Environmental Management (2026)76:161
https://doi.org/10.1007/s00267-026-02465-6

Fishers' Perceptions of Fishing Dynamics and Socio-environmental Threats in Coastal Protected Areas of Northeastern Brazil

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Received: 31 October 2025 / Accepted: 31 March 2026

Abstract

Small-scale fisheries are central to the economy, food security, and cultural continuity of many coastal communities across the Global South, yet fishing activities and community well-being are increasingly exposed to pressures from overfishing, pollution, and coastal ecosystem degradation. When fishing occurs within or near coastal protected areas, regulatory frameworks and livelihood dependence become tightly intertwined, making fishers' perceptions of the environment and fishing dynamics a socially structured dimension of these systems rather than merely individual views. We interviewed 105 fishers from three coastal protected areas in Northeastern Brazil (Paraiba and Pernambuco) to (1) analyze their perception of changes in small-scale fisheries and socio-environmental threats, and (2) examine how socioeconomic factors (e.g. sex, education, income, dependence on fishing) influence these perceptions. We did a content analysis of the qualitative interview data and applied multinomial logistic regression to model their perception of socio-environmental threats. Our findings showed that male fishers were significantly more likely to perceive pollution (odds ratio [OR] = 5.45) and overfishing (OR = 2.57) as major threats. Additionally, higher income was associated with a lower likelihood of perceiving overfishing (OR = 0.27) and pollution (OR = 0.009) as significant concerns, regardless of gender. Lower income levels were associated with greater sensitivity to socio-environmental threats, while gendered divisions of labor shaped distinct environmental perceptions. These findings demonstrate that socio-ecological dynamics in coastal protected areas are structured by poverty and social inequalities. Effective governance must therefore integrate biodiversity conservation with strategies that address livelihood security, gender inequities, and structural vulnerability in small-scale fisheries.

Keywords Conservation threats, Livelihoods, Marine governance, Coastal communities, Small-scale fisheries

Introduction

Small-scale fisheries represent a vital component of the economy and livelihoods of numerous coastal communities, particularly in the Global South, where natural resource use is closely tied to subsistence practices and household income (da Silveira and Ferreira 2024; Chambon et al. 2024). However, coastal ecosystems are increasingly

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Published online: 16 April 2026

burdened by drivers such as overfishing, pollution, and climate change—pressures that are widely recognized by coastal communities (Viegas et al. 2016; Martins et al. 2018; Mudge 2018; Sandoval Gallardo et al. 2021). These drivers not only contribute to the decline of fish stocks but also threaten the long-term sustainability of small-scale fisheries and the well-being of the communities (Sowman and Sunde 2018).

Perceptions are understood as subjective interpretations through which individuals observe, make sense of, and evaluate environmental conditions, actions, or outcomes (i.e., socially constructed judgments rather than objective assessments; Bennett 2016). While perceptions may be informed by experience and knowledge, they should not be conflated with scientific or experiential knowledge itself, as they reflect interpretative evaluations shaped by lived realities. From this perspective, variation in perceptions does not necessarily indicate differences in ecological knowledge, but rather differences in how environmental change and management are felt interpreted (Bennett 2016). Although environmental changes and threats to coastal ecosystems have been consistently perceived by small-scale fishers across generations (Martins et al. 2018; Medeiros et al. 2024), the perception of resource conditions and the effectiveness of fisheries management strategies may vary due to individual and social factors (Gehrig et al. 2018; Mudge 2018; dos Santos et al. 2024). Broader social dimensions, including local context, cultural practices, and belief systems, significantly shape fishers' environmental perceptions and attitudes (Alves et al. 2021). From a political economy perspective, these interpretative processes are deeply shaped by patterns of livelihood dependence, economic vulnerability, access to resources, and institutional marginalization (Béné and Friend 2011). In small-scale fisheries, where livelihoods are closely tied to common-pool resources, such structures condition whether environmental change is perceived as a manageable fluctuation, a threat to subsistence, or a constraint imposed by external development and governance dynamics (Béné and Friend 2011).

Several studies suggest that fishers who are financially dependent on fishing are less likely to comply with regulatory measures (Karper and Lopes 2014) and conservation initiatives targeting threatened species (Vieira et al. 2024). Conversely, younger fishers, who often diversify their livelihoods through alternative activities such as tourism, appear to show greater willingness to adopt management regulations (Karper and Lopes 2014; Silva and Lopes 2015; da Silveira and Ferreira 2024). At the same time, perceptions of declining fish abundance are also more frequently reported among older fishers with long-time fishing experience (Martins et al. 2018; Medeiros et al. 2024). Socioeconomic variables also affect the perception of the benefits and drawbacks of conservation initiatives in communities living in or near protected areas (PAs), as well as awareness of the objectives of these areas (Htun et al. 2012; Chechina et al. 2018). Individuals who report negative attitudes or perceive losses associated with PA management often frame these concerns in terms of economic impacts (Htun et al. 2012).

Cognitive and social psychology offer valuable theoretical frameworks for understanding the challenges individuals face in perceiving gradual environmental changes over time (Pauly 1995; Papworth et al. 2009; Baquiano 2016; Soga and Gaston 2018). One such framework is the shifting baseline syndrome (SBS) (Pauly 1995), which helps explain environmental generational and individual amnesia (Kahn Jr 2002; Papworth et al. 2009; Soga and Gaston 2018). Environmental generational amnesia occurs when each generation grows accustomed to the appearance and conditions of its own environment. In systems undergoing progressive degradation, younger generations fail to recognize the extent of environmental decline experienced by previous generations, leading to distinct baseline perceptions across age cohorts (Kahn Jr 2002; Fernández-Llamazares et al. 2015). In contrast, individual amnesia refers to the tendency of individuals to revise their perception of environmental conditions throughout their lives, often forgetting or downplaying the ecological states they experienced in the past (Essl et al. 2015; Fernández-Llamazares et al. 2015). However, critical perspectives caution that framing shifting baseline syndrome solely as a cognitive or generational phenomenon risks obscuring the role of socio-economic structures and power relations in shaping whose knowledge is recognized and whose environmental histories are marginalized. By privileging scientific reconstructions of past conditions over local ecological knowledge, baseline narratives may unintentionally reinforce epistemic inequalities and overlook the interdependent relationships between traditional communities and ecosystems (Campbell et al. 2009).

Beyond individual memory and experience, environmental perceptions are also socially constructed (Gehrig et al. 2018). They are influenced by interpersonal interactions, cultural beliefs, traditional practices, and historical contexts, all of which contribute to the social representations (e.g., collective understandings shared within a group) about the natural environment (Moscovici 1976).

In coastal Brazil, small-scale fisheries are legally defined as activities primarily dependent on family-based labor and fishing as the main source of livelihood (Brasil 2009). These fisheries operate within complex socio-environmental contexts marked by regulatory overlap in protected areas, limited institutional coordination, persistent poverty, and unequal access to decision-making arenas (Barros 2021). Recognizing the diversity of perceptions in fishing communities is essential for promoting participatory and

inclusive governance, as different groups have specific needs and priorities. Fishers' perceptions of environmental change influence their willingness to engage in conservation practices and comply with regulatory measures (Silva et al. 2021; Vieira et al. 2024). If communities do not perceive threats as severe, there may be resistance to conservation policies, which can undermine their effectiveness.

Despite a growing body of literature on fishers' perceptions of environmental change, much of this research remains analytically fragmented, often privileging either descriptive qualitative accounts or isolated quantitative predictors, with limited attention to how socioeconomic variables interact to produce distinct perception profiles rather than uniform responses (dos Santos et al. 2024). At the same time, quantitative studies commonly rely on binary or linear outcome structures, which tend to obscure the coexistence of multiple, qualitatively different perception states, such as recognizing specific threats, perceiving generalized environmental decline, or reporting no perceived threat at all. These limitations are particularly consequential in PAs, where regulatory regimes, livelihood diversification, and historical experiences with conservation can generate socially differentiated and non-linear patterns of threat perception, yet management interventions are frequently designed under assumptions of homogeneous problem recognition (Seixas and Kalikoski 2009). Consequently, understanding not only whether fishers perceive environmental change, but how different social groups represent socio-environmental threats remains an underexplored dimension in the literature.

In this context, this study addresses the question: How do fishers perceive the dynamics of fishing over time and the socio-environmental threats they face? By adopting a mixed-methods approach that integrates qualitative analysis with multinomial regression modeling, our objectives were: (1) to analyze the perception of changes in small-scale fisheries by fishers, and (2) to identify how socioeconomic factors may shape the perception of socio-environmental threats.

Materials and Methods

Study Areas

A global systematic review of research in marine protected area has shown that conservation initiatives are generally focused on biodiversity and the ecology of non-human species (Borges et al. 2020). In the Brazilian context, however, conservation studies tend to adopt more participatory and socially-oriented approaches, diverging from the dominant global trend (Borges et al. 2020). This orientation can, in part, be attributed to the National System of Protected Areas (Sistema Nacional de Unidades de Conservação—SNUC, Federal Law No. 9.985/2000), which defines two overarching objectives across the twelve categories of PAs: the full protection of biodiversity, and the sustainable use of natural resources, especially in territories traditionally inhabited and used by local communities.

Within this framework, fisheries management in Brazil has evolved through a wide range of participatory institutional arrangements, varying in the degree of involvement of fishers in decision-making processes (Seixas and Kalikoski 2009). In the context of fisheries resource use, governance effectiveness depends on clearly delineating territories of interest, customary practices, and patterns of resource use, particularly by identifying different degrees of dependence on fisheries resources. Such differentiation is central to defining who has access to resources and under what conditions, as well as to addressing conflicts related to access and property rights (Seixas et al. 2011). Evidence from different coastal and inland contexts shows that, even where legislation formally prescribes limited participation, management practices often incorporate consultative, shared, or advisory forms of co-management. However, these arrangements remain uneven and frequently fragile, with deliberative councils and shared governance instruments still in an embryonic stage in many PAs, reflecting persistent asymmetries of power between the State and traditional fishing communities (Seixas and Kalikoski 2009).

This study focuses on three Protected Areas (PAs) categorized under SNUC as sustainable use protected areas: Environmental Protection Areas (Áreas de Proteção Ambiental – APAs) and Extractive Reserves (Reservas Extrativistas – RESEXs) (Table 1). Although both types aim to promote sustainable resource use, they differ in emphasis. APAs are primarily designed to conserve biodiversity in the context of land-use planning and regional development, whereas RESEXs seek to safeguard the cultural heritage and livelihoods of traditional populations (BRASIL 2000). The PAs addressed in this study include two APAs, Barra do Rio Mamanguape (APABRM) and Tambaba State Environmental Protection Area (APAT), and one RESEX, the Acaú-Goiana Extractive Reserve (REAG). The three coastal PAs are located in the states of Paraíba and Pernambuco, in northeastern Brazil.

Established in 1993, the APABRM (6.776°S, 34.926°W) aims to protect critical ecosystems and species, including the West Indian manatee (peixe boi marinho - *Trichechus manatus manatus*), mangrove forests, remnants of the Atlantic Forest, and freshwater resources (Perazzo et al. 2013; Medeiros et al. 2023). The area encompasses the Mamanguape River Estuary, spanning approximately 16,400 hectares and comprising 32 small villages. Most residents along the riverbanks are small-scale fishers, whose

Table 1 Governance arrangements of the protected areas, distribution of interview participants, and their fishing activities

Coastal protected area	Jurisdiction	Council structure	Established (year)	Number of surveys (%) ($N = 105$)	Main fisheries operated
Acaú-Goiana Extractive Reserve (REAG)	National	Deliberative	2002	47 (45)	Shellfish gathering; lobster fishing
Barra do Rio Mamanguape Environmental Protection Area (APABRM)	National	Advisory	1993	32 (30)	Gillnet fishing; shellfish and crab gathering
Tambaba Environmental Protection Area (APAT)	Regional	Advisory	2002	26 (25)	Gillnet fishing; lobster fishing

livelihoods have traditionally depended on fishing (Mourão and Nordi 2018).

Created in 2002, APAT (7.417°S, 34.917°W) covers about 3,270 hectares across the municipalities of Conde, Pitimbu, and Alhandra. It was established to conserve coastal ecosystems, support territorial planning, and preserve scenic landscapes associated with tourism. Since 2005, parts of the coastal zones in Conde and Pitimbu have been legally designated for sea turtle conservation, overlapping with traditional small-scale fishing territories (Almeida 2006).

The REAG (7.566°S, 34.837°W), created in 2007, emerged from demands by traditional extractive communities in the municipalities of Pitimbu and Caaporã (Paraíba state) and Goiana (Pernambuco state) (Fadigas and Garcia 2010). Covering 6,676.62 hectares, the reserve includes six communities (Baldo do Rio, Tejucupapo, Povoação de São Lourenço, Carne de Vaca, Acaú, and Caaporã) (Rodrigues et al. 2017), whose residents engage in small-scale fishing and the harvesting of estuarine invertebrate resources such as the Venus clam (marisco - *Anomalocardia flexuosa*), and the crabs (caranguejos - *Callinectes danae*, *Goniopsis cruentata*, *Ucides cordatus*, and *Cardisoma guanhumi*). Historically, conflicts have arisen between these communities and industrial shrimp farming operations that have occupied areas within the Goiana River estuary particularly on Ilha do Tariri, previously used by traditional extractive populations (Fadigas and Garcia 2010).

None of the three PAs included in this study has an approved management plan (REAG) or systematically updated official records on the number of active small-scale fishers (APABRM and APAT). The absence of consolidated institutional data reflects long-standing challenges in monitoring and governance across these PAs.

Data Collection

We conducted a mixed-methods study involving 105 small-scale fishers from the three studied coastal PAs. Semi-structured, face-to-face interviews were carried out with adult fishers (aged 18 and older) of these PAs, who voluntarily agreed to participate in the study (see Ethics statement below). Participants were identified either during extractive activities (e.g., at fishing or shellfish harvesting sites) or through snowball sampling (Goodman 1961). While snowball sampling may introduce selection bias by over-representing more socially connected individuals, its use in this study was limited and complemented by direct field-based recruitment to reduce this effect.

During fieldwork, interviews were conducted with small-scale fishers identified as female or male based on observable biological characteristics and contextual social markers, rather than self-identification. All participants

responded to a unified interview protocol, irrespective of sex. Although gender diversity beyond the binary was not a central focus, the inclusion of both male and female fishers aimed to reflect distinct lived experiences within predominantly male fishing communities (Heidari et al. 2016; Freitas et al. 2020).

Data collection took place over a period of 20 days in each PA: in February, April, and July 2023 at APABRM, REAG, and APAT, respectively. Participant observation was employed as a complementary method to enrich data collection and strengthen trust between the lead researcher and participants. By engaging in everyday activities and informal interactions, the researcher reduced social distance and created conditions for more open, spontaneous, and contextualized exchanges (Albuquerque et al. 2014).

Open-ended questions were used during the interviews to reduce social desirability bias, defined as the tendency to overstate intentions in alignment with perceived social norms or expected pro-environmental behaviors (Juvan and Dolnicar 2016; Dean and Wilson 2023). Interviews were conducted in the presence of a community facilitator, who assisted with communication and, when authorized by the interviewees, took photographs of the activities (see Figs. S1, S2, and S3). Community facilitators did not influence interview responses; their role was limited to facilitating access, supporting communication, and helping establish trust between the researcher and participants. The interview protocol was structured into two main sections: (1) socio-economic characteristics (e.g. sex, age, education level, fishing experience, sources of income, monthly household income), and (2) perceptions of environmental and fishing dynamics (e.g. perceived environmental and fishing-related changes over time, shifts in fishing effort and gear use, and restrictions on species access and use). Monthly income data were expressed in Purchasing Power Parity (PPP) dollars and calculated by converting the Brazilian real to PPP dollars as of December 17, 2024. To refine the interview protocol, three pilot interviews were conducted; however, data from these interviews were not included in the final analysis.

Ethics Statement

This research was approved by the Ethics Committee of the Federal Rural University of Pernambuco (#5.897.834) and by SISBio (Biodiversity Authorization and Information System) (#81328-4), granting permission to conduct fieldwork within PAs and with traditional communities. Participation in the study was entirely voluntary. All participants were informed about the objectives of the research, the procedures involved, and the intended use of the data prior to participation. Informed consent was obtained from all participants, who were assured of the anonymity and confidentiality of their responses. Participants were also informed that they could refuse to answer any question or withdraw from the study at any time, without any consequences, including after the interviews had been completed. This research was informed by the Sex and Gender Equity in Research (SAGER) guidelines, which advocate for the systematic consideration of sex and gender in studies involving human subjects (Heidari et al. 2016; Van Epps et al. 2022).

Data Analysis

Categorizing Perception of Environmental and Fishing Dynamics and Threats

The analysis followed a fully inductive, two-phase qualitative approach. In the first phase, all responses from the semi-structured interviews were fully transcribed and subjected to manifest content analysis (Bardin 2011), focusing on the explicit statements made by fishers regarding perceived changes in small-scale fishing. Through repeated readings, responses were grouped into main themes reflecting broad dimensions of perceived change (e.g. changes in fish abundance, fishing effort, technology, or access to resources).

In the second phase, a latent content analysis was conducted to interpret the underlying meanings associated with these perceived changes, allowing the identification of a second analytical layer corresponding to perceived socio-environmental threats (Bengtsson 2016). These threats were not predefined in the interview script but emerged inductively from participants' narratives, often extending beyond strictly environmental aspects to include social, economic, and conservation-related concerns. Examples of main themes that emerged include overfishing, pollution, and food insecurity.

All main themes identified in first phase (perceived changes in small-scale fishing) and second phase (perceived socio-environmental threats) are presented in Figs. 1 and 2, respectively.

Coding was performed independently by two researchers and subsequently cross-validated through comparison to assess convergence; discrepancies were resolved through discussion until consensus was reached. The unit of analysis corresponded to individual response units rather than to respondents. Although 105 interviews were conducted, participants could mention more than one issue within a single answer, resulting in multiple response units derived from the same interview. Each response unit was assigned to a single main theme within each analytical phase.

The two analytical phases were conducted independently, generating distinct qualitative datasets. The coded material was compiled into a spreadsheet, and relative

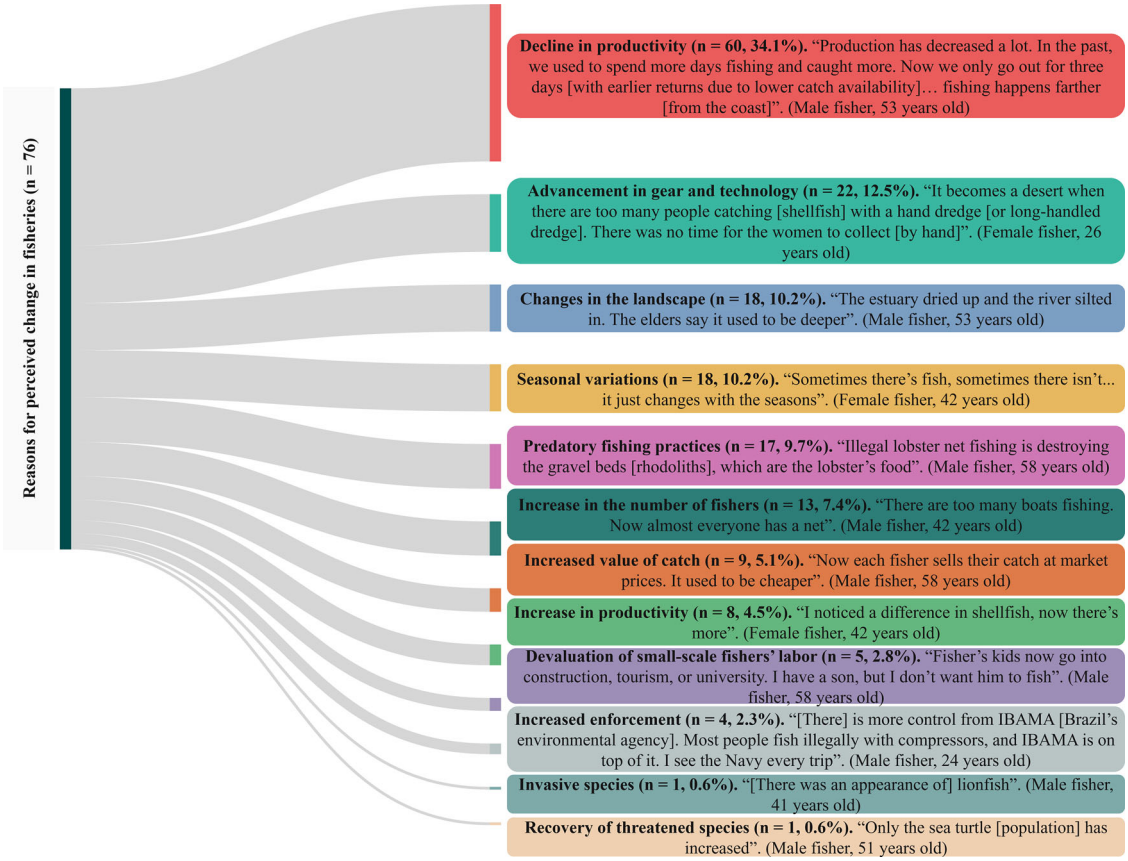

Fig. 1 Sankey diagram illustrating the perceived changes in environment and small-scale fishery. Flows represent the relative proportion (%) of response units derived from fishers' open-ended statements and grouped into main themes. As individual respondents could report more than one perceived change, multiple response units may originate from a single interview ($n = 176$). Quotes are used to illustrate fishers' perception for each theme

frequencies were calculated based on the total number of response units within each phase.

Statistical Analysis

A multinomial logistic regression model was employed to analyze the socioeconomic factors associated with fishers' perceptions of different socio-environmental threats, which were treated as the response variable. Five categories of perceived threats were defined: (1) overfishing, (2) pollution, (3) climate change, land use and occupation, (4) endangered biodiversity, and (5) food insecurity. An additional category, (6) no identified threat, was created to serve as the reference category in the model.

The explanatory variables included: age, years of fishing experience, household size, and fishing frequency per month (all treated as continuous variables); sex and dependence on fishing as the primary source of income (binary variables); and education level and monthly household income (categorical variables). The PA was not included as an explanatory variable, as comparing governance regimes across areas was beyond the analytical scope of this study and the sample size within each PA did not support robust between-group comparisons.

Multinomial logistic regression, estimated using the maximum likelihood method, is appropriate for modeling outcomes with more than two unordered response categories. It allows for the estimation of the probability of each outcome relative to a reference category (Hosmer et al. 2013; Agresti 2018). The model uses the *logit* link function, which transforms response probabilities into log-odds, facilitating interpretation of the resulting coefficients (McCullagh & Nelder, 1989). The general form of the multinomial logistic model is given by:

$$P(Y = k) = \frac{\exp(X\beta_k)}{\sum_{j=0}^{K} \exp(X\beta_j)}, \quad k = 1, 2 \ldots, K$$

where $\boldsymbol{X}$ represents the values of the explanatory variables, and $\boldsymbol{\beta}$ corresponds to the estimated coefficients of the model.

- $\boldsymbol{P(Y = k)}$: probability that the dependent variable $\boldsymbol{Y}$ falls into category $\boldsymbol{k}$.

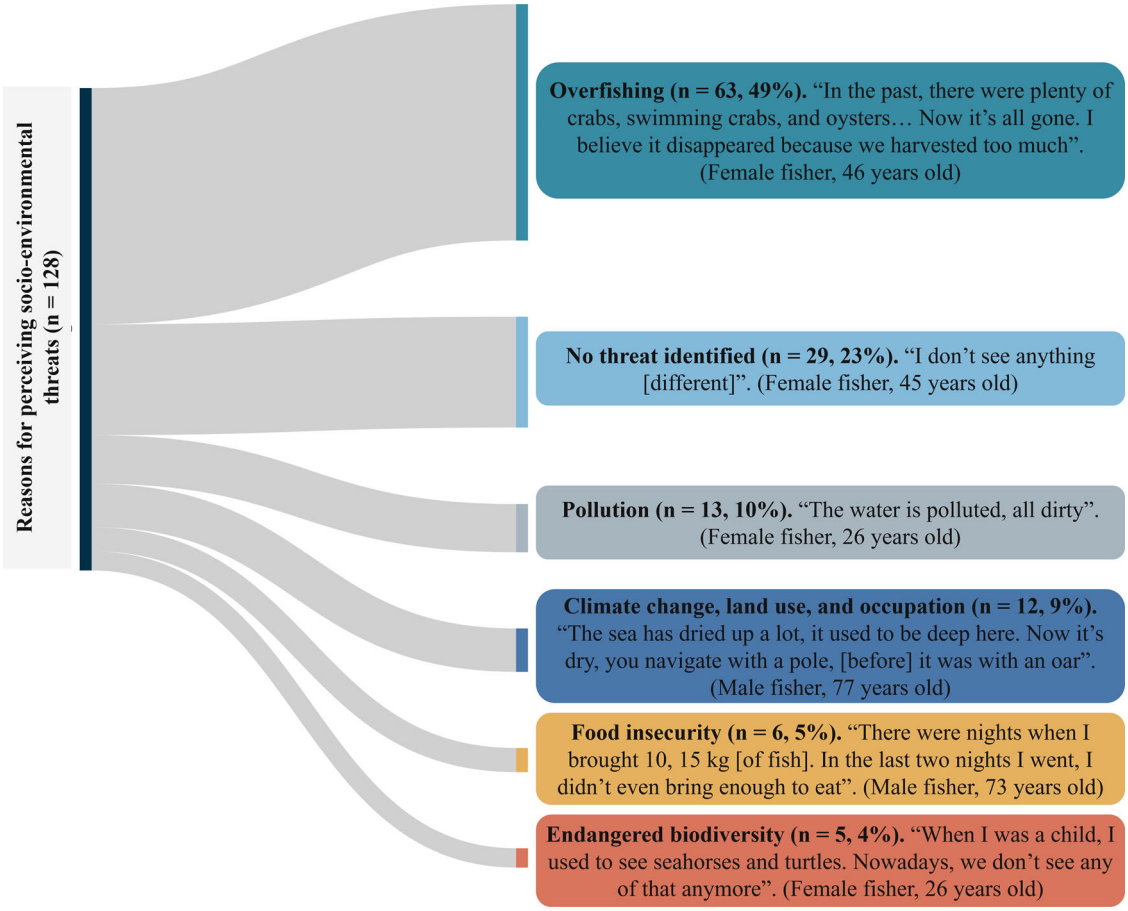

Fig. 2 Sankey diagram illustrating the perceived socio-environmental threats affecting small-scale fishery (n = 128). Flows represent the relative proportion (%) of response units derived from fishers' open-ended statements and grouped into main themes. As individual respondents could report more than one perceived change, multiple response units may originate from a single interview $n = 128$*). Quotes are used to illustrate fishers' perception for each theme

- $(\boldsymbol{X\beta_k})$ exponential of the product between the vector of explanatory variables $\boldsymbol{X}$ and the coefficient vector $\boldsymbol{\beta_k}$ for category $\boldsymbol{k}$.
- $\sum_{j=0}^{K} exp(X\beta_j)$: sum of the exponentials of all $\boldsymbol{X\beta_j}$ products across the $\boldsymbol{K}$ categories, ensuring the probabilities are properly normalized.

The analysis was performed using the *nnet* package in R software, version 4.2.3 (R Core Team 2023). The estimated coefficients for each threat category represent changes in the log-odds of perceiving a specific threat relative to perceiving no threat (Long & Freese, 2014).

To validate the model and determine the best fit, we applied the Akaike Information Criterion (AIC), which allows for comparison among models with differing numbers of parameters (Greene, 2018). The selection of the reduced model was based on the exclusion of non-significant predictors, as indicated by p-values ($p > 0.05$) and odds ratios (OR > 1: increases the likelihood of the event occurring; OR = 1: no association; OR < 1: decreases the likelihood of the event). Only predictors with statistically significant effects were retained in the final model.

To capture potential associations between monthly income and the perception of socio-environmental threats, we included linear, quadratic, and cubic terms specifically for this variable. The linear term accounts for proportional changes in threat perception as income increases. The quadratic term allows for curvilinear relationships, capturing non-constant changes in effect. The cubic term accounts for more complex variations, potentially identifying shifts in the direction of the relationship between income and threat perception.

We also applied an equivalence index to quantify the number of similar or overlapping responses among fishers, which ranged from one to four perceived threat categories (out of a total of six). This allowed us to adjust the proportions of perceived threats across all interviewed fishers.

Results

Participants were predominantly male (64.8%, $n = 68$), while female accounted for 35.2% of the sample ($n = 37$).

Table 2 Multinomial logistic regression results showing the association between socio-economic factors and the perception of socio-environmental threats

Socio-environmental threats	Independent variables							
	Sex		Linear Monthly Income		Quadratic Monthly Income		Cubic Monthly Income	
	Odds ratio	*p* value	Odds ratio	*p* value	Odds ratio	*p* value	Odds ratio	*p* value
Overfishing	2.567	0.063	1.007	0.992	0.277	**0.021**	0.610	0.305
Pollution	5.458	**0.032**	0.000	0.000	0.000	0.000	0.009	0.000
Climate change, land use and occupation	3.582	0.209	0.000	0.000	0.000	0.000	0.007	0.000
Biodiversity	5.855	0.144	0.000	0.000	0.000	0.000	0.007	0.000
Food insecurity	NA	0.874	0.008	0.988	0.000	0.968	0.065	0.980

Only significant variables are shown

Statistically significant values are highlighted in bold

In terms of age, the majority ranged from 40 to 66 years old (80%; $n = 84$; SD = 12.59). A significant portion of the fishers reported extensive fishing experience, with 87% ($n = 91$) having worked in the activity for over 27 years. Regarding educational attainment, 71.4% ($n = 75$) were either illiterate or had completed only primary education.

Fishing was the primary source of household income for 80% ($n = 84$) of respondents, often supplemented by governmental aid (71%; $n = 75$), including retirement benefits, social assistance programs, and other welfare support. Additional income sources included public service or temporary jobs (37%; $n = 39$), and informal work in the tourism sector (12%; $n = 13$). Nearly half of the participants (47.6%; $n = 50$) reported a monthly household income ranging from PPP USD 250.00 to 500.00. On average, households were composed of three members ($\mu = 3.4 \pm 0.72$), and respondents reported engaging in fishing activities an average of 17 days per month ($\mu = 17.35 \pm 5.86$).

Perceptions of changes in fishing dynamics and threats

When asked about perceived changes in fishing activity over time, respondents provided 12 distinct types of responses (Fig. 1), primarily highlighting threats related to resource availability and broader transformations in fishing dynamics. Their responses suggest an ongoing process of environmental degradation, often associated with interlinked environmental, technological, and social changes.

Although some narratives reflect a degree of resilience in adapting to these changes, the predominant perception is that small-scale fishing has undergone a process of socio-ecological reconfiguration, which directly compromises its long-term viability.

Based on the interpretation of fishers' open-ended responses, six categories of perceived socio-environmental threats were identified (Fig. 2). These reflect a shared perception that fishing practices themselves have contributed to the depletion of fish stocks, creating a cycle of increasing vulnerability. Although not all respondents recognized immediate risks, several narratives expressed growing concern about the impacts of human pressures on coastal, marine and estuarine ecosystems and local livelihoods.

Effect of Socio-economic Factors on Perceived Threats

Male respondents showed a higher perception of threats in comparison to female respondents, while monthly family income had a negative and significant effect, with the perception of threats decreasing as income increased (Table 2).

In the overfishing category, males were more likely to perceive this threat than female (odds ratio [OR] = 2.57, $p = 0.063$). The analysis of income indicated that higher income levels are associated with a significant decrease in the perception of overfishing (OR = 0.27, $p < 0.05$).

For pollution, males also showed a positive association with the perception of this threat (OR = 5.45, $p < 0.03$). Income had a negative effect, with significant *p*-values for the quadratic and cubic terms ($p < 0.05$). These results indicate that the relationship between income and the perception of pollution is not linear. As income increases, the likelihood of perceiving pollution as a threat tends to decrease, but the strength of this effect varies across income levels. Rather than reflecting a constant decline, the influence of income differs in intensity depending on the income bracket, indicating that individuals at different income levels interpret socio-environmental risks in distinct ways.

Except for pollution and a marginal effect for overfishing, the effect of sex was not statistically significant across the remaining threat categories, indicating no detectable gender differences in those perceptions. This lack of statistical significance indicates that, for most threat

categories, female and male fishers reported similar perceptions within the limits of the model.

With regard to endangered biodiversity, gender showed no significant effect (OR = 5.85, $p = 0.14$). However, income showed a significant negative association ($p < 0.05$), indicating that higher income levels reduce the perception of this threat, as well as for climate change, land use, and occupation.

For climate change, land use and occupation, the data do not suggest that the perception of these threats differs between male and female fishers ($p > 0.05$). As there were few mentions of the food insecurity threat ($n = 6$), the model did not provide satisfactory results for this category.

Finally, the variables age, years of fishing experience, fishing frequency per month, education level, household size, and dependence on fishing as the primary source of income had no significant effect on perceived threats ($p > 0.05$).

Discussion

Our study analyzes the perceptions of fishers regarding changes in small-scale fishery practices and socio-environmental threats, contributing to the understanding of how factors such as income and gender influence the formation of different interpretations of the environment. We interpret these perceptions in relation to small-scale fishers' livelihoods, socioeconomic vulnerability, and governance contexts within protected areas. Understanding how the perceptions of small-scale fishers are formed and structured is essential for identifying the challenges faced by resource users and for strengthening compliance with regulatory measures (Bennett 2016). Furthermore, knowledge about fishers' perceptions can inform the development of management and conservation strategies for fishery resources, taking into account territorial contexts and the specificities of local communities (Mcalvay et al. 2021; Bennett et al. 2021). It is important to highlight that traditional conservation models, often focused on species and area-based approaches, may be socially unjust and ineffective, which further reinforces the need to adapt public policies and conservation actions to local realities (Burbano and Meredith 2020; McClanahan and Abunge 2020).

Environmental Change, Technological Shifts, and Perceived Threats

Fishers' perceptions of changes in small-scale fishery practices reflect the paradox of reconciling economic viability and fishing efficiency with environmental sustainability. On the one hand, there has been increasing access to and development of fishing technologies aimed at enhancing fishing efficiency (Marchal et al. 2007; Torres-Irineo et al. 2014). On the other hand, a long-term decline in fishing productivity has also been observed and reported by fishers here and elsewhere (Teh and Sumaila 2007; Martins et al. 2018). These technological advances have not only optimized the capture of target species but also reduced the fishing effort required. An example includes the adoption of tools such as the long-handled dredge (named *gadanho de cabo*) and the use of plastic crates for shellfish size sorting (locally known as *galea*) (Fig. S2E and S2F), which have replaced manual collection and improved the efficiency of shellfish gathering, reducing the time required for these activities. However, it is important to highlight that there has also been an increase in the number of fishers using these tools, which can result in greater pressure on fishing stocks and lead to long-term unsustainable or predatory practices, as reported in the interviews.

Our findings reflect a critical global trend: the continued decline of fishing stocks in various parts of the world. This scenario is exacerbated by the fact that approximately 80% of global catches originate from fisheries that are unmonitored or have insufficient data (Costello et al. 2012), which significantly compromises sustainable management and evidence-based policy-making. In this regard, it is crucial that technological advances in the fishing sector, even if minor and manual, as detected here, be accompanied by adaptive and participatory management strategies that incorporate local knowledge and directly involve fishers in stock assessments and decision-making processes to ensure both ecological and economic viability of small-scale fishery (Castello et al. 2009; Tallman et al. 2019). Solely relying on techno-scientific solutions is insufficient in the face of the complexity of socio-ecological systems; it is necessary to integrate science, participatory governance, and social justice (Castello et al. 2009; Bennett et al. 2021).

Overfishing was identified as the main reason for the perception of socio-environmental threats among respondents from the studied coastal PAs. Our findings are in line with the existing literature, which shows that small-scale fishers often perceive coastal ecosystem degradation (Aldon et al. 2011), generational declines in catch volume (Panagopoulou et al. 2017; Martins et al. 2018; Medeiros et al. 2024), and attribute these changes to factors such as industrial and illegal fishing, increased fishing effort, and weak regulatory enforcement in the fisheries sector (Aldon et al. 2011; Martins et al. 2018).

Conversely, the absence of perceived threats was the second most common response among fishers. Several factors may explain this outcome. One possible reason is that many fishers view changes in species abundance as naturally seasonal, indicating an understanding of the reproductive and migratory cycles of the species with which they are familiar. This knowledge also reflects their ability

to predict variations in resource availability throughout the year for both subsistence and commercial species (Medeiros et al. 2018), reinforcing the argument that local ecological knowledge should be incorporated into fisheries management strategies (Tallman et al. 2019; Pita et al. 2019). However, the fact that seasonality is an aspect recognized by fishers may hinder their ability to distinguish between expected seasonal fluctuations and long-term changes in fishing stocks. This overlap of signals may obscure the perception of gradual declines in species abundance and diversity, constituting a second key factor behind the perceived absence of threats. This phenomenon may lead to delayed responses to biodiversity loss (Essl et al. 2015), particularly in contexts where changes in species abundance and diversity go unnoticed by local communities due to shifting baselines (i.e. situations in which reference conditions are gradually redefined over time) (Papworth et al. 2009; Daw 2010; Soga and Gaston 2018). This delayed perception of environmental change and threats may exacerbate existing issues, such as the impacts of climate change, overfishing, and food insecurity. Additionally, the absence of perceived threats may also be influenced by optimism bias (Weinstein 1987), where individuals tend to unrealistically imagine a low-risk future for themselves. In risk perception literature, it is common to observe a tendency to overestimate self-assessed abilities, particularly when individuals compare themselves to others perceived to be at greater risk (Joffe 2003).

Local sociocultural dynamics may further shape these perceptions, particularly in communities where fishing identity, attachment to place, and intergenerational continuity are central to social cohesion. In such contexts, acknowledging environmental degradation may conflict with narratives of resilience and stability, making the absence of perceived threat a socially embedded response rather than a simple lack of awareness (Farny and Dentoni 2025).

It is also important to consider that the difficulty in identifying threats may not stem solely from local perception but also from limitations in data collection. Although the qualitative approach adopted in the interviews was sufficient to capture fishers' perceptions, it could be improved with more targeted questions capable of better distinguishing between fishers' understanding of expected seasonal variations and a lack of perception of gradual ecological changes.

Pressures on Livelihoods and Gendered Experiences

Regarding the socioeconomic variables associated with the perception of socio-environmental threats, we found significance for gender and income. Our study reinforces the findings in the literature that different perceptions of the environment can be understood in light of the socioeconomic conditions of small-scale fishers, their livelihoods, and the characteristics of their fishing activities (Silva and Lopes 2015; Martins et al. 2018; dos Santos et al. 2024).

Male gender was significantly associated with a greater perception of threats, specifically concerning overfishing and pollution. This result could be explained by the social construction of occupational differences and involvement in fishing activities (Gehrig et al., 2018). The different types of fishing gear and techniques used in small-scale fishing (e.g., gill nets, lines, manual gathering, or the use of tools) may form distinct identities and create social networks that shape subgroups within the fishing community. The social interactions within these occupational subgroups lead to a shared perception of the environment, as they use similar fishing methods (Gehrig et al., 2018). Although our data indicate higher male participation in the fishing activities in the studied areas, it is important to recognize the gender-based division of labor in these coastal regions.

Socially and historically, males have been associated with operating in the "outer sea" or offshore areas, where they conduct boat-based fishing. Females, in turn, predominantly work in the "inner sea," that is, in areas closer to land and home, such as rivers, mangroves, and beaches (Alicia and Hellebrandt 2019). Female fishers play a crucial role in shellfish gathering, significantly contributing to family sustenance (Mourão et al. 2020). Beyond occupational differences, the social context also shapes gender roles in fishing activities, particularly concerning the spatial and temporal limitations imposed on them. Shellfish gathering becomes their primary activity, largely due to the accessibility of sandbanks, which do not require boats or expensive equipment. This practice, in addition to being carried out near residences, allows female fishers to balance work with childcare responsibilities (a double or even triple workload)., highlighting how social and structural factors influence the gendered division of labor in small-scale fishing (Kleiber et al. 2015; Alicia and Hellebrandt 2019). While males tend to perceive environmental impacts primarily in terms of declines in catch volume (i.e., fish quantity), females more often express concern about the rising cost of living and the implications of environmental degradation for household food security (Alicia and Hellebrandt 2019).

Our results indicate that small-scale fishers in the PAs of APABRM, APAT, and REAG have low levels of education, a high average age, and low income. Most respondents live at or below the poverty line, according to the World Bank's criteria (US$6.85 per day) (World Bank 2025). This reality mirrors that of other coastal regions in Brazil (Silva and Lopes 2015; Barros 2021; dos Santos et al. 2024) and comparable small-scale fisheries contexts elsewhere

(McClanahan and Abunge 2020), particularly where similar configurations of livelihood dependence, socioeconomic vulnerability, and governance constraints are present. Such a context poses significant challenges to the management of common-pool resources due to the socio-ecological complexity, as the maintenance of traditional fishing practices and the livelihoods of fishing communities are highly sensitive to changes in coastal and marine ecosystem quality and the availability of resources for subsistence.

Fishers living in conditions of greater socioeconomic vulnerability, with lower income and greater dependence on fishing for subsistence, tend to be more sensitive to changes in marine ecosystems, as these changes directly affect their ability to support their families (Cinner et al. 2014). In contexts where populations depend directly on natural resources and live near PAs, these communities may experience improvements in well-being and, to some extent, poverty alleviation (Andam et al. 2010), especially when involved in conservation initiatives that yield positive socioeconomic outcomes (Oldekop et al. 2016). This relationship reinforces the importance of incorporating human dimensions as central components in the planning and management of PAs, directing programs and policies specifically toward beneficiary communities while recognising local needs and social dynamics (Chechina et al. 2018)

One possible explanation for the absence of significance in the exclusive dependence on fishing as a source of income is the importance of income supplementation for households, particularly through government assistance. The results of our study indicate that fishers with lower family income tend to perceive environmental threats more acutely, while those with higher incomes do not show the same level of sensitivity. However, the majority of respondents consider fishing their primary source of income, in addition to receiving government assistance, which, while important, is not enough to lift them out of poverty, according to World Bank criteria (World Bank 2025). The condition of material insecurity, especially among individuals who rely directly on natural resources for subsistence, tends to contribute to a heightened perception of environmental risk (Htun et al. 2012; Lo 2014).

The relationship of these communities with nature extends beyond economic dimensions. These traditional populations in Northeastern Brazil rely on natural resources to ensure food sovereignty and decent livelihoods, while maintaining a strong commitment to sociobiodiversity. However, poverty disrupts this balance by constraining the freedoms necessary for people to lead the lives they value, including access to healthcare, education, and environmental protection (Barros 2021). Poverty and inequality scenarios highlight the importance of maintaining existing social policies, as well as the need to develop new strategies that combine social protection with the promotion of traditional small-scale fishing practices. In addition to the common social benefits of the Brazilian social security system (e.g., pensions, retirement, and unemployment benefits), the fishing sector also benefits from specific aids for this category of labor, such as payments during the closed season for certain species, such as lobster during its reproductive period (Barros 2021).

These perspectives connect to broader debates on poverty, demographic pressure, and resource depletion in small-scale fisheries. Hardin's (1968) "tragedy of the commons" framed overexploitation as the outcome of individually rational behavior in open-access systems, often used to justify regulatory control or privatization as primary solutions. However, subsequent empirical work has demonstrated that collective action can sustain common-pool resources under specific institutional conditions (Ostrom et al. 1999). Building on this shift, small-scale fisheries frequently operate as poverty safety nets, indicating that effective governance must address structural vulnerability alongside resource management (Béné and Friend 2011).

Since the interviewed fishers have similar levels of education and age, these characteristics may have influenced the absence of significance in their perception of threats (dos Santos et al. 2024). These results highlight that, in this specific socio-territorial context, differences in threat perception are more strongly structured by livelihood conditions and gendered experiences than by generational or educational variation.

Conclusion

This study shows that perceptions of fishing dynamics and socio-environmental change are shaped by income, and gendered experiences in coastal protected areas of northeastern Brazil. Overfishing was identified as the main perceived threat, even within protected areas, highlighting tensions between conservation objectives and local subsistence needs. Our results are aligned with empirical data on the global depletion of fish stocks. Technological advancements, such as modernization and greater access to equipment, despite increasing the efficiency of target species capture, bring long-term consequences, such as greater pressure on fishery resources. This perception, coupled with the persistence of predatory practices and a limited understanding of gradual changes in biodiversity, raises questions about the effectiveness of PAs in achieving biodiversity conservation objectives, the sustainable use of natural resources, and the protection of the livelihoods of traditional communities.

Lower income levels were associated with greater sensitivity to socio-environmental threats, while gendered divisions of labor influence distinct perceptions. These

dynamics reveal how socio-ecological complexity in coastal protected areas is deeply intertwined with structural inequalities. By integrating ecological perceptions with socioeconomic conditions, this study underscores the need for governance approaches that address poverty, gender inequities, and livelihood security alongside biodiversity conservation. Inclusive and context-sensitive policies are essential to sustaining small-scale fisheries and reducing socio-environmental vulnerability.

Data availability

The datasets generated and/or analyzed during the current study are not publicly available due to confidentiality agreements with participants but are available from the corresponding author on reasonable request.

Supplementary information The online version contains supplementary material available at https://doi.org/10.1007/s00267-026-02465-6.

Acknowledgements We thank all the fishers interviewed and the managers of the coastal protected areas for their collaboration. This work was developed in the scope of the "Rede Marangatu: Network of Citizen Science for Territorial Governance and the Promotion of Policies for the Preservation and Valuation of Coastal Marine Socio-biodiversity" project.

Author contributions All authors contributed to the conception and design of the study. YCBBO wrote the fi rst draft of the manuscript,collected the data, and prepared the figures. PFML contributed to the main structure and provided substantive corrections. TAO performed the statistical analyses. FA, DGV, MRTR, and JSM critically reviewed and edited the manuscript. All authors read and approved the fi nal version.

Funding Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, 88887.633854/2021-00; Conselho Nacional de Desenvolvimento Científico e Tecnológico, 351054/2024-3; Coordenação de Aperfeiçoamento de Pessoal de Nível Superior, 33781055000135. The Article Processing Charge (APC) for the publication of this research was funded by the Coordenação de Aperfeiçoamento de Pessoal de Nível Superior - Brasil (CAPES) (ROR identifier: 00x0ma614).

Compliance with ethical standards

Conflict of interests The authors declare no competing interests.

Publisher's note Springer Nature remains neutral with regard to jurisdictional claims in published maps and institutional affiliations.

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