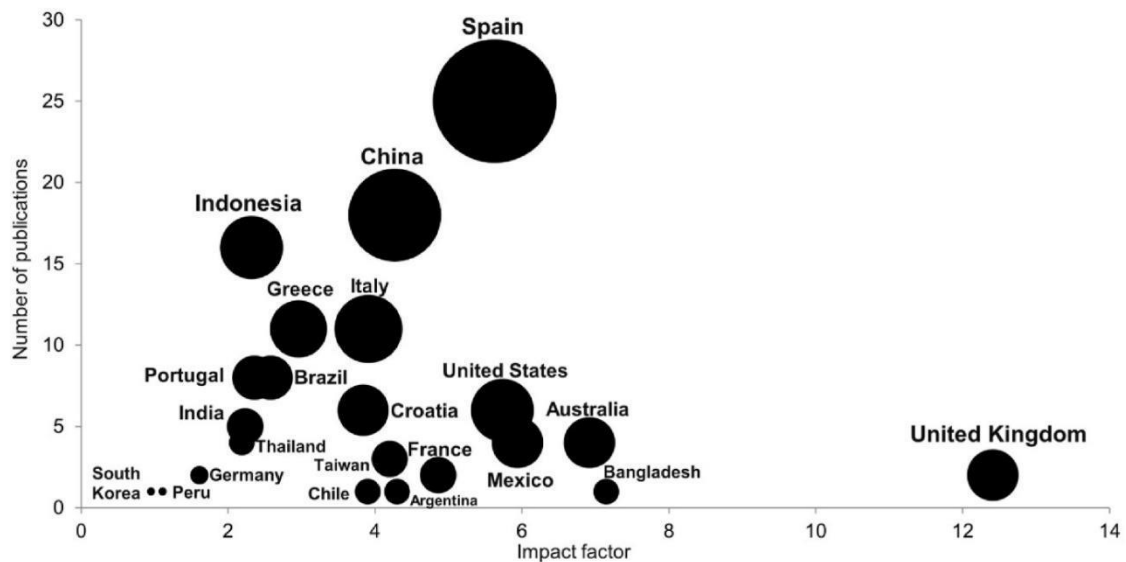


Fig. 4. Relationship between the number of publications and the impact factor of journal articles on tourist carrying capacity (TCC) on sandy beaches. The size of the points reflects the importance of the publications (number of articles $\times$ impact factor).

Studies conducted in Portugal (6 %, $n = 8$, $IF_{avg} = 2.4$) provide practical insights into the implementation of TCC on recreational beaches. Since 1993, the concept of TCC has been incorporated into legislation and regulating Coastal Development Plans (Decree-Law 309/93). Despite some methodological limitations, applying the concept of tourist capacity has significantly contributed to the planning and management of Portuguese beaches, addressing issues such as safety, infrastructure, accessibility, and parking facilities (Silva et al., 2020). In Italy (6 %, $n = 9$, $IF_{avg} = 3.9$), beaches on the islands of Sicily and Sardinia impose daily visitor limits during the summer and, in some cases, require payment of fees and advance reservations (Semeoshenkova and Newton, 2015).

Between 2019 and 2022, countries such as France, Spain, and Belgium applied the TCC method to minimize the local spread of the Severe Acute Respiratory Syndrome virus caused by SARS-CoV-2 (COVID-19) (Zielinski and Botero, 2020). In these locations, TCC was used to reduce crowding on beaches. In France, beachgoer limits were enforced through an online reservation system, which was mandatory prior to arriving at the beach (Berger, 2020). In Spain, real-time monitoring of beach carrying capacity was implemented using automated coastal videometry, with video cameras allowing managers to track the number of beachgoers and assess crowding (Epelde et al., 2021). In Belgium, a cell phone tracking system was adopted to monitor visitor density on specific beaches and redirect them to less crowded areas (Taylor, 2020).

3.2. Methodological approaches to assessing tourist carrying capacity (TCC)

In general, studies on tourist carrying capacity (TCC) indicate that most investigations are quantitative (85 %, n = 122), followed by theoretical studies (13 %, n = 19) and reviews (1 %, n = 2). Publications on TCC are more frequent at the local level (64 %, n = 92) compared to regional (25 %, n = 36), national (5 %, n = 7), and international (6 %, n = 8) studies (Table 1). The predominance of local-scale studies arises from the method's adaptability to the specific characteristics of each beach. Consequently, the method serves as a practical management tool that can be implemented by environmental technicians directly at the beach (Rodella et al., 2020; Diniz et al., 2024).

Table 1. Characterization of the profile of studies related to Tourist Carrying Capacity (TCC) by continent.

Type of study	Total	África	Oceania	America	Asia	Europe
Quantitative	122	0	3	23	43	53
Conceptual	19	0	1	4	3	11
Literature review	2	0	0	0	1	1
Meta-analysis	0	0	0	0	0	0
Coverage scale						
Local	92	0	0	22	28	42

Type of study	Total	África	Oceania	America	Asia	Europe
Regional	36	0	2	0	18	16
National	7	0	0	3	1	3
International	8	0	1	2	1	3
Method used						
Physical Carrying Capacity	99	0	2	16	36	45
Management Capacity	49	0	0	11	18	20
Social Carrying Capacity	49	0	2	9	18	22
Ecological Carrying Capacity	34	0	1	3	17	13
Economic carrying capacity	16	0	0	0	8	8

- The percentage exceeds 100 % because some articles evaluated more than one category.
- Social, ecological, and economic carrying capacities are components of the management capacity method.

Most TCC studies focused exclusively on the physical capacity of the beach (69 %, n = 99 articles). This emphasis aligns with the core concept of TCC, which determines the maximum number of visitors that a beach can support without compromising the sustainability of its natural resources (Silva, 2002; UNWTO, 2002; López-Dóriga et al., 2019). However, the impact on natural resources is not solely determined by visitor comfort or the physical capacity of beaches. Research shows that even minimal human activity can harm biodiversity and affect the sustainable use of resources (Muñoz-Lechuga et al., 2018). For example, during the pandemic, the halt in tourist activity on beaches resulted in noticeable improvements in environmental quality, even on beaches that usually attract only local and regional visitors and are not typically overcrowded (Israngkura, 2022; Costa et al., 2022).

Approximately 35 % of the studies considered Management Capacity (MC) in their TCC assessments (n = 49). These assessments are crucial for enhancing coastal management, as they facilitate the selection of beach quality indicators tailored to the specific tourism priorities of each location (Cifuentes, 1992; González et al., 2016). Beach quality indicators based on MC help estimate and guide coastal management efforts (Morales et al., 2018; Diniz et al., 2022). For instance, the Blue Flag Program, an international certification managed by the Foundation for Environmental Education (FEE) (Bernardi and Pires, 2015; Blue Flag, 2024), identifies critical aspects needing immediate intervention by local authorities, such as the conservation of native vegetation, water quality, and infrastructure (Lucrezi et al., 2016; Morales et al., 2018; Marchese et al.,

2021). According to Diniz et al. (2024), the MC tends to be more effective in less impoverished regions, highlighting the need to prioritize this measure in environmental management within emerging economies.

In addition to management capacity, other measures constituting the methodological basis of TCC were analyzed. The results showed a prioritization of the social dimension (35 %, $n = 50$) in the studies, followed by the ecological dimension (24 %, $n = 34$) and the economic one (11 %, $n = 16$) (Fig. 5). The emphasis on social dimension is due to its significance in enhancing tourism revenue for coastal municipalities, as it is directly linked to visitor satisfaction and the likelihood of repeat visits (Dodds and Holmes, 2019; Lukoseviciute and Panagopoulos, 2021). Studies on beach visitors' perceptions indicate that coastal scenery degradation, either due to increased litter (Krelling et al., 2017) or overcrowding (Zacarias et al., 2011), leads to the selection of alternative destinations. In a city in Paraná, Brazil, projections for the worst pollution scenario (15 items/m²) estimate annual economic losses between US\$ 3.2 and US\$ 8.5 million (Krelling et al., 2017).

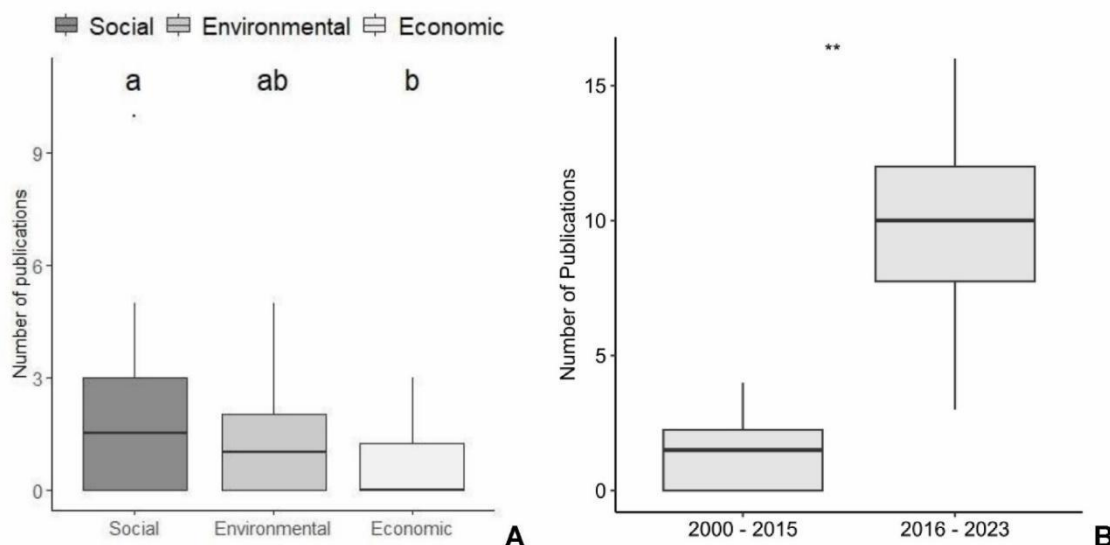


Fig. 5. A) Global distribution of publications on Tourism Carrying Capacity (TCC). Groups sharing the same letter do not exhibit significant differences. Conversely, groups with different letters indicate statistically significant differences ($p < 0.05$). B) Differences in publications incorporating the social, environmental, and economic dimensions between the periods 2000–2015 and 2016–2023 (** $p < 0.01$).

Of the articles analyzed, 20 % ($n = 28$) did not consider any dimension of sustainable development. This result highlights the need for further studies using the CCT method to advance the fulfillment of the Agenda 2030 criteria. The

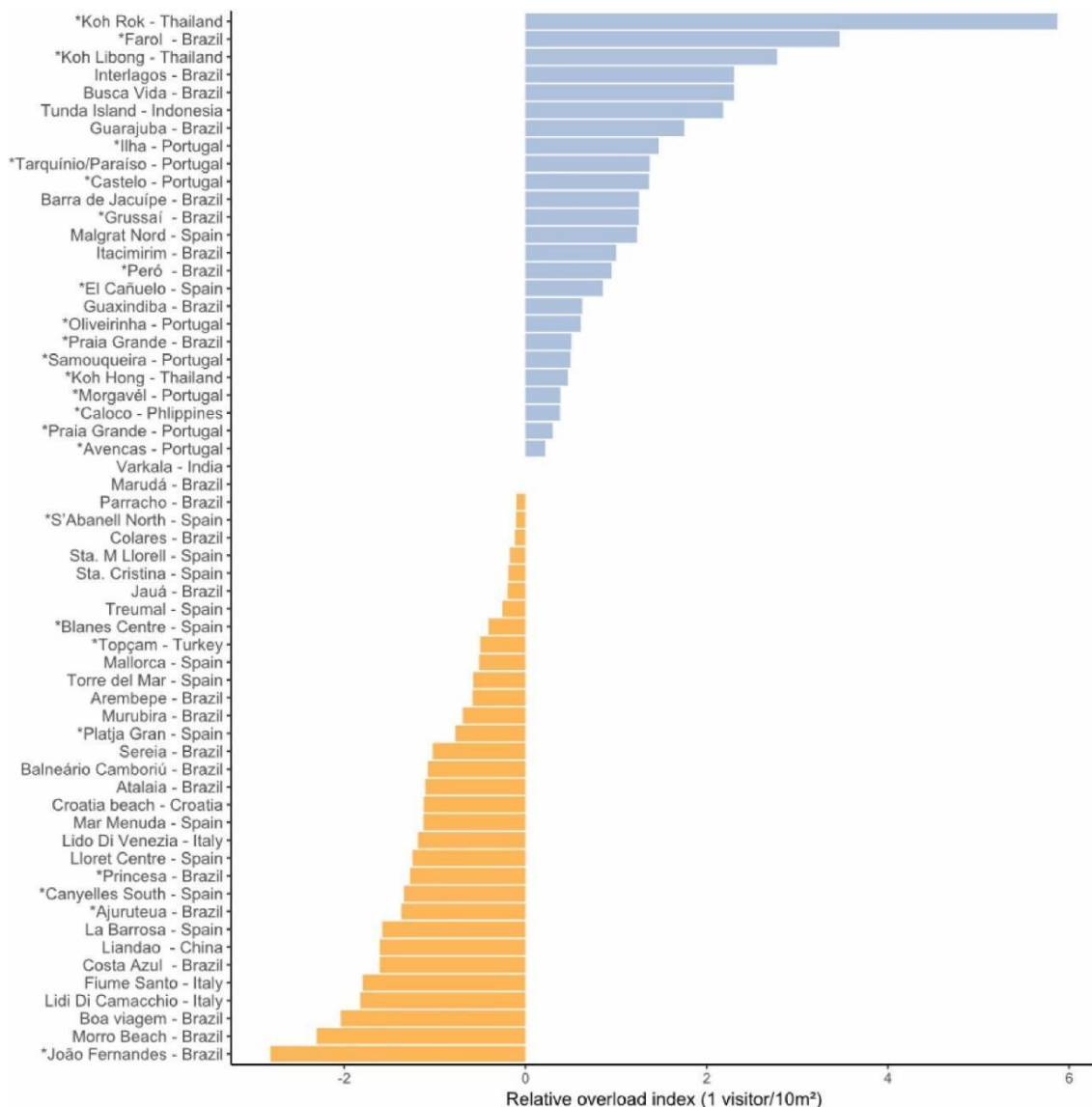
comparison between two time periods (2000–2015 and 2016–2023) shows that, in the first period, 25.49 % of the articles already mentioned objectives aligned with the SDGs, but after their official implementation in 2016, this number increased to 74.51 % (Fig. 5).

The increase in the number of publications in recent years that consider management based on TCC, with assessments aligned with the dimensions of sustainable development, is crucial for identifying problems in the social, environmental, and economic spheres (United Nations, 2018). The implementation of socio-environmental management strategies for beaches must account for local contexts. Urban beaches face distinct challenges compared to those in remote or protected areas, with more urbanized beaches being particularly vulnerable to biodiversity loss and the disruption of ecological processes. Recognizing these impacts on the beach ecosystem is essential for implementing sustainable solutions as outlined in the United Nations 2030 Agenda (Satterthwaite, 2016).

Among the dimensions, the average number of publications addressing the social aspect is significantly higher than those related to the economic dimension ($p < 0.05$). No significant differences were found between the averages of the other dimensions. These differences are attributed to the lack of standardization in evaluations, as well as the various beach typologies (e.g., protected areas, sites with environmental quality certification, urban and non-urban areas) (Yu and Gao, 2023). To strengthen this global commitment, the Inter-Agency and Expert Group on SDG Indicators proposed a global monitoring framework with indicators applicable at the national level (Global Taskforce, 2024). However, to achieve these global aspirations, local government commitment and action are essential (Liu et al., 2018). Monitoring these evaluations could be used to track the progress of sustainable urban development in implementing the 2030 sustainable development agenda (Gao et al., 2021).

3.3. Tourist overload index

Out of the 143 selected articles, 59 global beaches were analyzed for the available space per visitor (m^2) based on the tourism carrying capacity (TCC) assessment. Among these beaches, 54 % exhibited tourism overload based on the ideal space of 1 visitor per 10 m^2 (Fig. 6).



*Beaches in protected areas with environmental quality certification or management plan.

Fig. 6. Values related to the number of times each beach can still accommodate recreational users (positive values) and tourist overload (negative values).

Comparing the available space for recreation on environmentally protected beaches or those with environmental certification revealed a significant difference in the mean and median space available between certified and non-certified beaches. While the presence of environmental protection or certification has a significant effect on the space available per visitor ($p < 0.05$), it is important to recognize that this result may also be influenced by other factors. Certified beaches generally provide more space compared to those without certification (Fig. 7). However, as noted by other studies, certifications like the Blue Flag program can also contribute to the elitization or gentrification of coastal spaces, particularly in developing countries (Bispo and Santos, 2016). For instance, while,

destinations implementing the Blue Flag program generally exhibit high adherence to certification requirements, using it as a guarantee of compliance with the minimum standards established by current legislation and maintaining, overall, high-quality standards (Fraguell et al., 2015). In developing countries, such as Brazil, Colombia and Mexico, where there is a lack of qualified professionals in beach management, Blue Flag criteria can play a crucial role. In contrast, in developed countries, such as Canada, where beaches already meet the program's standards, the certification tends to serve primarily a marketing function (Dodds and Holmes, 2020; Botero and Zielinski, 2020).

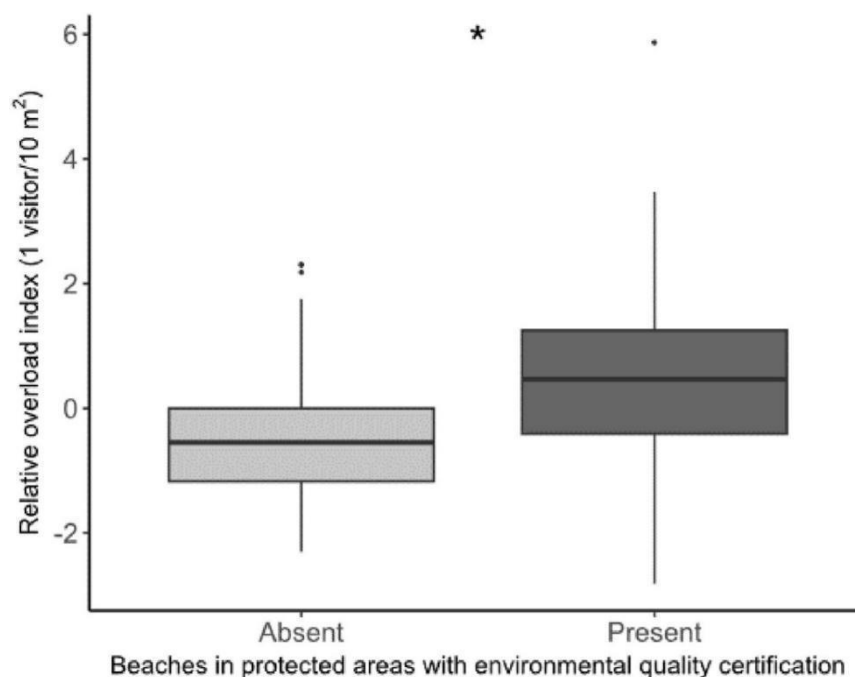


Fig. 7. Comparison of the space available for recreation based on tourist overload index, between beaches with protected areas or environmental quality certifications and beaches without any management plan or quality monitoring (* $p < 0.05$). The black points represent outliers.

These management approaches allow subnational governments to support global coastal management efforts by promoting sustainable practices and preserving local biodiversity. However, while this management aids in the regulation of beach space use, it does not directly account for high usage density and occupancy, resulting solely in an indirect contribution to beach management (Relano and Pauly, 2023).

According to shoreline retreat projections for 2050, it is estimated that approximately 21 % of the beaches currently experiencing tourism overload will disappear, and 39 % will suffer a reduction in available space due to shoreline

retreat (Fig. 8). This reduction directly exacerbates overcrowding by concentrating the same or a growing number of visitors into smaller areas, intensifying environmental pressure and reducing the quality of the tourist experience. In consequence, in a conservative scenario where the number of beach visitors remains constant and more optimistic forecasts of erosion and accretion dynamics are applied, the overload Index is projected to increase by 129 %.

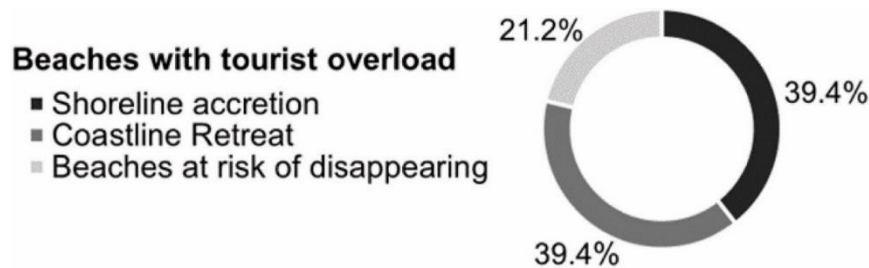


Fig. 8. Environmental trends for the year 2050 in shoreline dynamics on tourist-overloaded beaches, combined with shoreline accretion and retreat.

The average global rate of shoreline change is erosive, with an estimated global land retreat of -10.4 m by 2050. Approximately 31 % of the world's sandy beaches are located in low-lying coastal areas with a population density exceeding 500 people per km^2 . The regions projected to experience the most severe erosion include South Asia (-282.3 to -88.7 m), the Caribbean (-160 to -84.3 m), Central North America (-116.8 to -44.9 m), and Southeastern South America (-143.6 to -10.3 m).

To address this, it is essential to integrate tourism management strategies with coastal protection efforts. These include proactive planning tools such as zoning, beach carrying capacity assessments, visitor flow regulation, and ecosystem-based adaptation (e.g., dune and vegetation restoration), which can maintain tourism viability while reducing environmental degradation. Moderate mitigation of greenhouse gas emissions could prevent up to 40 % of shoreline retreat, reinforcing the importance of coordinated climate action and sustainable tourism planning (Vousdoukas, 2020; López-Dóriga et al., 2019).

3.4. Proposals to mitigate the impacts of tourist overload

Publications proposing solutions or suggestions to mitigate the impacts of tourism overload represent a significant minority (36 %, $n = 51$) compared to studies that evaluate TCC and investigate problems related to tourism overload (64 %, $n = 92$) ($p < 0.05$). A temporal comparison between two 12-year periods reveals that, during the first period analyzed (2000–2011), only 28 % of articles addressed solutions. However, in the second period (2012–2023), this proportion increased to 40 % (Fig. 9). However, the proportion of articles addressing problems in the recent period was still higher than the average proportion of articles proposing solutions ($p < 0.05$).

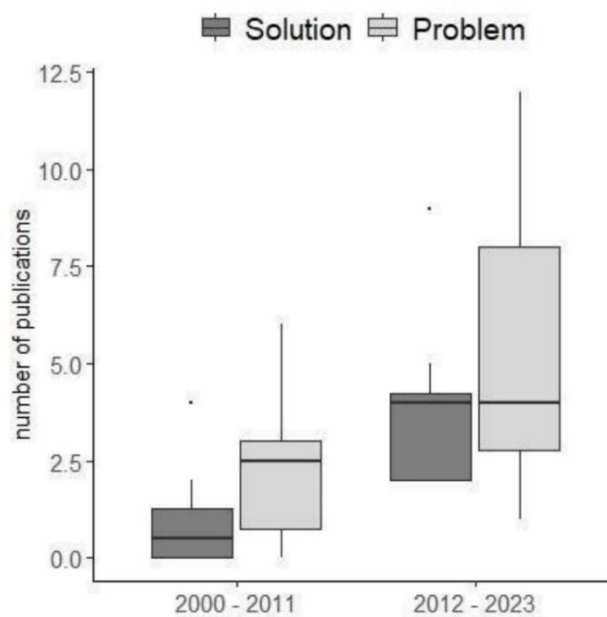


Fig. 9. Twelve-year time difference between the number of publications with proposed solutions to the impacts of tourist overload and publications focusing on analyzing the problems of tourist overload. The figure illustrates the shift in focus from analyzing problems to proposing solutions across two 12-year periods, highlighting the proportion of studies that address each aspect.

On average, only about half of the publications focus on solutions to mitigate the impacts of tourism overload. This proportion remains relatively low, considering the urgent need to change the use of natural resources in beach ecosystems. Financial support from national and international scientific research agencies could help prioritize research that proposes solutions. For instance, the European Union's Horizon 2020 program aims to seek solutions that focus on ecosystem services - such as provisioning, regulation, or cultural services (MEA, 2005) - and is designed to address social challenges while being economically

viable and providing environmental, social, and economic benefits (Eggermont et al., 2015; Raymond et al., 2017; Cohen-Shacham et al., 2019).

According to global publications on TCC, suggesting further scientific research is the least recommended measure for addressing the impacts of tourism overload (6 %, n = 11). Most actions are directed towards local coastal managers (53 %, n = 89) (Fig. 10). Based on the globally proposed solutions, a set of actions was organized to facilitate the practical application of measures to address tourism overload on sandy beaches (Box 2).

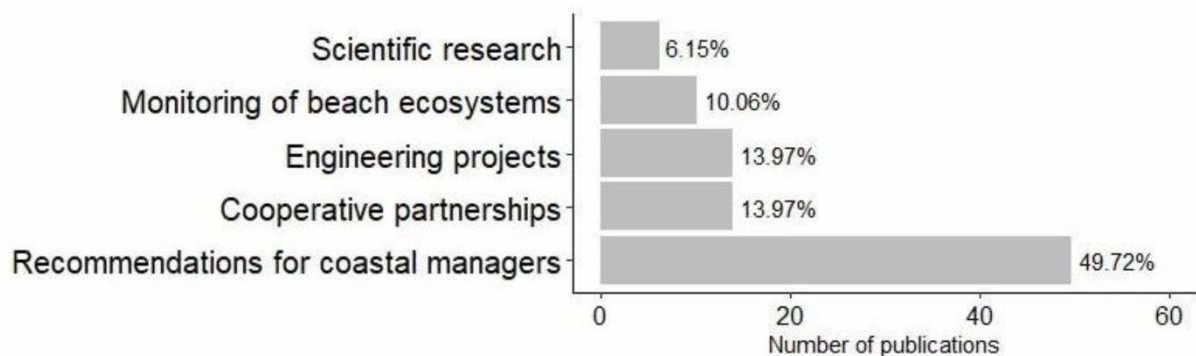


Fig. 10. Classification of suggestions to minimize or resolve the problems associated with tourist overload. The chart displays the proportion of recommendations directed towards scientific research, local coastal managers, and other categories.

The absence of a unified and comprehensive definition of the tourist carrying capacity (TCC) method, coupled with the variety of measurement approaches, has been criticized in the scientific literature (Rahmani et al., 2015). Coastal management, however, is a complex and dynamic process that seeks to reconcile various local interests (Polette and Silva, 2003; Cristiano et al., 2018). Despite these challenges, there is potential for adopting a set of standardized criteria for measuring TCC, which would accommodate different regional contexts (Scherer et al., 2020; Marchese et al., 2021).

Another challenge of the method is limiting the number of visitors to recreational beaches both spatially and temporally, as most beaches are publicly accessible in many countries (Barragan, 2016; Williams and Micallef, 2009). However, there are notable examples of success in reducing human activity during the COVID-19 pandemic (2020–2022) on beaches experiencing tourist overload. For instance, on Brazilian beaches, the recovery of ghost crab (*Ocypode quadrata*) populations was observed (Soto et al., 2021; Costa et al.,

2022). In Italy, a study reported the return of shorebirds (*Charadrius alexandrinus*) to sandy beaches where they had not been seen since 2016 (Manenti et al., 2020). Similarly, in marine national parks in southern Thailand, official reports documented an increase in sightings of dugongs (*Dugong dugon*), Fraser's dolphins (*Lagenodelphis hosei*), sea turtles (*Chelonia mydas*), hawksbill turtles (*Eretmochelys imbricata*), and false killer whales (*Pseudorca crassidens*) (Israngkura, 2022).

TCC assessments highlight several challenges that need addressing, such as the lack of standardized criteria aligned with sustainable development goals and the controversy surrounding visitor restrictions on beaches. Nonetheless, TCC studies underscore the relevance and benefits of this management tool for the sustainable development of coastal ecosystems. While improvements in TCC assessments with standardized criteria that encompass the various SDGs are needed, it is still possible to develop effective local, regional, and even national strategies to avoid tourist overload, provided that the method considers different local realities.

4. Conclusion

Over the years, there has been a notable increase in publications on Tourism Carrying Capacity (TCC). The TCC method has proven to be a valuable analytical tool for advancing the sustainable development goals outlined in the 2030 Agenda, as most studies integrate social, environmental, and economic dimensions into their analyses. Identifying the environmental and infrastructural aspects needing improvement through coastal management presents a crucial opportunity to enhance beach quality and promote sustainable tourism.

However, many of these studies have primarily focused on the problems related to tourist overload, often limited to calculating the number of visitors a beach can accommodate. Therefore, it is essential for future research to concentrate on developing effective solutions to mitigate the negative impacts of tourist overload and advance sustainable coastal management. The results of these studies offer a global-scale dataset with strategies to address tourism overexploitation. This information can facilitate the implementation of immediate practical actions within coastal ecosystems, providing valuable guidelines for coastal managers and scientists worldwide.

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APPENDIX

Appendix A. Scientific articles selected for the systematic review and beaches whose information was used in the meta-analysis.

Paper	Country	Beaches used to calculate the tourist overload index	Reference
Weaver 2000	Australia		Weaver, D. B. (2000). A broad context model of destination development scenarios. <i>Tourism management</i> , 21(3), 217-224.
Saveriades 2000	Cyprus		Saveriades, A. (2000). Establishing the social tourism carrying capacity for the tourist resorts of the east coast of the Republic of Cyprus. <i>Tourism management</i> , 21(2), 147-156.
Gössling 2000	Sri Lanka		Gössling, S. (2000). Tourism development in Sri Lanka: the case of Ethukala and Unawatuna. <i>Tourism Recreation Research</i> , 25(3), 103-114.
Clarke 2002	United States		Clarke, A. L. (2002). Assessing the carrying capacity of the Florida Keys. <i>Population and Environment</i> , 23, 405-418.
Farrell and Marion 2002	United States		Farrell, T. A., & Marion, J. L. (2002). The protected area visitor impact management (PAVIM) framework: A simplified process for making management decisions. <i>Journal of sustainable tourism</i> , 10(1), 31-51.
Clayton 2002	Caribbean		Clayton, A. (2002). Strategies for sustainable tourism development: the role of the concept of carrying capacity. <i>Social and Economic Studies</i> , 61-98.
Silva 2002	Portugal	Morgavél, Oliveirinha, Samouqueira, Grande and Ilha	Silva, C. P. (2002). Beach carrying capacity assessment: how important is it?. <i>Journal of Coastal Research</i> , (36), 190-197.
Liu 2003	United Kingdom		Liu, Z. (2003). Sustainable tourism development: A critique. <i>Journal of sustainable tourism</i> , 11(6), 459-475.
Polette and Raucci 2003	Brazil	Balneário Camboriú	Polette, M., & Raucci, G. D. (2003). Methodological proposal for carrying capacity analysis in sandy beaches: a case study at the central beach of Balneário Camboriú (Santa Catarina, Brazil). <i>Journal of Coastal Research</i> , 94-106.
Garcia and Servera 2003	Spain	Mallorca	Garcia, C., & Servera, J. (2003). Impacts of tourism development on water demand and beach degradation on the island of Mallorca (Spain). <i>Geografiska Annaler: Series A, Physical Geography</i> , 85(3-4), 287-300.
Micallef et al 2004	Croatia		Micallef, A., Williams, A. T., Radic, M., & Ergin, A. (2004). Application of a novel bathing area evaluation technique—a case study of Croatian island beaches. <i>World Leisure Journal</i> , 46(4), 4-21.
Jennings 2004	United Kingdom		Jennings, S. (2004). Landscape sensitivity and tourism development. <i>Journal of Sustainable Tourism</i> , 12(4), 271-288.
Yepes and Medina 2005	Spain		Yepes, V., & Medina, J. R. (2005). Land use tourism models in Spanish coastal areas. A case study of the Valencia region. <i>Journal of coastal research</i> , 83-88.
Tselentis et al 2006	Greece		Tselentis, B. S., Bousbouras, D., & Toanoglou, M. (2006). Carrying capacity assessment for the Greek islands of Kalymnos. In <i>Kos and Rhodes, Sustainable Tourism II International Conference</i> , Bologna.
valdemoro and jimenez 2006	Spain		Valdemoro, H. I., & Jiménez, J. A. (2006). The influence of shoreline dynamics on the use and exploitation of Mediterranean tourist beaches. <i>Coastal Management</i> , 34(4), 405-423.
Guillén et al 2007	Spain		Guillén, J., García-Olivares, A., Ojeda, E., Osorio, A., Chic, O., & González, R. (2008). Long-term quantification of beach users using video monitoring. <i>Journal of Coastal Research</i> , 24(6), 1612-1619.
Williams and Lemckert 2007	Australia		Williams, P., & Lemckert, C. (2007). Beach carrying capacity: Has it been exceeded on the gold coast?. <i>Journal of Coastal Research</i> , 50(sp1), 21-24.
Alipour et al 2007	Cyprus		Alipour, H., Altinay, M., Hussain, K., & Sheikhan, N. (2007). Perceptions of the Beach Users: A Case Study of the Coastal Areas of North Cyprus Towards Establishment of a. <i>Tourism Analysis</i> , 12(3), 175-190.
Jiménez et al 2007	Spain		Jiménez, J. A., Osorio, A., Marino-Tapia, I., Davidson, M., Medina, R., Kroon, A., ... & Aarmikhof, S. G. J. (2007). Beach recreation planning using video-derived coastal state indicators. <i>Coastal Engineering</i> , 54(6-7), 507-521.
Silva et al 2007	Portugal		Silva, C. D., Alves, F. L., & Rocha, R. (2007). The management of beach carrying capacity: The case of northern Portugal. <i>Journal of Coastal Research</i> , 50(sp1), 135-139.
Lankford et al 2008	United States		Lankford, S. V., Inui, Y., & Whittle, A. (2008). Exploring social carrying capacity based on perceived levels of crowding: A case

Bardolet and Sheldon 2008	Spain		study of Hanauma Bay, Hawaii. <i>Tourism in Marine Environments</i> , 5(1), 43-53.
Roca et al 2008	Spain	Malgrat Nord	Bardolet, E., & Sheldon, P. J. (2008). Tourism in archipelagos: Hawai'i and the Balearics. <i>Annals of Tourism Research</i> , 35(4), 900-923.
Silva et al 2008	Brazil	Boa viagem	Roca, E., Riera, C., Villares, M., Fragell, R., & Junyent, R. (2008). A combined assessment of beach occupancy and public perceptions of beach quality: A case study in the Costa Brava, Spain. <i>Ocean & Coastal Management</i> , 51(12), 839-846.
Quicoy and Briones 2009	Philippines		Silva, J. S., Leal, M. M. V., Araújo, M. C. B., Barbosa, S. C. T., & Costa, M. F. (2008). Spatial and temporal patterns of use of Boa Viagem Beach, Northeast Brazil. <i>Journal of Coastal Research</i> , (24), 79-86.
Cole and Razak 2009	United States		Quicoy, A. R., & Briones, N. D. (2010). Beach carrying capacity assessment of coastal ecotourism in Calatagan, Batangas, Philippines. <i>Journal of Environmental Science and Management</i> , 12(2).
Sardá et al 2009	Spain	S'Abanell North, Blanes Centre, Treumal, Sta. Cristina, Lloret Centre, Canyelles South, Sta. M Llorell, Platja Gran and Mar Menuda	Cole, S., & Razak, V. (2009). How far, and how fast? Population, culture, and carrying capacity in Aruba. <i>Futures</i> , 41(6), 414-425.
Tejada et al 2009	Spain		Sardá, R., Mora, J., Ariza, E., Avila, C., & Jimenez, J. A. (2009). Decadal shifts in beach user sand availability on the Costa Brava (Northwestern Mediterranean Coast). <i>Tourism Management</i> , 30(2), 158-168.
Jurado et al 2009	Spain	Torre del Mar and El Cañuelo	Tejada, M., Malvarez, G. C., & Navas, F. (2009). Indicators for the assessment of physical carrying capacity in coastal tourist destinations. <i>Journal of Coastal Research</i> , 1159-1163.
Haller et al 2011	German		Jurado, E., Dantas, A. G., & Silva, C. P. D. (2009). Coastal zone management: Tools for establishing a set of indicators to assess beach carrying capacity (Costa del Sol—Spain). <i>Journal of Coastal Research</i> , 1125-1129.
Zhong et al 2011	China		Haller, I., Stybel, N., Schumacher, S., & Mossbauer, M. (2011). Will beaches be enough? Future changes for coastal tourism at the German Baltic Sea. <i>Journal of Coastal Research</i> , (61), 70-80.
Anthony et al 2011	France		Zhong, L., Deng, J., Song, Z., & Ding, P. (2011). Research on environmental impacts of tourism in China: Progress and prospect. <i>Journal of environmental management</i> , 92(11), 2972-2983.
Mavris 2011	Cyprus		Anthony, E. J., Cohen, O., & Sabatier, F. (2011). Chronic offshore loss of nourishment on Nice beach, French Riviera: A case of over-nourishment of a steep beach?. <i>Coastal engineering</i> , 58(4), 374-383.
Silva et al 2011	Brazil	Parracho	Mavris, C. (2011). Sustainable environmental tourism and insular coastal area risk management in Cyprus and the Mediterranean. <i>Journal of Coastal Research</i> , (61), 317-327.
Cumberbatch and Moses 2011	Barbados		Silva Reimão, I., Rodrigues de Souza Filho, J., Fernandes Ferreira, D., & Gustavo Freitas Papi, A. (2011). Carrying capacity analysis of Praia do forte beach, Brazil. <i>Journal of Coastal Research</i> , (61), 440-445.
Lee 2011	South Korea		Cumberbatch, J., & Moses, J. (2011). Social carrying capacity in beach management in Barbados. <i>Journal of Coastal Research</i> , (61), 14-23.
Ribeiro et al 2011	Portugal	Avencas	Lee, S. (2011). Carrying capacity of sustainable tourism based on the balance concept between ecological damage loading and recovery capacity. <i>Journal of Coastal Research</i> , 1297-1301.
Sousa et al 2011	Brazil	Princesa, Atalaia and Ajuruteua	Ribeiro, M. F., Ferreira, J. C., & Silva, C. P. (2011). The sustainable carrying capacity as a tool for environmental beach management. <i>Journal of Coastal Research</i> , 1411-1414.
Zacarias et al 2011	Portugal		Sousa, R. C., Pereira, L. C. C., Silva, N. I. S., Oliveira, S. D., Pinto, K. S. T., & Da Costa, R. M. (2011). Recreational carrying capacity of three Amazon macrotidal beaches during the peak vacation season. <i>Journal of Coastal Research</i> , 1292-1296.
			Zacarias, D. A., Williams, A. T., & Newton, A. (2011). Recreation carrying capacity estimations to support beach management at Praia de Faro, Portugal. <i>Applied Geography</i> , 31(3), 1075-1081.

Simeone et al 2012	Italy			Simeone, S., Palombo, A. G. L., & Guala, I. (2012). Impact of frequentation on a Mediterranean embayed beach: implication on carrying capacity. <i>Ocean & coastal management</i> , 62, 9-14.
Jurado et al 2012	Spain			Jurado, E. N., Tejada, M. T., García, F. A., González, J. C., Macías, R. C., Peña, J. D., ... & Becerra, F. S. (2012). Carrying capacity assessment for tourist destinations. Methodology for the creation of synthetic indicators applied in a coastal area. <i>Tourism Management</i> , 33(6), 1337-1346.
Kalisch 2012	Germany			Kalisch, D. (2012). Relevance of crowding effects in a coastal National Park in Germany: results from a case study on Hamburger Hallig. <i>Journal of Coastal Conservation</i> , 16, 531-541.
McLachlan et al 2013	Australia			McLachlan, A., Defeo, O., Jaramillo, E., & Short, A. D. (2013). Sandy beach conservation and recreation: guidelines for optimising management strategies for multi-purpose use. <i>Ocean & coastal management</i> , 71, 256-268.
Rajan et al 2013	India	Varkala		Rajan, B., Varghese, V. M., & Pradeepkumar, A. P. (2013). Beach carrying capacity analysis for sustainable tourism development in the South West Coast of India. <i>Environmental Research, Engineering and Management</i> , 63(1), 67-73.
Göktuğ et al 2013	Turkey	Topçam		Göktuğ, T. H., Bulut, Y., Demir, M., & Yıldız, N. D. (2013). Estimating carrying capacity of Olympos Bey Mountains Coastal National Park. <i>Fresenius Environmental Bulletin</i> , 22(12), 3730-3738.
Jurado el al 2013	Spain			Jurado, E. N., Damian, I. M., & Fernández-Morales, A. (2013). Carrying capacity model applied in coastal destinations. <i>Annals of Tourism Research</i> , 43, 1-19.
Silva et al 2013	Portugal	Tarquinio/Paraíso Castelo	and	Silva, S. F., & Ferreira, J. C. (2013). Beach carrying capacity: The physical and social analysis at Costa de Caparica, Portugal. <i>Journal of Coastal Research</i> , (65), 1039-1044.
Filho et al 2014	Brazil	Busca Vida, Jauá, Interlagos, Barra de Jacupe, Guarajuba, Arembepe and Itacimirim		Filho, J. R., Santos, R. C., Silva, I. R., & Elliff, C. I. (2014). Evaluation of recreational quality, carrying capacity and ecosystem services supplied by sandy beaches of the municipality of Camaçari, northern coast of Bahia, Brazil. <i>Journal of Coastal Research</i> , (70), 527-532.
Fanini et al 2014	Greece			Fanini, L., Zampicinini, G., & Pafilis, E. (2014). Beach parties: a case study on recreational human use of the beach and its effects on mobile arthropod fauna. <i>Ethology Ecology & Evolution</i> , 26(1), 69-79.
Balouin et al 2014	France			Balouin, Y., Rey-Valette, H., & Picand, P. A. (2014). Automatic assessment and analysis of beach attendance using video images at the Lido of Sète beach, France. <i>Ocean & Coastal Management</i> , 102, 114-122.
Hassan et al 2014	Bangladesh			Hassan, S. R., Hassan, M. K., & Islam, M. S. (2014). Tourist-group consideration in tourism carrying capacity assessment: A new approach for the Saint Martin's island, Bangladesh. <i>Journal of Economics and Sustainable Development</i> , 5(19), 150-158.
Ku et al 2014	Taiwan			Ku, K. C., Chen, T. C., & Ying, T. C. (2014). A collaborative reference model for monitoring whale-watching quantity in the Hualien coastal area, Taiwan. <i>Ocean & coastal management</i> , 95, 26-34.
Sousa et al 2014	Brazil	Murubira, Colares and Marudá		Sousa, R. C., Pereira, L. C., da Costa, R. M., & Jiménez, J. A. (2014). Tourism carrying capacity on estuarine beaches in the Brazilian Amazon region. <i>Journal of Coastal Research</i> , (70), 545-550.
Reyes-Martínez et al 2015	Spain			Reyes-Martínez, M. J., Lercari, D., Ruiz-Delgado, M. C., Sánchez-Moyano, J. E., Jiménez-Rodríguez, A., Pérez-Hurtado, A., & García-García, F. J. (2015). Human pressure on sandy beaches: implications for trophic functioning. <i>Estuaries and coasts</i> , 38, 1782-1796.
Bera et al 2015	India			Bera, S., Majumdar, D. D., & Paul, A. K. (2015). Estimation of tourism carrying capacity for neil Island, south andaman, India. <i>Journal of coastal sciences</i> , 2(2), 46-53.
Polnyotee et al 2015	Thailand			Polnyotee, M., & Thadaniti, S. (2015). Community-based tourism: A strategy for sustainable tourism development of Patong Beach, Phuket Island, Thailand. <i>Asian Social Science</i> , 11(27), 90.
Iliopoulou-Georgudaki et al 2015	Greece			Iliopoulou-Georgudaki, J., Kalogeras, A., Konstantinopoulos, P., & Theodoropoulos, C. (2016). Sustainable tourism management and development of a Greek coastal municipality. <i>International</i>

		Journal of Sustainable Development & World Ecology, 23(2), 143-153.
Song et al 2016	China	Song, D. (2016). Countermeasure Study on Sustainable Utilization of Tourism Resources and Tourism Environmental Pollution in Coastal Areas of the Pearl River Delta, China. <i>Nature Environment and Pollution Technology</i> , 15(3), 873.
Manno et al 2016	Spain	Manno, G., Anfuso, G., Messina, E., Williams, A. T., Suffo, M., & Liguori, V. (2016). Decadal evolution of coastline armouring along the Mediterranean Andalusia littoral (South of Spain). <i>Ocean & Coastal Management</i> , 124, 84-99.
Cisneros et al 2016	Argentina	Cisneros, M. A. H., Sarmiento, N. V. R., Delrieux, C. A., Piccolo, M. C., & Perillo, G. M. (2016). Beach carrying capacity assessment through image processing tools for coastal management. <i>Ocean & Coastal Management</i> , 130, 138-147.
Chen and teng 2016	Taiwan	Chen, C. L., & Teng, N. (2016). Management priorities and carrying capacity at a high-use beach from tourists' perspectives: A way towards sustainable beach tourism. <i>Marine Policy</i> , 74, 213-219.
Ma et al 2017	China	Ma, P., Ye, G., Peng, X., Liu, J., Qi, J., & Jia, S. (2017). Development of an index system for evaluation of ecological carrying capacity of marine ecosystems. <i>Ocean & Coastal Management</i> , 144, 23-30.
Liu et al 2017	China	Liu, J., Zhang, J., & Fu, Z. (2017). Tourism eco-efficiency of Chinese coastal cities—Analysis based on the DEA-Tobit model. <i>Ocean & coastal management</i> , 148, 164-170.
Nuzula et al 2017	Indonesia	Nuzula, N. I., Armono, H. D., & Rosyid, D. M. (2017). Management of Baluran National Park resources for coastal ecotourism based on suitability and carrying capacity. <i>Applied Mechanics and Materials</i> , 862, 161-167.
Pérez-Maqueo et al 2017	Mexico	Pérez-Maqueo, O., Martínez, M. L., & Nahuacatl, R. C. (2017). Is the protection of beach and dune vegetation compatible with tourism?. <i>Tourism Management</i> , 58, 175-183.
Anfuso et al 2017	Cuba	Anfuso, G., Williams, A. T., Martínez, G. C., Botero, C. M., Hernández, J. C., & Pranzini, E. (2017). Evaluation of the scenic value of 100 beaches in Cuba: Implications for coastal tourism management. <i>Ocean & Coastal Management</i> , 142, 173-185.
Raheem et al 2017	India	Raheem, P., Vincy, M. V., Brilliant, R., & Jude, E. (2017). Estiation of Beach Carrying Capacity for Lakshadweep Island South India. <i>Global Journal of Curent Research Vincy MV et. Al</i> , 5(3).
Sousa et al 2017	Brazil	Sousa, R. C., Pereira, L. C. C., da Costa, R. M., & Jiménez, J. A. (2017). Management of estuarine beaches on the Amazon coast though the application of recreational carrying capacity indices. <i>Tourism Management</i> , 59, 216-225.
Lopez-del-Pino et al 2017	Spain	Lopez-del-Pino, F., & Grisóla, J. M. (2018). Pricing Beach Congestion: An analysis of the introduction of an access fee to the protected island of Lobos (Canary Islands). <i>Tourism Economics</i> , 24(4), 449-472.
Jiménez et al 2017	Spain	Jiménez, J. A., Valdemoro, H. I., Bosom, E., Sánchez-Arcilla, A., & Nicholls, R. J. (2017). Impacts of sea-level rise-induced erosion on the Catalan coast. <i>Regional environmental change</i> , 17, 593-603.
Dvaskas 2017	Croatia	Dvaskas, A. (2017). Dynamically linking economic models to ecological condition for coastal zone management: Application to sustainable tourism planning. <i>Journal of environmental management</i> , 188, 163-172.
Rodella et al 2017	Italy	Rodella, I., Corbau, C., Simeoni, U., & Utizi, K. (2017). Assessment of the relationship between geomorphological evolution, carrying capacity and users' perception: Case studies in Emilia-Romagna (Italy). <i>Tourism Management</i> , 59, 7-22.
Pikelj et al 2018	Croatia	Pikelj, K., Ružić, I., Ilić, S., James, M. R., & Kordić, B. (2018). Implementing an efficient beach erosion monitoring system for coastal management in Croatia. <i>Ocean & coastal management</i> , 156, 223-238.
Toimil et al 2018	Spain	Toimil, A., Díaz-Simal, P., Losada, I. J., & Camus, P. (2018). Estimating the risk of loss of beach recreation value under climate change. <i>Tourism Management</i> , 68, 387-400.
Gonzalez et al 2018	Spain	Gonzalez, V. M., Coromina, L., & Galí, N. (2018). Overtourism: residents' perceptions of tourism impact as an indicator of resident

			social carrying capacity-case study of a Spanish heritage town. <i>Tourism review</i> , 73(3), 277-296.
Iglesias et al 2018	Spain		Iglesias, B., Anfuso, G., Uterga, A., Arenas, P., & Williams, A. T. (2018). Scenic value of the Basque Country and Catalonia coasts (Spain): impacts of tourist occupation. <i>Journal of Coastal Conservation</i> , 22, 247-261.
Candia et al 2018	Italy		CANDIA, S., PIRLONE, F., & SPADARO, I. (2018). Sustainable development and the plan for tourism in Mediterranean coastal areas: Case study of the region of Liguria, Italy. <i>WIT Transactions on Ecology and the Environment</i> , 217, 523-534.
Wiyono et al 2018	Indonesia		Wiyono, K. H., Muntasib, E. K. S. H., & Yulianda, F. (2018, May). Carrying capacity of Peucang Island for ecotourism management in Ujung Kulon National Park. In <i>IOP Conference Series: Earth and Environmental Science</i> (Vol. 149, No. 1, p. 012018). IOP Publishing.
Han et al 2018	China		Han, Y., Wei, F., Ye, G., Yang, S., Ma, P., & Hu, W. (2018). A study on evaluation the marine carrying capacity in Guangxi Province, China. <i>Marine Policy</i> , 91, 66-74.
Han 2018	China		Han, J. (2018). Carrying capacity of low carbon tourism environment in coastal areas from the perspective of ecological efficiency. <i>Journal of Coastal Research</i> , (83), 199-203.
Gonson et al 2018	Australia		Gonson, C., Pelletier, D., & Alban, F. (2018). Social carrying capacity assessment from questionnaire and counts survey: Insights for recreational settings management in coastal areas. <i>Marine Policy</i> , 98, 146-157.
Sousa et al 2018	Portugal		Sousa, L. B., Loureiro, C., & Ferreira, O. (2018). Morphological and economic impacts of rising sea levels on cliff-backed platform beaches in southern Portugal. <i>Applied Geography</i> , 99, 31-43.
Rudan and Nižić 2018	Croatia	Croatia beach	Rudan, E., & Krstinić Nižić, M. (2018). The role of beaches in the tourism offering: the case study of the municipality of Lovran. <i>Pomorstvo</i> , 32(2), 219-227.
Giné et al 2018	Spain		Serrano Giné, D., Jurado Rota, J., Pérez Albert, M. Y., & Bonfill Cerveró, C. (2018). The Beach Crowding Index: A tool for assessing social carrying capacity of vulnerable beaches. <i>The Professional Geographer</i> , 70(3), 412-422.
Morales et al 2018	Mexico		Morales, G. G., Arreola-Lizárraga, J. A., & Grano, P. R. (2018). Integrated assessment of recreational quality and carrying capacity of an Urban Beach. <i>Coastal Management</i> , 46(4), 316-333.
Navarro 2019	Dominican Republic		Navarro, N. (2019). Community perceptions of tourism impacts on coastal protected areas. <i>Journal of Marine Science and Engineering</i> , 7(8), 274.
Santos et al 2019	Portugal		Santos, M., Radicchi, E., & Zagnoli, P. (2019). Port's role as a determinant of cruise destination socio-economic sustainability. <i>Sustainability</i> , 11(17), 4542.
Cruz and Zaragoza 2019	Spain		Simancas Cruz, M., & Peñarrubia Zaragoza, M. P. (2019). Analysis of the accommodation density in coastal tourism areas of insular destinations from the perspective of overtourism. <i>Sustainability</i> , 11(11), 3031.
Zhu et al 2019	China		Zhu, J., Wang, E., & Sun, W. (2019). Application of Monte Carlo AHP in ranking coastal tourism environmental carrying capacity factors. <i>Asia Pacific Journal of Tourism Research</i> , 24(7), 644-657.
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CAPÍTULO 2

Evaluation of tourist carrying capacity to support recreational beaches management

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Evaluation of tourist carrying capacity to support recreational beaches management

Abstract

The overexploitation of sandy beaches by tourism reduces ecological integrity, rendering natural conditions unsatisfactory for the needs of the population and resulting in negative socio-economic impacts. In this context, the assessment of tourist carrying capacity aims to support beach management from a social, environmental, and economic perspective. The objective of this study was to estimate the tourist carrying capacity at nine beaches in the states of Rio de Janeiro (RJ) and Espírito Santo (ES), southeastern Brazil. The physical carrying capacity was calculated based on the available space for recreation in scenarios of one user per 5 m² and 10 m². Subsequently, limiting environmental factors for recreational use such as sunlight, precipitation, strong winds, tidal range, and

temperature were considered, supporting the calculation of the tourist carrying capacity. For the calculation, management conditions (infrastructure and services) were estimated based on the scoring of 69 indicators, included in the international beach quality program called Blue Flag and in the main instrument for coastal management in Brazil, the Orla Project. At RJ beaches, the carrying capacity was not exceeded in the scenario of one user per 10 m², except in the central region with a higher tourist appeal. In ES state, the results indicated overload for all beaches in the central southern region; for example, one received six times more users than its tourist capacity. Overall, the highest percentages of management capacity were recorded at beaches with Blue Flag certification. The beaches that require the most improvements in coastal management are those located in regions with lower Human Development Index (HDI) and farther from major urban centers. The results suggest priority management actions and guide efforts towards potential beach certification. The management of services, infrastructure, and overload highlights the need for preventive measures to avoid the tourism paradox, including loss of environmental quality and revenue. Moreover, the flexibility of this evaluation tool allows for its application in beaches of any country. The integration of tourist carrying capacity and assessment of the coastal scenario provides a more comprehensive and effective framework for the sustainable management of beaches.

Keywords: Coastal management; Tourism; Quality indicators; Natural resources; Sandy beaches.

1. INTRODUCTION

Sandy beaches harbor a unique biodiversity and ecosystem services, primarily related to tourism (Harris & Defeo, 2022). However, tourist demand often disregards the conservation of marine fauna and ecosystems associated with the Active Littoral Zone (ALZ), such as beaches, tidal flats, and dunes (Mendoza-González et al., 2018; Fanini et al., 2021). Human interventions, including vehicle traffic (Schlacher & Thompson, 2007), trampling (Scapini et al., 2005; Machado et al., 2017), vegetation suppression (Rêgo et al., 2018), introduction of exotic species, and light and noise pollution (Longcore & Rich, 2004; Aguilera & González, 2023), result in negative ecological impacts on the ALZ. Therefore, the lack of adequate coastal management strategies jeopardizes the ecological integrity and the coastal resources themselves that attract users to the beaches, constituting the tourism paradox (Fanini et al., 2020; Defeo & Elliott, 2020).

As an alternative, the establishment of management tools can provide a scientific basis to enhance the beach ecosystem in the social, environmental, and

economic realms (Marchese et al., 2021). Among the tools used in environmental planning, the study of tourist carrying capacity stands out (Cifuentes, 1992; Morales et al., 2018; Rodella et al., 2020b), driven by the growth of tourism and demographic pressure (Kay & Alder, 1999; Zacarias, 2013). Tourist carrying capacity is based on the assumption that the area available for recreation and environmental factors limit the number of users a beach can accommodate. Exceeding this limit can compromise the sustainability of natural resources or the recreational experience of users (Cifuentes et al., 1990; Morales et al., 2018; Rodella et al., 2020b; Leka et al., 2022).

However, establishing limits on the number of users does not guarantee beach sustainability (Fernández-Villarán et al., 2020); thus, tourist carrying capacity serves as an indicator of the number of users approaching the maximum supported by the beach (Aranguren et al., 2008). Consequently, it is possible to identify when the infrastructure and natural conditions become insufficient to meet the needs of users (i.e., residents and tourists), informing anticipatory management actions to prevent economic losses (Coccossis, 2004).

Concurrently with studies on tourist carrying capacity, the coastal scenario assessment method based on beach quality certifications has also been developed to estimate support capacity and guide coastal management (Cristiano et al., 2018; Morales et al., 2018; Diniz et al., 2022). The Blue Flag Program, operated internationally by the Foundation for Environmental Education (FEE) (Bernardi & Pires, 2015; Blue Flag, 2023), is the only current certification in the Brazilian territory. This assessment is voluntary and conducted annually to identify aspects that require immediate intervention, such as the degree of conservation of native vegetation, water quality, and infrastructure (Lucrezi et al., 2016; Morales et al., 2018; Marchese et al., 2021). The use of criteria covered in the Blue Flag can be crucial for beaches in developing countries, unlike the developed ones where beaches already meet the standards set by this program, limiting certification to marketing purposes (Dodds & Holmes, 2020; Botero & Zielinsk, 2020).

In Brazil, the main coastal management instrument is the 'Projeto Orla' (Orla Project), incorporated into the National Coastal Management Plan since the enactment of Law No. 7.661/1988 (Brazil, 1988; Brazil, 2002). However, the criteria aimed at beach managers lack specific methods that encompass different regional realities. Consequently, most Brazilian coastal cities do not have

practical measures to minimize, prevent, or address the socio-ecological conflicts associated with the impacts of tourism on beaches (Bulhões et al., 2016; Scherer et al., 2020a; Marchese et al., 2021). Given the intensive touristic use of Brazilian beaches, the need for zoning and coastal management plans has become urgent (Sousa et al., 2017).

Management tools such as estimating tourist carrying capacity and assessing the coastal scenario can assist managers in developing appropriate plans, promoting sustainable development, and mitigating socio-environmental impacts intensified by uncontrolled tourism (Botero et al., 2018; Diniz et al., 2022; Garola et al., 2022; Sulis et al., 2023). This study aimed to estimate the tourist carrying capacity of nine beaches in the southeastern region of Brazil. In beaches located in protected areas and recognized for environmental quality, it is expected to find better conditions in tourism planning, scenic and water quality, education, and environmental information. To achieve this, we adapted the tourist carrying capacity model, integrating an assessment of the coastal scenario quality, considering indicators covered in the international Blue Flag beach quality certification program and the Orla Project. The integration of these tools provides a replicable scientific foundation to enhance beach management and tourism quality, offering insights for adaptable management in any beaches.

2. MATERIALS AND METHODS

Study Area

The study was conducted in one mesoregion along the coast of two states, Espírito Santo (ES) and Rio de Janeiro (RJ). The selected tourist destinations in the Northern region of RJ were Guaxindiba Beach (São Francisco de Itabapoana), Grussaí Beach (São João da Barra) located in the Dunes and Coastal Woodlands Environmental Protection Area, and Farol de São Thomé Beach (Campos dos Goytacazes). These locations are relevant for holding local tourist significance, particularly during the high summer season (January to March) (Machado et al., 2017; Suciú et al., 2017). However, the main economic activities are associated with agriculture, livestock, petroleum, and gas sectors (Cruz & Terra, 2020). There are approximately 565,000 inhabitants in this

municipalities, mainly in Campos dos Goytacazes, with 367,000 people (IBGE, 2022). The beaches in this region feature a wide coastal strip, with areas that are more urbanized and receive approximately three times as many people during the summer on certain beaches, while others experience low anthropogenic pressure (Machado et al., 2016; Costa et al., 2017).

In Central area of RJ, also referred as the Lakes Region, the following beaches were considered: João Fernandes Beach, located in a Marine Environmental Protection Area (PMAB, 2023); Praia Grande Beach, situated in a Marine Extractive Reserve (ICMBIO, 2023); and Però beach, which has been internationally certified by Blue Flag since the 2018/2019 tourist season (Blue Flag, 2023), and is also located in the *Pau-Brasil* Environmental Protection Area (INEA, 2023). The region's primary economic drivers are fishing and both domestic and international tourism, particularly during winter and summer vacations as well as on public holidays (Mendonça et al., 2013). Approximately 293,000 individuals reside in these municipalities, with Cabo Frio being the most populous, with more than 200,000 people (IBGE, 2022).

In the central southern region of Espírito Santo state, the study focused on Sereia Beach (Vila Velha), Morro Beach (Guarapari) and Costa Azul Beach (Anchieta). These beaches were chosen due to their significant tourist appeal within the state and its neighbors (Mendes et al., 2014; Pinto-coelho, 2021). Particularly, Sereia Beach stands out as the only beach in Espírito Santo certified by the international Blue Flag certification for the 2021/2022 season (Blue Flag, 2023) (Fig. 1). Vila Velha is the municipality with the highest population, with approximately 467,000 inhabitants, followed by Guarapari and Anchieta, which have approximately 125,000 and 6,000 individuals, respectively (IBGE, 2022).

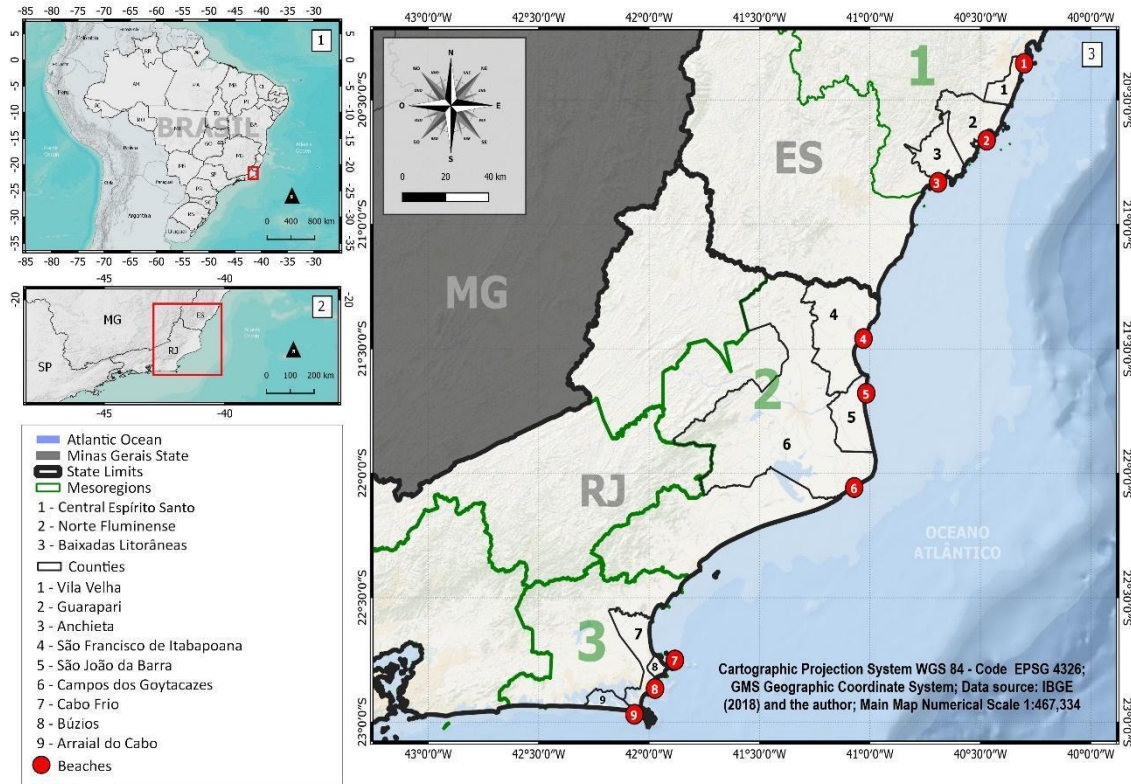


Figure 1. Map of Brazil indicating the states of Rio de Janeiro and Espírito Santo, and the geographical location of the studied beaches: 1 - Sereia Beach (ES), 2 - Morro Beach (ES), 3 - Costa Azul Beach (ES), 4 - Guaxindiba Beach (RJ), 5 - Grussaí Beach (RJ), 6 - Farol de São Thomé Beach (RJ), 7 - João Fernandes Beach (RJ), 8 - Però Beach (RJ), and 9 - Praia Grande Beach (RJ).

2.1 Tourist Carrying Capacity (TCC)

The Tourist Carrying Capacity (TCC) evaluation was conducted using a methodology developed for protected areas (parks, natural monuments, and biological reserves) by Cifuentes et al. (1990), Cifuentes (1992), and Cifuentes et al. (1999), adapted for the beach ecosystem by Melo et al. (2006) and Maciel et al. (2008). TCC estimates the maximum number of users an area can support taking into account physical, environmental, social, and management conditions, considering three metrics (Eq.1): physical carrying capacity (PCC), which corresponds to the maximum number of users an area can accommodate; real carrying capacity (RCC), which takes into account environmental factors that limit beach use and reduce PCC; and effective carrying capacity (ECC), which indicates the maximum number of users a beach can support when considering both RCC and beach management conditions (Cifuentes et al., 1999).

$$TCC = PCC > RCC \geq ECC \quad (\text{Eq. 1})$$

2.2 Physical Carrying Capacity (PCC)

PCC is defined as the maximum number of visitors that a specific area can accommodate, considering the average time each visitor spends on the beach (Eq. 2). Google Earth satellite images were used to calculate the physical dimensions of the beaches (total area), considering the entire sandy strip between the shoreline and physical structures or the beginning of the resting vegetation. Visitor counts were conducted hourly in a 10,000 m² plot, from 8:00 AM to 5:00 PM, to determine the maximum number of users on the beach (Zacarias et al., 2011). This data was gathered during the summer of 2023 on days with the highest tourist influx (holidays and weekends).

$$PCC = A/a * T \quad (\text{Eq. 2})$$

Here **PCC** represents the physical carrying capacity; **A** is the total area of the beach available for tourist use; **a** is the visitor density scenario (in m²); and **T** is the average time each user spends on the beach. For **a**, two scenarios were considered: one user per 5 m² and one user per 10 m², as higher densities are typically considered uncomfortable by visitors (Yepes, 2002). For **T**, three hours were considered, following Silva et al. (2007) and Zacarias (2013).

2.3 Real Carrying Capacity (RCC)

The area and time taken into account when calculation PCC are not sufficient to determine the number of users the area can support. Therefore, RCC is determined when PCC is subjected to a series of correction factors (CF) (Eq. 3). The intensity of beach use is not homogeneous on a daily and seasonal basis, as certain environmental factors restrict tourist activity (Cifuentes et al., 1999). Thus, RCC is calculated as follows:

$$RCC = PCC * (CF1 * CF2 * CF3 * CF4 * CF5) \quad (\text{Eq. 3})$$

The Real Carrying Capacity (RCC) is determined by the Physical Carrying Capacity (PCC) and five correction factors (CFs) chosen for this study: lack of sunlight (CF1), rainfall (CF2), strong winds (CF3), tides (CF4), and air temperature (CF5). These CFs are defined according to the unique characteristics of each beach that either impact user satisfaction or limit beach usage, and they are typically included in global assessments (Zacarias et al.,

2011; Corbau et al., 2019; Soria-Díaz et al., 2022). The CFs are calculated using the following equation (Eq. 4):

$$CF_x = 1 - L_m/T_m \quad (\text{Eq. 4})$$

Here, **CF_x** represents the variable correction factor (CF1, CF2, CF3, CF4, and CF5); **L_m** is the limiting magnitude for beach use; **T_m** is the total variable magnitude. The values of **MI** and **Mt** were calculated in hours or days depending on CF_x (Appendix A).

Data from the National Institute of Meteorology – INMET (INMET, 2023) were used to estimate the limiting magnitude for lack of sunlight (CF1), precipitation (CF2), and temperature (CF3). Tide information (CF4) was obtained from the national oceanographic database (Brazilian Navy, 2023). Strong winds (CF5) were assessed based on the Beaufort wind force scale, with weather conditions featuring wind speeds over 5.5 m/s considered uncomfortable for beachgoers due to increased wave size, sand movement, and potential displacement of beach umbrellas (Khodkar, 2019).

L_m is defined as the annual average of minimum temperature and tide levels, as well as the daily average number of sunlight hours, precipitation, and strong wind. T_m is the annual average of maximum temperature and tide levels, along with the total number of hours in a year (8,760 hours).

2.4 Effective Carrying Capacity (ECC)

The effective carrying capacity (ECC) or tourist carrying capacity (TCC) (Eq. 5) represents the optimal number of visitors that a location can sustain., considering RCC and the management capacity (MC). MC reflects the current tourism management condition on the beach, highlighting the necessary improvements in management capacity to enhance the beach's recreational conditions. This involves considerations of infrastructure, services, and amenities such as restrooms, restaurants, and lifeguard services (Sousa et al., 2014; Morales et al., 2018). The ECC is calculated using the following equation:

$$ECC = RCC * MC/100 \quad (\text{Eq. 5})$$

Where, ECC represents the effective carrying capacity; RCC is the real carrying capacity; MC is the management capacity expressed as a percentage.

For the latter metric, 69 indicators of coastal scenery quality were taken into account (Diniz et al., 2022). These indicators were based on the criteria set forth in the main plan for the Brazilian coast (Projeto Orla) and the international beach quality certification (Blue Flag) (see Appendix 1). (Appendix 1). Each beach was assigned a score for each indicator using the following scale: low quality = 1; intermediate quality = 2; high quality = 3 (Leatherman, 1997; Peña-Alonso et al., 2018). The Management Capacity was then determined based on these indicator scores as follows (Eq. 6):

$$MC = IC/AC \quad (\text{Eq. 6})$$

Where, **MC** represents the management capacity; IC denotes the installed capacity (sum of the values assigned to each indicator); AC signifies the adequate capacity (sum of the maximum score of all indicators).

2.5 Data Analysis

The tourist overload for each beach was estimated as a percentage, calculated by the difference between the suitable number of people (tourist carrying capacity, considering one user per 5 m²) and the number of observed number of people in the recreational area, normalized by the suitable number of individuals. The scenario of one person per 5 m² was applied as it represents the most severe condition in terms of human density.

The correlation between tourist overload and environmental or anthropogenic predictors was analyzed through a linear model, with coefficients derived using the 'anova' function from the 'stats' package (R Core Team, 2023). The predictors included the management capacity, which refers to the infrastructure and services provided at the beach, the Human Modification Metric, which evaluates alterations in the coastal landscape using the 'raster' package (Hijmans, 2018; R Core Team, 2019), the Basic Education Development Index (INEP, 2021), utilized to assess educational advancement in each locality, the Human Development Index (UNDP, 2013), which measures socioeconomic progress, and the distance from urban centers, measured in kilometers using satellite images to determine the level of urbanization.

Cluster analysis was employed to assess the similarity between groups of beaches in terms of tourist carrying capacities, management capacities, and the

estimated number of users. The selection criteria were predicated on the characteristics linked with the three assessed dimensions (infrastructure, available area, and effective use) and the absence of collinearity among these variables. The variable values were centered and standardized (mean = 0 and standard deviation = 1), applying Euclidean distance between groups of beach values, followed by constructing the similarity matrix using the Ward method with the 'hclust' function from the 'stats' package. A dendrogram was constructed using the 'dendextend' package (Galili, 2015). All analyses and plots were conducted using the R software (R Core Team, 2023).

3. RESULTS

In the beaches under study, the areas designated for tourism displayed specific characteristics for the PCC in scenarios of one user per 5 m² and 10 m². At Morro (ES), Sereia (ES), Costa Azul (ES), and João Fernandes (RJ) beaches, the entire shoreline is utilized by visitors, providing the least amount of sand available for use (Table 1). In other areas, the user flow is focused on a recreational area (RA) that does not equate to the total area (TA). These beaches have an extensive shoreline, such as Farol de São Thomé Beach (RJ), Praia de Grussaí Beach (RJ), and Praia Grande Beach (RJ).

When incorporating the correction factors (Appendix 2) into the calculation of RCC (Eq. 3), the values for each beach decreased and differed in both scenarios of one user per 5 m² and one user per 10 m² (Table 1).

Table 1. Shoreline extent (total area and recreational zone), maximum user capacity based on the physical carrying capacity (PCC), and actual carrying capacity (RCC) of the examined beaches were evaluated. This assessment considered scenarios with one user per 5 m² and 10 m²

	Area (m²)	Physical Carrying Capacity (Maximum number of users)		Real Carrying Capacity (Maximum number of users)	
		One user per 5 m²	One user per 10 m²	One user per 5 m²	One user per 10 m²
CENTRAL SOUTH REGION – ES					
Costa Azul Beach (TA)*	9,800	5,880	2,940	715	357
Sereia Beach (TA)*	13,590	8,154	4,077	991	496

Morro Beach (TA)*	105,280	63,168	31,584	7,679	3,840
CENTRAL REGION – RJ					
João Fernandes Beach (TA)*	5,457	3,274	1,637	576	288
Peró Beach (TA)	112,478	67,487	33,743	2,212	1,106
Peró Beach (RA)	21,401	12,840	6,420	11,626	5,813
Praia Grande Beach (TA)	566,404	424,803	169,921	15,783	7,892
Praia Grande Beach (RA)	152,706	91,624	45,812	73,178	29,271
NORTHERN REGION – RJ					
Guaxindiba Beach (TA)	141,798	85,079	42,539	4,679	2,339
Guaxindiba Beach (RA)	49,615	29,769	14,884	14,872	6,685
Grussaí Beach (TA)	609,328	365,597	182,798	52,440	8,242
Grussaí Beach (RA)	174,799	104,879	52,440	182,798	28,731
Farol de São Thomé Beach (TA)	700,000	420,000	210,000	63,877	10,163
Farol de São Thomé Beach (RA)	212,924	127,754	63,877	210,000	33,414

* The entire beach length is utilized for recreation.

TA = Total area

RA = Recreational area

Beaches with Blue Flag certification, such as Peró Beach and Sereia Beach, showed management capacity values exceeding 80% (Appendix 3). On the other hand, Guaxindiba Beach (61%) and João Fernandes Beach (63%) presented the lowest percentages (Fig. 2).

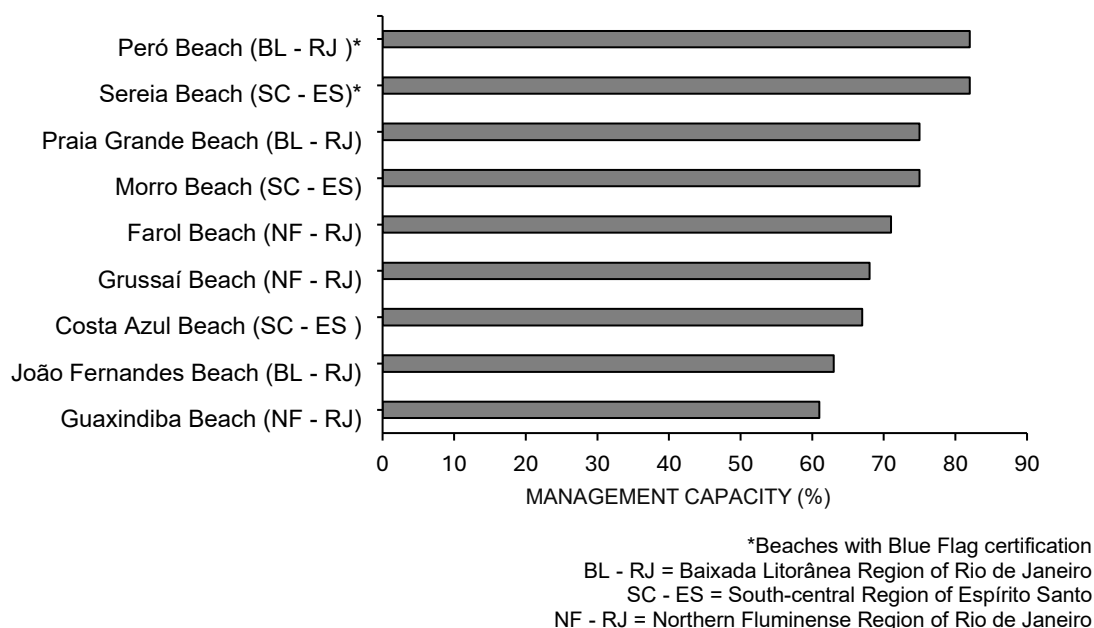


Figure 2. Management capacity (%) recorded at the studied beaches.

Touristic overload was identified in five out of the nine beaches (Fig. 3), classified as uncomfortable (one user/< 5m²) (Table 2). All beaches in ES had a number of users exceeding the recommended TCC. At Costa Azul Beach and Sereia Beach, the available space per user is less than 2 m² and 3.6 m²,

respectively. Morro Beach was overcrowded, with less than one user per 1 m² and receiving six times more users than its touristic carrying capacity.

In the state of RJ, João Fernandes Beach exceeded the limit established by the TCC by approximately seven times (Fig. 3). Other locations such as Farol Beach, Grussaí Beach, Praia Grande, Guaxindiba Beach, and Però Beach did not reach the TCC (Fig. 3) and were classified as comfortable for use. However, when considering only the recreational area, the density at Praia Grande Beach was also considered uncomfortable (one user/4.2 m²).

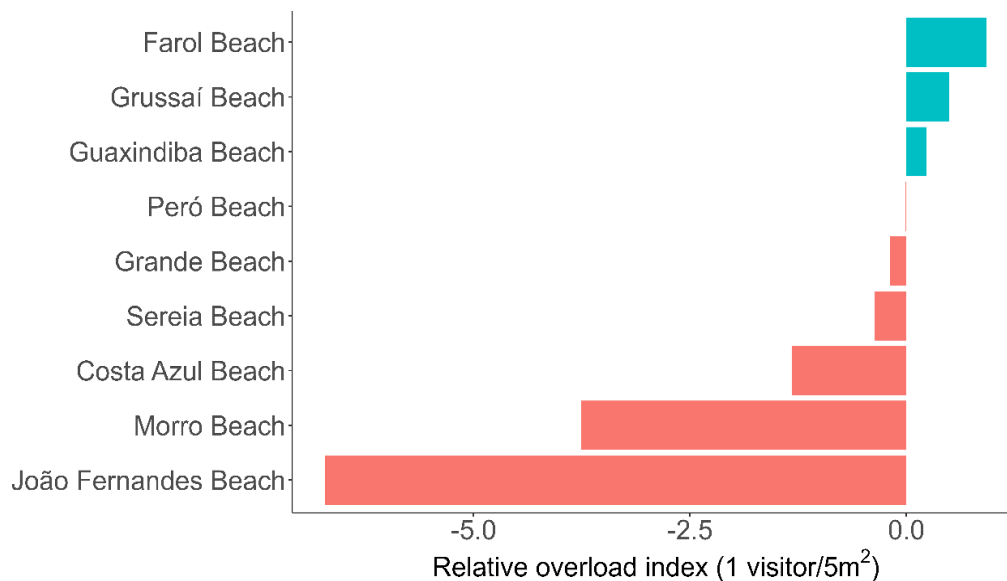


Figure 3. Values related to the number of times each beach can still accommodate recreational users (positive values) and tourist overload (negative values).

Table 2. Number of users obtained by the tourist carrying capacity and actual number of users on the beaches. Classification of current human density in the recreational area: ≤ 4 m² uncomfortable - U; ≥ 5 m² acceptable - A; and ≥ 10 m² comfortable - C (Adapted from Yepes, 1999).

	TOURIST CARRYING CAPACITY		CURRENT ESTIMATE OF USERS		
	One user per 5 m ²	One user per 10 m ²	Number of users	Space per user (m ²)	Comfort level
CENTRAL SOUTH REGION – ES					
Morro Beach (TA)*	5,759	2,880	27,373	1	U
Costa Azul Beach (TA)*	479	239	1,140	2	U
Sereia Beach ^B (TA)*	813	407	1,114	3.6	U
CENTRAL REGION – RJ					
João Fernandes Beach (TA)*	363	181	2,800	0.6	U
Praia Grande Beach (RA)	11,837	5,919	14,048	4.2	U
Praia Grande Beach (TA)	54,883	21,953	14,048	16.6	C

Peró Beach ^B (RA)	1,814	907	1,840	4.9	U
Peró Beach ^B (TA)	9,533	4,767	1,840	25.9	C
NORTHERN REGION – RJ					
Guaxindiba Beach (RA)	2,854	1,426	2,183	6.5	A
Guaxindiba Beach (TA)	9,071	4,078	2,183	18.7	C
Grussaí Beach (RA)	11,070	5,604	5,593	10	C
Grussaí Beach (TA)	38,591	19,537	5,593	34.9	C
Farol Beach (RA)	14,432	7,216	1,043	69.1	C
Farol Beach (TA)	66,827	33,414	1,043	320.3	C

^B Beaches with Blue Flag certification; * The entire length of the beach is used for recreation.

TA = Total area

RA = Recreational area.

The tourist overload on the beaches was influenced by MC, HDI and proximity to major urban centers (Fig. 4). There was a positive correlation between HDI and MC, indicating that the higher the HDI of the municipalities where the beaches are located, the higher the MC. Furthermore, it was observed that beaches located in municipalities with a high HDI and MC are close to major urban centers (Fig. 4).

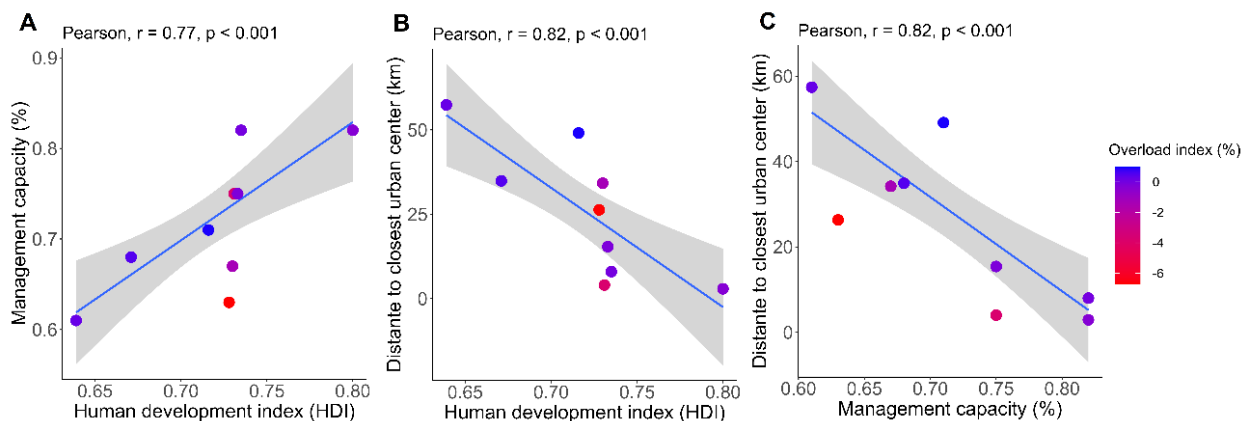


Figure 4. A - Linear regression testing the effect of management capacity, B - Human Development Index, and C - distance from major urban centers on beach overcrowding.

The cluster analysis revealed the presence of three main groups of beaches. The first group consists of Guaxindiba, João Fernandes, and Costa Azul beaches with low CM values. The second group includes Peró and Sereia beaches, certified with the Blue Flag label, and with a high CM value. The last group is formed by Farol, Grussaí, Praia Grande, and Morro beaches with long shorelines (Fig. 5).

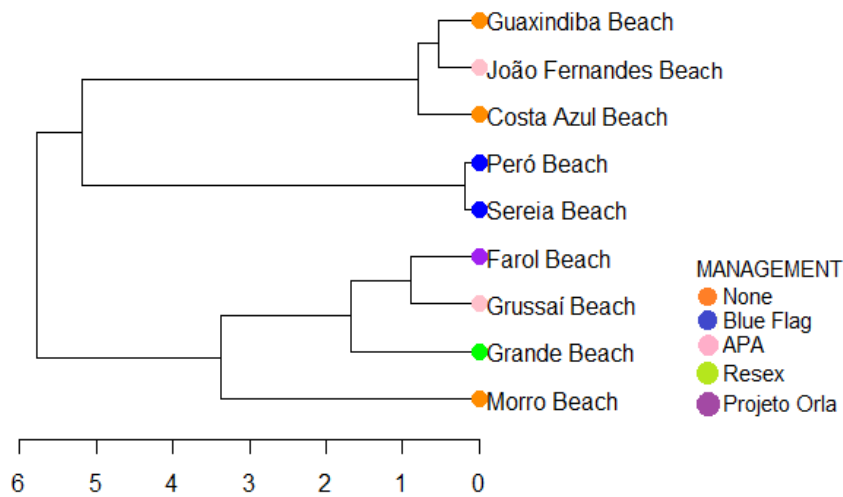


Figure 5. Cluster diagram for grouping beaches based on tourist carrying capacity, management capacity, and number of users in the summer.

4. Discussion

Among the tourist destinations studied, nearly half (44%) exceeded the recommender number of visitors to the tourist carrying capacity (TCC), including beaches with Blue Flag certification. This suggests that the available area for recreation is a critical factor, and the presence of certification does not guarantee user comfort. These findings highlight the importance of effective management strategies for conserving coastal natural resources and mitigating the impacts of tourism (Pavez et al., 2015; Andolina et al., 2021).

The positive relationship between the Human Development Index (HDI) and management capacity (CM) reinforces the environmental Kuznets hypothesis. This hypothesis states that, in the early stages of economic growth, income and environmental degradation are directly related. However, as income increases, the degradation of natural resources tends to decrease (Luzzati, 2015; Santiago & Couto, 2020). Economic growth driven by tourism is a priority for many Brazilian municipalities (Marroni & Asmus, 2013). However, tourism pressure on coastal ecosystems requires significant investments in infrastructure and services to ensure the sustainability of coastal resources. The lack of these investments can lead to user attrition and consequent loss of tourism revenue (Krelling et al., 2017; Diniz et al., 2022).

The reduced area of the coastlines of João Fernandes, Costa Azul, and Sereia beaches has led to a high concentration of tourists along the entire beachfront, thereby reducing the tourist carrying capacity of these areas. Despite

its significant size of 105,280 m², Praia do Morro also experiences a high density of visitors (1 user/m²). This level of overcrowding could potentially deter tourists from visiting the region in the future. Intense recreational activities, such as trampling and the removal of dunes and vegetation (Sobocinski et al., 2010; Zielinski et al., 2019), are often linked to adverse impacts on beach biodiversity (Martín et al., 2015; Machado et al., 2017; Costa et al., 2017).

The beaches that did not experience tourist overcrowding (Guaxindiba, Grussaí, and Farol) have extensive shorelines (> 141,798 m²), but recreational activities are concentrated in one area. This results in a zoning pattern is characterized by: a) areas devoid of recreational activities due to the absence of facilities, accessibility, and awareness; b) buffer zones with sparse users; and c) recreational zones that attract a high volume of tourists due to the availability of infrastructure (Polette et al., 2003; Suciú et al., 2017).

In recreational zones, intense tourist activity without proper mitigation strategies can lead to the depletion of natural resources and the creation sacrifice zones. These areas endure ongoing environmental damage without receiving adequate interventions such as planning, investments, or mitigation actions to address issues like erosion, pollution, construction, or the removal of native vegetation (Widener, 2018; Williams et al., 2018). Strategies for biodiversity conservation, environmental education, citizen science, traffic monitoring, manual cleaning with beach cleaners, and beach cleaning events can reduce anthropogenic impact on biodiversity. After the removal or mitigation of the main causes of coastal habitat degradation, beaches can be restored passively by mobile species or those with indirect development with oceanic larval stages (Elliott et al., 2007). An example is the recovery of ghost crab (*Ocypode quadrata*) populations on Brazilian beaches during the reduction of human activity in the COVID-19 pandemic (Soto et al., 2021; Costa et al., 2022). Similarly, in Italy, a study found that shorebirds (*Charadrius alexandrinus*) began building nests on sandy beaches during the pandemic where they had not been seen between 2016 and 2019 (Manenti et al., 2020).

Praia Grande Beach, a protected area since 1997, and Però Beach, protected since 2002, attract more visitors than the recommended capacity by the TCC (1 visitor per 4.9 m²) in their recreational zones, despite their high management capacity (> 75%). Given the extensive length of their sandy shores, a more balanced distribution of visitors along the entire coastline of both beaches

could comfortably accommodate the visitor numbers within the TCC's guidelines, resulting in 1 visitor per 16.4 m² at Praia Grande Beach and 1 visitor per 25.9 m² at Però Beach. Therefore, management strategies that encourage a more uniform utilization of the beaches should be promoted through appealing access conditions and infrastructure. In Portugal, the coastal management plan incorporated shoreline zoning, considering sensitive environmental areas, intensive urban use areas, and non-recreational areas with tourism potential (Silva et al., 2007). The need to expand recreational infrastructure emerged due to limited recreational space. Consequently, there was an increase in access points, parking facilities, and infrastructure investments in less frequented areas of beaches with extensive coastlines and those distant from urban centers (Silva et al., 2020).

João Fernandes Beach, located within a protected area since 2009, experiences tourist activity spanning its entire length and received a low assessment regarding management capacity (63%) and space per user (one user/0.6 m²). Therefore, the effectiveness of the environmental protection area housing the beach could be called into question due to the high density of use and occupancy, potentially categorizing it as a typical "paper park" (Relano & Pauly, 2023). A global concern is that the creation of conservation units might serve as a mechanism solely to increase revenue through the transfer of resources from the state to the municipality via taxes like the Ecological ICMS (Busch et al., 2021). This mechanism allows subnational governments to contribute to worldwide ecosystem restoration efforts, though it calls for more appropriate management tools in Brazil. In this beach area, there are many permanent structures along the shoreline and a lack of facilities for people with disabilities, lifeguards, police, informative signs, environmental education activities, post-beach vegetation cover, and zoning for various recreational activities. Indeed, while sandy beaches are among the most protected environments in terms of conservation units in Brazil (Monteiro-Neto & Neto, 2009), there remains a need for additional financial resources and skilled professionals for effective management of these protected areas (Motta et al., 2021).

The Però and Sereia beaches were internationally certified with the Blue Flag, due to their high performance in Management Capacity (MC) (> 80%). However, at Sereia Beach, there is a need for strategies to address the overload

of TCC. Despite the Blue Flag certification, it does not ensure the ecological integrity of the beaches, and should be supplemented with conservation and restoration efforts (Gilburn, 2012). The certification does not encompass crucial aspects of sustainable tourism, such as limiting visitor numbers, restoring native vegetation, or imposing construction boundaries (Zielinski & Botero, 2015; Fraguell et al., 2016). Ecotourism activities can be essential mechanisms for developing a biocentric perspective of the beaches and supporting management measures for the conservation of natural resources.

While the beaches of Guaxindiba, Grussaí, and Farol have yet to reach their carrying capacity, they are still susceptible to various human-induced impacts such as litter, permanent structures, and artificial lighting. As such, it's crucial to prioritize the coastal scenery quality indicators that were rated poorly in our assessment in the management plans for these beaches. Enhancements to the scenic features can be achieved by regulating permanent constructions along the coastline, restoring native vegetation, and minimizing litter pollution. For Guaxindiba and Grussaí beaches, safety measures could be improved by increasing the presence of lifeguards and law enforcement. Additionally, the current infrastructure including restrooms, water fountains, and showers is inadequate and needs improvement.

At the beaches of Morro, Costa Azul, Sereia, João Fernandes, and Praia Grande, the negative impacts resulting from an excess of tourists can be mitigated through measures to enhance MC, such as environmental education and enforcement of illegal activities. It's important to note that anthropogenic impacts are not always directly proportional to the number of tourists, but rather related to the nature and intensity of their activities (Budiantoro et al., 2019; Pavón, 2023). Therefore, enhancing MC is a strategy approach to improve coastal management. Based on the indicators that scored the lowest in the MC evaluation, we have formulated proposals to enhance coastal management of the studied beaches (Table 4).

Table 4. Strategies aimed at enhancing beach management, with set execution deadlines, based on indicators integral to the capacity for beach management: João Fernandes (FER), Praia Grande (GRA), Però (PER), Guaxindiba (GUA), Grussaí (GRU), Farol de São Thomé (FAR), Costa Azul (COS), Morro (MOR), and Sereia (SER).

MANAGEMENT STRATEGIES	BEACHES								
	FER	GRA	PER	GUA	GRU	FAR	COS	MOR	SER
Facilities such as ramps and walkways to enhance accessibility for wheelchair users and the elderly. (ABNT NBR 9050 Standard).	●	●		●	●	●	●		
Establishment of bicycle lanes and pedestrian paths.	●		●	●		●			
Developing a monitoring program for ecosystems associated with beaches (coral reefs, dunes, mangroves, and coastal scrubland).	●	●	●	●	●	●	●	●	
Efforts to restore native vegetation.	●	●		●	●	●			
Formation of a specific beach management committee.	●			●	●				
Enforcement of laws and regulations.		●		●		●			
Control of permanent facility construction along the coast.	●	●	●	●	●	●	●	●	●
Ensuring an adequate number of sanitary facilities in hygienic conditions, with cleaning frequency tied to usage intensity, and proper waste disposal.	●			●	●	●			
Provision of showers and drinking water fountains with potable water.	●	●	●	●	●	●	●	●	●
Installation of recreational facilities (e.g., courts and kayak rentals).			●	●	●	●	●	●	
Placement of selective waste bins in sufficient numbers.	●	●	●	●	●	●	●	●	●
Demolition of irregular constructions and regular maintenance of buildings to prevent risky situations and accidents.	●			●			●		
Adequate number of first aid equipment, lifeguards, and police.	●	●	●	●			●	●	●
Development of a zoning plan to organize the use activities on the beach.	●	●		●	●	●	●	●	
Installation of informative signs providing information about water quality, code of conduct, and beach map.	●	●		●	●	●	●	●	●
Regular environmental education activities targeting tourists and local residents.	●			●	●	●	●		
Promotion of citizen science through beach research.	●	●	●	●	●	●	●	●	●

Although Brazilian legislation does not regulate the number of users on beaches, TCC is a strategy to limit access to sensitive areas, like the coastal dunes and sandy plains found in Praia Grande and Però (Corbau et al., 2019), or shorebird nesting and feeding areas (Martín et al., 2015). Regulating visitor number can also reduce the impacts of free and autonomous diving activities at João Fernandes Beach, preventing further harm to coral reef ecosystems (Naranjo-Arriola, 2021). At loggerhead turtle (*Caretta caretta*) nesting sites such

as Guaxindiba, Grussaí and Farol beaches (Tiwari et al., 2010), overcrowding can decrease turtle survival rates (Siqueira et al., 2021; Pavón, 2023). Moreover, educational signage can be employed to limit recreational activities in beach areas hosting turtle nests (Costa et al., 2023). Other countries recommend environmental policies to limit or redirect users in locations that exceed the TCC, with the goal of preserving long-term socio-ecological benefits. Studies conducted on beaches in the Indonesian Islands (Adrianto et al., 2021), Portugal (Silva et al., 2020), Spain (Murillo & Rio, 2023), Mexico (Cupul-Magaña et al., 2017; Pavón, 2023), and Italy (Martínez et al., 2020) underscore the importance of these measures.

Among the studied beaches, only Farol Beach has a management plan based on the Orla Project. Few municipalities in the country have adopted the Orla Project, the main coastal planning initiative in Brazil since 2002 (Scherer et al., 2020). Furthermore, only a few beaches in the country have received international quality certification (Blue Flag, 2023), and there is a lack of science-based approaches to coastal management (Marchese et al., 2021). Touristic carrying capacity is an objective and easily implementable metric, being important for socioeconomic and environmental matters, as well as promoting regional cooperation for sustainable development. International agencies like the UN, UNESCO, and UNWTO have integrated sustainability into their tourism sector strategies (EU Commission, 2017; Cooper et al., 2018). Organized and conscious tourism is considered as a tool to achieve the Sustainable Development Goals outlined in the Agenda 2030 (Colglazier, 2015).

5. CONCLUSION

The suggested Touristic Carrying Capacity (TCC) values for João Fernandes Beach, Morro Beach, Costa Azul Beach, and Sereia Beach are lower than the actual number of tourists they receive during the summer season. The limited carrying capacity percentages at João Fernandes, Costa Azul, and Guaxindiba beaches justify the need for increased efforts by local public managers, supported by federal agencies, to address the unmet environmental and infrastructure criteria. Collaboration with third-sector organizations and universities engaged in scientific research, environmental monitoring, and environmental education could significantly enhance the management of these beaches. The Blue Flag Program has proven its effectiveness in meeting beach

quality standards, as evidenced by the superior carrying capacity performance of Perú and Sereia beaches, both of which have received the certification. While these values are relative, the results of this study offer a scientific foundation for proposing sustainable management strategies in alignment with the 2030 Agenda for Sustainable Development for tourist management in Brazilian beaches and those of other countries.

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APPENDIX

Appendix 1: Coastal Scenario Assessment Indicators, adapted from Leatherman (1997) and Peña-Alonso et al. (2018), with classification and evaluation method. ^b Indicators aligned with the Blue Flag Program (Blue Flag, 2021) and ^o Indicators in line with the Orla Project (MMA, 2006; Brasil, 2022).

INDICATORS	CLASSIFICATION			Method
	1 (low)	2 (intermediate)	3 (high)	
ACCESSIBILITY				
1. Facilities for Individuals with Special Needs ^b	Absent	Insufficient	Adequate	Direct observation
2. Accessible Restrooms for Individuals with Special Needs ^b	Absent	Present and inadequate	Present and adequate	Direct observation
3. Human-Made Structures Impeding Beach Visitor Mobility	High	Low	Absent	Direct observation
4. Beach-face slope	> 10°	5° - 10°	<5°	Level ruler
5. Level difference to the beach	Uneven with inadequate stairs or ramp	Uneven with adequate stairs or ramp	Smooth surface	Direct observation
6. Beach access ^{b,o}	No access	Inadequate (Unpaved)	Adequate (Paved)	Direct observation
7. Public Transit ^{b,o}	Absent	inadequate	Adequate	Direct observation
8. Designated Parking Spaces for Individuals with Disabilities and the Elderly ^b	Absent	Low	High	Direct observation
9. Bike lanes ^{b,o}	Absent	inadequate	Adequate	Direct observation
10. Pedestrian pathways ^{b,o}	Absent	inadequate	Adequate	Direct observation
11. Natural Formations Affecting Beach Accessibility (e.g., Beach Sandstones)	Absent	Low	Absent	Direct observation
ENVIRONMENTAL QUALITY				
12. Unpleasant Smells	Strong	Detectable	Absent	Direct observation

13. Presence of dead animals (fish or other organisms)	Frequent	Occasionally present	Absent	Reports or official records
14. Noise (Vehicle Traffic and Loud Music) ^{b,o}	High	Medium	Low	Direct observation
15. Vegetation coverage after beach use ^o	No vegetation on more than 50% of the extension.	Non-native vegetation covering more than 50% of the extension.	Native vegetation covering more than 50% of the extension.	Direct observation
16. Coastal ecosystems (coral reefs, dunes, mangroves, and restinga) ^o	Absent	Presence of an ecosystem.	Presence of at least two ecosystems.	Department of Environment
17. Monitoring Beach-Associated Ecosystems ^{b,o}	Absent	Insufficient	Adequate	Department of Environment
18. Stinging Organisms (Jellyfish)	Frequent	Occasionally present	Absent	Lifeguard
19. Enforcement of laws and regulations ^b	Absent	Present and inadequate	Present and adequate	Department of Environment
20. Beach management committee ^{b,o}	Absent	Present and unspecific	Present and specific	Department of Environment
WATER QUALITY				
21. Microbial quality of water ^{b,o}	> 400 NMP/100ml	100-400 NMP/100 ml	< 100 NMP/100 ml	www.inea.rj.gov.br
22. Oil on the beach or in the water ^b	Frequent	Occasionally present	Absent	Lifeguard
23. Floating debris (wood, plastic, glass, rubber, or other substances) ^b	Frequent	Occasionally present	Absent	Lifeguard
24. Monitoring of physicochemical water parameters ^{b,o}	Absent	Irregular	Regular	Department of Environment
25. Frequency of water quality monitoring ^b	Absent	Inappropriate	Monthly	www.inea.rj.gov.br
26. Red tide	Frequent	Occasionally present	Absent	News articles or official records

COMFORT

27. Large waves (> 1m) breaking directly on the beach face ^o	Frequent	Occasionally present	Absent	Direct observation
28. Sediment on the beach face	Rocks or clay	Pebbles, granules, coarse sand	Fine or medium sand	Direct observation
29. Beach face width at low tide ^o	Narrow (<10m)	Intermediate (10 - 30m)	Wide (>30m)	Direct observation
30. Sediment in the bathing zone	Gravel	Coarse sand	Fine or medium sand	Direct observation
31. Competition for unrestricted beach use (e.g., fishermen, sailors, and sports enthusiasts)	High	Medium	Low	Direct observation
32. Tidal range ^o	Large (>3m)	Intermediate (1-3)	Small (<1m)	Tide table
33. Water temperature ^o	<21°C	21-24°C	>24°C	portal.inmet.gov.br/
34. Bathing zones	Exposed beach	Partially sheltered	Sheltered beach	Direct observation
35. Algae on the sand or in the water column	Frequent	Low quantity	Absent	Direct observation
SCENIC QUALITY				
36. Beachfront typology in terms of urbanization ^o	Consolidated urbanization	In the process of urbanization	No urbanization	Direct observation
37. Coastal erosion vulnerability ^o	High	Medium	Low	Specialist
38. Permanent Structures ^o	In the post-beach area	In the coastal zone adjacent to the post-beach	Absent	Direct observation
39. Beach sediment coloration	Dark	Yellow	Light (White)	Direct observation
40. Water turbidity	<0,5 meters	1-0,5 meters	>1 meters	Secchi disk
SERVICES AND INFRASTRUCTURE				
41. Sanitary facilities in good hygiene condition ^b	Absent	Present and inadequate	Present and adequate	Direct observation
42. Number of Sanitary Facilities ^b	Absent	Insufficient	Adequate	Direct observation

43. Sanitary facilities with proper waste disposal ^b	Absent	Present and inadequate	Present and adequate	Direct observation
44. Showers and drinking fountains ^b	Absent	Present and insufficient	Present and sufficient	Direct observation
45. Unauthorized camping, vehicle circulation, or debris dumping ^b	High	Low	Absent	Direct observation
46. Snack bars, bars, and restaurants ^o	Absent	Insufficient	Adequate	Direct observation
47. Accommodation choices ^o	Absent	Insufficient	Adequate	Direct observation
48. Parking ^b	Absent	Inadequate	Adequate	Direct observation
49. Recreational facilities (e.g., courts and kayak rentals) ^o	Absent	Present and insufficient	Present and sufficient	Direct observation
50. Trash bins ^b	Absent	Low	Adequate	Direct observation
51. Recycling bins ^b	Absent	Present and insufficient	Present and sufficient	Direct observation
52. Beach cleanliness ^b	Absent	Irregular	Regular	Department of Environment
53. Cleaning of natural debris or seaweed ^b	Regular	Absent	Irregular	Department of Environment
54. Discharge of wastewater, industrial, or urban waters ^{b,o}	High	Low	Absent	Direct observation
55. Litter accumulation ^{b,o}	High	Low	Absent	Direct observation
56. Dogs and other domestic animals ^b	Frequent	Low	Absent	Direct observation
57. Building conservation status ^{b,o}	No maintenance	Irregular maintenance	Regular maintenance	Direct observation
SAFETY				
58. Lifeguards ^b	Absent	Insufficient	Adequate	Direct observation
59. First aid equipment ^b	Absent	Inadequate	Adequate	Lifeguard
60. Police officers ^b	Absent	Insufficient	Frequent	Direct observation
61. Rip currents	Frequent	Occasionally present	Absent	Lifeguard

62. Public alert system if the beach becomes unsafe	Absent	Present and inadequate	Present and adequate	Department of Environment
63. Emergency plans for addressing risks from environmental accidents ^b	Absent	Present and inadequate	Present and adequate	Department of Environment
64. Zoning for bathers, swimmers, surfers, and users of motorized watercraft ^{b, o}	Absent	Present and inadequate	Present and adequate	Department of Environment
ENVIRONMENTAL EDUCATION AND INFORMATION				
65. Environmental education activities provided to beachgoers ^b	Absent	Irregular	Regular	Department of Environment
66. Current information on water quality displayed on informative plaques ^b	Absent	Present and inadequate	Present and adequate	Direct observation
67. Information about local ecosystems, natural phenomena, sensitive natural areas, and culturally significant areas available on informational plaques ^b	Absent	Present and inadequate	Present and adequate	Direct observation
68. Beach map ^b	Absent	Present and inadequate	Present and adequate	Direct observation
69. Code of conduct displayed on informational plaques ^b	Absent	Present and inadequate	Present and adequate	Direct observation

Appendix 2. Correction factors identified as factors limiting tourist use in the real carrying capacity (RCC) during the period from 2019 to 2022.

	Environmental Factors	Limiting magnitude (Lmx)	Total magnitude (Tmx)	Correction factor Cf = 1 – (Lmx/Lmx)
CENTRAL REGION - RJ				
João Fernandes Beach	Absence of sun	4,406 hours	8,760 hours	0.50
	Precipitation	201 hours	8,760 hours	0.98
	Strong winds	2,767,5 hours	8,760 hours	0.68
	Tide	0.04 meters	1.18 meters	0.96
	Temperature	15.1 °C	33.8 °C	0.55
Praia Grande Beach	Absence of sun	4,406 hours	8,760 hours	0.50
	Precipitation	201 hours	8,760 hours	0.98
	Strong winds	2,767.5 hours	8,760 hours	0.68
	Tide	0.06 meters	1.08 meters	0.94
	Temperature	15.1 °C	33.8 °C	0.55
Peró Beach	Absence of sun	4,406 hours	8,760 hours	0.50
	Precipitation	201 hours	8,760 hours	0.98
	Strong winds	2,767.5 hours	8,760 hours	0.68
	Tide	0.06 meters	1.08 meters	0.94
	Temperature	15.1 °C	33.8 °C	0.55
NORTHERN REGION - RJ				
Guaxindiba Beach	Absence of sun	4,406 hours	8,760 hours	0.50
	Precipitation	201 hours	8,760 hours	0.98
	Strong winds	871 hours	8,760 hours	0.90
	Tide	0.29 meters	1.54 meters	0.81
	Temperature	17.9 °C	32.1 °C	0.44
Grussaí Beach	Absence of sun	4,406 hours	8,760 hours	0.50
	Precipitation	201 hours	8,760 hours	0.98
	Strong winds	871 hours	8,760 hours	0.90
	Tide	0.28 meters	1.41 meters	0.80
	Temperature	17.9 °C	32.1 °C	0.44
Farol de São Thomé Beach	Absence of sun	4,406 hours	8,760 hours	0.50
	Precipitation	201 hours	8,760 hours	0.98
	Strong winds	871 hours	8,760 hours	0.90
	Tide	0.26 meters	1.46 meters	0.82
	Temperature	17.9 °C	32.1 °C	0.44
CENTRAL SOUTH REGION – ES				
Costa Azul Beach	Absence of sun	4,406 hours	8,760 hours	0.50
	Precipitation	212 hours	8,760 hours	0.95
	Strong winds	1,226 hours	8,760 hours	0.93
	Tide	0.19 meters	1.35 meters	0.86
	Temperature	19 °C	27.8 °C	0.32
Morro Beach	Absence of sun	4,406 hours	8,760 hours	0.50
	Precipitation	212 hours	8,760 hours	0.95
	Strong winds	1,226 hours	8,760 hours	0.93
	Tide	0.19 meters	1.35 meters	0.86
	Temperature	19 °C	27.8 °C	0.32
Sereia Beach	Absence of sun	4,406 hours	8,760 hours	0.50
	Precipitation	212 hours	8,760 hours	0.95
	Strong winds	1,226 hours	8,760 hours	0.93
	Tide	0.19 meters	1.38 meters	0.86
	Temperature	19 °C	27.8 °C	0.32

Appendix 3. Indicators of coastal scenery quality were utilized to evaluate the management capacity of nine beaches: João Fernandes (FER), Praia Grande (GRA), Però (PER), Guaxindiba (GUA), Grussaí (GRU), Farol de São Thomé (FAR), Costa Azul (COS), Morro (MOR), and Sereia (SER). The classification of coastal scenery categories was determined based on the average of the evaluated indicators, categorized as low (0.33 to 0.55), intermediate (0.56 to 0.77), or high (0.78 to 1) (Diniz et al., 2022). ^bThe indicators align with those outlined in the Blue Flag Program (Blue Flag, 2019) and ^othe Orla Project (MMA, 2006).

INDICATORS	FER	GRA	PER	GUA	GRU	FAR	COS	MOR	SER
ACCESSIBILITY	0.55	0.85	0.76	0.58	0.76	0.70	0.79	0.94	0.91
1. Facilities for Individuals with Special Needs ^b	1	2	2	1	2	1	2	3	3
2. Accessible Restrooms for Individuals with Special Needs ^b	1	1	2	1	1	1	2	3	3
3. Human-Made Structures Impeding Beach Visitor Mobility	1	3	3	3	3	3	2	2	2
4. Beach-face slope	2	3	3	1	2	1	3	3	2
5. Level difference to the beach	1	2	2	3	3	3	2	2	2
6. Beach access ^{b,o}	3	3	3	2	3	3	3	3	3
7. Public Transit ^{b,o}	3	3	3	2	3	3	3	3	3
8. Designated Parking Spaces for Individuals with Disabilities and the Elderly ^b	1	2	2	1	2	1	2	3	3
9. Bike lanes ^{b,o}	1	3	1	1	1	1	1	3	3
10. Pedestrian pathways ^{b,o}	1	3	1	1	2	3	3	3	3
11. Natural Formations Affecting Beach Accessibility (e.g., Beach Sandstones)	3	3	3	3	3	3	3	3	3
ENVIRONMENTAL QUALITY	0.67	0.81	0.81	0.52	0.70	0.78	0.74	0.70	0.74
12. Unpleasant Smells	3	3	3	3	3	3	3	2	3
13. Presence of dead animals (fish or other organisms)	2	3	2	2	2	2	2	2	2
14. Noise (Vehicle Traffic and Loud Music) ^{b,o}	3	1	2	2	2	2	2	2	2
15. Vegetation coverage after beach use ^o	1	3	3	1	1	2	1	1	1
16. Coastal ecosystems (coral reefs, dunes, mangroves, and restinga) ^o	2	3	3	2	2	3	2	2	2
17. Monitoring Beach-Associated Ecosystems ^{b,o}	2	2	1	1	2	2	2	2	3
18. Stinging Organisms (Jellyfish)	1	2	2	1	3	2	2	2	2
19. Enforcement of laws and regulations ^b	3	2	3	1	3	2	3	3	3
20. Beach management committee ^{b,o}	1	3	3	1	1	3	3	3	2
WATER QUALITY	0.78	0.94	1	0.83	0.83	0.83	0.56	0.72	0.78
21. Microbial quality of water ^{b,o}	3	3	3	3	3	3	1	1	1
22. Oil on the beach or in the water ^b	3	3	3	3	3	2	2	2	2
23. Floating debris (wood, plastic, glass, rubber, or other substances) ^b	1	3	3	2	2	2	2	2	2
24. Monitoring of physicochemical water parameters ^{b,o}	1	3	3	1	1	2	1	3	3
25. Frequency of water quality monitoring ^b	3	3	3	3	3	3	1	2	3
26. Red tide	3	2	3	3	3	3	3	3	3
COMFORT	0.74	0.85	0.81	0.85	0.81	0.81	0.74	0.70	0.78
27. Large waves (> 1m) breaking directly on the beach face ^o	3	3	3	3	2	2	2	2	2
28. Sediment on the beach face	3	3	3	3	3	3	3	3	3
29. Beach face width at low tide ^o	1	3	2	3	3	3	2	2	2
30. Sediment in the bathing zone	3	3	3	3	3	3	3	3	3
31. Competition for unrestricted beach use (e.g., fishermen, sailors, and sports enthusiasts)	1	3	3	3	3	3	1	1	2
32. Tidal range ^o	2	2	2	2	2	2	2	2	2
33. Water temperature ^o	2	2	2	3	3	3	2	2	2
34. Bathing zones	2	1	1	2	1	1	3	2	3
35. Algae on the sand or in the water column	3	3	3	1	2	2	2	2	2
SCENIC QUALITY	0.67	0.73	0.80	0.60	0.60	0.53	0.53	0.60	0.67
36. Beachfront typology in terms of urbanization ^o	1	1	2	2	2	2	1	1	1
37. Coastal erosion vulnerability ^o	3	3	3	3	3	2	2	3	3

38. Permanent Structures ^o	1	1	1	1	1	1	1	1	1
39. Beach sediment coloration	2	3	3	2	2	2	2	2	2
40. Water turbidity	3	3	3	1	1	1	2	2	3
SERVICES AND INFRASTRUCTURE	0.69	0.75	0.80	0.57	0.59	0.69	0.73	0.82	0.84
41. Sanitary facilities in good hygiene condition ^b	1	2	3	1	1	1	3	2	2
42. Number of Sanitary Facilities ^b	1	3	3	1	1	1	2	3	2
43. Sanitary facilities with proper waste disposal ^b	1	1	3	1	1	1	3	3	2
44. Showers and drinking fountains ^b	1	2	2	1	1	2	2	2	2
45. Unauthorized camping, vehicle circulation, or debris dumping ^b	2	2	3	2	2	2	2	3	3
46. Snack bars, bars, and restaurants ^o	3	3	3	3	2	3	3	3	3
47. Accommodation choices ^o	3	3	3	3	2	3	3	3	3
48. Parking ^b	2	2	3	1	3	3	2	2	3
49. Recreational facilities (e.g., courts and kayak rentals) ^o	3	3	1	2	1	2	2	2	3
50. Trash bins ^b	2	2	2	2	2	2	2	2	3
51. Recycling bins ^b	1	1	1	1	1	1	1	2	2
52. Beach cleanliness ^b	3	2	3	2	3	3	3	3	3
53. Cleaning of natural debris or seaweed ^b	3	2	1	2	1	2	1	2	1
54. Discharge of wastewater, industrial, or urban waters ^{b,o}	2	3	3	2	2	2	2	2	3
55. Litter accumulation ^{b,o}	3	3	3	3	3	3	2	2	2
56. Dogs and other domestic animals ^b	2	1	1	1	1	1	2	3	3
57. Building conservation status ^{b,o}	2	3	3	1	3	3	2	3	3
SAFETY	0.48	0.38	0.71	0.52	0.57	0.71	0.52	0.71	0.86
58. Lifeguards ^b	1	2	2	2	2	2	1	3	3
59. First aid equipment ^b	1	1	1	1	2	2	1	1	1
60. Police officers ^b	1	1	2	2	2	3	3	3	3
61. Rip currents	3	1	1	3	2	2	2	3	3
62. Public alert system if the beach becomes unsafe	1	1	3	1	1	3	1	1	3
63. Emergency plans for addressing risks from environmental accidents ^b	2	1	3	1	2	2	1	3	3
64. Zoning for bathers, swimmers, surfers, and users of motorized watercraft ^{b,o}	1	1	3	1	1	1	2	1	2
ENVIRONMENTAL EDUCATION AND INFORMATION	0.33	0.6	0.93	0.47	0.53	0.47	0.4	0.47	0.87
65. Environmental education activities provided to beachgoers ^b	1	3	3	2	2	2	1	3	3
66. Current information on water quality displayed on informative plaques ^b	1	1	2	1	1	1	2	1	3
67. Information about local ecosystems, natural phenomena, sensitive natural areas, and culturally significant areas available on informational plaques ^b	1	2	3	2	2	2	1	1	1
68. Beach map ^b	1	1	3	1	1	1	1	1	3
69. Code of conduct displayed on informational plaques ^b	1	2	3	1	2	1	1	1	3
GENERAL INDEX OF COASTAL SCENE QUALITY	0.63	0.75	0.82	0.61	0.68	0.71	0.67	0.75	0.82

CAPÍTULO 3

How coastal scenery quality and visitor perception affect tourism profitability on beaches in southeastern Brazil

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VISITORS' PERCEPTION, COASTAL SCENERY QUALITY AND TOURISM PROFITABILITY ON SANDY BEACHES - SOUTHEASTERN BRAZIL

ABSTRACT

Unmanaged coastal tourism threatens beach ecosystems across many tropical coastlines. Using 540 questionnaires on beaches in southeastern Brazilian beaches, we evaluated the relation visitors' perception, coastal scenery quality, and tourism profitability under scenarios of overcrowding and solid-waste pollution. The study covered nine beaches in Rio de Janeiro (RJ) and Espírito Santo (ES) states, across three mesoregions with varying tourism potential (local, regional, and national/international). Visitors overestimated coastal scenery quality by 30% compared to expert evaluations, especially on nationally famous beaches in Rio de Janeiro such as Praia Grande and João Fernandes. Overall, beachgoers showed more tolerance for overcrowding (51% would still visit under the worst overcrowding scenario – 5 m² per person) than for pollution (70% would avoid the beach with the worst solid waste scenario – 15 items per m²). Most were willing to change plans when faced with degraded settings. On locally attractive beaches, 74% would consider changing to another regional destination, whereas on nationally attractive ones, 55% would opt for a nearby site within the same municipality. Estimated municipal revenue losses from tourist displacement could reach US\$ 52 million per summer season in Praia Grande-RJ, located in the Região dos Lagos mesoregion. These findings underscore the socio-ecological value of beaches and the need for integrated management. Although recreational preferences may conflict with conservation goals, tourism influenced by social media presents an opportunity to support coastal management and foster environmental awareness among visitors.

Keywords: coastal management, sustainable tourism, environmental quality, economic impact, marketing.

1. INTRODUCTION

Sandy beaches, characterized by their unique biodiversity and the provision of various ecosystem services, particularly those related to tourism, face significant challenges due to the neglect of conservation in Active Coastal Zone (ACZ) habitats, including intertidal zones, and dunes along with their vegetation (Mendoza-González et al., 2018; Fanini et al., 2021; Harris & Defeo, 2022). The lack of effective coastal management strategies compromises the ecological integrity and natural resources that support much of the touristic appeal of these areas (Defeo & Elliott, 2020). Environmental management tools based on visitors' perceptions can complement technical assessments and support participatory coastal governance (Akgün et al., 2020).

The coastal scenery quality of beaches, influenced by factors such as anthropogenic waste, visitor density, and infrastructure, is a critical determinant of tourist choice and satisfaction (Jarvis et al., 2016; Diniz et al., 2022). An increase in the number of visitors can exceed the carrying capacity of tourist destinations, leading to degradation of the coastal landscape (Corraini et al., 2018), reduced visitor comfort (Yepes, 2002), and competition for space usage (Basterretxea-Iribar et al., 2019). The presence of litter negatively affects the natural aesthetic (Williams et al., 2016), lowers the perceived coastal scenery quality (Galgani et al., 2010), and discourages visitation (Moore, 2009). According to beachgoers in Europe (Balas et al., 2003), the United States, Mexico (Cervantes & Espejel, 2008), and the Caribbean (Botero et al., 2003; Rangel-Buitrago et al., 2013), litter is among the five most important indicators of beach quality.

In general, the perception of beach environments varies across different socioeconomic groups and visitor types (Nelson et al., 2000). Residents tend to exhibit a stronger connection to the place, placing greater value on the quality of natural attributes (Stedman, 2006; Hiltunen, 2007). In contrast, tourists show lower loyalty and are more likely to avoid returning to beaches that do not meet their expectations (Krelling et al., 2017). However, there is limited information regarding the degree of agreement between technical assessments and beachgoers' perceptions in the evaluation of coastal scenario quality. Existing studies merely suggest the implementation of environmental quality monitoring at tourist beaches, incorporating both user and expert perspectives to support more effective coastal management (Roca & Villares, 2009; Defeo et al., 2009; Botero et al., 2015).

Factors such as beach popularity, tourism potential, and scenic characteristics can shape visitors' perceptions of beach quality. For instance, beachgoers' tolerance to pollution and human crowding may vary between beaches with different levels of development and tourism marketing (Roca & Villares, 2008; Liu et al., 2021; Lukoseviciute & Panagopoulos, 2021). In any case, the way visitors evaluate the quality of the coastal landscape influences their decisions to stay and consume, which is reflected in tourism revenue (Leggett et al., 2014).

Beach user perception, thus, is an important supporting criterion for the governance of coastal ecosystems, as it can contribute to more effective planning and decision-making (Ariza et al., 2014; Mensah et al., 2014). Moreover, participatory management not only addresses local demands but also has greater potential to

prevent socio-environmental injustices. In this context, the present study aimed to understand the extent to which visitor perception can serve as a reliable indicator of the multisectoral quality of the coastal environment and whether this perception can be used as a supporting tool for beach management and conservation. In addition, we analyzed how the quality of the coastal landscape affects the perceptions of beach visitors (residents and tourists) and the potential economic impacts of marine litter and human crowding in these environments.

2. METHODS

2.1 Study area

The study was conducted in three mesoregions with distinct tourism potentials in southeastern Brazil: one located along the coast of the state of Espírito Santo (ES) and two in the state of Rio de Janeiro (RJ). Mesoregions are territorial subdivisions that gather municipalities with similar economic, social, and geographical characteristics within a state (IBGE, 2017). The Northern mesoregion of Rio de Janeiro has predominantly local tourism potential, whereas the South-Central region of Espírito Santo is characterized by regional tourism. In contrast, the Baixada Litorânea region in Rio de Janeiro holds national and international tourism significance.

In the Northern mesoregion of Rio de Janeiro, the study focused on Guaxindiba Beach, Grussaí Beach (located within the “Dunas e Restinga” Environmental Protection Area), and Farol de São Thomé Beach (Fig. 1). These beaches hold local tourism significance, particularly during the austral summer (January to March) (Machado et al., 2017; Suciú et al., 2017). However, the regional economy is predominantly based on agriculture, livestock, oil, and gas sectors (Cruz & Terra, 2020).

In the South-Central region of Espírito Santo, the study included Sereia Beach, Morro Beach, and Costa Azul Beach. The selection of these beaches was based on their tourism potential, as they attract visitors from both within the state and neighboring states (Mendes et al., 2014; Pinto-Coelho, 2021).

In the Baixada Litorânea region of Rio de Janeiro, nationally and internationally known as “Região dos Lagos”, the study included João Fernandes Beach, Praia Grande Beach (located within the Arraial do Cabo Marine Extractive Reserve, RESEX) (ICMBIO, 2023), and Però Beach in Cabo Frio municipality. The latter has held the

international Blue Flag certification since the 2018/2019 tourist season (Blue Flag, 2025) and is part of the “Pau-Brasil” Environmental Protection Area (APAPBR) (INEA, 2023). The region’s main economic activities are fishing and tourism, with municipalities attracting both national and international visitors, especially during the austral winter holidays (July and August), summer, and long weekends (Mendonça et al., 2013).

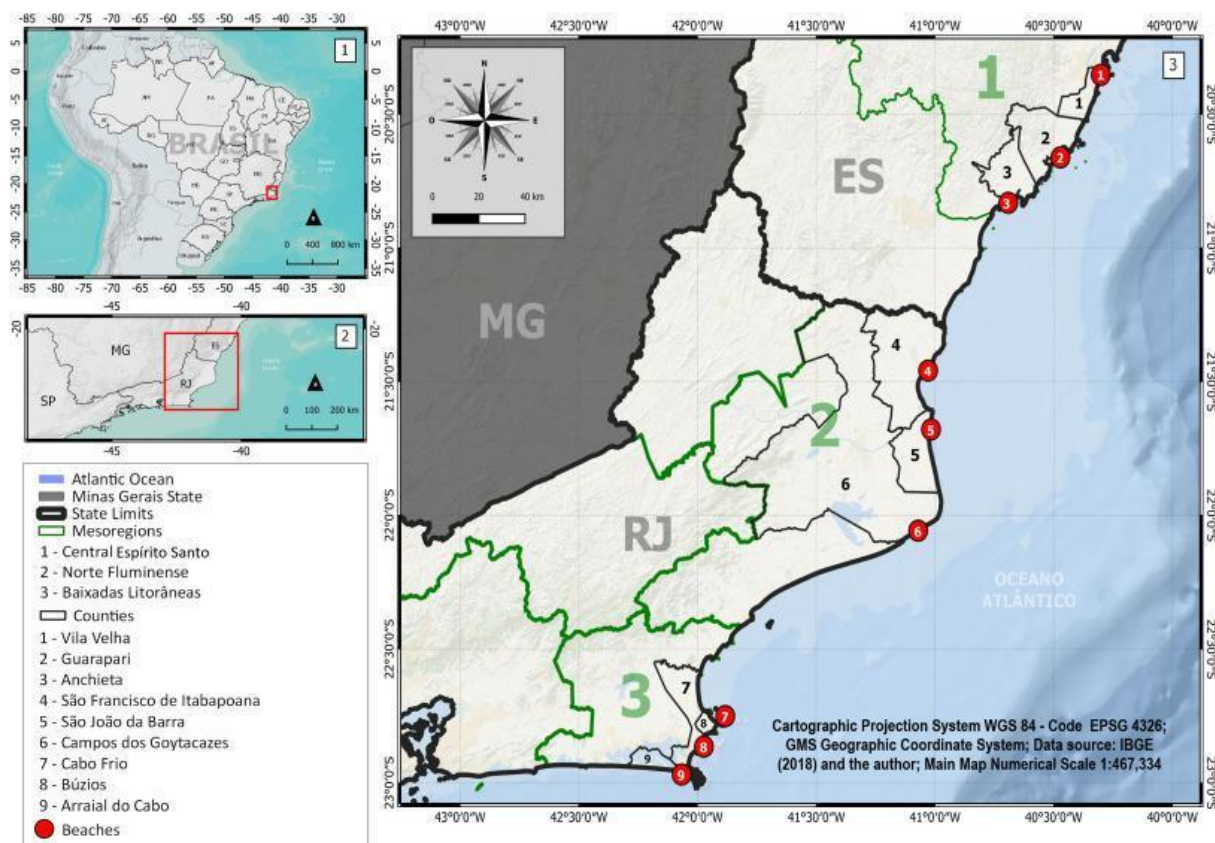


Figure 1. Studied beaches in the states of Espírito Santo and Rio de Janeiro, Brazil: 1 – Sereia Beach (ES), 2 – Morro Beach (ES), 3 – Costa Azul Beach (ES), 4 – Guaxindiba Beach (RJ), 5 – Grussaí Beach (RJ), 6 – Farol de São Thomé Beach (RJ), 7 – João Fernandes Beach (RJ), 8 – Però Beach (RJ), and 9 – Praia Grande Beach (RJ).

2.2 Perception of coastal scenery quality by beachgoers

The assessment of beachgoers’ perception of coastal scenery quality was conducted during the summer of 2023, the peak tourist season, between 9:00 a.m. and 5:00 p.m. At each beach, 60 semi-structured questionnaires were administered (Appendix A). The questionnaires addressed socioeconomic aspects as well as users’ perceptions of the coastal scenery quality and tourism potential of the beaches

(Krelling et al., 2017; Rodella et al., 2017). Surveys were conducted randomly and limited to individuals over 18 years of age (Kendall, 2008). To ensure sample independence, only one individual belonging to the same group or family was included in the sampling.

The socioeconomic section of the questionnaire was designed to characterize the profile of beach users by collecting information on gender, age, education level, place of origin, visitation frequency, time of stay, and motivation for visiting the beach. In the analysis of the 60 questionnaires administered at each beach, users were categorized into two groups: residents (RL) and non-residents or tourists (NR). Classification was based on three main criteria: place of origin, frequency of visits, and duration of stay. The detailed criteria used for this classification are provided in Appendix B.

The technical assessment of beach quality used in this study was entirely based on previously published data by Diniz et al. (2024), which evaluated eight dimensions using a three-point scale ranging from 1 (low) to 3 (high) quality: accessibility, environmental quality, water quality, scenic quality, comfort, safety, availability of services and infrastructure, and environmental education and information. User perceptions of these same dimensions were also measured using a three-point scale, ranging from 1 (dissatisfied) to 3 (satisfied), following the methodology adapted from Chen and Teng (2016).

To investigate users' perceptions of human impacts on beaches and the potential for visitor displacement, a visual survey method was employed. This approach included to the visitors some photographs with hypothetical scenarios of a gradient of solid waste density (Fig. 2) (Krelling et al., 2017) and human crowding (Fig. 3) (Needham et al., 2008; Ceurvorst & Needham, 2012).

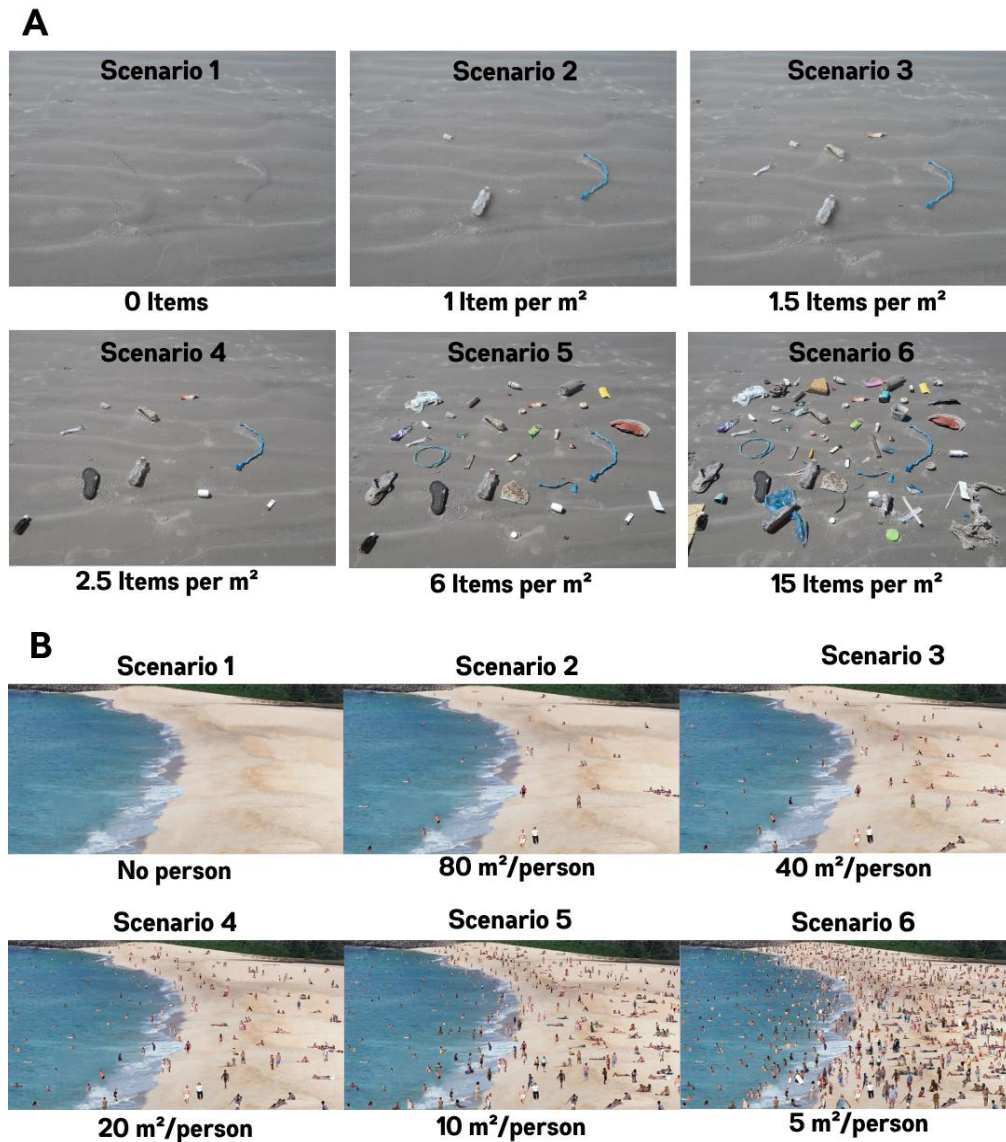


Figure 2. A - Hypothetical litter pollution scenarios with density per square meter (m²) (adapted from Krelling et al., 2017). B - Hypothetical human crowding scenarios on the beach, indicating square meters (m²) per person (adapted from Needham et al., 2008).

2.2.1 Assessment of economic loss due to tourist destination change

The assessment of the potential economic impact of tourism on the local economy was conducted using a formula adapted from Krelling et al. (2017). The change in tourist destination in response to hypothetical scenarios of solid waste or human crowding was used to estimate economic losses for the municipality (Equation 1) (Jang et al., 2014), as follows:

$$PTR = [(n * PR) * E] * d$$

Where **PTR** represents the potential reduction in tourism revenue due to increased solid waste or human overcrowding; **n** is the estimated total number of beach users at the studied sites, according to estimates provided by Diniz et al. (2024); **PR** is the

reduction in beachgoers in response to the selected hypothetical scenario (percentage for each scenario); **E** is the average daily expenditure per person, obtained through the questionnaires; and **d** is the estimated number of days spent at the beach per trip.

The summer season is defined as a 90-day period corresponding to the summer months. The questionnaires included minimum and maximum value ranges for expenditure-related responses, allowing the projection of both optimistic (minimum value) and more pessimistic (maximum value) economic-financial scenarios for each beach. To avoid overestimations in the calculations, the minimum reported values for daily expenses on transportation, accommodation, and goods purchases were considered (Adapted from Jang et al., 2014 and Krelling et al., 2017).

2.3 Analysis of coastal scenery quality and human impacts conducted by experts

The assessment of coastal scenery quality by experts was conducted based on indicators aligned with the criteria established by the Projeto Orla Brazil's primary coastal zoning plan (Brasil, 2025) and the international Blue Flag certification (FEE, 2025). Each beach was evaluated using a qualitative scale: low quality (1), intermediate quality (2), and high quality (3). The database employed in this study was provided by Diniz et al. (2024) (Appendix C).

Human density was analyzed using satellite imagery from Google Earth to calculate the physical dimensions of each beach (total area), considering the entire stretch of sand between the shoreline and either physical structures or the beginning of the dune vegetation. On-site user counts were conducted every hour within 10,000 m² plots from 8:00 a.m. to 5:00 p.m. to determine the peak number of users occupying the beach. Data surveys occurred during the 2023 summer season (with high tourist traffic), such as weekends and holidays (data published by Diniz et al., 2024).

The quantification of solid waste contamination was carried out through field sampling during the high tourist season in January 2024. The method was an adaptation of the protocol developed by the National Oceanic and Atmospheric Administration (NOAA) (Burgess et al., 2021). Five transects were established perpendicular to the waterline at low tide, spaced 20 meters apart, covering the entire exposed and unvegetated area of each sampling point. Along each transect, all visible waste items were collected within a 1-meter-wide strip.

Observational data on the coastal landscape, solid waste density, and human crowding obtained by field experts were then compared with beachgoers' perceptions. To assess this, the difference between user evaluations and expert assessments was calculated for each beach. Negative values indicate an underestimation by visitors, while positive values reflect an overestimation relative to the observed conditions.

2.4 Popularity of beaches and social media engagement

Social media engagement was measured using data from Instagram, based on the number of hashtag mentions associated with the beaches and their respective municipalities (e.g., #praiaGrandearraialrj), as well as the number of geotagged photo posts (Appendix D). The number of mentions was interpreted as an indicator of popularity. In addition to Instagram, user comments were collected from travel platforms such as TripAdvisor (<https://www.tripadvisor.com.br/>) and Google Reviews (<https://www.google.com/search>) (Taecharungroj & Mathayomchan, 2019). Each metric was used to rank the beaches according to the number of accesses and user-generated content. The overall ranking was determined by averaging the number of hashtag mentions and geotagged posts on Instagram, along with the number of reviews on TripAdvisor and Google Reviews. Data collection was carried out in January 2025.

User perception of the beaches was assessed through a qualitative analysis conducted on the comments available at TripAdvisor and Google Reviews. Comments were categorized as positive characterized by praise and favorable evaluations; neutral describing experiences in an objective manner without explicit value judgments; and negative expressing dissatisfaction or criticism.

Furthermore, comments were classified according to key categories of the coastal setting, including accessibility, water quality, environmental quality, scenic quality, safety, services/infrastructure, comfort, and environmental education (Diniz et al., 2022).

2.5 Data analysis

The dataset was subjected to chi-square tests (χ^2) with contingency tables to evaluate significant associations between responses (e.g., alternative tourist destinations and educational level) and user profiles (tourists and residents).

To investigate the relationship between beach popularity and visitor avoidance in response to perceived environmental degradation, a simple linear regression analysis was conducted. The dependent variable was the avoidance rate, defined as the percentage of respondents who indicated they would choose an alternative destination outside the municipality where the beach is located after being exposed to hypothetical scenarios of litter and crowding. The independent variable was beach popularity, measured by the number of social media mentions referring to each beach. All analyses were performed using R software (version 4.5.0).

3. RESULTS

Residents and tourists differed significantly in their perspectives and behaviors related to the beaches regarding daily expenditure, choice of alternative tourist destinations, perception of coastal scenery quality, perceived litter density, and litter tolerance (Tab. 1).

On average, tourists reported a daily expenditure four times higher than that of residents. In contrast, residents demonstrated greater loyalty to local beaches, with 20% indicating they would not choose an alternative destination, compared to only 8% of tourists.

Table 1. Different profiles of beach visitors identified through interviews based on the analysis of socioeconomic background responses.

	Beach Tourists X Residents		
	χ^2	df	p
Daily expenditure	11.1	6	<0.001
Alternative tourist destination	47.5	7	<0.001
Perception of coastal scenery quality	23.5	4	<0.001
Perception of current litter density	18.7	6	<0.01
Tolerance to litter	37.3	5	<0.001
Perception of current human crowding	14.7	6	NS
Tolerance to human crowding	5.3	6	NS

<0.001: Significant difference; <0.01: Moderate evidence of significant difference; p=NS: No significant difference.

Residents and tourists generally assigned slightly higher ratings to coastal scenery quality compared to expert assessments (Fig. 3), although the difference was not statistically significant ($t(71) = 0.32$, $p = 0.75$, 95% CI = $[-0.033; 0.046]$), indicating no evidence of overestimation by beachgoers relative to experts.

However, when considering the tourism potential of the beaches, the differences between evaluations varied significantly among the groups (ANOVA, $F(2,69) = 6.84$, $p < 0.01$). Post hoc tests revealed that beaches with regional ($p < 0.001$) and national/international ($p < 0.05$) tourism potential showed significantly greater differences between visitor and expert assessments compared to beaches with local tourism potential.

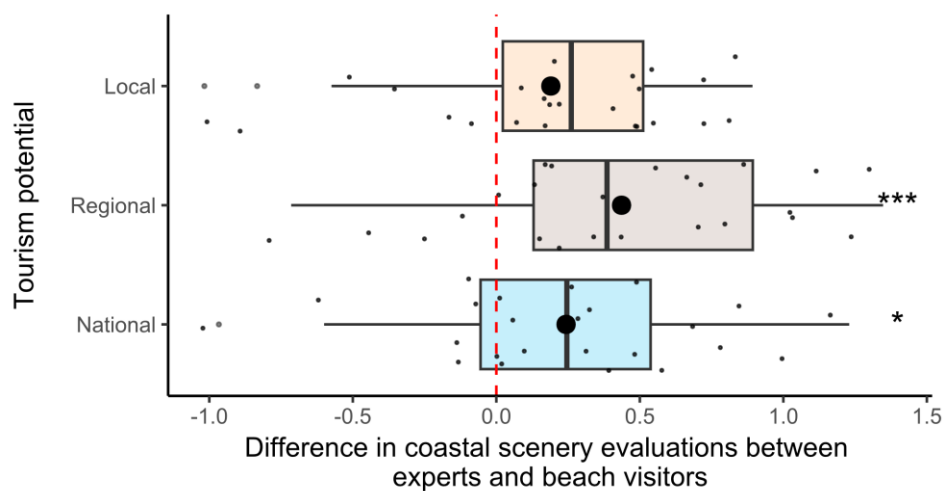


Figure 3. Difference in coastal scenery assessments between experts and visitors. Positive values indicate overestimation by visitors, while negative values indicate underestimation. The red dashed line denotes the zero reference. The scattered points represent individual evaluations of coastal scenery categories by beach. Horizontal lines within the boxes indicate the median, while larger dots represent the means. The boxes define the interquartile range, and the upper and lower whiskers correspond to non-outlier limits. Asterisks indicate statistically significant differences.

When analyzing the categories that comprise the coastal scenery quality, it was found that, across all beaches, visitors significantly overestimated scenic quality ($p < 0.001$), while accessibility was underestimated ($p < 0.01$) compared to expert evaluations (Fig. 4). For the remaining categories, interval estimates show that the difference between expert and visitor ratings is statistically indistinguishable from zero.

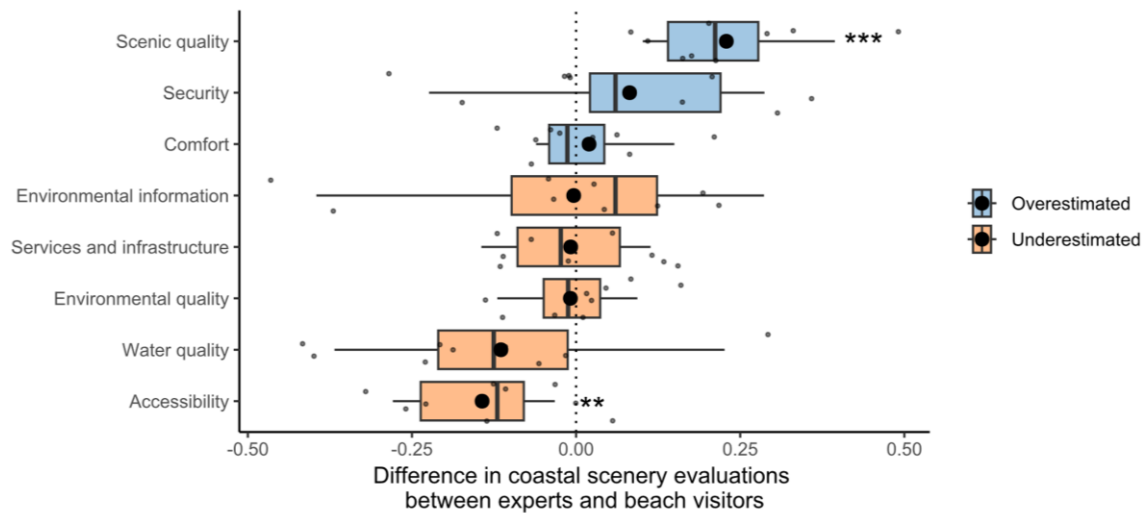
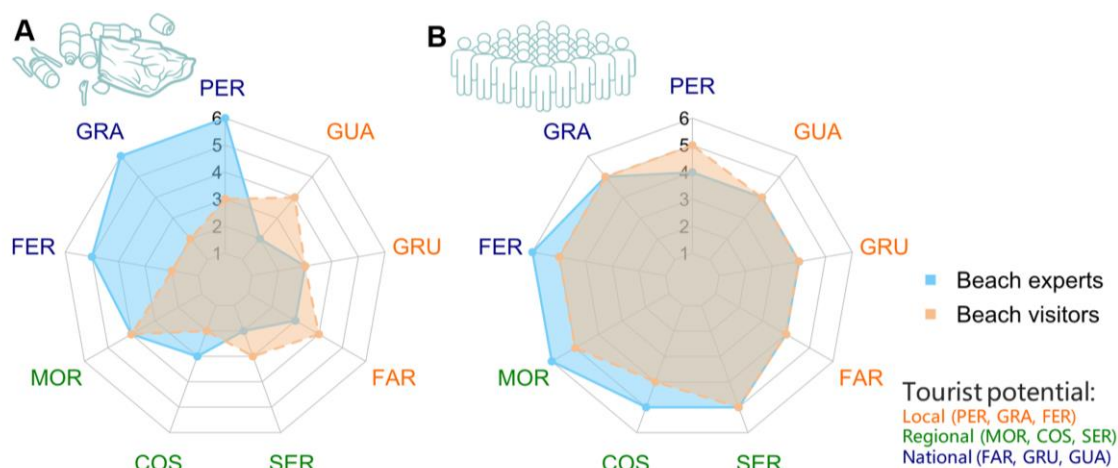


Figure 4. Difference in the evaluation of coastal scenario categories between beach experts and visitor opinions. Positive values indicate overestimation by visitors, while negative values indicate underestimation. The scattered dots represent individual evaluations of coastal scenario categories for each beach. The horizontal lines within the boxes indicate the median, while the larger dots represent the means. The boxes outline the interquartile ranges, and the upper and lower whiskers represent non-outlier limits. Asterisks denote statistically significant differences.

At nationally significant tourist beaches, visitors assigned, on average, lower levels of litter density compared to those recorded by expert field assessments, with differences reaching up to four pollution scenarios. In contrast, at locally relevant beaches, visitor-assigned values were generally higher than expert observations, except at Grussaí Beach, where perceived and observed data were consistent (Fig. 6).

Regarding human crowding, average visitor perceptions aligned with expert assessments at all locally important beaches (scenario 4, with 2.5 people/m²). However, at beaches of regional and international relevance, one crowding scenario was rated by visitors with a lower density than that recorded in field measurements (Fig. 5).



PER = Peró Beach, GRA = Praia Grande Beach, FER = João Fernandes Beach, MOR = Morro Beach, COS = Costa Azul Beach, SER = Sereia Beach, FAR = Farol Beach, GRU = Grussaí Beach, GUA = Guaxindiba Beach.

Figure 5. Comparison between beachgoers' perception and expert technical assessments regarding two types of hypothetical scenarios: (A) solid waste contamination and (B) crowding. The radar charts display the average ratings assigned by experts (in blue) and visitors (in orange) for each of the nine evaluated beaches, coded by tourism potential: local, regional, and national, as indicated in the legend. (A) The pollution scenarios correspond to increasing waste densities (0, 1.5, 2.5, 6, and 15 items/m²), representing scenario levels from 1 (no waste) to 6 (maximum pollution). (B) The crowding scenarios reflect different human densities expressed as available area per person (0, 80, 40, 20, 10, and 5 m²/person), also organized from scenario 1 (no people) to scenario 6 (maximum crowding).

Overall, visitors to beaches of local significance were more tolerant of increased pollution from anthropogenic solid waste (Fig. 6). In contrast, beachgoers at nationally significant beaches showed lower tolerance toward rising litter density.

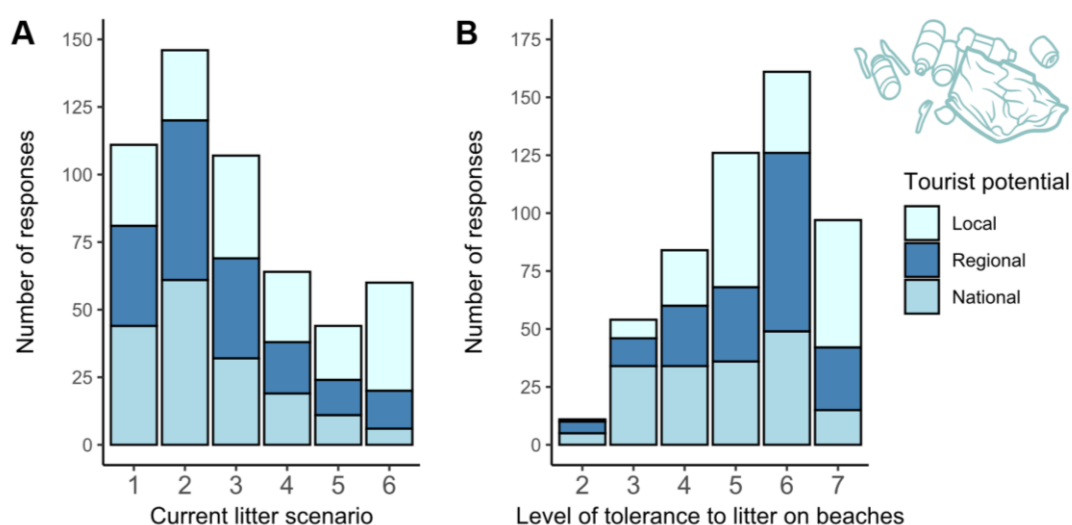


Figure 6. (A) Distribution of responses regarding the current perception of litter presence on the beaches, based on six hypothetical scenarios of increasing pollution

(1 = lowest litter density, 6 = highest). (B) Visitors' tolerance levels toward the presence of litter on beaches: values from 1 to 6 represent the pollution scenario at which respondents would stop visiting the beach, while value 7 indicates willingness to visit regardless of the litter level. Stacked bars represent the number of responses categorized by the tourism potential of the beaches (local, regional, or national).

Across all evaluated beaches, visitors demonstrated high tolerance to human density, accepting crowding levels equivalent to Scenario 6 (5 m²/person). Even at beaches with local tourism potential and lower average visitor density, tolerance to potential overcrowding remained high (Fig. 7).

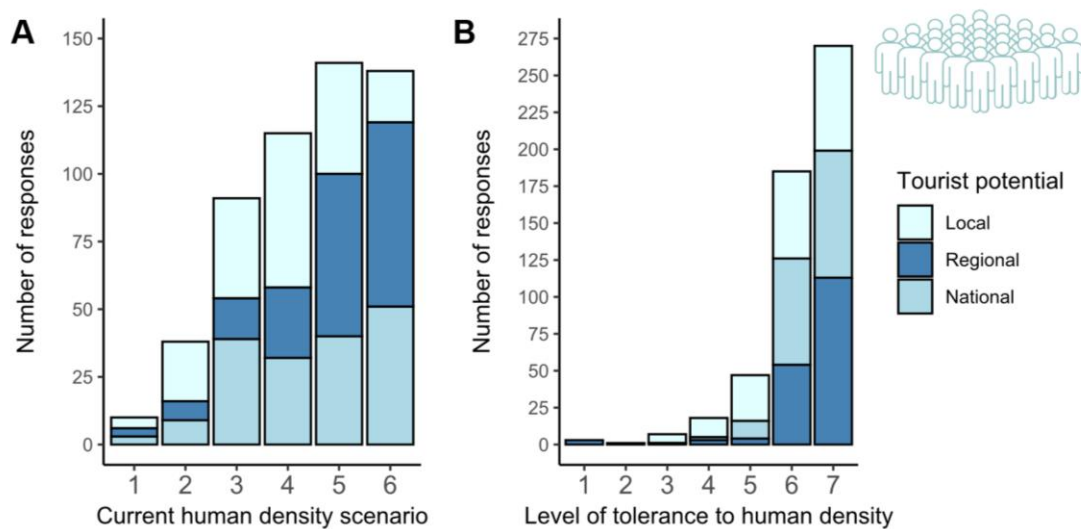


Figure 7. (A) Distribution of responses regarding the current perception of visitor density at the beaches, based on six increasing crowding scenarios (1 = lowest density, 6 = highest density). (B) Visitor tolerance levels toward beach crowding: values from 1 to 6 indicate the crowding scenario at which participants would stop visiting the beach, while value 7 indicates that the individual would be willing to visit the beach under any scenario, regardless of the level of crowding. The stacked bars represent the number of responses per level of tourism potential (local, regional, or national).

Regarding the willingness to change tourist destinations, differences were observed among the mesoregions, with particular emphasis on beaches of national relevance. At these sites, 55% of visitors preferred to remain at beaches located within the same municipality, and 80% chose destinations within the same mesoregion (Fig. 8).

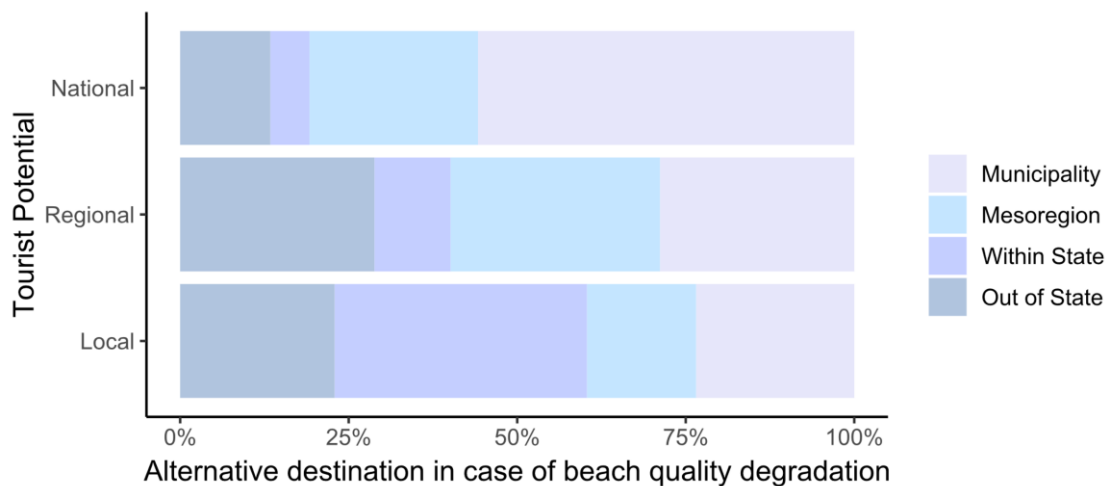


Figure 8. Indication of change in tourist destination due to the degradation of beach quality, caused by anthropogenic impacts such as the presence of litter and human crowding, as well as by the evaluation of the coastal scenario, including services/infrastructure.

The levels of tourism potential, in terms of average popularity, differed significantly, $F(2, 6) = 5.59$, $p = 0.042$. Beaches as Praia Grande (1st) and Però (4th), both located in the Baixada Litorânea mesoregion (RJ) and classified as having national/international tourism potential, showed the highest popularity ranking, followed by Morro Beach (3rd), located in the Centro-Sul mesoregion (ES) and classified with regional tourism potential. In contrast, beaches having local tourism potential exhibited the lowest average popularity values (Tab. 2). Tukey's post-hoc test showed that beaches with national/international potential were significantly more popular than those with local potential ($p = 0.043$). No significant differences were observed between the national and regional groups ($p = 0.109$) or between regional and local groups ($p = 0.747$).

Table 2. Popularity ranking of the beaches based on access and posts on search engines, social media, and travel review platforms.

Rank	Beach	Instagram		TripAdvisor	Google Reviews	AVERAGE
		Hashtags	Geolocalização			
1st	Praia Grande - RJ (NAT)	43,100	615,100	3,566	2,889	132,933
2nd	João Fernandes - RJ (NAT)	28,500	365,800	7,424	1,841	80,714
3rd	Morro - ES (REG)	34,300	278,500	1,882	14,847	65,908
4th	Peró - RJ (NAT)*	60,300	200,800	1,902	5,714	53,745
5th	Guaxindiba - RJ (LOC)	2,100	82,100	33	332	16,913
6th	Grussaí - RJ (LOC)	7,700	59,500	204	2,124	13,906
7th	Farol - RJ (LOC)	1,200	64,000	129	757	13,218
8th	Costa Azul – ES (REG)	200	19,600	57	702	4,112
9th	Sereia - ES (REG)*	700	6,100	512	10,438	3,551

NAT = National tourism potential; REG = Regional tourism potential; LOC = Local tourism potential. Beaches marked with an asterisk () are certified with the international Blue Flag label.*

User reviews on platforms such as TripAdvisor and Google Reviews were analyzed to understand public opinion regarding the beaches in the study area. Overall, satisfaction levels were high regardless of the beaches' tourism potential, with an average of 64% positive reviews, 20% neutral, and 15% negative (Fig. 9). Exceptions were observed in categories such as water quality, environmental education, and safety, which, despite receiving fewer comments, showed a similar proportion of positive and negative evaluations.

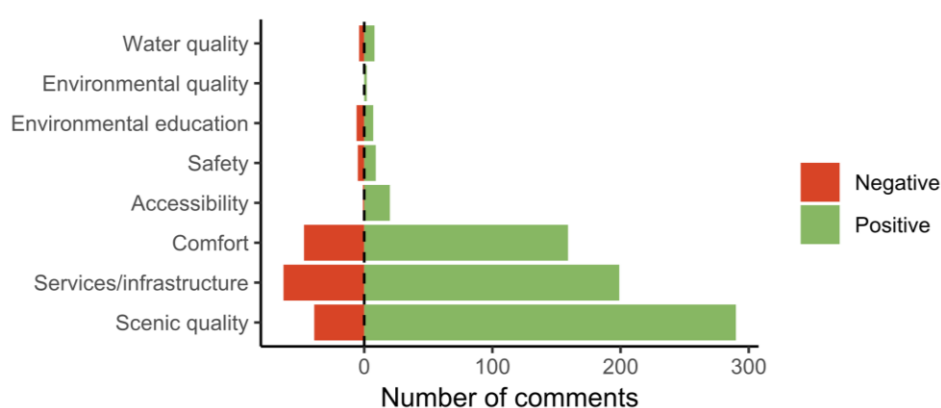
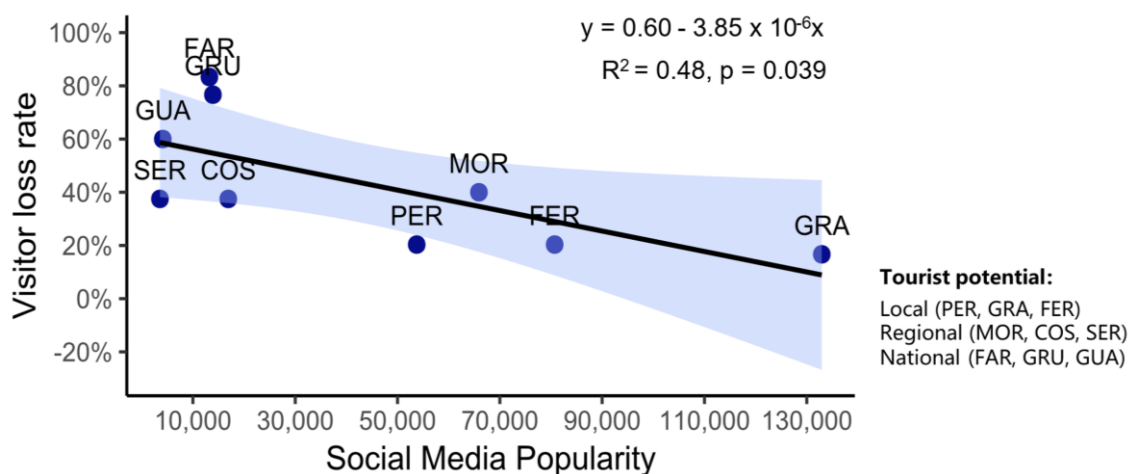


Figure 9. Comments on tourist beaches, classified by coastal scenery quality categories, based on reviews from TripAdvisor and Google Reviews.

A negative trend was observed between tourist avoidance and beach popularity, indicating that more popular beaches exhibited lower avoidance rates (Fig.

10). This pattern suggests that social engagement may mitigate the effects of perceived environmental degradation on visitor behavior.



PER = Perú Beach, GRA = Grande Beach, FER = João Fernandes Beach, MOR = Morro Beach, COS = Costa Azul Beach, SER = Sereia Beach, FAR = Farol Beach, GRU = Grussaí Beach, GUA = Guaxindiba Beach.

Figure 10. Simple linear regression between visitor avoidance rate and beach popularity, based on perceived scenarios of environmental degradation (litter pollution and human crowding). The black line represents the model fit, and the gray band indicates the 95% confidence interval. The model showed an $R^2 = 0.49$ and was statistically significant ($p < 0.05$).

Approximately 50% of respondents indicated they would avoid visiting beaches under the worst-case scenario of human crowding ($5 \text{ m}^2/\text{person}$) (Fig. 11, Appendix E). Morro Beach is estimated to experience a loss of approximately USD 2.7 million during the summer due to its high tourist influx. Similarly, João Fernandes Beach is projected to lose about USD 1.5 million. Projections suggest that beaches with national/international tourism potential may face even more significant losses if they reach the worst crowding scenario, as observed for Praia Grande, with an estimated loss of USD 27.2 million.

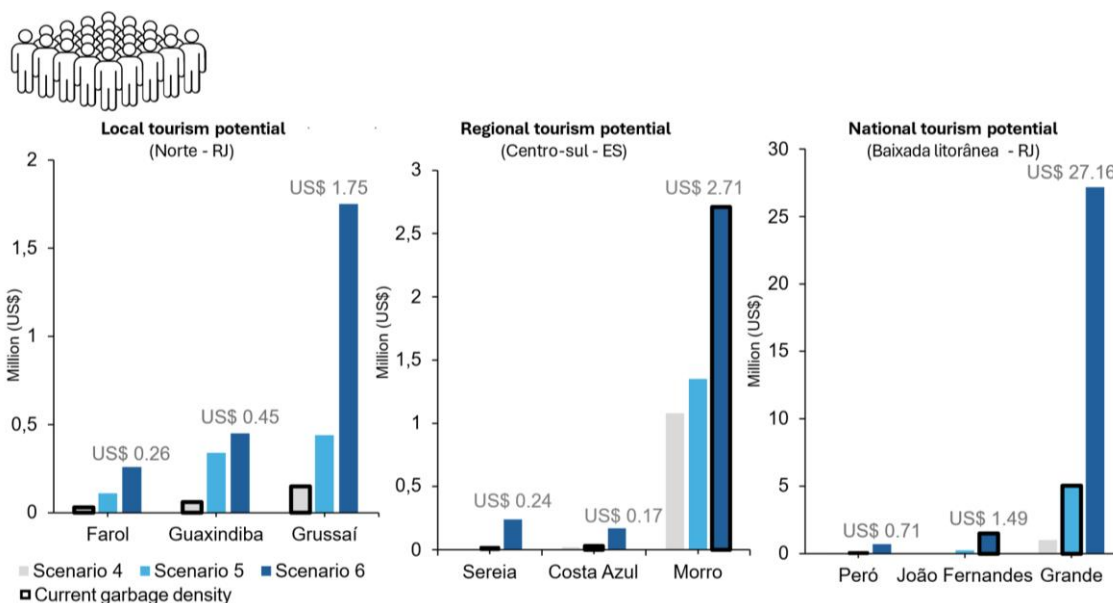


Figure 11. Estimated municipal economic losses (in millions of U.S. dollars) during the summer season, associated with visitor avoidance due to excessive crowding on beaches. The bars represent different simulated scenarios of human density (Scenarios 4 to 6), with increasing levels of crowding and their respective impacts on the tourism economic potential. Bars outlined in black indicate losses currently observed.

Perceived pollution by solid waste showed an even more pronounced impact on visitor behavior: approximately 82% of respondents stated they would avoid beaches under the most critical pollution scenario (15 items/m²) (Figure 12). Some high-potential tourist beaches have already reached these levels, such as Peró Beach, despite holding the international Blue Flag certification, with an estimated economic loss of US\$ 1.2 million, and Praia Grande, with projected losses of US\$ 52.32 million during the summer season.

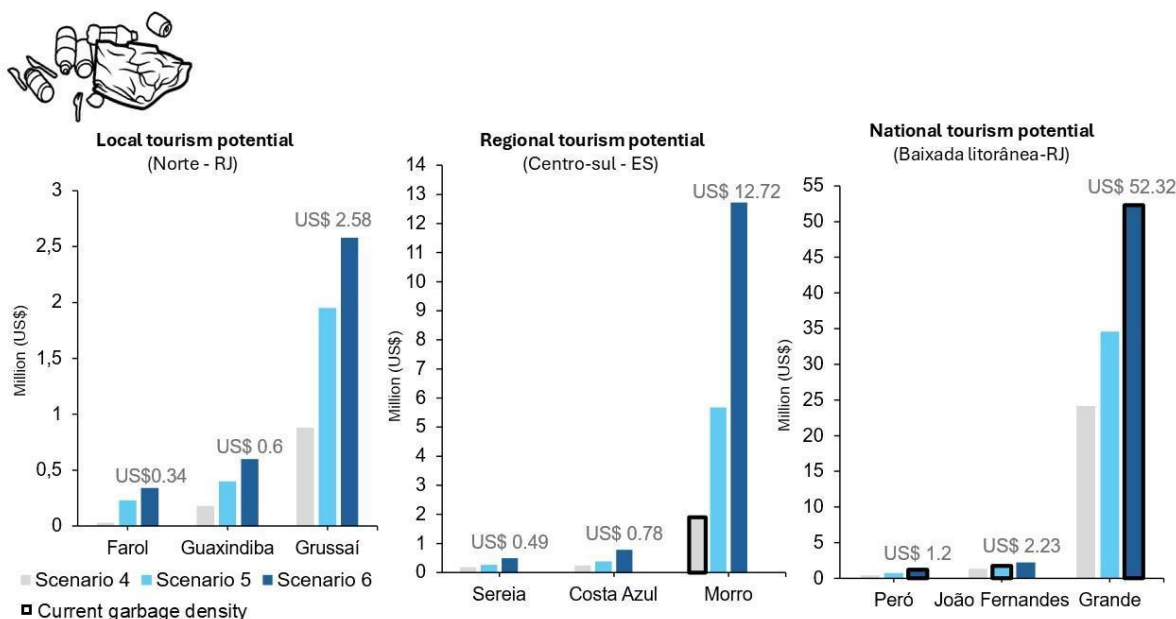


Figure 12. Estimated municipal economic losses (in millions of dollars) during the summer season, resulting from visitor avoidance caused by the presence of solid waste on the beaches. The bars represent different solid waste density scenarios (4 to 6), simulating increasing levels of environmental contamination and their impacts on the economic potential of tourism. Bars outlined in black indicate losses currently observed.

4. DISCUSSION

The comparison between subjective perceptions of beach visitors and field data collected by experts generally revealed convergence between the assessments, reinforcing the validity of public perception as a complementary management tool. However, it was observed that beaches with higher popularity tend to exhibit an overestimation in their evaluations, possibly influenced by tourism marketing strategies and the symbolic appeal of these locations. Although this perceptual distortion may reduce visitor avoidance, it can obscure real socio-environmental issues, thereby compromising management and conservation efforts (Roca & Villares, 2008; Sahabuddin et al., 2024).

The study demonstrated that beaches are frequented by distinct social segments, such as tourists and residents, who exhibit statistically significant differences in average daily expenditure, choice of alternative destinations, perception of coastal scenery quality, and tolerance to the presence of litter. These variations indicate that sociodemographic factors influence user perceptions and behaviors,

underscoring the importance of management strategies tailored to different visitor profiles to promote sustainable coastal governance (Phillips & House, 2009; Dodds & Holmes, 2019).

The analysis of visitor perception revealed a significant overestimation of the coastal scenery quality in beaches with national and regional tourism potential when compared to technical indicators. This discrepancy was particularly evident in beaches sharing similar structural characteristics, such as a high degree of urbanization, intense tourist pressure, and pronounced solid waste contamination, with average litter densities ranging from 1.5 to 6 items/m², as observed in João Fernandes Beach (national tourism potential), Morro Beach (regional tourism potential), and Costa Azul Beach (regional tourism potential). Costa Azul Beach offers approximately 2 m² of free space per user, while Morro and João Fernandes Beach register only 1 m² and 0.6 m² per person, respectively values that exceed by up to six times the recommended carrying capacity to ensure visitor well-being (Diniz et al., 2024). The overestimation of coastal scenery quality may be associated with factors such as the high tourist marketing toward these beaches.

Indeed, across all analyzed beaches, visitors consistently overestimated scenic quality compared to technical assessments conducted by experts. This finding suggests that subjective factors, such as emotional attachment and nostalgia associated with regularly visited places, may positively influence perceived attractiveness, leading to an overvaluation of the destination despite objective evidence of environmental degradation (Akgün et al., 2020). A concrete example of this phenomenon is the management of casuarina trees (*Casuarina equisetifolia*) at Farol Beach (local tourism potential), an exotic species widely appreciated by beachgoers for providing shade and contributing to the traditional landscape. Although environmental managers recommend its removal due to negative impacts on native vegetation, suppression efforts have faced social resistance and generated negative evaluations, as documented in posts on social media and review platforms (TripAdvisor, 2025; Instagram, 2025).

On the other hand, accessibility was underestimated by visitors, which may reflect a critical evaluation of the quality of available facilities, even when these meet the minimum criteria established by technical assessments (Cabezas-Rabadán et al., 2019). The absence of boardwalks and the need for long walks to reach the sea, combined with the limited willingness of users to walk, may contribute to this negative

perception and may even be associated with tolerance toward vehicle traffic on the sand, a common practice at some of the studied beaches (Rodella et al., 2017; Schlacher et al., 2008). The “accessibility” category includes the presence of amphibious chairs, access ramps, adapted restrooms, and other technical parameters aimed at inclusion (Diniz et al., 2022). However, such resources may not be fully recognized or valued by users who do not directly depend on these amenities, resulting in a limited perception of this dimension.

The categories that showed the greatest agreement between visitors’ and experts’ evaluations were environmental quality, services and infrastructure, comfort, and environmental education. These aspects are more easily perceptible during a beach visit, as they involve tangible elements directly related to the user's immediate experience, such as sand cleanliness, the presence of waste bins (Alharbi & Rangel-Buitrago, 2022), the availability of restrooms, shaded areas, and seating spaces (Lukoseviciute & Panagopoulos, 2021). Similarly, environmental education initiatives are often visible through informational signage and awareness campaigns (Cristiano et al., 2020). Perceptions of environmental quality, in particular, may be influenced by visual indicators like clean sand and the availability of waste bins, which contribute to the overall assessment of the coastal environment (Alharbi & Rangel-Buitrago, 2022).

Another visible factor in the coastal landscape is the density of human occupancy. Beach scenarios with a higher number of people were consistently rated as tolerable by the majority of respondents. This trend was observed even at beaches with local tourism potential, which are traditionally characterized by lower visitor flows. Previous studies have suggested that, on beaches predominantly frequented by local residents, high user densities are typically associated with recreational discomfort (Szuster & Peng, 2021). However, this relationship was not confirmed in the present study, indicating that higher concentrations of beachgoers are not perceived as a discomfort factor in the regions analyzed. This high tolerance to crowding may reflect cultural factors, such as the value placed on social interaction in recreational settings. Crowded beaches are often associated with a greater range of leisure opportunities, increasing their attractiveness even under visitor-saturated conditions. This behavior exemplifies the “tourism paradox” (Fanini et al., 2020), in which the popularity of destinations contributes to their environmental degradation, thereby compromising the sustainability of the tourism experience.

In hypothetical scenarios of solid waste pollution, visitors showed greater sensitivity compared to those involving high population density. This trend was particularly evident on beaches with local tourism potential, where most respondents indicated they would not change their destination or would opt for alternative beaches outside the region, even when the perceived level of pollution was at least twice as high as the values recorded in the field. This overestimation of litter presence may be explained by the profile of beachgoers, predominantly composed of local residents or property owners who frequently visit these beaches and, as a result, tend to observe a higher accumulation of waste. Another possible explanation is linked to specific features of the coastal landscape. The presence of algae on the sand strip has been interpreted as a sign of dirtiness, as identified in user comments on TripAdvisor and Google Reviews (2025). The studied beaches with local tourism potential are also located in areas influenced by river mouths, which contributes to changes in the visual characteristics of the coastal landscape, such as darker water and sand coloration. These alterations negatively affect environmental quality perception, as darker coloration is commonly associated with poor beach cleanliness (Pranzini et al., 2010; Mestanza-Ramón et al., 2020). There is a clear tendency to value beaches with lighter-colored water and sand, such as those with national tourism potential in the Região dos Lagos, which are often perceived as ecologically preserved (Botero et al., 2014; Dadon, 2018; Pon et al., 2022).

Visitor avoidance in beach areas, driven by environmental degradation due to the accumulation of solid waste and overcrowding, has the potential to reduce user frequency and generate substantial economic losses. This effect is exemplified by Morro Beach (regional tourism potential), with estimated losses of USD 12,72 million, and Praia Grande Beach (national and international tourism potential), with projected losses of USD 52,32 million during the peak season. Both cases are associated with critical scenarios involving high levels of pollution and crowding (Scenario 6).

The economic loss estimates identified in this study corroborate evidence from previous research that employed hypothetical scenarios of solid waste pollution. For example, in Grussaí Beach, characterized by local tourism, losses during the high season may reach USD 2 million. Similarly, in the subtropical coast of Paraná, Brazil, Krelling et al. (2017) estimated annual losses of up to USD 3 million in a local tourism destination predominantly used as a secondary residence by over 70% of visitors. On an international scale, Jang et al. (2014) estimated an annual revenue reduction of

USD 29 million on Geoje Island, South Korea, due to marine debris originating from the Nakdong River. Additionally, Ofiara and Brown (1999) calculated economic losses of approximately USD 379 million associated with the decline in beach tourism following a debris pollution event in 1988 in New York Bay, United States. All these studies adopted conservative projections in their calculations, which reinforces the comparability of the data and estimates.

Actions aimed to preserve the natural landscape can be incorporated as part of strategies to public engagement, simultaneously strengthening environmental sustainability and destination attractiveness. Beaches with higher popularity rankings at the national level exhibited lower rates of tourist loss. Beyond environmental concerns, visual appeal has become a decisive factor in coastal destination choice, driven by the phenomenon of “Instagrammable tourism” (Oh et al., 2020), which can be leveraged as a strategic tool to reverse environmental degradation and promote good coastal management practices (Mendoza-González et al., 2018). The growing demand for aesthetically appealing landscapes, frequently shared on social media, reconfigures environmental valuation as a competitive advantage rather than solely an ecological imperative (Alegre & Cladera, 2006; Chan, 2014). In this context, popularity may mitigate the negative effects of environmental degradation on visitation, highlighting a possible trade-off between aesthetic appeal, marketing strategies, and conservation (Botero et al., 2013; Walsh & Dodds, 2022; Butler & Dodds, 2019).

To strengthen this integration, managers can implement environmental education campaigns, participatory decision-making mechanisms, incentives for sustainable practices among tourists and local businesses, and, lastly, conservation social engagement in conservation actions by acting as mobilizing that evoke empathy and public support (Veríssimo et al., 2014, Veríssimo et al., 2009). The awareness generated by these campaigns tends to produce positive effects on the protection of coexisting species and their habitats (Miralles et al., 2019; Costa et al., 2023). Additional complementary measures include regulating visitor flow in sensitive areas, improving waste collection services, and promoting environmental certifications for beaches (Diniz et al., 2022). Thus, by aligning environmental conservation with visitor experience, it is possible to ensure the sustainable use of beaches for tourism, preserving their ecosystem services and securing long-term benefits for both the environment and the local economy (Friedrich et al., 2020).

5. CONCLUSION

The results demonstrate that visitor perception can serve as a valid and complementary tool to assess the environmental quality of beaches, particularly when convergent with technical data. However, more popular beaches tend to exhibit overestimated evaluations, which may obscure real environmental impacts or reveal social aspects not captured by technical assessments.

Perceptions differ between tourists and residents, influencing usage patterns, avoidance behavior, and acceptance of coastal scenic degradation. Overall, public sensitivity to solid waste is higher than to human crowding. Indeed, there is a high tolerance for crowding, even on beaches with lower tourist flows and under conditions of evident tourism overload. Therefore, the preferences and opinions of beachgoers should be interpreted with caution, as they may reflect specific interests that do not always align with environmental conservation objectives.

The relationship between popularity and reduced visitor avoidance highlights a dilemma between aesthetic appeal, tourism marketing, and environmental conservation. In this context, social media-driven tourism can be integrated into coastal management as a vector for environmental promotion, provided it is coupled with effective conservation actions, environmental education, and service quality improvements. By integrating user perception with ecological criteria, coastal management can achieve sustainable solutions amid the contemporary challenges faced by coastal environments.

ETHICAL PROCEDURES

This study was approved by the Research Ethics Committee on Human Subjects of the Federal University of Espírito Santo, Brazil (CAAE: 64070822.9.1001.8151).

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APPENDICES

Appendix A. Questionnaire for assessing user profiles and perceptions of beach quality in relation to the presence of litter and human crowding.

SOCIOECONOMIC PROFILE

01. Sex _____

02. Age: _____ years

03. Education level

- a) No formal education () d) Undergraduate degree ()
b) Elementary school () e) Graduate degree ()
c) High school ()

05. Length of stay at this beach

- a) _____ days ()
b) I own property near the beach ()
c) Not staying overnight at the beach ()

06. Frequency of visit to this beach

- a) First time visiting ()
b) Visit once per year ()
c) Visit _____ times per year ()
d) Visit on weekends ()

04. Current place of residence: _____

USERS' PERCEPTION OF THE BEACH

07. Please indicate your level of satisfaction with the following aspects of this beach:

Aspect	Dissatisfied 1	Neutral 2	Satisfied 3
Accessibility			
Environmental quality			
Water quality			
Comfort			
Scenic quality			
Services and infrastructure			
Safety			
Environmental education and information			

08. Which litter scenario best represents the current condition of the beach?

- a) Scenario 1 () d) Scenario 4 ()
b) Scenario 2 () e) Scenario 5 ()
c) Scenario 3 () f) Scenario 6 ()

09. From which of these litter scenarios onwards would you avoid visiting this beach?

- a) Scenario 1 () d) Scenario 4 ()
b) Scenario 2 () e) Scenario 5 ()
c) Scenario 3 () f) Scenario 6 ()

10. Which human crowding scenario best represents the current condition of the beach?

- a) Scenario 1 () d) Scenario 4 ()
b) Scenario 2 () e) Scenario 5 ()
c) Scenario 3 () f) Scenario 6 ()

11. From which of these human crowding scenarios onwards would you avoid visiting this beach?

- a) Scenario 1 () d) Scenario 4 ()
b) Scenario 2 () e) Scenario 5 ()
c) Scenario 3 () f) Scenario 6 ()

IMPORTANCE OF TOURISM FOR THE LOCAL ECONOMY

12. Which other beach would you visit if you were prevented from visiting this one? Why?

13. What is your average daily cost at the beach, including all expenses (food, accommodation, purchases, and others)?

- a) 10 to 50 reais () d) 500 to 1000 reais ()
b) 50 to 200 reais () e) 1000 to 3000 reais ()
c) 200 to 500 reais ()

14. How many people are included in the daily cost indicated above? _____

Appendix B. Classification criteria for resident and tourist users.

Research participants were classified into two main categories, residents and tourists.

This classification was based on the combination of three criteria:

- Place of origin (whether they reside in the municipality of the evaluated beach);
- Frequency of visit (number of visits to the beach in the last 12 months);
- Length of stay (average duration per visit).

Table 1. Classification place of origin matrix

Place of Origin	Frequency of Visit	Length of Stay	Classification
Same municipality	Any	Property near the beach	Resident
Different municipality	Frequent	Long (e.g., entire season ¹) / Property near the beach	Second residence ²
Different municipality	Frequent (≥ 1 time per month)	Short (≤ 3 days)	Tourist
Different municipality	Low frequency (≥ 1 time per year)	Short or medium (between 7 and 15 days)	Tourist

¹ Entire season refers to a prolonged stay during the months of highest tourist activity, especially summer, typically ranging from 1 to 3 continuous months.

² In cases classified as "Second residence," the individual maintains long-term and frequent ties to the region, despite having their main residence in another municipality. For analytical purposes, these participants are considered residents.

Appendix C. Indicators of coastal scenery quality were utilized to evaluate the management capacity of nine beaches: João Fernandes (FER), Praia Grande (GRA), Però (PER), Guaxindiba (GUA), Grussaí (GRU), Farol de São Thomé (FAR), Costa Azul (COS), Morro (MOR), and Sereia (SER). The classification of coastal scenery categories was determined based on the average of the evaluated indicators, categorized as low (0.33 to 0.55), intermediate (0.56 to 0.77), or high (0.78 to 1) (Diniz et al., 2022). ^bThe indicators align with those outlined in the Blue Flag Program (Blue Flag, 2019) and of ^othe Orla Project (MMA, 2006).

INDICATORS	FER	GRA	PER	GUA	GRU	FAR	COS	MOR	SER
ACCESSIBILITY	0.55	0.85	0.76	0.58	0.76	0.70	0.79	0.94	0.91
1. Facilities for Individuals with Special Needs ^b	1	2	2	1	2	1	2	3	3
2. Accessible Restrooms for Individuals with Special Needs ^b	1	1	2	1	1	1	2	3	3
3. Human-Made Structures Impeding Beach Visitor Mobility	1	3	3	3	3	3	2	2	2
4. Beach-face slope	2	3	3	1	2	1	3	3	2
5. Level difference to the beach	1	2	2	3	3	3	2	2	2
6. Beach access ^{b,o}	3	3	3	2	3	3	3	3	3
7. Public Transit ^{b,o}	3	3	3	2	3	3	3	3	3
8. Designated Parking Spaces for Individuals with Disabilities and the Elderly ^b	1	2	2	1	2	1	2	3	3
9. Bike lanes ^{b,o}	1	3	1	1	1	1	1	3	3
10. Pedestrian pathways ^{b,o}	1	3	1	1	2	3	3	3	3
11. Natural Formations Affecting Beach Accessibility (e.g., Beach Sandstones)	3	3	3	3	3	3	3	3	3
ENVIRONMENTAL QUALITY	0.67	0.81	0.81	0.52	0.70	0.78	0.74	0.70	0.74
12. Unpleasant Smells	3	3	3	3	3	3	3	2	3
13. Presence of dead animals (fish or other organisms)	2	3	2	2	2	2	2	2	2
14. Noise (Vehicle Traffic and Loud Music) ^{b,o}	3	1	2	2	2	2	2	2	2
15. Vegetation coverage after beach use ^o	1	3	3	1	1	2	1	1	1
16. Coastal ecosystems (coral reefs, dunes, mangroves, and restinga) ^o	2	3	3	2	2	3	2	2	2
17. Monitoring Beach-Associated Ecosystems ^{b,o}	2	2	1	1	2	2	2	2	3
18. Stinging Organisms (Jellyfish)	1	2	2	1	3	2	2	2	2
19. Enforcement of laws and regulations ^b	3	2	3	1	3	2	3	3	3
20. Beach management committee ^{b,o}	1	3	3	1	1	3	3	3	2
WATER QUALITY	0.78	0.94	1	0.83	0.83	0.83	0.56	0.72	0.78
21. Microbial quality of water ^{b,o}	3	3	3	3	3	3	1	1	1
22. Oil on the beach or in the water ^b	3	3	3	3	3	2	2	2	2
23. Floating debris (wood, plastic, glass, rubber, or other substances) ^b	1	3	3	2	2	2	2	2	2
24. Monitoring of physicochemical water parameters ^{b,o}	1	3	3	1	1	2	1	3	3

Continues

Appendix C. Continued

INDICATORS	FER	GRA	PER	GUA	GRU	FAR	COS	MOR	SER
25. Frequency of water quality monitoring ^b	3	3	3	3	3	3	1	2	3
26. Red tide	3	2	3	3	3	3	3	3	3
COMFORT	0.74	0.85	0.81	0.85	0.81	0.81	0.74	0.70	0.78
27. Large waves (> 1m) breaking directly on the beach face ^o	3	3	3	3	2	2	2	2	2
28. Sediment on the beach face	3	3	3	3	3	3	3	3	3
29. Beach face width at low tide ^o	1	3	2	3	3	3	2	2	2
30. Sediment in the bathing zone	3	3	3	3	3	3	3	3	3
31. Competition for unrestricted beach use (e.g., fishermen, sailors, and sports enthusiasts)	1	3	3	3	3	3	1	1	2
32. Tidal range ^o	2	2	2	2	2	2	2	2	2
33. Water temperature ^o	2	2	2	3	3	3	2	2	2
34. Bathing zones	2	1	1	2	1	1	3	2	3
35. Algae on the sand or in the water column	3	3	3	1	2	2	2	2	2
SCENIC QUALITY	0.67	0.73	0.80	0.60	0.60	0.53	0.53	0.60	0.67
36. Beachfront typology in terms of urbanization ^o	1	1	2	2	2	2	1	1	1
37. Coastal erosion vulnerability ^o	3	3	3	3	3	2	2	3	3
38. Permanent Structures ^o	1	1	1	1	1	1	1	1	1
39. Beach sediment coloration	2	3	3	2	2	2	2	2	2
40. Water turbidity	3	3	3	1	1	1	2	2	3
SERVICES AND INFRASTRUCTURE	0.69	0.75	0.80	0.57	0.59	0.69	0.73	0.82	0.84
41. Sanitary facilities in good hygiene condition ^b	1	2	3	1	1	1	3	2	2
42. Number of Sanitary Facilities ^b	1	3	3	1	1	1	2	3	2
43. Sanitary facilities with proper waste disposal ^b	1	1	3	1	1	1	3	3	2
44. Showers and drinking fountains ^b	1	2	2	1	1	2	2	2	2
45. Unauthorized camping, vehicle circulation, or debris dumping ^b	2	2	3	2	2	2	2	3	3
46. Snack bars, bars, and restaurants ^o	3	3	3	3	2	3	3	3	3
47. Accommodation choices ^o	3	3	3	3	2	3	3	3	3
48. Parking ^b	2	2	3	1	3	3	2	2	3
49. Recreational facilities (e.g., courts and kayak rentals) ^o	3	3	1	2	1	2	2	2	3
50. Trash bins ^b	2	2	2	2	2	2	2	2	3
51. Recycling bins ^b	1	1	1	1	1	1	1	2	2
52. Beach cleanliness ^b	3	2	3	2	3	3	3	3	3
53. Cleaning of natural debris or seaweed ^b	3	2	1	2	1	2	1	2	1
54. Discharge of wastewater, industrial, or urban waters ^{b,o}	2	3	3	2	2	2	2	2	3

Continues

Appendix C. Continued

INDICATORS	FER	GRA	PER	GUA	GRU	FAR	COS	MOR	SER
55. Litter accumulation ^{b,o}	3	3	3	3	3	3	2	2	2
56. Dogs and other domestic animals ^b	2	1	1	1	1	1	2	3	3
57. Building conservation status ^{b,o}	2	3	3	1	3	3	2	3	3
SAFETY	0.48	0.38	0.71	0.52	0.57	0.71	0.52	0.71	0.86
58. Lifeguards ^b	1	2	2	2	2	2	1	3	3
59. First aid equipment ^b	1	1	1	1	2	2	1	1	1
60. Police officers ^b	1	1	2	2	2	3	3	3	3
61. Rip currents	3	1	1	3	2	2	2	3	3
62. Public alert system if the beach becomes unsafe	1	1	3	1	1	3	1	1	3
63. Emergency plans for addressing risks from environmental accidents ^b	2	1	3	1	2	2	1	3	3
64. Zoning for bathers, swimmers, surfers, and users of motorized watercraft ^{b,o}	1	1	3	1	1	1	2	1	2
ENVIRONMENTAL EDUCATION AND INFORMATION	0.33	0.6	0.93	0.47	0.53	0.47	0.4	0.47	0.87
65. Environmental education activities provided to beachgoers ^b	1	3	3	2	2	2	1	3	3
66. Current information on water quality displayed on informative plaques ^b	1	1	2	1	1	1	2	1	3
67. Information about local ecosystems, natural phenomena, sensitive natural areas, and culturally significant areas available on informational plaques ^b	1	2	3	2	2	2	1	1	1
68. Beach map ^b	1	1	3	1	1	1	1	1	3
69. Code of conduct displayed on informational plaques ^b	1	2	3	1	2	1	1	1	3
GENERAL INDEX OF COASTAL SCENE QUALITY	0.63	0.75	0.82	0.61	0.68	0.71	0.67	0.75	0.82

Appendix D. Geographic coordinates used to identify Instagram publications by geolocation, along with selected hashtags associated with each beach and its respective municipality. The number of georeferenced photo posts was retrieved from Instagram on January 15, 2025. NAT = National tourism potential; REG = Regional tourism potential; LOC = Local tourism potential. Beaches marked with an asterisk (*) are certified with the international Blue Flag label. On platforms like Instagram an emoji inside a hashtag is treated as part of the hashtag itself.

Beach	Geolocation	Identified hashtags	Number of mentions
Guaxindiba - RJ (LOC)	21°28'36.6"S, 41°3'24.0"W	#praiadeguaxindiba	500
		#praiadeguaxindiba 😊	100
		#praiadeguaxindibacom	100
		#praiadeguaxindibasemfiltro	100
		#praiadeguaxindibaa	100
		#guaxindibabeach	1000
		#guaxindibabeach♥	100
Grussaí - RJ (LOC)	21°41'38.1"S, 41°1'28.7"W	#guaxindibabeach 🍷🍷🍷	100
		#praiadegrussai	500
		#praiadegrussaí	100
		#praiadegrussai🇧🇷	100
		#praiadegrussaíverão	100
		#praiadegrussaíréveillon	100
		#praiadegrussai 🏖️	100
		#praiadegrussaisjb	100
		#praiadegrussaihj	100
		#praiadegrussaí♥	100
		#praiadegrussai 🌊🌊	100
		#praiadegrussaí 🏖️	100
		#grussaibeach	5000
		#grussaibeach	1000
Farol - RJ (LOC)	22°2'25.4"S, 41°2'41.9"W	#grussaibeach 😊🌊🌊🍷🍷	100
		#grussaibeach 🌊	100
		#praiadofaroldesãotomé	500
		#praiadofaroldesaotome	100
		#praiadofaroldesãotome	100
		#praiadofaroldesãotomé7	100
		#praiado faroldesãothomé	100
		#praiadofaroldesaothome	100
		#praiadofaroldesaothomé	100
		#praiadofaroldesáothome	100
Sereia - ES (REG)*	20°19'50.8"S, 40°16'24.8"W	#praiadasereiavilavelha	500
		#praiadasereiavilavelhaes	100
		#praiadasereiaes	100
Costa Azul – ES (REG)	20°49'51.1"S, 40°41'36.2"W	#praiadacostaazuliriri	100
		#praiadacostaazules	100
		#praiadomorroguarapari	32500
		#praiadomorroguaraparies	500
		#praiadomorroguarapari 🌊	100
Morro - ES (REG)	20°39'21.0"S, 40°29'23.8"W	#praiadomorroguarapariespiritosanto	100
		#praiadomorroguarapari 🌊😊😊😊😊😊😊😊😊	100
		#praiadomorroguaraparilugarlindo	100
		#praiadomorroguarapari 🏖️🏖️🏖️	100
		#praiadomorroguaraparibanana	100
		#praiadomorroguarapail	100
		#praiadomorroguarapari* 🏖️	100
		#praiadomorroguarapari 😊😊	100
		#praiadomorroguarapari 🌊😊🌊😊	100
		#praiadomorroguarapari 🏖️	100

		#praia domroguarapari 🌊🌴🌊	100
		#praia domroguarapari 🌊🌴🌊	100
João Fernandes - RJ (NAT)	22°44'30.8"S, 41°52'30.2"W	#praiajoaofernandes	24000
		#praiajoãofernandes	1000
		#praiajoaofernandesbúziosrj	100
		#praiajoaofernandesbuzios	100
		#praiajãofernandes	100
		#praiajoãofernandesbúzios	100
		#praiajoaofernandes♥	100
		#praiajoãofernandes	100
		#praiajoaõfernandes	100
		#joaofernandesbuzios	1000
		#joaofernandesbuziosbrasil	500
		#joaofernandesbeach	1000
		#joãofernandesbeach	100
		#joãofernandesbeachbúzios	100
Praia Grande - RJ (NAT)	22°58'28.6"S, 42°1'53.9"W	#praia grandearraialdocabo	39900
		#praia grandearraial	1000
		#praia grandearraialdocaborj	1000
		#praia grandearraialdocabo 🌊	100
		#praia grandearraialdocabo 🌊	100
		#praia grandearraialdocaboriodejaneiro	100
		#praia grandearraialdocabopordosol 🌞🌞🌞	100
		#praia grandearraialdocabo 🌊🌴🌊	100
		#praia grandearraialrj	100
		#praia grandearraialdocabo 🌊🌞	100
		#praia grandearraialdocabo ♥	100
		#praia grandearraialcabo	100
		#praia grandearraialdocabo 🙌🙌😊🙌	100
		#praia grandearraial♥	100
		#praia grandearraialdocabo ♥	100
Peró - RJ (NAT)*	22°51'34.97"S, 41°59'9.32"W	#praia doperó	16000
		#praia dopero	41200
		#praia doperórj	100
		#praia doperocabofrio	1000
		#praia doperócabofrio	100
		#perobeach	1000
		#peróbeach	100
		#praia dopero 🌊🌊🌊	100
		#praia doperócabofriorj	100
		#praia doperorj	100
		#praia doperóhoje	100
		#praia doperóedasconchas	100
		#praia doperó 😊	100
		#praia dopero 🌊	100
		#praia doperocabofrio ♥	100

Appendix E. Projected Economic Losses (in Million USD) Due to Human Crowding (A) and Solid Waste Pollution (B) under Hypothetical Scenarios.

A. Estimated losses in tourism revenue (in million USD) due to human crowding, per scenario and beach.

Beach	Scenario 4	Scenario 5	Scenario 6
Farol - RJ (LOC)	0.03	0.11	0.26
Guaxindiba - RJ (LOC)	0.06	0.34	0.45
Grussaí - RJ (LOC)	0.15	0.44	1.75
Peró - RJ (NAT)*	0.05	0.09	0.71
João Fernandes - RJ (NAT)	–	0.25	1.49
Praia Grande - RJ (NAT)	1.01	5.03	27.16
Sereia - ES (REG)*	0.00	0.02	0.24
Costa Azul – ES (REG)	0.02	0.03	0.17
Morro - ES (REG)	1.08	1.35	2.71

NAT = National tourism potential; REG = Regional tourism potential; LOC = Local tourism potential. Beaches marked with an asterisk () are certified with the international Blue Flag label.*

B. Estimated losses in tourism revenue (in million USD) due to solid waste pollution, per scenario and beach.

Beach	Scenario 4	Scenario 5	Scenario 6
Farol - RJ (LOC)	0.03	0.23	0.34
Guaxindiba - RJ (LOC)	0.18	0.40	0.60
Grussaí - RJ (LOC)	0.88	1.95	2.58
Peró - RJ (NAT)*	0.41	0.76	1.20
João Fernandes - RJ (NAT)	1.31	1.74	2.23
Praia Grande - RJ (NAT)	24.15	34.57	52.32
Sereia - ES (REG)*	0.18	0.26	0.49
Costa Azul – ES (REG)	0.24	0.38	0.78
Morro - ES (REG)	1.90	5.68	12.72

NAT = National tourism potential; REG = Regional tourism potential; LOC = Local tourism potential. Beaches marked with an asterisk () are certified with the international Blue Flag label.*

CAPÍTULO 4

PRIORIDADES DE GESTÃO EM PRAIAS ARENOSAS: UMA ABORDAGEM MULTI- INTEGRADA EM DIFERENTES POTENCIAIS TURÍSTICOS

PRIORIDADES DE GESTÃO EM PRAIAS ARENOSAS: UMA ABORDAGEM MULTI-INTEGRADA

RESUMO

As praias são sistemas socioecológicos complexos e suscetíveis à superexploração turística e à degradação ambiental. Este estudo aplica, em praias do sudeste do Brasil, uma abordagem de avaliação e gestão multi-integrada baseada no Índice de Prioridade de Gestão de Praias (IPGP), que integra três componentes: capacidade de carga turística, avaliação técnica do cenário costeiro e percepção dos visitantes. Os resultados mostram que a prioridade de gestão está mais associada à pressão de uso e a limitações de serviços e infraestrutura. Entre os atributos avaliados, educação ambiental e qualidade ambiental apresentaram os menores desempenhos, indicando fragilidades recorrentes. O IPGP evidenciou-se como ferramenta integrada, operacionalmente simples e de baixo custo, com aplicabilidade direta à gestão pública, apoiando decisões preventivas e favorecendo o equilíbrio entre conservação ambiental e uso recreativo em praias arenosas.

Palavras-chave: Impacto humano; gestão costeira; tomada de decisão; indicadores ambientais; sobrecarga turística.

1. INTRODUÇÃO

As praias arenosas enfrentam pressões de urbanização, poluição e especulação imobiliária que comprometem sua integridade ecológica e turística, agravadas por deficiências de infraestrutura e gestão costeira (Pereira et al., 2003; Zacarias et al., 2011; Defeo e Elliott, 2020). A gestão costeira, enquanto processo dinâmico e multidimensional, deve integrar interesses econômicos, políticos, sociais e ambientais (Polette e Silva, 2003; Cristiano et al., 2018). Nesse contexto, torna-se essencial o uso de metodologias com embasamento científico, capazes de subsidiar avaliações robustas do valor socioecológico das praias e orientar decisões de manejo (Marchese et al., 2021).

Entre as ferramentas de planejamento ambiental turístico, a capacidade de carga destaca-se por avaliar os limites de uso das praias diante do crescimento do turismo e da pressão demográfica (Cifuentes, 1992; Kay e Alder, 1999; Morales et al.,

2018; Rodella et al., 2020b). Fundamenta-se na premissa de que fatores ambientais restringem o número de visitantes que o ecossistema pode suportar sem comprometer os recursos naturais ou a qualidade da experiência recreativa (Cifuentes et al., 1990; Pires, 2005; Morales et al., 2018).

Paralelamente aos estudos de capacidade de carga turística, foram desenvolvidos métodos para avaliar a qualidade do cenário costeiro (ACC), frequentemente comprometido por impactos antrópicos, como aglomeração, erosão, resíduos sólidos, esgoto e urbanização excessiva, além do manejo deficiente das praias (Kay e Alder, 1999; Swanwick, 2002; Kirillova et al., 2014). A ACC constitui uma ferramenta para mensurar tais impactos, associados à perda de integridade ecológica e ao risco de evasão dos usuários, oferecendo suporte à gestão costeira (Kay e Alder, 1999; Swanwick, 2002; Kirillova et al., 2014). Seu uso é incentivado por possibilitar tanto a conservação e proteção da paisagem quanto a criação de novas perspectivas e o aprimoramento das políticas de gerenciamento (Rangel-Buitrago et al., 2013; Cristiano et al., 2016; Ergin, 2019).

Diversos instrumentos foram propostos para a avaliação de cenários costeiros, como o *Integrated Beach Value Index* (IBVI) (Cervantes and Espejel, 2008), o *Beach Quality Index* (BQI) (Ariza et al., 2010), o *Índice de Calidad Ambiental en Playas Turísticas* (ICAPTU) (Botero et al., 2014) e a *Bathing Area Registration and Evaluation* (BARE) (Micallef et al., 2011). Além disso, selos ambientais, como o programa de certificação ambiental Bandeira Azul, têm se difundido em países do mundo inteiro pelo potencial de apoiar estratégias de gestão costeira e atração turística (Bernardi e Pires, 2015; Bandeira Azul, 2019).

Nos países em desenvolvimento, a adoção de selos ambientais, como o Bandeira Azul, assume maior relevância diante da fragilidade da legislação e da limitada capacidade de fiscalização, observada em contextos como Colômbia, Brasil e México (Russell e Vaughan, 2003; Blackman, 2010), diferentemente de países desenvolvidos, onde o selo tem função predominantemente voltada ao marketing turístico devido a políticas de gestão já consolidadas. Em contextos de regulamentação frágil, ele pode desempenhar papel estratégico ao incentivar a proteção ambiental (Blackman et al., 2014), fortalecer a reputação internacional do turismo (Mihalič, 2000), promover aprendizagem, *networking* e adoção de melhores práticas em gestão costeira (Klein e Dodds, 2017).

Embora as avaliações de cenário costeiro possam apoiar o gerenciamento e a certificação da qualidade das praias, sua aplicação na América Latina permanece incipiente (Nelson et al., 2000). No caso específico do programa Bandeira Azul, apesar de priorizar a recreação, a certificação apresenta limitações ao não incorporar de forma sistemática as perspectivas das comunidades locais, pescadores, turistas e demais usuários (Roca e Villares, 2008; Lozoya et al., 2014; Lucrezi et al., 2016). Além disso, tende a negligenciar aspectos críticos como a sobrecarga turística e os conflitos sociais associados ao uso das praias, o que pode reduzir sua efetividade como instrumento de gestão costeira.

A governança de ecossistemas costeiros deve integrar a dimensão humana, incorporando a percepção dos usuários como elemento central para subsidiar o planejamento e a tomada de decisões (Roca et al., 2008; Roca et al., 2009; Ariza et al., 2014; Mensah et al., 2014). A consideração dessas perspectivas confere legitimidade às ações de gestão e permite alinhar estratégias às expectativas sociais e recreativas. Ademais, a redução da satisfação dos visitantes pode intensificar impactos econômicos locais, comprometendo a sustentabilidade do turismo costeiro (Micallef e Williams, 2003; Cervantes e Espejel, 2008; Ariza et al., 2012; Krelling et al., 2017; Rodella et al., 2020a).

A promoção do desenvolvimento econômico sustentável é particularmente urgente no setor do turismo (Paci e Marrocu, 2014). Entretanto, o crescimento da atividade tem sido acompanhado por intensas transformações socioeconômicas que afetam a qualidade de vida das populações locais e ampliam impactos ambientais, como erosão, poluição, geração de resíduos e perda de habitats (GSTC, 2013). A concentração de turistas intensifica a pressão sobre recursos hídricos, infraestrutura e comunidades (Onofri e Nunes, 2013). A insustentabilidade do setor é atribuída, em grande parte, à baixa adoção de práticas efetivamente pró-ambientais, enquanto muitas iniciativas rotuladas como “turismo sustentável” limitam-se a estratégias de *marketing* ou maximização de lucros (Hall, 2011; Gössling et al., 2012; Weaver, 2009). Nesse contexto, são necessárias transformações estruturais, embora ainda persista a incerteza quanto aos instrumentos mais eficazes para promover a sustentabilidade, sobretudo em curto prazo (Gössling et al., 2012).

Avaliações integradas adotam uma abordagem holística, considerando o máximo de características mensuráveis do ambiente praias para subsidiar planejamento e gestão (Lucrezi et al., 2016). Neste sentido, as avaliações periódicas

permitem identificar alterações na qualidade da praia, alinhadas a normas legais, políticas ambientais e processos de melhoria contínua (Botero et al., 2014). A manutenção da qualidade das praias depende de uma abordagem integrada que combine planejamento, controle e medidas preventivas e corretivas, sob pena de colapso econômico e ambiental decorrente do turismo descontrolado (Chen e Teng, 2016; Marchese, 2019).

Uma perspectiva multidimensional fornece base científica para aprimorar o ordenamento e a qualidade turística, combinando ferramentas complementares com focos distintos. A capacidade de carga turística foca na preservação sustentável dos recursos costeiros e recreativos, enquanto a avaliação do cenário costeiro identifica áreas que requerem atenção imediata, como gestão de habitats, água, limpeza, serviços e infraestrutura. A experiência dos usuários, por sua vez, influencia ambos os instrumentos, refletindo suas preferências e percepções. Nesse contexto, o presente estudo teve como objetivo desenvolver uma ferramenta de gestão para identificar prioridades de intervenção em praias, a partir de uma abordagem multi-integrada que combina as principais metodologias identificadas na literatura científica, incluindo a capacidade de carga turística, a avaliação do cenário costeiro e a percepção dos visitantes.

2. MATERIAL E MÉTODOS

2.1 Área de estudo

O estudo foi realizado em nove praias distribuídas em três mesorregiões com diferentes potenciais turísticos no sudeste do Brasil: uma localizada no litoral do estado do Espírito Santo (ES) e duas no estado do Rio de Janeiro (RJ) (Figura 1). As mesorregiões representam subdivisões territoriais que agrupam municípios com características econômicas, sociais e geográficas semelhantes dentro de um estado (IBGE, 2017). A mesorregião Norte do RJ apresenta um potencial turístico predominantemente local, enquanto o Centro-Sul do ES se destaca pelo turismo regional. Já a Baixada Litorânea do RJ, conhecida nacional e internacionalmente como Região dos Lagos, possui relevância turística em níveis nacional e internacional.

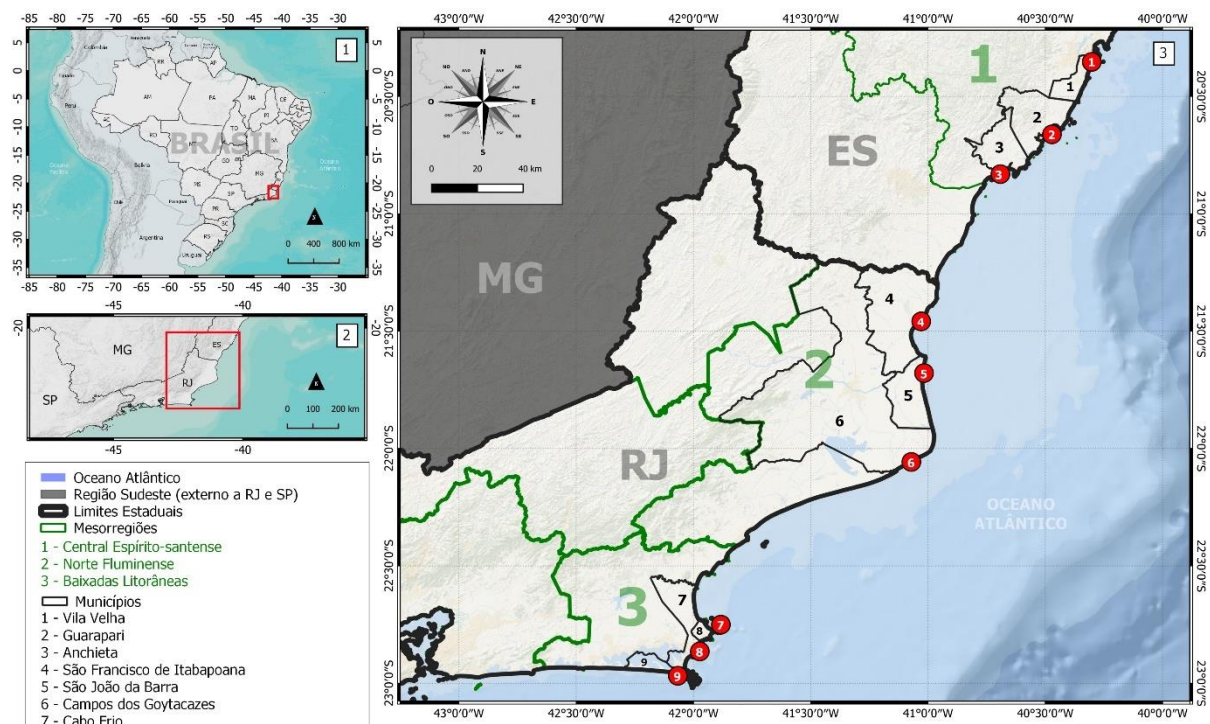


Figura 1. Mapa do Brasil com a indicação dos estados do Rio de Janeiro e Espírito Santo, e a localização geográfica das praias estudadas: 1 - Praia da Sereia (ES), 2 - Praia do Morro (ES), 3 - Praia da Costa Azul (ES), 4 - Praia de Guaxindiba (RJ), 5 - Praia de Grussaí (RJ), 6 - Praia do Farol de São Thomé (RJ), 7 - Praia de João Fernandes (RJ), 8 - Praia do Perú (RJ) e 9 - Praia Grande (RJ).

2.2 Abordagem multi-integrada para avaliação turística de praias arenosas

Este estudo utilizou uma abordagem multi-integrada, baseada em Cervantes and Espejel (2008) e Lucrezi et al. (2016), que combina os resultados de três ferramentas de gestão: capacidade de carga turística, avaliação do cenário costeiro realizada por especialistas em campo e percepção de visitantes e residentes. Todos os indicadores, assim como o índice final de cada ferramenta de gestão, foram pontuados em uma escala de 1 (baixa qualidade de gestão) a 3 (alta qualidade de gestão).

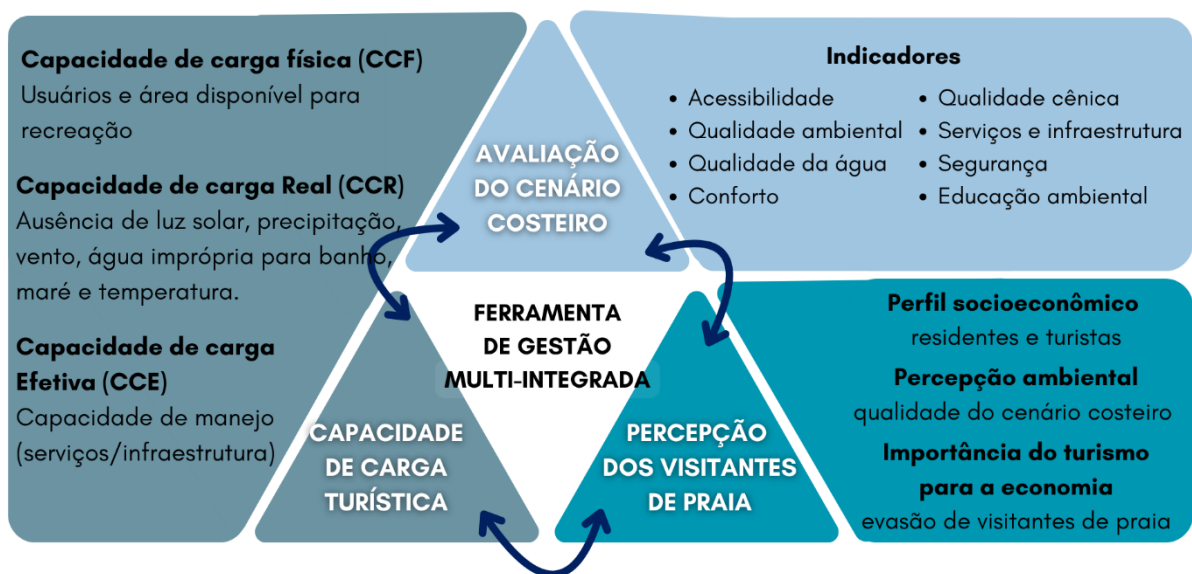


Figura 2. Estrutura metodológica multi-integrada para a avaliação das praias, considerando a avaliação do cenário costeiro, a capacidade de carga turística e a percepção dos visitantes de praias.

2.2.1 Capacidade de carga turística

A capacidade de carga turística (CCT) foi estimada para quantificar o número máximo de visitantes que cada praia pode acomodar sem comprometer a sustentabilidade dos recursos costeiros e suas condições físicas, ambientais e sociais, por meio de três métricas (Eq. 1): capacidade de carga física (CCF), que indica o número máximo de usuários em uma área; capacidade de carga real (CCR), que ajusta a CCF com base em restrições ambientais; e capacidade de carga efetiva (CCE), que integra a CCR às condições de manejo da praia. O procedimento metodológico seguiu a estrutura de Cifuentes et al. (1999), amplamente aplicada ao manejo costeiro (Sousa et al., 2014; Morales et al., 2018), com adaptações propostas por Diniz et al. (2024) para incorporar a avaliação da qualidade do cenário costeiro como componente das condições de manejo.

$$CCT = CCF > CCR \geq CCE \quad (\text{Equação 1})$$

A capacidade de carga física (CCF) corresponde ao limite teórico de usuários que uma praia pode acomodar e foi calculada a partir da área total disponível para

uso recreativo (A), da densidade média de ocupação (a) e do tempo médio de permanência dos visitantes (T) (Eq. 2).

$$CCF = A/a * T \quad (\text{Equação 2})$$

Dois cenários de densidade foram considerados, 1 usuário/5 m² e 1 usuário/10 m² de acordo com os parâmetros de conforto definidos por Yepes (2002), e tempo médio de permanência de três horas, conforme Zacarias (2013) e Silva et al. (2008).

A capacidade de carga real (CCR) foi obtida a partir da CCF corrigida por fatores de correção (FC), que representam limitações ambientais, ausência de luz solar, precipitação, ventos fortes, maré e temperatura do ar, conforme Cifuentes et al. (1999). Cada fator é calculado pela razão entre a magnitude limitante e a magnitude total da variável (Eq. 3).

$$FCx = 1 - MI/Mt \quad (\text{Equação 3})$$

A CCR resulta da aplicação conjunta desses fatores à CCF (Eq. 4). Para estimar a magnitude limitante referente à ausência de luz solar (FC1), à precipitação (FC2) e à temperatura (FC3), utilizou-se dados do Instituto Nacional de Meteorologia – INMET (portal.inmet.gov.br/). A maré (FC4) foi obtida no site Tábua de Marés (www.tabuademarkes.com). Os ventos fortes (FC5) foram baseados na escala da força dos ventos de Beaufort, considerando-se desconfortáveis para os usuários da praia as condições climáticas com velocidade do vento superior a 5.5 m/s, pois provocam ondas maiores e movimentam areia e papel (Khodkar, 2019).

$$CCR = CCF * (FC1 * FC2 * FC3 * FC4 * FC5) \quad (\text{Equação 4})$$

Onde FCx é o fator de correção para a variável x , MI é a magnitude limitante e Mt a magnitude total considerada.

Por fim, a capacidade de carga efetiva (CCE) foi calculada integrando a CCR à capacidade de manejo (CM), que reflete as condições administrativas e operacionais de gestão turística, abrangendo infraestrutura, serviços e equipamentos de apoio, como banheiros, restaurantes e postos de salva-vidas (Sousa et al., 2014; Morales et al., 2018). A CM foi expressa em percentual (Eq. 5).

$$CCE = CCR * CM/100$$

(Equação 5)

Assim, a CCT foi expressa como um indicador composto ($CCF > CCR \geq CCE$) que integra o potencial recreativo e a eficiência de manejo das praias, permitindo avaliar a sustentabilidade do uso turístico em diferentes contextos ambientais e de gestão.

2.2.2 Avaliação do cenário costeiro

A capacidade de carga efetiva (CCE) foi calculada a partir da capacidade de carga real (CCR) ajustada pela capacidade de manejo (CM), expressa em porcentagem. Para isso, adaptamos o modelo padrão de capacidade de carga turística, integrando a avaliação da qualidade do cenário costeiro, baseada em indicadores do programa internacional Bandeira Azul e do Projeto Orla, principal plano de ordenamento da costa brasileira (Diniz et al., 2022; Diniz et al., 2024) (Eq. 6). Um total de 69 indicadores de qualidade distribuídos em oito categorias: acessibilidade (11 indicadores), qualidade ambiental (9 indicadores), qualidade da água (6 indicadores), conforto (7 indicadores), qualidade cênica (5 indicadores), serviços e infraestrutura (17 indicadores), segurança (7 indicadores) e educação e informação ambiental (5 indicadores) (Apêndice 2). Cada indicador do cenário costeiro foi pontuado em escala de 1 (qualidade baixa) a 3 (qualidade alta).

$$CM = CI/CA$$

(Equação 6)

Em que CI é a capacidade instalada (soma dos valores atribuídos a cada indicador) e CA a capacidade adequada (soma das pontuações máximas de todos os indicadores). Os resultados integrados da CCT com a qualidade do cenário costeiro para as praias estudadas encontram-se publicados previamente em Diniz et al. (2024).

Os indicadores supracitados foram avaliados durante o verão de 2023 através de observação direta e análise de variáveis ambientais como transparência da água (cm) com disco de Secchi (~1,5 m), declividade da face da praia através de régua de nível, temperatura da água a partir dos dados disponíveis do Instituto Nacional de Meteorologia (portal.inmet.gov.br) e a avaliação da balneabilidade com dados do Instituto Estadual do Ambiente (www.inea.rj.gov.br e <https://iema.es.gov.br/>). Os parâmetros que não foram mensurados in situ (e.g., correntes de retorno, marés vermelhas, presença de água-viva, comitê de gestão de praia, aplicação de leis e

regulamentos) foram avaliados por entrevistas com os gestores ou responsáveis da Secretária de Meio Ambiente ou Turismo de cada município (Popoca e Espejel, 2009).

2.2.3 Percepção de visitantes de praia

A percepção dos visitantes das praias ocorreu durante o verão de 2023 (alta temporada, janeiro), aplicando-se 60 questionários semiestruturados por praia, totalizando 540 questionários (Tab. 1) (Mason, 2010). Os questionários abordaram características socioeconômicas dos participantes, bem como sua percepção sobre a qualidade e o potencial turístico das praias (Krelling et al., 2017; Rodella et al., 2017). A amostragem foi aleatória, restrita a indivíduos maiores de 18 anos (Kendall, 2008), garantindo independência amostral ao evitar a participação de pessoas pertencentes ao mesmo grupo ou família (Apêndice 3). Este estudo foi aprovado pelo Comitê de Ética em Pesquisa com Seres Humanos da Universidade Federal do Espírito Santo, Brasil (CAAE: 64070822.9.1001.8151).

A avaliação técnica da qualidade do cenário costeiro, utilizada para calcular a capacidade de manejo na CCT, considerou oito dimensões: acessibilidade, qualidade ambiental, qualidade da água, qualidade cênica, conforto, segurança, oferta de serviços e infraestrutura, além de educação e informação ambiental (Diniz et al., 2022; Apêndice 2). Complementarmente, a percepção dos frequentadores (turistas e moradores) sobre esses aspectos foi avaliada por meio de uma escala de 1 (insatisfeito) a 3 (satisfeito) (Chen e Teng, 2016).

2.3 Ferramenta de gestão multi-integrada

O Índice de Prioridade de Gestão de Praias (IPGP) foi desenvolvido como uma ferramenta de gestão integrada, combinando múltiplos indicadores relacionados à capacidade de carga turística, avaliação técnica do cenário costeiro e percepção dos visitantes. Essa abordagem segue a tendência recente de formulação de índices compostos aplicados à gestão de praias, que integram variáveis ambientais, sociais e operacionais de manejo para orientar decisões sustentáveis (Botero e Hurtado, 2015; Botero e Pereira, 2018).

O componente de capacidade de carga turística baseou-se na metodologia clássica de Cifuentes et al. (1999), posteriormente adaptada em diversos estudos para contextos costeiros e insulares (Silva et al., 2008; Zacarias, 2013; Morales et al.,

2018). Essa etapa fornece uma medida quantitativa do limite físico e ambiental de uso da praia, alinhada a metodologias recentes de capacidade de carga turística (Serrano Giné et al., 2018; Diniz et al., 2024). A classificação seguiu os seguintes critérios: valor 1 (baixa qualidade) quando o número de usuários for inferior à CCT em um cenário de 5 m² por pessoa; valor 2 (qualidade intermediária) quando a densidade de ocupação for entre 5 e 10 m² por pessoa (considerado ideal); e valor 3 (alta qualidade) quando o número de usuários for inferior ao limite da CCT da praia (valores de conforto baseado em Yepes 2002).

A avaliação técnica da qualidade do cenário costeiro (Q_{tec}) e a percepção dos visitantes (Q_{vis}) seguiram abordagens participativas amplamente recomendadas em estudos de gestão costeira, que valorizam a integração entre conhecimento técnico e percepção social (Botero e Pereira, 2018; Lukoseviciute, 2021). O uso de pesos de importância atribuídos pelos visitantes às diferentes categorias de análise reforça o caráter participativo da ferramenta, permitindo a ponderação dos aspectos mais relevantes à experiência recreativa e à sustentabilidade (Sousa et al., 2014). A avaliação técnica (Q_{tec}) e a percepção dos visitantes (Q_{vis}) sobre qualidade do cenário costeiro (Q) foi conduzida com base em oito categorias de análise do cenário costeiro: acesso, qualidade ambiental, qualidade da água, conforto, qualidade cênica, serviços e infraestrutura, segurança e educação e informação ambiental. Cada categoria recebeu pontuação entre 1 e 3, sendo a média aritmética das categorias utilizada como indicador da qualidade técnica média (Eq. 7). Adicionalmente, cada visitante atribuiu um grau de importância (w_i) para cada categoria, também em escala de 1 a 3, considerando os seguintes pesos: 3 (atributo mais importante para a melhoria da qualidade da praia), 2 (segundo mais importante) e 1 (terceiro mais importante).

$$Q_{tec} = (\sum_{i=1}^8 Q_{tec, i}) / 8 \quad \text{(Equação 7)}$$

O $\sum_{i=1}^8$ é símbolo de soma, indicando que todas as categorias i , da 1 até a 8, devem ser somadas. $Q_{tec, i}$ é a avaliação técnica da categoria e representa a pontuação (1 a 3) atribuída a uma das oito categorias analisadas. O número 8 (no denominador) se refere ao número total de categorias avaliadas tecnicamente.

A avaliação ponderada da percepção dos visitantes (Q_{vis}) é o valor final que sintetiza as percepções atribuídas pelos visitantes às oito categorias de avaliação, ajustadas pelos pesos de importância (Equação 8).

$$Q_{vis} = (\sum_{i=1}^8 (Q_{vis, i} * wi)) / \sum_{i=1}^8 wi \quad (\text{Equação 8})$$

$\sum_{i=1}^8$ é o símbolo de soma, indicando que todas as categorias, da 1 até 8, devem ser consideradas. $Q_{vis, i}$ é a avaliação por percepção da categoria e representa a nota (1 a 3) atribuída pelos visitantes para uma determinada categoria da praia; wi é o peso de importância da categoria e reflete o grau de importância atribuído pelos visitantes a cada categoria, permitindo que algumas tenham maior influência na avaliação final do que outras. Esse valor é usado como normalizador, garantindo que a média ponderada esteja ajustada pela relevância relativa de cada categoria.

O Índice de Prioridade de Gestão de Praias (IPGP) foi então obtido pela integração da capacidade de carga turística (CCT), da avaliação técnica (Q_{tec}) e da percepção ponderada dos visitantes (Q_{vis}) (Eq. 9).

$$IPGP = (CCT + Q_{tec} + Q_{vis})/3 \quad (\text{Equação 9})$$

O índice varia de 1 a 3, sendo que valores próximos de 1 indicam alta prioridade de gestão, enquanto valores próximos de 3 indicam baixa prioridade de gestão. O IPGP foi categorizado em três níveis de prioridade: alta prioridade ($IPGP \leq 2$), média prioridade ($2,0 < IPGP \leq 2,5$) e baixa prioridade ($IPGP > 2,5$). Essa classificação possibilitou a identificação das praias mais vulneráveis e, portanto, mais demandantes de ações de gestão prioritária.

3. RESULTADOS

3.1 Capacidade de carga turística

A sobrecarga turística foi identificada em quatro de nove praias, classificadas como desconfortáveis (densidade > 1 usuário/5 m²) (Apêndice 4). Todas as praias de potencial regional ultrapassaram a CCT recomendada e receberam valor 1 na classificação por carga (Tab. 1). Em Costa Azul e Sereia, o espaço disponível foi $< 2,0$ m² e 3,6 m² por usuário, respectivamente; Morro apresentou < 1 m² por usuário e fluxo seis vezes acima da CCT. Entre as praias de potencial nacional, João Fernandes excedeu a CCT em seis vezes. Por outro lado, Farol, Grussaí, Praia Grande,

Guaxindiba e Però não ultrapassaram a CCT (valor 3) e foram classificadas como confortáveis para o uso recreativo.

Tabela 1. Classificação das praias segundo o potencial turístico, a capacidade de carga (CCT) e os valores médios de qualidade do cenário costeiro obtidos por especialistas e visitantes. A qualidade foi categorizada em três níveis: alta (3), intermediária (2) e baixa (1).

Potencial turístico/Praia	Carga turística	Qualidade do cenário costeiro		
		Avaliação técnica (especialistas)	Percepção (visitantes)	Cenário costeiro (total)
Local				
Guaxindiba - RJ	3	1,85	2,02	1,90
Grussaí - RJ	3	2,03	2,28	2,13
Farol - RJ	3	2,07	2,13	2,07
Regional				
Sereia - ES*	1	2,41	2,46	2,40
Costa Azul - ES	1	1,88	2,67	2,28
Morro – ES	1	2,13	2,51	2,30
Nacional/Internacional				
Peró - RJ*	3	2,49	2,53	2,49
João Fernandes - RJ	1	1,83	2,41	2,11
Grande - RJ	3	2,22	2,37	2,27

*Certificação internacional Bandeira Azul

3.2 Avaliação do cenário costeiro e percepção de visitantes de praia

A avaliação do cenário costeiro evidenciou que a principal prioridade de gestão foi a categoria educação ambiental (Tab. 2), seguida por acessibilidade que apresentou o maior número de praias com pontuação inferior a 2,0. Entre as praias locais, Guaxindiba, Grussaí e Farol de São Thomé destacaram-se com múltiplos indicadores críticos, enquanto Costa Azul (regional) e João Fernandes (nacional) também apresentaram baixos desempenhos em diferentes categorias. Especificamente, Guaxindiba apresentou valores críticos (<2,0) em cinco categorias, configurando-se como a área de maior prioridade para intervenção de gestão. Entre as categorias analisadas, destacaram-se segurança (2,64), qualidade da água (2,53) e qualidade ambiental (2,32) como as de maior importância atribuída pelos visitantes, valores que foram utilizados na ponderação das notas das categorias.

Tabela 2. Praias prioritárias para a gestão por categoria (score <2.00) de qualidade do cenário costeiro por especialistas e visitantes de praia.

Praia	Acessibilidade	Qualidade ambiental	Qualidade da água	Serviços e infraestrutura	Segurança	Educação ambiental
Local						
Guaxindiba - RJ	X	X		X	X	X
Grussaí - RJ				X		X
Farol - RJ	X			X		X
Regional						
Sereia - ES*			X			X
Costa Azul - ES	X		X	X	X	X
Morro – ES			X			X
Nacional/Internacional						
Peró - RJ*						X
João Fernandes - RJ	X	X			X	X
Grande - RJ	X				X	X

*Certificação internacional Bandeira Azul

3.3 Índice de Prioridade de Gestão (IPG)

A avaliação integrada evidenciou padrões distintos entre categorias de potencial turístico. Praias locais (Guaxindiba, Grussaí e Farol) apresentaram alta capacidade de carga (CCT = 3) combinada a qualidade costeira baixa/intermediária (valores totais 1,90–2,13). Os valores de percepção, tanto dos especialistas quanto da população foram próximos.

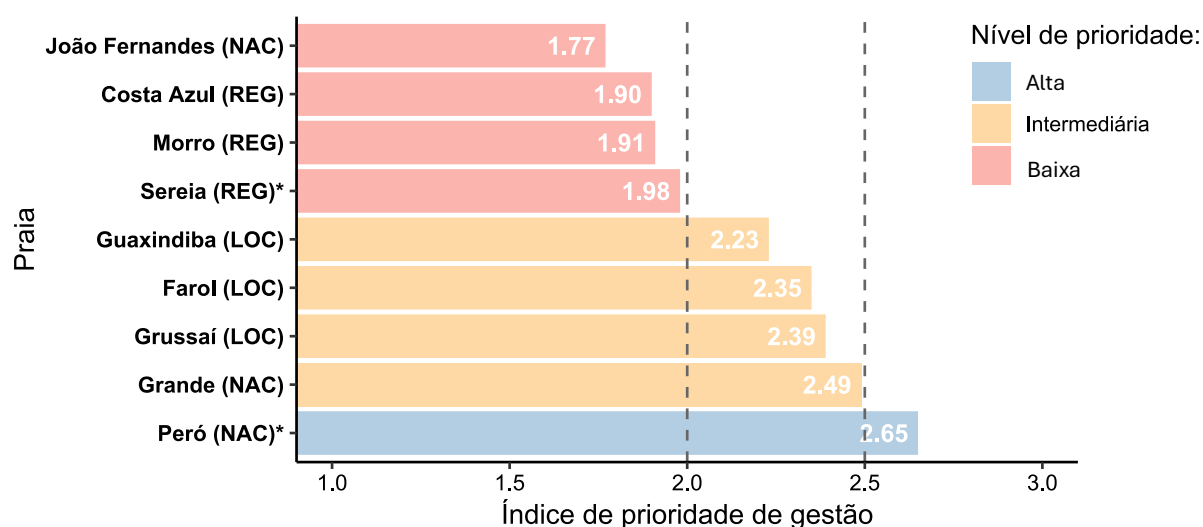
Nas praias de potencial regional (Sereia, Costa Azul e Morro), observou-se baixa capacidade de carga (CCT = 1) e maiores médias de qualidade do cenário costeiro (2,28–2,40), refletindo boa estrutura recreativa e percepção positiva dos usuários.

Entre as praias de potencial nacional/internacional, os resultados foram heterogêneos: Praia do Peró (Bandeira Azul) obteve a maior qualidade (2,49), indicando gestão ambiental mais consolidada; Praia Grande apresentou desempenho intermediário (2,27), com boa percepção dos visitantes, espaço físico extenso sem sobrecarga turística. João Fernandes registrou a menor pontuação (2,11), configurando área crítica de sobrecarga turística e limitação de capacidade de manejo.

As praias de João Fernandes (1,77), Costa Azul (1,90), Morro (1,91) e Sereia (1,98) foram enquadradas na categoria de alta prioridade de gestão (IPGP $\leq$ 2,0) (Fig. 3). Essas praias, de potencial turístico regional e nacional, apresentam baixa capacidade de carga turística (CCT = 1) associada a cenários costeiros de

intermediária/alta qualidade, evidenciando alta pressão antrópica e prioridade no manejo de serviços/infraestrutura (Fig. 3).

As praias Guaxindiba, Farol, Grussaí e Praia Grande foram classificadas como de prioridade média ($2,0 < \text{IPGP} \leq 2,5$), refletindo condições intermediárias de uso turístico e de efetividade de manejo. Apenas a Praia do Perú (2,65), certificada com o selo Bandeira Azul, foi categorizada como de baixa prioridade de gestão ($\text{IPGP} > 2,5$), apresentando o melhor desempenho ambiental e operacional do conjunto analisado.



Potencial turístico: local (LOC), regional (REG) e nacional (NAC)

*Praia Bandeira Azul

Figura 3. Classificação da prioridade de gestão de praias com base no Índice de Prioridade de Gestão (IPG). As praias estão ordenadas em alta Prioridade ($\text{IPG} \leq 2,0$), média Prioridade ($2,0 < \text{IPG} \leq 2,5$) e baixa Prioridade ($\text{IPG} > 2,5$), com linhas tracejadas verticais indicando os limiares.

4. DISCUSSÃO

Os resultados indicam que praias de alta popularidade, classificadas com potencial turístico nacional ou internacional, não correspondem necessariamente às áreas mais urgentes de manejo. As maiores prioridades de gestão estão concentradas nas praias que apresentam sobrecarga turística, evidenciando que a pressão desta sobrecarga e de manejo exerce maior influência sobre a necessidade de intervenção na gestão do que o desempenho do potencial turístico das praias.

Praias com grande extensão de orla e de faixa arenosa, mesmo sem apresentar sobrecarga turística, como Guaxindiba, Grussaí e Farol, apresentam riscos decorrentes da ausência de infraestrutura básica, iluminação inadequada e gestão deficiente de resíduos sólidos (Brasil, 2019). A gestão dessas áreas deve priorizar a requalificação da paisagem costeira, restauração da vegetação nativa e melhoria dos serviços essenciais, elementos indispensáveis para a atratividade e a sustentabilidade local (Zamith and Scarano, 2006; Diniz et al. 2022).

Já nas praias de maior fluxo turístico como as praias do Morro, Costa Azul, Sereia e João Fernandes, as estratégias devem concentrar-se em programas permanentes de educação ambiental e fiscalização de atividades ilegais, considerando que a intensidade das atividades turísticas é o principal fator determinante da magnitude dos impactos (Budiantoro et al., 2019; Pavón, 2023; Diniz et al., 2025). Praias de alta densidade de uso e baixa capacidade de gestão, como João Fernandes, área protegida desde 2009, mostra as vulnerabilidades típicas dos chamados “parques de papel” (*paper parks*), nos quais a existência formal de instrumentos de proteção não se traduz em efetividade de manejo (Relano e Pauly, 2023). Esses casos ressaltam a importância de fortalecer a governança e o financiamento das áreas protegidas, assegurando recursos humanos e técnicos para a implementação de ações de monitoramento, fiscalização e recuperação ambiental (Motta et al., 2021).

No índice proposto de integração, a Praia do Perú apresentou baixa prioridade de gestão, mantendo a certificação Bandeira Azul há sete temporadas consecutivas, indicando eficiência operacional e aderência a padrões internacionais de qualidade ambiental (Blue Flag, 2025). Em diferentes destinos, a adoção do selo tende a consolidar a conformidade com requisitos mínimos legais e padrões de qualidade, associando-se a alta fidelidade dos gestores à premiação (Fraguell et al., 2015). Em contextos com lacunas de capacidade técnica na gestão de praias, como o brasileiro, os critérios do programa podem funcionar como referencial mínimo de boas práticas; já em países com ampla conformidade prévia, como o Canadá, Espanha e Portugal a certificação frequentemente assume papel predominantemente promocional de *marketing* (Dodds e Holmes, 2020; Botero e Zielinski, 2020).

A Praia da Sereia, única no Espírito Santo a obter o selo por duas temporadas (2021/2022–2022/2023), perdeu a certificação por não atender aos parâmetros de qualidade da água. Concomitantemente, registrou sobrecarga turística (densidade <

5 m² por usuário), indicador não contemplado pelos critérios do programa, o que limita sua utilidade como instrumento de gestão da pressão de uso. A recomendação é complementar a certificação com outras estratégias de gestão, como zoneamento de uso e espaço e restauração ecológica. Somente a certificação não assegura a integridade ecológica das praias (Fraguell et al., 2016; Gilburn, 2012).

As categorias prioritárias de gestão evidenciaram fragilidades no cumprimento de critérios de educação e informação ambiental em todas as praias analisadas. Embora a certificação Bandeira Azul inclua, entre seus critérios obrigatórios, a promoção de atividades de educação ambiental, observou-se que praias certificadas não alcançaram pontuações elevadas nesse componente (Bandeira Azul, 2025). Essa discrepância indica que a conformidade formal com a certificação não assegura a efetividade das ações educativas, sugerindo priorização de critérios estruturais e de balneabilidade em detrimento de dimensões sociais (Lucrezi et al., 2016; McKenna et al., 2011). No contexto brasileiro, ações de educação e sensibilização ambiental em praias são frequentemente conduzidas por universidades, por meio de projetos de extensão e por organizações da sociedade civil com forte participação voluntária; exemplos incluem o Projeto TAMAR (Fundação Projeto Tamar, 2025), com centros de visitantes e programas contínuos de sensibilização, e iniciativas de ONGs marinhas como Projeto Albatroz (Projeto Albatroz, 2025) e Instituto Baleia Jubarte, voltadas à educação e à cultura oceânica (Instituto Baleia Jubarte, 2025).

Diferenças entre as pontuações do cenário costeiro atribuídas por especialistas e por visitantes evidenciam vieses de superestimação ou subestimação, capazes de obscurecer impactos mensuráveis ou, inversamente, revelar dimensões sociais não captadas por indicadores técnicos (Roca e Villares, 2008; Sahabuddin et al., 2024). Entre os determinantes de viés positivo, destacam-se a popularidade do destino, a qualidade cênica e o apego afetivo a locais de uso regular, como as praias selecionadas neste estudo de potencial turístico local, majoritariamente frequentadas por residentes, fatores que elevam a atratividade percebida mesmo diante de evidências de degradação (Pranzini et al., 2010; Akgün et al., 2020; Mestanza-Ramón et al., 2020). Há também a tendência de valorizar praias de águas mais claras, frequentemente interpretadas como ecologicamente preservadas, o que pode induzir julgamentos equivocados, como é o caso das praias analisadas com potencial turístico nacional/internacional (Botero et al., 2014; Dadon, 2018; Pon et al., 2022).

Diante de lacunas operacionais e estruturais na governança costeira, uma abordagem multidimensional que integre aspectos ambientais, ecológicos e sociais se mostra essencial para orientar decisões baseadas em evidências. No Brasil, o Projeto Orla, principal instrumento de ordenamento da zona costeira, permanece limitado por fragmentação institucional, desigualdade na implementação e ausência de monitoramento contínuo (Monteiro-Neto e Neto, 2009; Bohrer et al., 2023). Paralelamente, o estabelecimento de Áreas Marinhas Protegidas (AMPs) tem se consolidado como a principal estratégia para a proteção de habitats sensíveis, como áreas de desova de tartarugas marinhas, alimentação de aves costeiras e suporte à pesca sustentável (Araujo et al., 2013; Ferreira et al., 2022). No entanto, a efetividade dessas unidades é comprometida pela escassez de recursos financeiros, baixa fiscalização e implementação em zonas de intenso apelo recreativo (Motta et al., 2021).

Nesse contexto, ferramentas de gestão baseadas em indicadores tornam-se fundamentais para apoiar o planejamento costeiro. O Índice de Prioridade de Gestão de Praias (IPGP) permite a alocação eficiente de recursos, a definição de prioridades e a implementação de estratégias preventivas voltadas à sustentabilidade e à resiliência dos ecossistemas praias. Essa abordagem alinha-se às diretrizes internacionais de gestão integrada de zonas costeiras, que recomendam instrumentos multidimensionais e baseados em evidências (Botero e Pereira, 2018; Cendrero et al., 2019).

Diversos índices internacionais reforçam o valor de ferramentas integradas de apoio à decisão. Os índices *Clean Coast Index* (CCI) (Alkalay et al., 2007), *Ocean Health Index* (Halpern et al., 2012), *Coastal Environmental Sustainability Index* (CESI) (Merlotto et al., 2025) e *Comprehensive Index for Beaches* (CIB) (Basurto-Cedeno et al., 2025) exemplificam modelos de avaliação que incorporam aspectos ecológicos, urbanísticos e de infraestrutura. Esses índices oferecem diagnósticos distintos e permitem análises comparáveis ao longo do tempo e entre diferentes regiões (Nardo et al., 2008). Embora sintetize múltiplas dimensões em um único escore, o IPGP proposto nessa abordagem multi-integrada possibilita uma interpretação holística dos dados, incluindo a capacidade de carga e os indicadores sociais, ambientais e ecológicos. Tal característica permite não apenas a priorização entre praias, mas também o planejamento de ações setoriais conforme as demandas específicas de cada componente em contextos locais. Reconhecer esses impactos no ecossistema

praiano é essencial para a implementação de soluções sustentáveis, conforme delineado na Agenda 2030 das Organização das Nações Unidas (Satterthwaite, 2016). No entanto, para alcançar essas aspirações globais, o compromisso e a ação dos governos locais são essenciais (Liu et al., 2018). O monitoramento dessas avaliações pode ser utilizado para acompanhar o progresso do desenvolvimento urbano sustentável na implementação da Agenda 2030 para o Desenvolvimento Sustentável (Gao et al., 2021).

5. CONCLUSÃO

Os resultados demonstraram que a prioridade de gestão das praias não está necessariamente vinculada ao seu potencial turístico ou à visibilidade do destino, mas emerge da interação entre a capacidade de carga e a qualidade ambiental. Praias com baixa capacidade de suporte, mesmo aquelas menos frequentadas, demandam maior atenção, pois se mostram mais suscetíveis a impactos ambientais e sociais decorrentes da intensificação do uso e de limitações estruturais. A alta prioridade de gestão foi particularmente observada em praias com faixa de areia e orla estreitas, como as praias João Fernandes (RJ), Sereia e Costa Azul (ES).

Entre os componentes avaliados, conforto e qualidade da água apresentaram os melhores desempenhos, enquanto segurança, serviços, infraestrutura, educação e informação ambiental indicaram alta prioridade de gestão, inclusive em praias com certificação internacional, como Però (RJ) e Sereia (ES), o que requer ações imediatas do poder público. Esses achados reforçam a necessidade de que políticas de manejo costeiro transcendam métricas convencionais de popularidade ou certificações formais, adotando abordagens integradas e contextuais que considerem simultaneamente as dimensões física, ecológica e social das praias arenosas.

Nesse cenário, o Índice de Prioridade de Gestão de Praias (IPGP) se destaca como uma ferramenta científica e operacionalmente robusta para orientar decisões de manejo, subsidiar a alocação de recursos e promover estratégias preventivas de gestão costeira. Essa abordagem permite não apenas hierarquizar praias segundo a urgência de intervenção, mas também explicitar os fatores determinantes da prioridade, como sobrecarga de uso, qualidade da água, segurança, infraestrutura e práticas educativas.

Ao sintetizar múltiplas dimensões em um escore comparável, o IPGP favorece o monitoramento temporal da efetividade de políticas, possibilita comparações justas entre praias com perfis distintos e oferece comunicação clara para gestores, técnicos e sociedade. Ao mesmo tempo, sua decomposição por indicadores permite interpretações setoriais e planejamento específico, promovendo uma gestão mais adaptativa e baseada em evidências. O índice é replicável, adaptável a diferentes realidades costeiras e deve ser utilizado em conjunto com diagnósticos específicos, garantindo transparência metodológica, atualizações periódicas e maior efetividade na gestão integrada da zona costeira brasileira.

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APÊNDICES

Apêndice 1. Fatores de correção identificados como elementos limitantes ao uso turístico na capacidade de carga real (RCC) durante o período de 2019 a 2022.

Região / Praia	Fator Ambiental	Lmx	Tmx	Cf = 1 – (Lmx/Tmx)
REGIÃO CENTRAL – RJ				
Praia João Fernandes	Ausência de sol	4.406 h	8.760 h	0,50
	Precipitação	201 h	8.760 h	0,98
	Ventos fortes	2.767,5 h	8.760 h	0,68
	Maré	0,04 m	1,18 m	0,96
	Temperatura	15,1 °C	33,8 °C	0,55
Praia Grande	Ausência de sol	4.406 h	8.760 h	0,50
	Precipitação	201 h	8.760 h	0,98
	Ventos fortes	2.767,5 h	8.760 h	0,68
	Maré	0,06 m	1,08 m	0,94
	Temperatura	15,1 °C	33,8 °C	0,55
Praia do Perú	Ausência de sol	4.406 h	8.760 h	0,50
	Precipitação	201 h	8.760 h	0,98
	Ventos fortes	2.767,5 h	8.760 h	0,68
	Maré	0,06 m	1,08 m	0,94
	Temperatura	15,1 °C	33,8 °C	0,55
REGIÃO NORTE – RJ				
Praia de Guaxindiba	Ausência de sol	4.406 h	8.760 h	0,50
	Precipitação	201 h	8.760 h	0,98
	Ventos fortes	871 h	8.760 h	0,90
	Maré	0,29 m	1,54 m	0,81
	Temperatura	17,9 °C	32,1 °C	0,44
Praia de Grussaí	Ausência de sol	4.406 h	8.760 h	0,50
	Precipitação	201 h	8.760 h	0,98
	Ventos fortes	871 h	8.760 h	0,90
	Maré	0,28 m	1,41 m	0,80
	Temperatura	17,9 °C	32,1 °C	0,44
Farol de São Thomé	Ausência de sol	4.406 h	8.760 h	0,50
	Precipitação	201 h	8.760 h	0,98
	Ventos fortes	871 h	8.760 h	0,90
	Maré	0,26 m	1,46 m	0,82
	Temperatura	17,9 °C	32,1 °C	0,44
REGIÃO CENTRO-SUL – ES				
Praia de Costa Azul	Ausência de sol	4.406 h	8.760 h	0,50
	Precipitação	212 h	8.760 h	0,95
	Ventos fortes	1.226 h	8.760 h	0,93
	Maré	0,19 m	1,35 m	0,86
	Temperatura	19 °C	27,8 °C	0,32
Praia do Morro	Ausência de sol	4.406 h	8.760 h	0,50
	Precipitação	212 h	8.760 h	0,95
	Ventos fortes	1.226 h	8.760 h	0,93
	Maré	0,19 m	1,35 m	0,86
	Temperatura	19 °C	27,8 °C	0,32
Praia da Sereia	Ausência de sol	4.406 h	8.760 h	0,50
	Precipitação	212 h	8.760 h	0,95
	Ventos fortes	1.226 h	8.760 h	0,93
	Maré	0,19 m	1,38 m	0,86
	Temperatura	19 °C	27,8 °C	0,32

Apêndice 2. Indicadores de Avaliação do Cenário Costeiro, adaptados de Leatherman (1997) e Peña-Alonso et al. (2018), com classificação e método de avaliação.^b Indicadores alinhados ao Programa Bandeira Azul (Blue Flag, 2021) e ^o Indicadores em consonância com o Projeto Orla (MMA, 2006; Brasil, 2022).

INDICADORES	1 (Baixo)	2 (Intermediário)	3 (Alto)	Método
ACESSIBILIDADE				
1. Instalações para pessoas com necessidades especiais	Ausente	Insuficiente	Adequado	Observação direta
2. Banheiros acessíveis para pessoas com necessidades especiais	Ausente	Presente e inadequado	Presente e adequado	Observação direta
3. Estruturas antrópicas que impedem a mobilidade dos visitantes	Alto	Baixo	Ausente	Observação direta
4. Declividade da da praia	> 10°	5° - 10°	< 5°	Nível de mão / Régua
5. Desnível para a praia	Irregular com escada ou rampa inadequada	Irregular com escada ou rampa adequada	Superfície suave/plana	Observação direta
6. Acesso à praia	Sem acesso	Inadequado (Não pavimentado)	Adequado (Pavimentado)	Observação direta
7. Transporte Público	Ausente	Inadequado	Adequado	Observação direta
8. Vagas de estacionamento reservadas para pessoas com necessidades especiais e idosos	Ausente	Baixo	Alto	Observação direta
9. Ciclovias	Ausente	Inadequado	Adequado	Observação direta
10. Vias de pedestres / Calçada	Ausente	Inadequado	Adequado	Observação direta
11. Formações naturais que afetam a acessibilidade (ex: arenitos de praia)	Ausente	Baixo	Ausente*	Observação direta
QUALIDADE AMBIENTAL				
12. Odores desagradáveis	Forte	Detectável	Ausente	Observação direta
13. Presença de animais mortos (peixes ou outros organismos)	Frequente	Ocasionalmente presente	Ausente	Relatórios ou registros oficiais
14. Ruído (Tráfego de Veículos e Música Alta)	Alto	Médio	Baixo	Observação direta
15. Cobertura vegetal após uso da praia	Sem vegetação em mais de 50% da extensão	Vegetação exótica (não nativa) cobrindo mais de 50% da extensão	Vegetação nativa cobrindo mais de 50% da extensão	Observação direta
16. Ecossistemas costeiros (recifes de coral, dunas, manguezais e restinga)	Ausente	Presença de um ecossistema	Presença de pelo menos dois ecossistemas	Secretária de Meio Ambiente/turismo
17. Monitoramento de ecossistemas associados à praia	Ausente	Insuficiente	Adequado	Secretária de Meio Ambiente/turismo
18. Organismos Urticantes (Águas-vivas/Caravelas)	Frequente	Ocasionalmente presente	Ausente	Guarda-vidas

19. Aplicação de leis e regulamentos	Ausente	Presente e inadequado	Presente e adequado	Secretária de Meio Ambiente/turismo
20. Comitê de gestão específico da praia	Ausente	Presente e inespecífico	Presente e específico	Secretária de Meio Ambiente/turismo
QUALIDADE DA ÁGUA				
21. Qualidade microbiana da água	> 400 NMP/100ml	100-400 NMP/100 ml	< 100 NMP/100 ml	www.inea.rj.gov.br
22. Óleo na praia ou na água	Frequente	Ocasionalmente presente	Ausente	Guarda-vidas
23. Resíduos flutuantes (madeira, plástico, vidro, borracha ou outros)	Frequente	Ocasionalmente presente	Ausente	Guarda-vidas
24. Monitoramento de parâmetros físico-químicos da água	Ausente	Irregular	Regular	Secretária de Meio Ambiente/turismo
25. Frequência do monitoramento da qualidade da água	Ausente	Inapropriado	Mensal	www.inea.rj.gov.br
26. Maré vermelha	Frequente	Ocasionalmente presente	Ausente	Notícias ou registros oficiais
CONFORTO				
27. Ondas grandes (> 1m) quebrando diretamente na face da praia	Frequente	Ocasionalmente presente	Ausente	Observação direta
28. Sedimento na face da praia	Rochas ou argila	Seixos, grânulos, areia grossa	Areia fina ou média	Observação direta
29. Largura da face da praia na maré baixa	Estreita (<10m)	Intermediária (10 - 30m)	Larga (>30m)	Observação direta
30. Sedimento na zona de banho	Cascalho	Areia grossa	Areia fina ou média	Observação direta
31. Competição pelo uso irrestrito da praia (ex: pescadores, velejadores e esportistas)	Alta	Média	Baixa	Observação direta
32. Amplitude de maré	Grande (>3m)	Intermediária (1-3m)	Pequena (<1m)	Tábua de marés
33. Temperatura da água	<21°C	21-24°C	>24°C	portal.inmet.gov.br
34. Zonas de banho	Praia exposta	Parcialmente abrigada	Praia abrigada	Observação direta
35. Algas na areia ou na coluna d'água	Frequente	Baixa quantidade	Ausente	Observação direta
QUALIDADE CÊNICA				
36. Tipologia da orla em termos de urbanização	Urbanização consolidada	Em processo de urbanização	Sem urbanização	Observação direta
37. Vulnerabilidade à erosão costeira	Alta	Média	Baixa	Especialista
38. Estruturas Permanentes	Na área de pós-praia (post-beach)	Na zona costeira adjacente ao pós-praia	Ausente	Observação direta
39. Coloração do sedimento da praia	Escuro	Amarelo	Claro (Branco)	Observação direta

40. Turbidez da água	< 0,5 metros	1 - 0,5 metros	> 1 metro	Disco de Secchi
SERVIÇOS E INFRAESTRUTURA				
41. Instalações sanitárias em boas condições de higiene	Ausente	Presente e inadequado	Presente e adequado	Observação direta
42. Número de Instalações Sanitárias	Ausente	Insuficiente	Adequado	Observação direta
43. Instalações sanitárias com descarte adequado de resíduos	Ausente	Presente e inadequado	Presente e adequado	Observação direta
44. Chuveiros e bebedouros	Ausente	Presente e insuficiente	Presente e suficiente	Observação direta
45. Acampamento não autorizado, circulação de veículos ou despejo de entulho	Alto	Baixo	Ausente	Observação direta
46. Lanchonetes, bares e restaurantes	Ausente	Insuficiente	Adequado	Observação direta
47. Opções de hospedagem	Ausente	Insuficiente	Adequado	Observação direta
48. Estacionamento	Ausente	Inadequado	Adequado	Observação direta
49. Instalações recreativas (ex: quadras e aluguel de caiaques)	Ausente	Presente e insuficiente	Presente e suficiente	Observação direta
50. Lixeiras	Ausente	Baixo (Poucas)	Adequado	Observação direta
51. Lixeiras de reciclagem (Coleta Seletiva)	Ausente	Presente e insuficiente	Presente e suficiente	Observação direta
52. Limpeza da praia	Ausente	Irregular	Regular	Secretária de Meio Ambiente/turismo
53. Limpeza de detritos naturais ou algas/sargaço	Regular	Ausente	Irregular	Secretária de Meio Ambiente/turismo
54. Descarga de águas residuais, industriais ou urbanas	Alto	Baixo	Ausente	Observação direta
55. Acúmulo de lixo	Alto	Baixo	Ausente	Observação direta
56. Cães e outros animais domésticos	Frequente	Baixo	Ausente	Observação direta
57. Estado de conservação das edificações	Sem manutenção	Manutenção irregular	Manutenção regular	Observação direta
SEGURANÇA				
58. Guarda-vidas	Ausente	Insuficiente	Adequado	Observação direta
59. Equipamento de primeiros socorros	Ausente	Inadequado	Adequado	Guarda-vidas
60. Policiais / Policiamento	Ausente	Insuficiente	Frequente	Observação direta
61. Correntes de retorno (Rip currents)	Frequente	Ocasionalmente presente	Ausente	Guarda-vidas
62. Sistema de alerta público se a praia se tornar insegura	Ausente	Presente e inadequado	Presente e adequado	Secretária de Meio Ambiente/turismo
63. Planos de emergência para lidar com riscos de acidentes ambientais	Ausente	Presente e inadequado	Presente e adequado	Secretária de Meio Ambiente/turismo
64. Zoneamento para banhistas, nadadores, surfistas e usuários de embarcações motorizadas	Ausente	Presente e inadequado	Presente e adequado	Secretária de Meio Ambiente/turismo

65. Atividades de educação ambiental oferecidas aos frequentadores	Ausente	Irregular	Regular	Secretária de Meio Ambiente/turismo
66. Informações atuais sobre a qualidade da água exibidas em placas informativas	Ausente	Presente e inadequado	Presente e adequado	Observação direta
67. Informações sobre ecossistemas locais, fenômenos naturais, áreas naturais sensíveis e áreas culturalmente significativas em placas informativas	Ausente	Presente e inadequado	Presente e adequado	Observação direta
68. Mapa da praia	Ausente	Presente e inadequado	Presente e adequado	Observação direta
69. Código de conduta exibido em placas informativas	Ausente	Presente e inadequado	Presente e adequado	Observação direta

Apêndice 3. Os indicadores de qualidade cênica costeira foram utilizados para avaliar a capacidade de gestão de nove praias: João Fernandes (FER), Praia Grande (GRA), Però (PER), Guaxindiba (GUA), Grussaí (GRU), Farol de São Thomé (FAR), Costa Azul (COS), Morro (MOR) e Sereia (SER). A classificação das categorias de qualidade cênica costeira foi determinada com base na média dos indicadores avaliados, categorizada como baixa (0,33 a 0,55), intermediária (0,56 a 0,77) ou alta (0,78 a 1) (Diniz et al., 2022). ^b Os indicadores estão alinhados ao Programa Bandeira Azul (Blue Flag, 2019) e ^o ao Projeto Orla (MMA, 2006).

INDICADORES	FER	GRA	PER	GUA	GRU	FAR	COS	MOR	SER
ACESSIBILIDADE	0,55	0,85	0,76	0,58	0,76	0,7	0,79	0,94	0,91
1. Instalações para Pessoas com Necessidades Especiais	1	2	2	1	2	1	2	3	3
2. Banheiros Acessíveis para Pessoas com Necessidades Especiais	1	1	2	1	1	1	2	3	3
3. Estruturas Antrópicas que Impedem a Mobilidade dos Visitantes	1	3	3	3	3	3	2	2	2
4. Declividade da face da praia	2	3	3	1	2	1	3	3	2
5. Desnível para a praia	1	2	2	3	3	3	2	2	2
6. Acesso à praia	3	3	3	2	3	3	3	3	3
7. Transporte Público	3	3	3	2	3	3	3	3	3
8. Vagas de Estacionamento Reservadas para Pessoas com Deficiência e Idosos	1	2	2	1	2	1	2	3	3
9. Ciclovias	1	3	1	1	1	1	1	3	3
10. Vias de pedestres / Calçadão	1	3	1	1	2	3	3	3	3
11. Formações Naturais que Afetam a Acessibilidade (ex: Arenitos de praia)	3	3	3	3	3	3	3	3	3
QUALIDADE AMBIENTAL	0,67	0,81	0,81	0,52	0,7	0,78	0,74	0,7	0,74
12. Odores Desagradáveis	3	3	3	3	3	3	3	2	3
13. Presença de animais mortos (peixes ou outros organismos)	2	3	2	2	2	2	2	2	2
14. Ruído (Tráfego de Veículos e Música Alta)	3	1	2	2	2	2	2	2	2
15. Cobertura vegetal após uso da praia	1	3	3	1	1	2	1	1	1
16. Ecossistemas costeiros (recifes de coral, dunas, manguezais e restinga)	2	3	3	2	2	3	2	2	2
17. Monitoramento de Ecossistemas Associados à Praia	2	2	1	1	2	2	2	2	3
18. Organismos Urticantes (Águas-vivas)	1	2	2	1	3	2	2	2	2
19. Aplicação de leis e regulamentos	3	2	3	1	3	2	3	3	3
20. Comitê de gestão da praia	1	3	3	1	1	3	3	3	2
QUALIDADE DA ÁGUA	0,78	0,94	1	0,83	0,83	0,83	0,56	0,72	0,78
21. Qualidade microbiana da água	3	3	3	3	3	3	1	1	1
22. Óleo na praia ou na água	3	3	3	3	3	2	2	2	2
23. Resíduos flutuantes (madeira, plástico, vidro, borracha, etc.)	1	3	3	2	2	2	2	2	2
24. Monitoramento de parâmetros físico-químicos da água	1	3	3	1	1	2	1	3	3

25. Frequência do monitoramento da qualidade da água	3	3	3	3	3	3	1	2	3
26. Maré vermelha	3	2	3	3	3	3	3	3	3
CONFORTO	0,74	0,85	0,81	0,85	0,81	0,81	0,74	0,7	0,78
27. Ondas grandes (> 1m) quebrando diretamente na face da praia	3	3	3	3	2	2	2	2	2
28. Sedimento na face da praia	3	3	3	3	3	3	3	3	3
29. Largura da face da praia na maré baixa	1	3	2	3	3	3	2	2	2
30. Sedimento na zona de banho	3	3	3	3	3	3	3	3	3
31. Competição pelo uso irrestrito da praia (ex: pescadores, velejadores, esportistas)	1	3	3	3	3	3	1	1	2
32. Amplitude de maré	2	2	2	2	2	2	2	2	2
33. Temperatura da água	2	2	2	3	3	3	2	2	2
34. Zonas de banho	2	1	1	2	1	1	3	2	3
35. Algas na areia ou na coluna d'água	3	3	3	1	2	2	2	2	2
QUALIDADE CÊNICA	0,67	0,73	0,8	0,6	0,6	0,53	0,53	0,6	0,67
36. Tipologia da orla em termos de urbanização	1	1	2	2	2	2	1	1	1
37. Vulnerabilidade à erosão costeira	3	3	3	3	3	2	2	3	3
38. Estruturas Permanentes	1	1	1	1	1	1	1	1	1
39. Coloração do sedimento da praia	2	3	3	2	2	2	2	2	2
40. Turbidez da água	3	3	3	1	1	1	2	2	3
SERVIÇOS E INFRAESTRUTURA	0,69	0,75	0,8	0,57	0,59	0,69	0,73	0,82	0,84
41. Instalações sanitárias em boas condições de higiene	1	2	3	1	1	1	3	2	2
42. Número de Instalações Sanitárias	1	3	3	1	1	1	2	3	2
43. Instalações sanitárias com descarte adequado de resíduos	1	1	3	1	1	1	3	3	2
44. Chuveiros e bebedouros	1	2	2	1	1	2	2	2	2
45. Acampamento não autorizado, circulação de veículos ou despejo de entulho	2	2	3	2	2	2	2	3	3
46. Lanchonetes, bares e restaurantes	3	3	3	3	2	3	3	3	3
47. Opções de hospedagem	3	3	3	3	2	3	3	3	3
48. Estacionamento	2	2	3	1	3	3	2	2	3
49. Instalações recreativas (ex: quadras e aluguel de caiaques)	3	3	1	2	1	2	2	2	3
50. Lixeiras	2	2	2	2	2	2	2	2	3
51. Lixeiras de reciclagem (Coleta Seletiva)	1	1	1	1	1	1	1	2	2
52. Limpeza da praia	3	2	3	2	3	3	3	3	3
53. Limpeza de detritos naturais ou algas/sargaço	3	2	1	2	1	2	1	2	1
54. Descarga de águas residuais, industriais ou urbanas	2	3	3	2	2	2	2	2	3
55. Acúmulo de lixo	3	3	3	3	3	3	2	2	2
56. Cães e outros animais domésticos	2	1	1	1	1	1	2	3	3
57. Estado de conservação das edificações	2	3	3	1	3	3	2	3	3

SEGURANÇA	0,48	0,38	0,71	0,52	0,57	0,71	0,52	0,71	0,86
58. Guarda-vidas	1	2	2	2	2	2	1	3	3
59. Equipamento de primeiros socorros	1	1	1	1	2	2	1	1	1
60. Policiais / Policiamento	1	1	2	2	2	3	3	3	3
61. Correntes de retorno	3	1	1	3	2	2	2	3	3
62. Sistema de alerta público se a praia se tornar insegura	1	1	3	1	1	3	1	1	3
63. Planos de emergência para lidar com riscos de acidentes ambientais	2	1	3	1	2	2	1	3	3
64. Zoneamento para banhistas, nadadores, surfistas e usuários de embarcações motorizadas	1	1	3	1	1	1	2	1	2
EDUCAÇÃO E INFORMAÇÃO AMBIENTAL	0,33	0,6	0,93	0,47	0,53	0,47	0,4	0,47	0,87
65. Atividades de educação ambiental oferecidas aos frequentadores	1	3	3	2	2	2	1	3	3
66. Informações atuais sobre a qualidade da água exibidas em placas informativas	1	1	2	1	1	1	2	1	3
67. Informações sobre ecossistemas locais, fenômenos naturais, áreas naturais sensíveis e áreas culturalmente significativas em placas	1	2	3	2	2	2	1	1	1
68. Mapa da praia	1	1	3	1	1	1	1	1	3
69. Código de conduta exibido em placas informativas	1	2	3	1	2	1	1	1	3
ÍNDICE GERAL DE QUALIDADE DO CENÁRIO COSTEIRO	0,63	0,75	0,82	0,61	0,68	0,71	0,67	0,75	0,82

Apêndice 4. A extensão da linha de costa (área total e zona de recreação), a capacidade máxima de usuários com base na capacidade de carga física (CCF) e a capacidade de carga real (CCR) das praias analisadas foram avaliadas. Essa avaliação considerou cenários com um usuário por 5 m² e 10 m².

Praia / Região	Área (m²)	CCF 1 usuário/ 5 m²	CCF 1 usuário/10 m²	CCR 1 usuário/ 5 m²	CCR 1 usuário/ 10 m²
REGIÃO CENTRAL SUL – ES					
Costa Azul Beach (TA)*	9.800	5.880	2.940	715	357
Sereia Beach (TA)*	13.590	8.154	4.077	991	496
Morro Beach (TA)*	105.280	63.168	31.584	7.679	3.840
REGIÃO CENTRAL – RJ					
João Fernandes Beach (TA)*	5.457	3.274	1.637	576	288
Peró Beach (TA)	112.478	67.487	33.743	2.212	1.106
Peró Beach (RA)	21.401	12.840	6.420	11.626	5.813
Praia Grande Beach (TA)	566.404	424.803	169.921	15.783	7.892
Praia Grande Beach (RA)	152.706	91.624	45.812	73.178	29.271
REGIÃO NORTE – RJ					
Guaxindiba Beach (TA)	141.798	85.079	42.539	4.679	2.339
Guaxindiba Beach (RA)	49.615	29.769	14.884	14.872	6.685
Grussaí Beach (TA)	609.328	365.597	182.798	52.440	8.242
Grussaí Beach (RA)	174.799	104.879	52.440	182.798	28.731
Farol de São Thomé Beach (TA)	700.000	420.000	210.000	63.877	10.163
Farol de São Thomé Beach (RA)	212.924	127.754	63.877	210.000	33.414

* Todo o comprimento da praia é utilizado para recreação.

TA = Área total

RA = Área de recreação

Considerações finais

Esta tese demonstra que a sustentabilidade do uso recreativo em praias arenosas requer uma abordagem integrada e adaptativa, estruturada em três eixos complementares de manejo: Capacidade de Carga Turística (CCT), avaliação técnica do cenário costeiro e percepção dos frequentadores de praia. No Capítulo 1, observou-se, no panorama internacional, crescimento consistente das publicações sobre CCT ao longo do tempo. Contudo, a literatura permanece majoritariamente centrada no número de visitantes e no cálculo da capacidade de carga física, com limitada tradução desses limites em soluções operacionais de gestão. A síntese apresentada nesta tese organiza um conjunto global de estratégias para mitigação da sobrecarga e oferece orientações práticas imediatas para gestores e pesquisadores, favorecendo a implementação de ações baseadas em evidências.

Integrando a Capacidade de Carga Turística (CCT) à avaliação do cenário costeiro em nove praias do Sudeste do Brasil, identificou-se, no Capítulo 2, que nas praias do Morro, João Fernandes, Costa Azul e Sereia, os valores recomendados de CCT ficaram abaixo dos fluxos reais de verão, caracterizando sobrecarga turística. Em João Fernandes, Costa Azul e Guaxindiba, a baixa capacidade de manejo (serviços e infraestrutura) exige o fortalecimento da governança e cooperação interinstitucional, envolvendo esferas federais, universidades e organizações do terceiro setor, para atender critérios ambientais e de infraestrutura ainda pendentes. Observou-se que a adoção de padrões claros e monitorados, como os preconizados pelo Programa Bandeira Azul, associa-se a desempenho relativamente superior, exemplificado pela Praia do Perú e Sereia, sem, contudo, dispensar investimentos estruturais contínuos. Em conjunto, os achados oferecem base metodológica replicável para orientar estratégias de manejo sustentável de praias no Brasil e em outros contextos costeiros.

No Capítulo 3, na interface ambiente-economia, demonstrou-se que a percepção dos visitantes é uma métrica válida e complementar às avaliações técnicas, sobretudo quando há convergência entre ambas; contudo, destinos de alta popularidade tendem a apresentar superestimação sistemática, capaz de mascarar impactos reais ou revelar dimensões socioculturais não capturadas por indicadores técnicos. Verificou-se diferenças entre turistas e residentes; a sensibilidade pública a resíduos sólidos foi, em geral, maior do que à aglomeração, e observou-se elevada tolerância à lotação mesmo em contextos de sobrecarga. Esses resultados exigem

cautela na interpretação de preferências, reforçam a necessidade de triangulação entre dados técnicos, percepção social e métricas de uso real e apontam oportunidades para mobilizar o turismo mediado por redes sociais como vetor de engajamento e educação ambiental, desde que articulado a ações comprováveis de conservação e à qualificação contínua de serviços.

O Capítulo 4 evidencia que a priorização de manejo não decorre da visibilidade do destino nem do potencial turístico declarado, mas emerge da interação entre capacidade de suporte e qualidade ambiental. Praias com baixa CCT, ainda que menos frequentadas, demandam atenção imediata em razão de maior vulnerabilidade a impactos ambientais e sociais. Entre os componentes avaliados, conforto e qualidade da água apresentaram melhor desempenho, ao passo que segurança, serviços, infraestrutura e educação/informação ambiental exibiram déficits que requerem ações prioritárias do poder público. Esses achados indicam que políticas de gestão costeira devem transcender métricas de popularidade e a mera obtenção de certificações, adotando abordagens integradas e contextuais que considerem, simultaneamente, dimensões físicas, ecológicas e sociais.

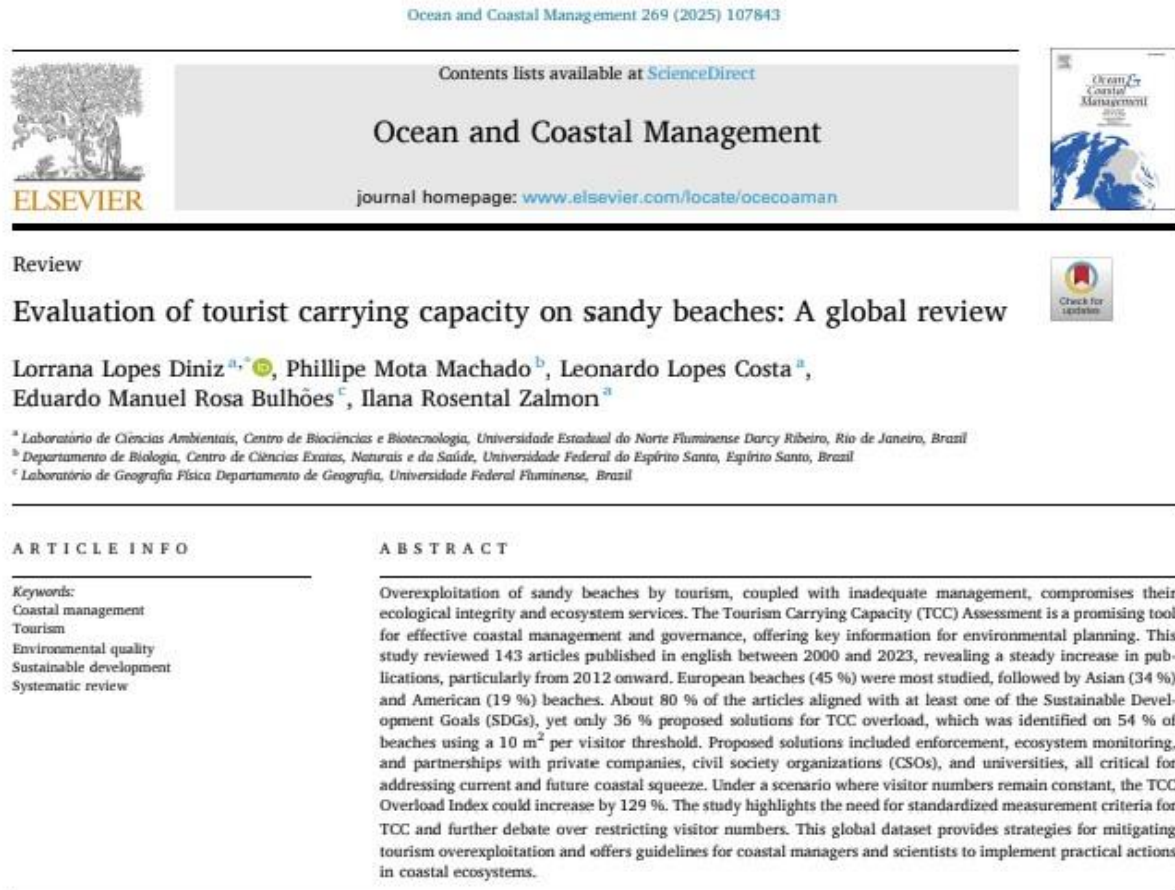
Como produto aplicado, o Índice de Prioridade de Gestão de Praias (IPGP) consolida-se como ferramenta científica operacional para a gestão costeira. Ao integrar capacidade de carga turística, avaliação técnico-ambiental do cenário costeiro e percepção dos visitantes, o IPGP hierarquiza praias segundo a urgência de intervenção e explicita os determinantes dessa prioridade (sobrecarga de uso, qualidade da água, segurança, infraestrutura e práticas educativas). Sua estrutura, passível de decomposição por indicadores, viabiliza diagnósticos setoriais e planejamento específico; adicionalmente, sustenta o monitoramento temporal da efetividade de políticas, permite comparações entre praias de perfis distintos e aprimora a comunicação com gestores, equipes técnicas e sociedade. Em conjunto, o IPGP favorece um manejo adaptativo, transparente e baseado em evidências.

Os resultados se traduzem em recomendações implementáveis: ajustar metas de ordenamento espacial, gerir fluxos e picos de visitação e alinhar as campanhas de promoção à capacidade efetiva de suporte e à disponibilidade de serviços e educação ambiental. Certificações como a Bandeira Azul devem operar como auxílio na gestão de melhoria contínua, integradas à CCT operacional, a rotinas de monitoramento permanente e à participação social. Quando CCT, qualidade do cenário costeiro e percepção dos visitantes são integradas, a gestão pública previne a sobrecarga

turística, reduz perdas econômicas e salvaguarda a base ecológica que sustenta o turismo de sol e praia. Este trabalho apresenta um diagnóstico integrado sensível às particularidades de cada praia, explicita critérios de prioridade de gestão, incorpora a percepção dos visitantes e propõe um processo de implementação replicável e adaptativo para a gestão da zona costeira.

ANEXOS

Anexo 1. Folha de rosto do artigo - Diniz, L. L., Machado, P. M., Costa, L. L., Bulhões, E. M. R., & Zalmon, I. R. (2025). Evaluation of tourist carrying capacity on sandy beaches: A global review. *Ocean & Coastal Management*, 269, 107843. <https://doi.org/10.1016/j.ocecoaman.2025.107843>



1. Introduction

Sandy beaches are rich in biodiversity and provide many ecosystem services, but they are suffering from inadequate conservation efforts. Human activities such as unplanned coastal urban development and the intensification of mass tourism have historically impacted the ecological integrity of these environments. All the social-ecological dimensions in the habitats of the Littoral Active Zone (LAZ), such as sandbanks, intertidal zones, and dunes, are now threatened (Mendoza-González et al., 2018; Fanini et al., 2021; Harris and Defeo, 2022). The lack of effective coastal management strategies, combined with the intensification of mass tourism, threatens the ecological integrity and coastal resources that attract tourists to beaches, creating a tourism paradox (Fanini et al., 2020; Defeo and Elliott, 2020).

In addition to long-standing issues like vehicle traffic (Schlacher and Thompson, 2007), trampling (Machado et al., 2017), vegetation suppression (Régo et al., 2018), and light and noise pollution negatively

impact the LAZ (Longcore and Rich, 2004; Aguilera and González, 2023). For instance, visitors react negatively to the presence of solid waste, despite the fact that beach users themselves are significant sources of pollution (Botero et al., 2013; Krelling et al., 2017). Another issue is overcrowding, which has led to increased tourist avoidance and sub-national economic losses (Zacarias et al., 2011; Krelling et al., 2017).

These pre-existing coastal challenges are now being compounded by the effects of climate change, which adds a new and increasingly urgent dimension to beach management. The physical dimensions of beaches determine the surface area available to users and the services provided, while morphodynamic processes will influence coastal use and exploration (Valdemoro and Jiménez, 2006). Climate change is affecting ocean dynamics in several ways, including warming waters, changes in average wave height (Casas-Prat and Sierra, 2013; O'Grady et al., 2021), rising sea levels and coastal squeeze (Nicholls and Cazenave, 2010; Palmer et al., 2021). As a result, the available surface area for recreation

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Anexo 2. Folha de rosto do artigo - Diniz, L. L., Machado, P. M., do Nascimento, A. B., Costa, L. L., da Costa, I. D., Cordeiro, C. A. M. M., & Zalmon, I. R. (2024). Evaluation of tourist carrying capacity to support recreational beaches management. *Ocean & Coastal Management*, 249, 107022. <https://doi.org/10.1016/j.ocecoaman.2024.107022>

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Evaluation of tourist carrying capacity to support recreational beaches management

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ABSTRACT

The overexploitation of sandy beaches by tourism reduces ecological integrity, rendering natural conditions unsatisfactory for the needs of the population and resulting in negative socio-economic impacts. In this context, the assessment of tourist carrying capacity aims to support beach management from a social, environmental, and economic perspective. The objective of this study was to estimate the tourist carrying capacity at nine beaches in the states of Rio de Janeiro (RJ) and Espírito Santo (ES), southeastern Brazil. The physical carrying capacity was calculated based on the available space for recreation in scenarios of one user per 5 m² and 10 m². Subsequently, limiting environmental factors for recreational use such as sunlight, precipitation, strong winds, tidal range, and temperature were considered, supporting the calculation of the tourist carrying capacity. For the calculation, management conditions (infrastructure and services) were estimated based on the scoring of 69 indicators, included in the international beach quality program called Blue Flag and in the main instrument for coastal management in Brazil, the Orla Project. At RJ beaches, the carrying capacity was not exceeded in the scenario of one user per 10 m², except in the central region with a higher tourist appeal. In ES state, the results indicated overload for all beaches in the central southern region; for example, one received six times more users than its tourist capacity. Overall, the highest percentages of management capacity were recorded at beaches with Blue Flag certification. The beaches that require the most improvements in coastal management are those located in regions with lower Human Development Index (HDI) and farther from major urban centers. The results suggest priority management actions and guide efforts towards potential beach certification. The management of services, infrastructure, and overload highlights the need for preventive measures to avoid the tourism paradox, including loss of environmental quality and revenue. Moreover, the flexibility of this evaluation tool allows for its application in beaches of any country. The integration of tourist carrying capacity and assessment of the coastal scenario provides a more comprehensive and effective framework for the sustainable management of beaches.

1. Introduction

Sandy beaches harbor a unique biodiversity and ecosystem services, primarily related to tourism (Harris and Defeo, 2022). However, tourist demand often disregards the conservation of marine fauna and ecosystems associated with the Active Littoral Zone (ALZ), such as beaches, tidal flats, and dunes (Mendoza-González et al., 2018; Fanini et al., 2021). Human interventions, including vehicle traffic (Schlacher and

Thompson, 2007), trampling (Scapini et al., 2005; Machado et al., 2017), vegetation suppression (Rego et al., 2018), introduction of exotic species, and light and noise pollution (Longcore and Rich, 2004; Aguilera and González, 2023), result in negative ecological impacts on the ALZ. Therefore, the lack of adequate coastal management strategies jeopardizes the ecological integrity and the coastal resources themselves that attract users to the beaches, constituting the tourism paradox (Fanini et al., 2020; Defeo and Elliott, 2020).

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Anexo 3. Folha de rosto do artigo - Diniz, L. L., Machado, P. M., Costa, L. L., Côgo, N. B., Madureira, J. F., & Zalmon, I. R. (2026). Visitors' perception, coastal scenery quality and tourism profitability on sandy beaches-Southeastern Brazil. *Marine Policy*, 187, 107065. <https://doi.org/10.1016/j.marpol.2026.107065>

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Full length article

Visitors' perception, coastal scenery quality and tourism profitability on sandy beaches - Southeastern Brazil

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ABSTRACT

Unmanaged coastal tourism threatens beach ecosystems across many tropical coastlines. Using 540 questionnaires from beaches in southeastern Brazilian beaches, we evaluated the relationships among visitors' perceptions, coastal scenery quality, and tourism profitability under scenarios of overcrowding and solid-waste pollution. The study covered nine beaches in the states of Rio de Janeiro (RJ) and Espírito Santo (ES), across three mesoregions with varying tourism potential (local, regional, and national/international). Visitors overestimated coastal scenery quality by 30 % compared to expert evaluations, especially on nationally famous beaches in Rio de Janeiro such as Praia Grande and João Fernandes. Overall, beachgoers showed more tolerance for overcrowding (51 % would still visit under the worst overcrowding scenario – 5 m² per person) than for pollution (70 % would avoid the beach with the worst solid waste scenario – 15 items per m²). Most were willing to change plans when faced with degraded settings. On locally attractive beaches, 74 % would consider changing to another regional destination, whereas on nationally attractive ones, 55 % would opt for a nearby site within the same municipality. Estimated municipal revenue losses from tourist displacement could reach US\$ 52 million per summer season in Praia Grande-RJ, located in the Região dos Lagos mesoregion. These findings underscore the socio-ecological value of beaches and the need for integrated management. Although recreational preferences may conflict with conservation goals, tourism influenced by social media presents an opportunity to support coastal management and foster environmental awareness among visitors.

1. Introduction

Sandy beaches, characterized by their unique biodiversity and the provision of various ecosystem services, particularly those related to tourism, face significant challenges due to the neglect of conservation in Active Coastal Zone (ACZ) habitats, including intertidal zones, and dunes along with their vegetation [27,32,48]. The lack of effective coastal management strategies compromises the ecological integrity and natural resources that support much of the touristic appeal of these areas [22]. Environmental management tools based on visitors' perceptions can complement technical assessments and support participatory coastal governance [1].

The coastal scenery quality of beaches, influenced by factors such as anthropogenic waste, visitor density, and infrastructure, is a critical

determinant of tourist choice and satisfaction [25,39]. An increase in the number of visitors can exceed the carrying capacity of tourist destinations, leading to degradation of the coastal landscape [17], reduced visitor comfort [78], increased noise levels, and competition for space usage [6]. The presence of litter negatively affects the natural aesthetic [77], lowers the perceived coastal scenery quality [31], and discourages visitation [41,52]. According to beachgoers in Europe [5], the United States, Mexico [13], and the Caribbean [8,61], litter is among the five most important indicators of beach quality and is also included among the big five beach quality indicators proposed by Williams and Micallef (2009) [76].

In general, the perception of beach environments varies across different socioeconomic groups and visitor types [54]. Residents tend to exhibit a stronger connection to the place, placing greater value on the

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