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Papua New Guinea
Nivaldo Piorski,
Federal University of Maranhão, Brazil

*CORRESPONDENCE

Maria Laura Fontelles Ternes
✉ marialaura.ft@gmail.com

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Local ecological knowledge provides important conservation guidelines for a threatened seahorse species in mangrove ecosystems

Maria Laura Fontelles Ternes^{1*}, Natalie V. Freret-Meurer^{2,3},
Rodolfo Leandro Nascimento⁴, Marcelo Derzi Vidal⁵
and Tommaso Giarrizzo^{1,6}

¹Aquatic Ecology and Fisheries Post-graduate Program, Núcleo de Ecologia Aquática e Pesca da Amazônia (NEAP), Universidade Federal do Pará, Belém, Brazil, ²Laboratório de Comportamento Animal e Conservação, Universidade Santa Úrsula, Rio de Janeiro, Brazil, ³Projeto Cavalos-Marinheiros/RJ, Rio de Janeiro, Brazil, ⁴TaxoN – Laboratório de poliqueta, Instituto de Biologia, Departamento de Zoologia, Universidade Federal do Rio de Janeiro, Rio de Janeiro, Brazil, ⁵Centro Nacional de Pesquisa e Conservação da Sociobiodiversidade Associada a Povos e Comunidades Tradicionais, Instituto Chico Mendes de Conservação da Biodiversidade, São Luís, Maranhão, Brazil, ⁶Instituto de Ciências do Mar (LABOMAR), Universidade Federal do Ceará, Fortaleza, Ceará, Brazil

Local Ecological Knowledge and social perceptions of human communities that depend on natural resources can provide important baseline information on local threats and impacts at a fine scale for conservation management. Seahorses play important economic role in Brazilian mangroves, being sought-after for seahorse-watching tours. This touristic activity is not yet formally regulated and our work is a contribution to seahorse-watching management at three study sites located in two Marine Protected Areas (MPAs) – Jericoacoara National Park, and Delta do Parnaíba Environmental Protection Area – in the Brazilian northeast states of Ceará, Piauí, and Maranhão. Through semi-structured interviews, we investigated the perception of seahorse-watching operators regarding seahorse abundance, local threats, and conservation insights in mangrove ecosystems. We interviewed all 38 existing informants at the study sites. Approximately half of the informants rely exclusively on seahorse-watching as an income source. Overall, 55.3% highlighted declines in seahorse abundance, 100% believed that seahorses are threatened with extinction. Silting (57.9%), fishing (55.3%), and pollution (37%) were cited as main threats to seahorses and mangroves. Among the proposed conservation actions, environmental surveillance (57.9%), zoning (26.3%), education (26.3%) were the most cited. Respondents support the MPAs but would like to see greater engagement of management institutions towards the communities, considering their local needs. Some differences in perception between communities reflect local realities and social contexts, which should be considered for conservation and management effectiveness. Our study contributes supporting this approach, as local scale studies on social perceptions can improve conservation and local management, especially for data-poor species.

KEYWORDS

Syngnathidae, *Hippocampus reidi*, tourism, management, threats, Jericoacoara National Park, Delta do Parnaíba Environmental Protection Area, Brazil

1 Introduction

Local Ecological Knowledge (LEK) and social perceptions from human communities that depend on the exploitation of natural resources for their subsistence can provide important baseline information when there is a lack of scientific data, informing threats and impacts at a finer scale that can help inform management activities (Bennett, 2016; Cortés-Avizanda et al., 2018; Cullen-Unsworth et al., 2018). Mangroves are sensitive coastal ecosystems that play a critical social and ecological role through the provisioning of vital ecosystem services, alongside being an important nursery environment for marine life (Ferreira and Lacerda, 2016). Among numerous species inhabiting mangroves, seahorses are considered a threatened flagship species for marine conservation. Human activities such as fishing, pollution and habitat degradation are responsible for seahorse declines worldwide (Foster and Vincent, 2004; Vincent et al., 2011; Zhang and Vincent, 2019). Seahorse conservation is urgent given the species depletion, besides human economic activities that depend on their presence in suitable habitats (Foster and Vincent, 2004; Vincent et al., 2011).

The long-snout seahorse (*Hippocampus reidi*) is a threatened species (MMA, Ministério do Meio Ambiente 2014) which plays an important economic role being sought-after for seahorse-watching tours on Brazilian mangroves (Ternes et al., 2016). Local communities offer boat tours inside mangrove areas for tourists to observe seahorses which are commonly found attached to mangrove roots. When found, seahorses are manually captured and transferred with water into a transparent glass recipient to be shown to tourists, and then they are returned to their natural environment. This activity is not yet formally regulated, and our study is a contribution for seahorse-watching management in

communities of two Marine Protected Areas (MPAs) in Brazil: Jericoacoara National Park (JNP) and Delta do Parnaíba Environmental Protection Area (DPEPA). Both MPAs are the home habitat of the long-snout seahorse, *Hippocampus reidi* (Mai and Rosa, 2009; Martins et al., 2022), and are equally extremely popular tourist destinations where local human communities depend on this species and the mangrove for touristic activities as an income source. Our study aimed to provide conservation guidelines for a threatened seahorse species in ecologically important mangrove ecosystems from the Northeastern Brazilian coast, investigating the perceptions of seahorse-watching operators regarding seahorse abundance trends, local threats, and conservation insights.

2 Method

2.1 Study site

This study focused on three sites on the northeastern Brazilian Atlantic coast where seahorse-watching takes place (states of Ceará, Piauí, and Maranhão), located within two MPAs: Jericoacoara National Park (JNP) and Delta do Parnaíba Environmental Protection Area (DPEPA) (Figure 1). JNP is a no-take protected area created in 2002, surrounding the Guriú River estuary (02°52'S; 40°34'W), bordering the municipalities of Jijoca de Jericoacoara and Camocim, in Ceará. DPEPA is a partially protected area created in 1996, encompassing the region of Cajueiro da Praia municipality in Piauí (02°55'S, 41°24'W), and Tutóia municipality in Maranhão (2°45'S, 42°16'W).

Both MPAs are 160km apart, but share common features, including mangroves, dunefields and sandy beaches with a tidal

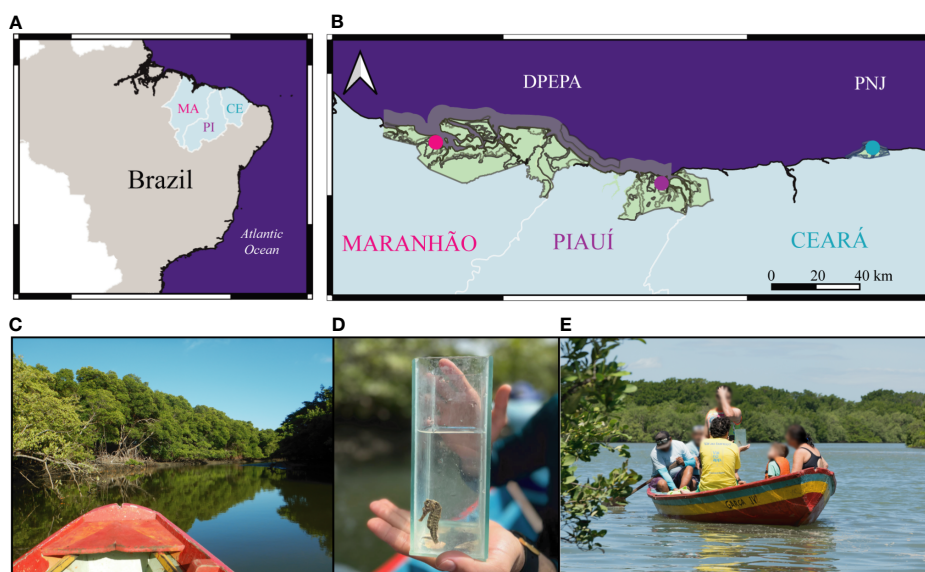


FIGURE 1

(A, B) Study areas, northeastern Brazil. PNJ, Jericoacoara Nacional Park. DPEPA, the Delta do Parnaíba Environmental Protection Area. Communities surveyed are represented by colored dots: Mangue Seco in the state of Ceará (turquoise), Cajueiro da Praia, in Piauí (violet), and Tutóia in Maranhão (pink). (C–E) seahorse-watching activities on mangroves.

amplitude of up to 3 meters. Wind velocities are high, driving erosion, transportation and deposition of sediment by strong wind (mean = 7.8 m.s⁻¹), with a dry season between August and December, and a rainy season from January through July (Hesp et al., 2009). The main economic activities are tourism, artisanal fishing, shrimp farming, and livestock.

2.2 Data collection

This ethnoecological study was approved by the Research Ethics Committee of Universidade Federal do Pará (CAAE 99615418.1.0000.0018) and authorized by Sistema de Autorização e Informação em Biodiversidade - SISBIO permits #56811-1 and #67298-1. Semi-structured interviews were applied individually under previous consent of each seahorse-watching operator in Ceará, Piauí and Maranhão. Following Ternes et al. (2016) our questionnaire encompassed the interviewee perceptions on seahorse abundance, local threats, and conservation insights.

2.3 Data analysis

We used word cloud to present the perception of threats to seahorses and their environment, as well as conservation insights by seahorse-watching operators for each locality. The method is a visual presentation distinguishing words more and less frequently used (McNaught and Lam, 2010), herein representing a pattern of shared ideas in response to the following questions: (1) What are the local threats to seahorses and their environment? and (2) What should be done to conserve seahorses and their environment? Responses were tabulated, and non-informative elements such as “stop words” were removed. Words were ranked by frequency of use. Analyses were carried out using the R software, v 4.0.3, packages “tm”, “wordcloud” (R Core Team, 2020). Responses were further summarized and fitted into categories to create a Venn Diagram for an integrative comparison, illustrating intersections and particularities between the study sites.

3 Results

3.1 Socioeconomic profile

We interviewed 38 informants encompassing 100% of the total 12 seahorse-watching operators in JNP in 2016 and 100% of the total 26 operators in DPEPA in 2019–2020. Seahorse-watching is a community-based tourism activity held in small and isolated coastal villages, carried out for just a few local operators, despite being situated in extremely popular tourist destinations. Interviewees were all male, age ranging from 16 to 50 years (mean = 32 ± 8.9 years ± s.d.), with seahorse-watching experience of 6–11 years in JNP (mean = 8.3 ± 3.0 years) and three months to 15 years in DPEPA (mean = 6.6 ± 4.6 years). Approximately half of the informants rely exclusively on seahorse-watching as an income source, while others even depending on this tourism

have also complementary economic activities (Table S1, Supplementary Material).

3.2 Perceptions on seahorse abundance trends

All informants believe seahorses are threatened and can become extinct. In general, most informants (55.3%, n = 21/38) highlighted population decline. This trend was reported by all Ceará and the majority of Piauí informants. Each estuary has its own particularities regarding natural dynamics and anthropogenic stressors, influencing abundance trend perceptions (Table S2, Supplementary Material).

3.3 Perceptions on local threats to seahorses and mangroves

The most cited threats among all informants (Figures 2, 3) were: silting in the mangrove (58% n = 22/38); anthropogenic impacts, such as fishing (55% n = 21/38, mostly illegal fishing); trash, mostly plastic (37% n = 14/38); motor boat impacts such as erosion from wake wash, oil, and noise (34% n = 13/38); shrimp farming (21% n = 8/38).

Regarding exclusive local perceptions (Figures 2A–C), Ceará reported fire in mangrove forests, seahorse population decline and lack of environmental surveillance as local threats. Piauí quoted uncontrolled urbanization, jet skis and diving in seahorse-watching area as also having impacts. Maranhão reported specific threats related to illegal/destructive fishing practices, including trawling and a regional, non-selective type of net, known as *zangaria*, which is used as a weir, with mesh size smaller than permitted by law (SUDEPE, 1988).

3.4 Conservation insights

Environmental surveillance (58% n = 22/38), zoning (26% n = 10/38), educational approaches towards conservation (26% n = 10/38), seahorse-watching tourism regulation (18% n = 7/38), and enhancement of seahorse populations and habitats (16% n = 6/38), were overall consensus categories of recommendation at all sites (Figure 4). Considering each study site reality, the need for scientific research through seahorse monitoring was highlighted in Ceará, actions against plastics pollution in Piauí, and the request for alternative income sources in Maranhão (Figures 2B, D, F).

4 Discussion

4.1 Perceptions on seahorse abundance trends

All informants believe seahorses are threatened and can go extinct, matching national and international red lists where

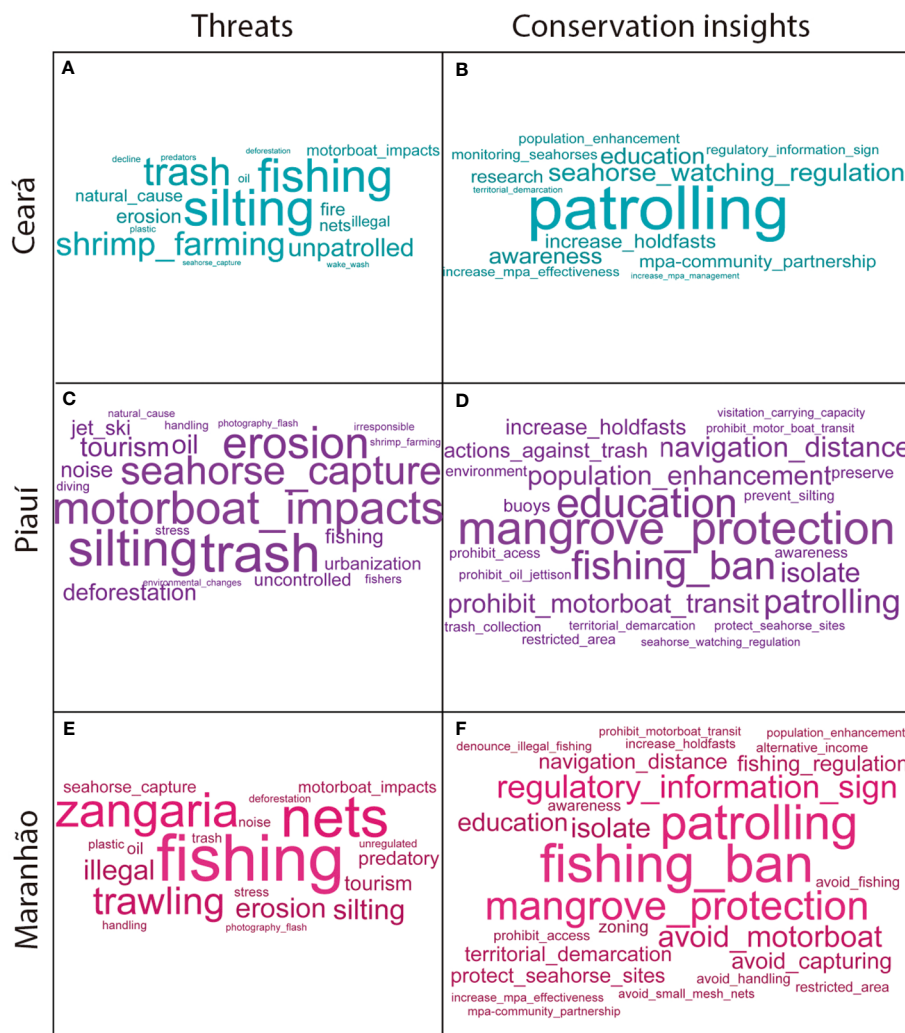


FIGURE 2 Word clouds based on interviewees’ perception of seahorse local threats (A) Ceará; (C) Piauí; (E) Maranhão) and insights for conservation (B) Ceará; (D) Piauí; (F) Maranhão). The word size represents its frequency of occurrence, larger words express main concerns.

Hippocampus reidi is under Vulnerable and Near Threatened categories, respectively (MMA ordinance 445/2014; IUCN 2017). For our study site, population assessments have been ongoing (Ternes et al. *in prep.*) to compare current population parameters with past biological data available from 2006 and 2007 (Mai and Rosa, 2009), suggesting current abundance declines, besides short-term variations also perceived by Piauí and Maranhão informants (Table S2).

4.2 Perceptions on local threats to seahorses and mangroves

The impacts perceived by the informants represent threats globally reported for seahorses (Foster and Vincent, 2004; Vincent et al., 2011). Brazil is the third country in mangrove extension on Earth, but aquaculture, urbanization, industrial

development among others, have devastated more than 50,000 ha of Brazilian mangroves over the past three decades (Ferreira and Lacerda, 2016). Seahorses are sedentary fish that rely on mangrove vegetation structures, such as roots and branches, as anchoring points (Foster and Vincent, 2004; Mai and Rosa, 2009). Habitat loss is herein represented by geological processes such as sand sedimentation onto mangrove areas, interpreted by interviewees as a coastal dynamics’ natural phenomenon (“natural cause” Figure 2), besides other anthropic impacts such as deforestation. Erosion of mangrove margins caused by wake wash from motor boat traffic, includes consequent noise perturbation and occasional oil spill that can negatively impact seahorses causing physiological/behavioral stress, and site abandonment (e.g., Palma et al., 2019; Delunardo et al., 2020).

The three most cited threats in our study - silting (habitat alteration), fishing, and pollution (trash) - correspond to the top three public perceptions of marine threats around the world (Lotze

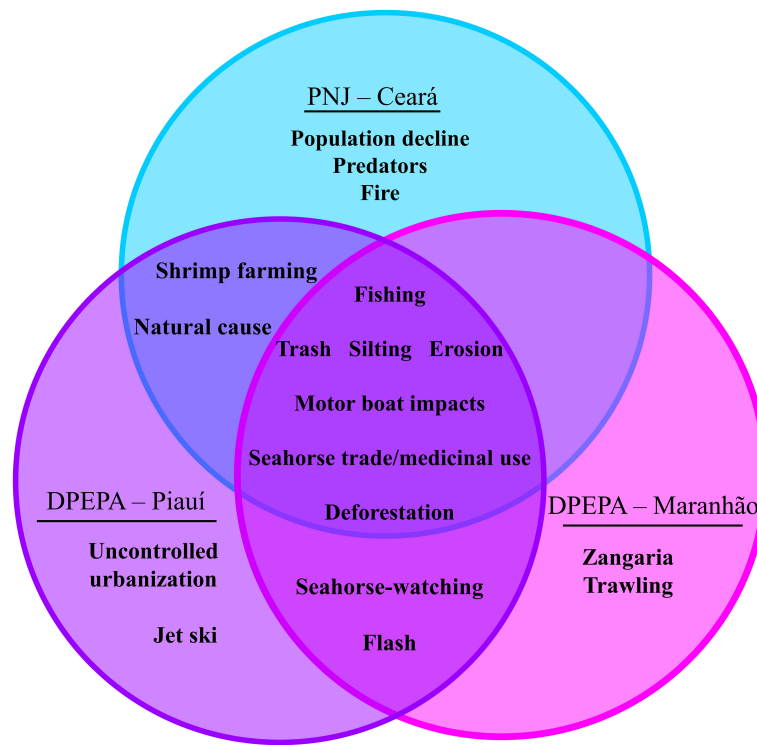


FIGURE 3
Venn diagram of principal categories of threat perceived by the informants, illustrating intersections and particularities between study sites.

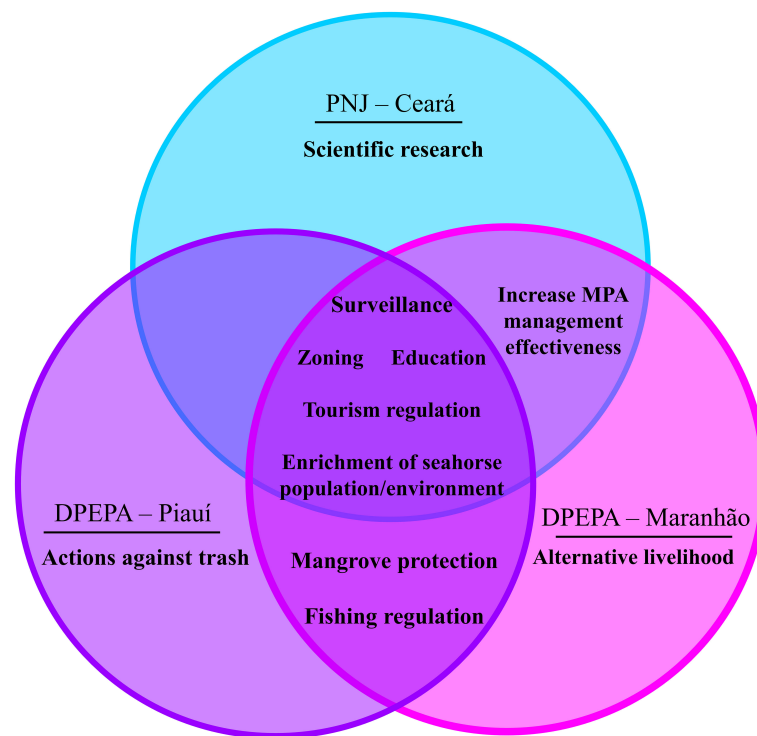


FIGURE 4
Venn Diagram of principal categories of conservation insights provided by the informants, illustrating intersections and particularities between study sites.

et al., 2018), reflecting global threats being locally reproduced. A cumulative human-impact study also highlighted fishing and pollution as most important anthropogenic stressors affecting seahorses worldwide (Zhang and Vincent, 2019).

In our study sites, there was a conflict related to fishing practices, mostly illegal and destructive (“predatory” Figure 2E), denouncing lack of both environmental surveillance (“unpatrolled” Figure 2A) and community compliance. In addition, all sites reported illegal seahorse capture for commercial or medicinal use, despite being prohibited by federal law since 2014 (MMA ordinance 445/2014). This could be driven by socioeconomic vulnerability or even unawareness towards fishing regulations in the two protected areas. In MPAs in developing countries such as Brazil, socioeconomic risks (i.e., poverty, social inequality, lack of basic rights such as education, health) are linked to dependency on natural resources, which exacerbates environmental threats (Oliveira-Júnior et al., 2021).

Marine pollution by plastics is an extremely visible environmental impact also emphasized by the media and environmental campaigns (Lotze et al., 2018). Seahorses are particularly vulnerable to an invisible consequence of that: microplastic pollution. Since newborn on early developing stages, seahorses can ingest microplastics, accumulating particles that may cause physical obstructions in their guts (Domínguez-López et al., 2022).

Shrimp farming is a sensitive issue on Ceará and Piauí (Figures 2A, C). Ceará informants witnessed massive mortality of fish in 2014 and during our data collection, when the estuary water became “milky”, and many fish, including seahorses, were found dead (authors’ pers. obs.). Informants linked this mortality to effluent discharge by an upstream shrimp farm. Major shrimp farming environmental impacts include effluents pollution, loss of ecosystem services, carbon storage depletion, biodiversity loss, also threatening the survival of local human populations that rely on mangrove ecosystem for subsistence (Lacerda et al., 2021). Many Brazilian shrimp farms were established prior to the creation of environmental regulations. The inefficiency of legislation compliance and lack of participatory environmental management including local communities, have aggravated the socio-environmental impacts of shrimp farming in Brazil (Silva-Júnior et al., 2020).

Mangrove deforestation in Brazil has already devastated 20% of this ecosystem (Souza et al., 2020) and this threat was highlighted in Piauí and Maranhão, both located in the same partially-protected MPA, reinforcing the need for management actions. Tourism and seahorse stress while being captured/handled were also addressed. Seahorse-watching impacts are still unclear, but it is likely that capture and confinement leads to stress and behavioral disruptions. For scuba diving tourism, divers touching *H. Reidi* or approaching them to within 36 cm caused the seahorses to abandon their holdfasts and escape (Giglio et al., 2018). Not all informants saw seahorse watching as a threat, as the case of Ceará interviewees that

were the most poorly literate and dependent group on seahorse-watching as an income source (Table S1), which may influence them not to question the sustainability of their activity. Maybe this could explain different perceptions, while Maranhão and Piauí share the highest scholarships and awareness. From a conservationist perspective, it is important that seahorse-watching operators are concerned about the sustainability of their activities, which can be explored as a universal concern, stimulating dialog among operators, researchers, and managers towards seahorse conservation (Ternes et al., 2016). Additionally, seahorse-watching impacts need to be investigated and mitigated, informing management actions.

4.3 Conservation insights

Environmental surveillance and educational interventions, claimed by all surveyed communities, are urgent to minimize conflicts and accomplish management and conservation goals (Figures 3B, D, F, 4). Enforcement of regulations is a priority frequently requested by MPA users around the world (Abecasis et al., 2013) and constant surveillance is an ostensive strategy to ensure this goal, while punishing illegalities. Environmental education programs (addressing seahorse conservation, mangrove protection, alternative livelihoods etc.) should be prioritized given that they can increase knowledge and engagement, contributing to compliance in MPAs (e.g., Leisher et al., 2012; Arias et al., 2015).

The need for actions towards management and regulation of seahorse-watching tourism were quoted in all sites, which is positive once these actions are mandatory for the exploitation of Vulnerable species, according to the Brazilian list of threatened species (MMA ordinance 445/2014). The Brazilian federal environmental agency – Instituto Chico Mendes de Conservação da Biodiversidade, ICMBio – is willing to regulate seahorse-watching in MPAs where this touristic activity previously exists, and our pioneer research is an important contribution. As a result, our study marked ICMBio’s rapprochement with seahorse-watching stakeholders in JNP and regulation is already in progress in this MPA (Martins et al., 2022).

Linked to regulation, informant from all sites highlighted the need for spatial zoning to safeguard their livelihoods and protect seahorses, through the demarcation of seahorse-watching sites as exclusive no-take areas for tourism, with warning signs informing regulations and prohibitions. Zoning is critical for management, delimiting areas for specific purposes, controlling human activities, mitigating conflicts between different uses (Herrera-Montes, 2018). For example, establishment of navigation distance and exclusion areas may be a practicable strategy for mitigating motor boat impacts (e.g., Palma et al., 2019).

Environmental enhancement (Figure 4) through artificial habitat structures can be effective for animal conservation against habitat loss and degradation impacts (Watchorn et al., 2022). Given the life history traits of seahorses (e.g., site fidelity, reduced mobility,

small home range), this strategy, has shown to successfully support populations of the endangered seahorse *H. whitei* in the absence of natural habitats (Simpson et al., 2020). Informants' suggestion of increasing holdfasts (Figures 2, 4) could be a suitable strategy facing habitat alterations. On the other hand, attempts to enhance seahorse stocks by releasing captive-bred individuals into the wild have revealed potential risks, including ecological impacts and loss of genetic diversity (e.g., Fraser, 2008; Luo et al., 2022). Therefore, its applicability should be cautiously discussed and investigated before any intervention. Most importantly, the causes of population decline must be addressed and mitigated as a priority (Fraser, 2008) and our study provides valuable information on local threats at a fine scale.

Fishing ban and mangrove protection were cited in Piauí and Maranhão (Figure 4). Both sites belong to DPEPA, a partially-protected MPA which is 35 times larger than PNJ, lacking no-take zones in the surveyed communities. Recently, a destructive fishing highlighted in Maranhão ("zangaria"), was officially banned in all DPEPA territories. This advance was supported by our study, which amplified stakeholders' voices, informing the MPA managers about zangaria impacts.

Ceará informants demonstrated awareness and interest in scientific research, such as seahorse population assessments, which is promising and should be implemented at all seahorse-watching sites, once the Brazilian list of threatened species requires it as mandatory for evaluating the sustainable exploitation of Vulnerable species (MMA ordinance 445/2014).

5 Conclusions and recommendations

Our study demonstrates seahorse-watching operators have a clear understanding that seahorses are threatened species, and that habitat alterations, fishing, and pollution are major threats shared among other local anthropogenic impacts. The informants' conservation strategies were comprehensive, addressing multiple threats, involving integrated management actions including zoning, surveillance and educational approaches as viable tools for achieving seahorse and mangrove conservation. In general, respondents support the MPAs and want more engagement from the management institutions towards the communities, considering local needs and thus increasing conservation effectiveness. Certain differences in the perception of threats between communities reflect the particularity of local realities and, possibly, also different levels of awareness, education, LEK, and dependence on seahorse-watching as an income source (c.f. Cortés-Avizanda et al., 2018). It is important to consider social perceptions in conservation planning, once they are often spatially heterogeneous.

Local scale studies on social perceptions from a LEK perspective can improve conservation and environmental management at a fine scale in large countries, such as Brazil, especially for data-poor species. Broad-scale management is unlikely to succeed when based on a single local data. Each locality has its own specifications to be

addressed to ensure effective conservation of vulnerable species and habitats, as well as ensuring continued livelihood benefits. Our study has shown that local scale studies are worthwhile for supporting such an approach, more adjusted to the local realities. It also indicates that social perceptions should be employed to monitor threats and evaluate management and conservation strategies, integrating social and ecological indicators.

Data availability statement

The raw data supporting the conclusions of this article will be made available by the authors, without undue reservation.

Ethics statement

The studies involving human participants were reviewed and approved by Universidade Federal do Pará. Written informed consent to participate in this study was provided by the participants' legal guardian/next of kin.

Author contributions

MLFT conceived the ideas, designed this study, collected data and wrote the original manuscript. RLN completed data analysis. MLFT, NVFM, RLN, and TG discussed the results. MLFT, NVFM, RLN, MDV, and TG revised and improved the manuscript. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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Supplementary material

The Supplementary Material for this article can be found online at: <https://www.frontiersin.org/articles/10.3389/fmars.2023.1139368/full#supplementary-material>

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