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Traditional and local communities as key actors to identify climate-related disaster impacts: a citizen science approach in Southeast Brazilian coastal areas

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The impacts of climate-related disasters can be estimated by climate models. However, climate models are frequently downscaled to specific settings to facilitate Disaster Risk Management (DRM) to better understand local impacts and avoid overlooking uncertainties. Several studies have registered the increasing importance of recognizing traditional knowledge, co-design, and collaboration with local communities in developing DRM strategies. The objective of this research was co-design local-scale observations with traditional and local communities to characterize their local context regarding the impacts of climate-related disasters. The citizen science approach coupled with participatory action research was conducted with two traditional communities in the Southeast of the Brazilian coast: Quilombo do Campinho da Independência in Paraty, Rio de Janeiro, and the Caiçara (artisanal fishing) community of Ubatumirim in Ubatuba, São Paulo. Working groups were organized with leaders to become community researchers, conducting interviews and actively mobilizing their communities. A structured questionnaire was developed, adapting 22 variables taken from the Protocol for the Collection of Cross-Cultural Comparative Data on Local Indicators of Climate Change Impacts—LICCI Protocol. A total of 366 impacts were analyzed, after combining the georeferencing form data collected—Survey123 (280 impacts) and the interviews with community leaders (86 impacts). The results showed a significant level of cohesion ($\alpha = 0.01$) between the Caiçara (artisanal fishers) and Quilombola (Afro-descendants) perceptions of climate-related events associated with their subsistence practices and climate variability. These findings highlighting the importance of DRM proposals that recognize traditional peoples and local communities as frontline vulnerable populations

while acknowledging their role as key actors in identifying impacts, collecting data on land use and territory, subsistence-oriented activities, and cosmovision. However, it is still necessary to address climate change challenges at different scales. To do this, it is crucial to promote cognitive justice though the recognition of the values of the memories, perceptions and local knowledge, by scaling up locally-driven observations that empower local communities to lead their own climate adaptation efforts.

KEYWORDS

collaborative research, climate change impacts, vulnerability, local indicators of climate change, disaster risk management

1 Introduction

The Intergovernmental Panel on Climate Change (IPCC) warned that climate change could have disastrous consequences for humanity in the near future (Assessment Report 6). The report is based on a wide range of studies and scientific evidence to estimate the risks of climate change. These risks are expressed in terms of probabilities while the confidence levels show how uncertain these estimates are. In this context, the academic community has increasingly recognized the importance of considering local impacts in recent years (Berkes et al., 2003; Klenk et al., 2017), which climate models cannot cover at local scales (Rudiak-Gould, 2013). This has led to the development of climate models that more accurately reflect the local realities of different regions (Barnett, 2001; Ensor and Berger, 2009; Reyes-García et al., 2016, 2019).

The IPCC report emphasizes the importance of incorporating local knowledge about climate change, especially from traditional and indigenous communities. Analysis of more than 10,000 observations made by these communities (Savo et al., 2016) has shown that local observations can help validate climate models and improve their accuracy. Finnis et al. (2015) indicate that local validation of climate models, for example through the observation of climate variability, can reduce inaccuracies and provide a more accurate estimation of the damage caused by climate change to local populations.

However, scientists' efforts to incorporate local knowledge may not be sufficient to guarantee climate adaptation and disaster prevention. Brondízio and Moran (2008) state that it is not the scientist's assessment of vulnerability that leads to behavioral change, but rather the community's perception of vulnerability. Adger et al. (2009) argue that cultural, epistemological, and ethical contexts must be considered to promote significant transformations toward climate adaptation, and that social limits must be considered.

Research on socio-ecological systems reveals that addressing complex issues such as climate change requires an investigation of human-nature relationships across ecological, social, political, and economic dimensions (Bograd et al., 2019; Salgueiro-Otero and Ojea, 2020). Local data on these dimensions should not be complementary inputs to conventional planning (Adams, 2000; Naess, 2013) but essential components. Local knowledge is inherent in adapting to constantly changing environments (Naess, 2013). Coexistence with risks occurs at the local level (Sulaiman and Aledo, 2016), and the often-inaccessible potential for transformation relies on external factors that must be re-designed to align with the local reality.

To enable climate adaptation, it is crucial to incorporate the principles of cognitive justice, recognizing and addressing power imbalances between different knowledge systems (Tengö et al., 2014; David-Chavez and Gavin, 2018). Long-term partnerships are vital in fostering collaborative efforts and knowledge exchange between diverse stakeholders (Serrao-Neumann et al., 2020). These partnerships should be based on mutual respect and trust, allowing for the co-creation of knowledge and the development of climate adaptation strategies that reflect the needs and aspirations of local communities. Community autonomy in carrying out activities and projects led by community members themselves should be strengthened (Pisor et al., 2022), and solutions developed by local people should be prioritized over those imposed by external institutions (Wisner and Lavell, 2017).

In Brazil, several studies are in development to build a community-based disaster risk management (Marchezini et al., 2017, 2018; Marchezini and Londe, 2018; Marchezini, 2020). However, these initiatives need to consider the different social and cultural contexts of these communities in order to provide solutions at the municipal or country level. Given these scenarios, we discuss key questions:

(a) What are the climate-related disasters observed by traditional communities in coastal territories of Brazilian Southeast?
(b) What are community-based strategies for climate change adaptation?
(c) Are there differences in perceptions between communities, depending on the context where they live?

Citizen science approach involves volunteers and citizens in various stages of scientific research (Shirk et al., 2012; Haklay et al., 2021), seeking to offer people a structured way to record their observations, share them with experts and effectively participate in the production of scientific knowledge. In this sense, an important issue has been the level of participation in local observations of climate change impacts that involve people in training processes. It is essential to consider the training of citizen scientists for better climate-related disasters responsiveness and

communities' involvement (Shirk et al., 2012; Albagli and Iwama, 2022).

Scientists and community members are increasingly valuing the following research elements: developing local capacities (Albagli and Iwama, 2022); identifying grassroots innovations (Pereira et al., 2022a; Trejo-Rangel et al., 2022); building networks and partnerships (Sato et al., forthcoming; Araos et al., 2019) to design solutions with community (Norstrom et al., 2020); and empowering individuals to access and participate in research as a fundamental right (Appadurai, 2006; Stevens et al., 2014; Albagli and Iwama, 2022).

In the Atlantic Forest in the coastal zone of Southeast Brazil, this approach has been used to address the impacts of heavy rains, floods, and landslides in recent decades (Iwama et al., 2016; Londe et al., 2018; Alcântara et al., 2023). Here initiatives have emerged that seek to work with local communities on joint solutions to reduce climate-related disasters.

To discuss the findings on impacts and adaptation strategies identified, we consider a cognitive justice perspective that traditional communities' knowledge "emerges from social and political struggles and cannot be separated from such struggles" (Santos, 2018).

2 Study area

The study area is located in the Southeast coastal region of Brazil in the municipalities of Paraty and Ubatuba. The region is characterized by over 60 traditional and indigenous communities [Observatório de Territórios Sustentáveis e Saudáveis da Bocaina (OTSS), 2022], which have been historically impacted by climate-related disaster events associated with flood events, landslides, coastal erosion, and strong winds [CPRM (Serviço Geológico do Brasil), 2014; Iwama et al., 2021; Albagli and Iwama, 2022] as well as territorial conflicts, deforestation, land use changes, oil exploration, industrial fishing, and other environmental pressures. The region between Ubatuba and Paraty (Figure 1C) is home to increasingly vulnerable communities living in these traditional coastal territories, many of which are informal settlements located on slopes, along bodies of water, and/or in areas known to be at high risk.

The region is also part of the Atlantic Forest Biome, one of the most biodiverse ecosystems on the planet, which originally covered 17 states and had an area of 1.36 million km² (Capobianco, 2004), but now has only 7.5% of its original size left [Myers et al., 2000; SOS Mata Atlântica (Fundação SOS Mata Atlântica), and INPE (Instituto Nacional de Pesquisas Espaciais), 2023]. This degradation has made the region more susceptible to climate-related disasters. The study area is located in a region that is prone to flooding or mass movements. These areas were mapped by the Institute for Technological Research of the state of São Paulo (IPT) and the federal Geological Survey of Brazil (CPRM). The map (Figure 1) shows that most of the urban areas in the study area are located in areas prone to flooding. However, there are also communities and important roads in areas prone to mass movement.

The combination of climate change, environmental degradation, and human activities has created a high-risk situation for the communities in the region. It is important to develop strategies to mitigate the risk of disasters in this area. These strategies should focus on protecting the environment, reducing vulnerability of the communities, and improving disaster preparedness.

2.1 The traditional communities in the study area

The study area is home to two traditional communities: the Caiçara community of Ubatumirim and the Quilombo do Campinho da Independência.

The Caiçara community of Ubatumirim consists of descendants of Portuguese and indigenous communities (Begossi, 1996). They are mostly self-sufficient, relying on farming and fishing. Since the early 1990s, tourism and immigration have become increasingly important in the region, and the Caiçaras have had to adapt (Raimundo, 2015). They have been working to preserve their traditional culture and way of life, and they are involved in several organizations and events that promote the interests of traditional communities in the region.

These efforts show how determined and persistent the Caiçaras are in finding new ways to preserve their culture and traditional identity. They are often involved in the city's cultural life and political and social groups to make sure their voices are heard in the local decision-making processes.

The Quilombo do Campinho da Independência was founded by three women in the late 19th century (OTSS, 2022). Quilombos are communities of descendants of African slaves who escaped from captivity and formed their own communities (Schmitt et al., 2002), which are now protected by the Brazilian Constitution and National Policy for the Sustainable Development of Traditional Peoples and Communities (Brasil—Federal Constitution of Brazil, 1988; Brasil—National Policy for the Sustainable Development of Traditional Peoples and Communities, 2007). The community, nested in the Atlantic Rainforest, is home to over 170 families (OTSS, 2022) and is known for its strong cultural heritage and its commitment to sustainable development (Maretti and Simões, 2020), relying on community-based tourism as one of the main income-providing activities carried out by the community (OTSS, 2022).

Figure 2 shows the territories of both communities, showing that both communities are located in areas with significant remnants of the Atlantic Forest (85.22% of Ubatumirim and 74.47% of Campinho). Both communities are susceptible to flooding, while Campinho is also largely susceptible to landslides.

3 Methodology

The methodological approach consisted of the following five stages:

(1) *Working groups* were formed to carry out action research between the scientific researchers and the traditional communities.

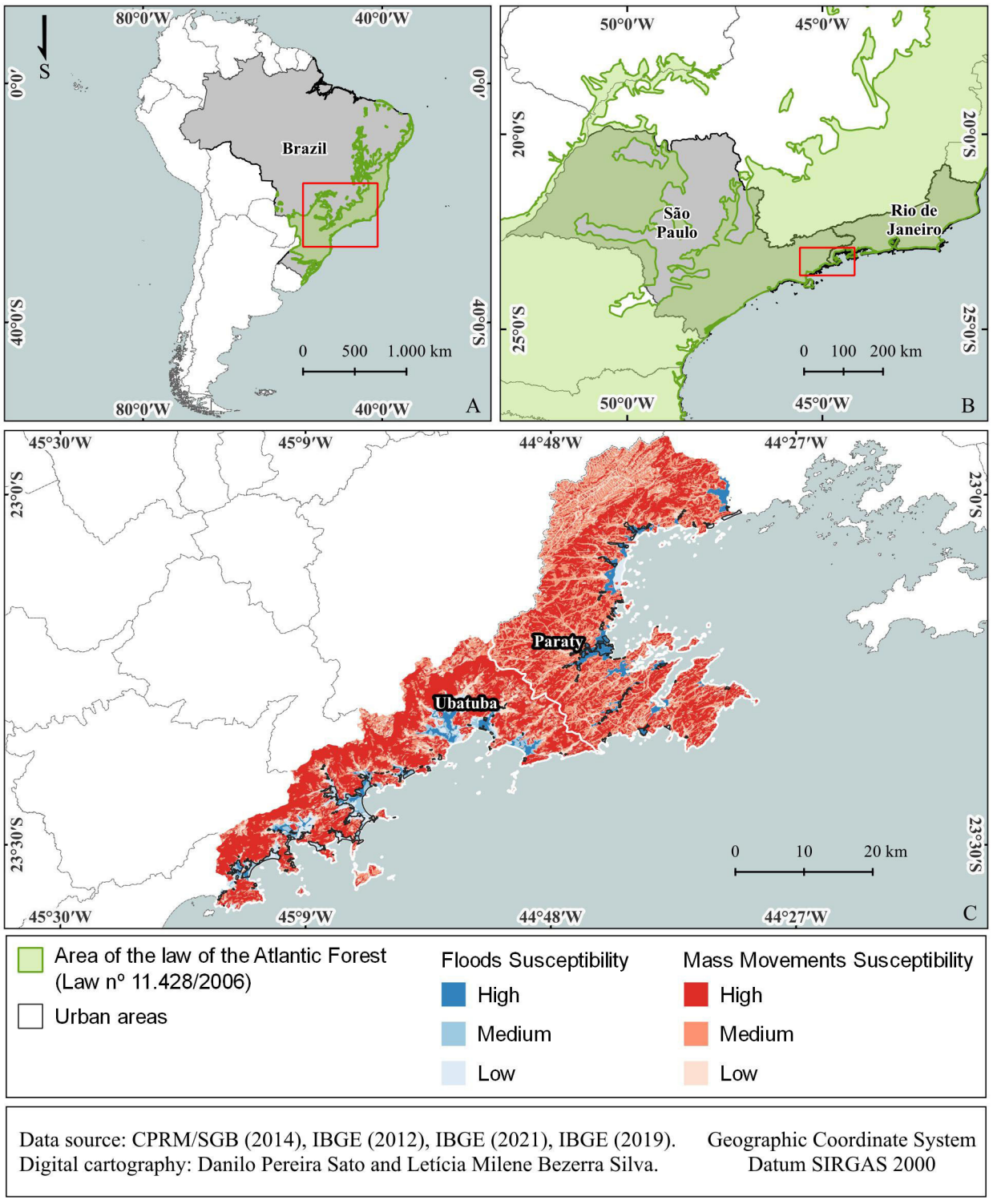

FIGURE 1
Location of the Atlantic Forest law area in relation to Brazil **(A)** and the states of São Paulo - SP and Rio de Janeiro - RJ **(B)**. Location and mass movements and flood susceptibility map of territories of Ubatuba (SP) and Paraty (RJ) with urban areas **(C)**. Data source: CPRM (Serviço Geológico do Brasil) (2014) and IBGE (Instituto Brasileiro de Geografia e Estatística) (2009, 2019, 2021). Geographic Coordinate System. Digital cartography: Danilo Pereira Sato and Leticia Milene Bezerra Silva. Datum SIRGAS 2000.

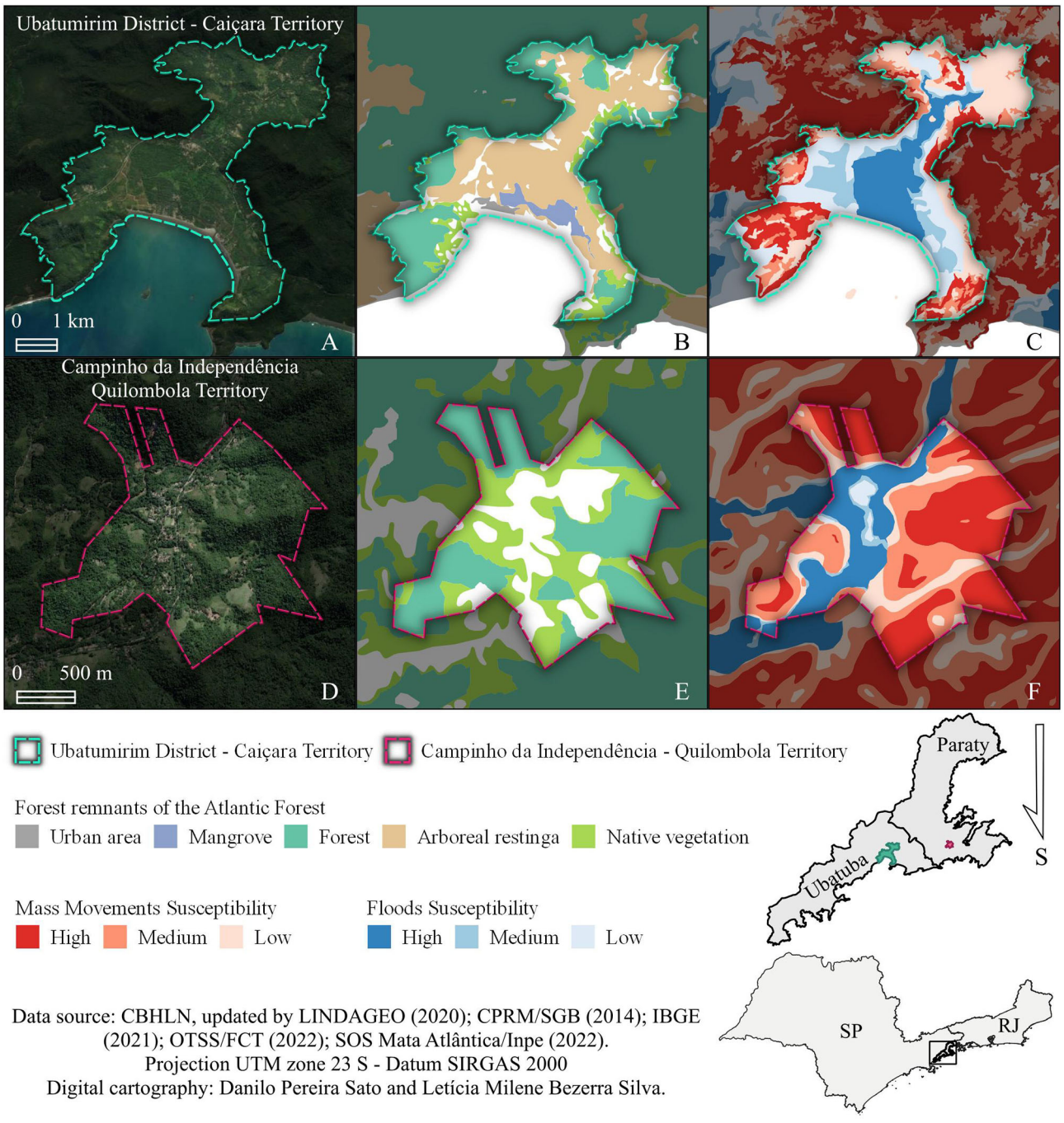

FIGURE 2
Location of the Caiçara Territory of Ubatumirim (Ubatuba/SP), **(A–C)** and the Quilombola Territory of Campinho da Independência (Paraty/RJ), **(D–F)**. Forest remnants of the Atlantic Forest for each territory **(B, E)**. Mass movements and flood susceptibility map of territories **(C, F)**. Data source: CBHLN, updated by IPT (Instituto de Pesquisas Tecnológicas) and CPRM/SGB (Serviço Geológico do Brasil) (2014), CBHLN (Comitê de Bacia Hidrográfica do Litoral Norte) (2020), IBGE (Instituto Brasileiro de Geografia e Estatística) (2021), SOS Mata Atlântica (Fundação SOS Mata Atlântica), and INPE (Instituto Nacional de Pesquisas Espaciais) (2023), and INCRA (Instituto Nacional de Colonização e Reforma Agrária) (2022). Projection UTM zone 23 S—Datum SIRGAS 2000. Digital cartography: Danilo Pereira Sato and Leticia Milene Bezerra Silva.

(2) *Workshops* were held to explain the citizen science approach on the use of smartphones to collect data on impacts and adaptation strategies for climate change.

(3) *Semi-structured interviews* using geotechnologies were conducted with local communities to contextualize the observations.

(4) *Observations were classified according to the LICCI classification* tree protocol, which has categories such as Physical, Climatic, Biological, and Socioeconomic/Cultural Systems.
(5) *Statistical analysis* was conducted on the data collected.

The research was collaboratively designed across four steps in the fieldwork. The initial two fieldwork occasions provided technology training to enhance communities' autonomy in data collection. The third and fourth fieldwork steps were focused on the comprehensive evaluation of research outcomes. The continuous dialogues with the community succeeded in supporting strategies for each phase, while concurrently assessing the various stages of the research process (Kasten et al., 2021; Albagli and Iwama, 2022). These processes played a pivotal role in community mobilization, facilitating mutual introductions, fostering cultural and knowledge exchanges, engaging in pragmatic discussions regarding data collection strategies, offering hands-on training with equipment, reinforcing team cohesion, and collectively constructing a narrative for dissemination materials, including the content of this article.

The shared responsibilities were divided as follows: community researchers contributed to data collection in traditional coastal territories, actively mobilized their communities, and administered survey questionnaires to identify climate-related disaster impacts. Academic researchers conducted interviews, and transcribed and analyzed the interviews and data from surveys.

3.1 Participatory action-research coupled with a citizen science approach

The methodological approach was based on participatory action research (PAR), which is a research design that aims to solve a specific community problem and brings together a community of practice and learning to collectively act to promote changes in the studied reality (Ferraro Júnior and Sorrentino, 2014; Trajber et al., 2019).

PAR is a collaborative approach that involves researchers and community members working together to identify problems, develop solutions, and implement those solutions. This approach is based on the belief that the people who are most affected by a problem are the best people to solve it.

The PAR was used citizen science data collection to investigate the impacts of climate change on traditional coastal communities in Brazil. The research team worked with community members to identify the climate-related risks that they were facing, develop adaptation strategies, and implement those strategies.

The research process was divided into four phases:

(1) *Problem identification*: The research team worked with community members to identify the climate-related risks that they were facing. This was done through interviews, focus groups, and workshops.
(2) *Solution development*: The research team worked with community members to develop adaptation strategies to address the climate-related risks that they had identified with citizen data collecting. This was done through a process of brainstorming, discussion, and negotiation.
(3) *Solution implementation*: The research team worked with community members to implement the adaptation strategies that they had developed. This involved providing training, technical assistance, and financial support.
(4) *Evaluation*: The research team evaluated the effectiveness of the adaptation strategies that had been implemented. This was done through a series of interviews, focus groups, and surveys.

The PAR approach was successful in helping these traditional coastal communities in Brazil to address the impacts of climate change. The research team was able to work with community members to identify the problems that they were facing, develop solutions that were tailored to their needs, and implement those solutions. The results of the research have the potential to inform the development of climate change adaptation strategies in other communities around the world.

The citizen science data collecting was oriented by the project coordinator so that two researchers were responsible for facilitating the local research in traditional coastal territories, and a volunteer offered to support the team's actions. Thus, in the initial phase of aligning agendas, four researchers and four leaders met to discuss the details of the data collected using citizen science. The leaders mobilized community members to collect the data, and a total of 1community researchers were involved in citizen data collection activities. The team was expanded to 17 members, and this group remained active in data collection and meetings to discuss the research strategy from September 2021 to February 2022.

3.2 Local observations using field data collection

To record the observations, a structured questionnaire was developed by academic researchers using the Survey123 app (a collaborative tool for surveys), collaborative collection data, analysis, and data sharing to support the citizen science strategy.

Two workshops were held, one in each community, with the objective of building local capacity and enabling community leaders who had familiarity with digital devices to take ownership of mapping and observation collection tools. The workshops lasted ∼2 h. Mapping kits containing a GPS, voice recorder, notebook, pen, and interview scripts were provided. The Survey123 app was installed on the cellphones and tablets of community researchers.

Data collection was carried out from September 2021 to February 2022 by community researchers. Passing on techniques learned in the workshops, community leaders taught other members of the community how to install the app and conduct surveys, thereby gaining autonomy in defining strategies for local observation collection in their respective territories.

3.3 Data classification and analysis

The survey collected data was classified according to the LICCI Protocol (Reyes-Garcia et al., 2021), a document that guides data collection among Indigenous Peoples and Local Communities (IPLC) emphasizing the role of Traditional Local Knowledge (TLK) to advance climate research. We used the TLK to state knowledge that has been accumulated across generations

TABLE 1 Overview of organizations with active membership from Campinho (Q) and Ubatumirim (U).

Institution/organization name	Type	Objective/activities	Scale
Association of Friends of the Caiçara Museum-AAMUC (C)	Community organization	Preservation and promotion of caiçara culture and heritage, social rights defense.	Local
Association of Residents of the Campinho da Independência Quilombo-AMOQC (Q)	Community organization	Community development, social rights defense, sustainable tourism.	Local
Forum of Traditional Communities/Observatory of Healthy and Sustainable Territories of Bocaina-FCT/OTSS (C) (Q)	Political organization	Promotion of Indigenous People and Local Communities (IPLC) development in Angra dos Reis (RJ), Paraty (RJ), and Ubatuba (SP) coastal cities; cultural heritage protection; research and knowledge generation.	Regional
National Coordination for the Articulation of Black, Rural, and Quilombola Communities-CONAQ (Q)	Political organization	Advocacy for collective use of territory, implementation of sustainable development projects in quilombola territories, empowerment of quilombola youth and women.	National
Secretary of Policies for Quilombolas, African Diasporic Peoples and Traditional Communities, and Romani People, Brazilian Ministry of Racial Equality (Q)	Government institution	Development and implementation of policies for quilombolas, African diasporic peoples, traditional communities, and Romani people.	National
Black Coalition for Rights (Q)	Political organization	Advocacy for the rights of black people, addressing racial inequality, discrimination, and systemic racism through political engagement, advocacy campaigns, and policy initiatives.	International

as collective and cultural practices in the environments and local ecologically dependent communities. In this research, we are working with artisanal fishers and Quilombola communities, where TLK includes Indigenous knowledge, traditional knowledge, traditional ecological knowledge, local ecological knowledge, farmers' knowledge, folk knowledge, and Indigenous science (Berkes, 2009; Nakashima et al., 2012; Klenk et al., 2017).

This broad classification enabled performing an integrated analysis of observations using a common vocabulary. Each observation was related to a corresponding variable, and the variables were grouped into classes, climatic (e.g., changes in rainfall patterns), physical (e.g., changes in coastal erosion), biological (e.g., biodiversity loss), and socioeconomic systems (e.g., subsistence practices)—see Table 1.

The classification and analysis of observations were shared among the team from April to November 2022. It was not the intention of this research to comparatively analyze the local impacts identified within their anthropological context, but rather to register the particularities of climate-related disaster impacts observed by members of both communities.

3.4 Kolmogorov–Smirnov analysis

Studies on the theoretical aspect of risk perception have discussed how the environment influences or shapes people's perceptions (Veyret, 2007; Adger et al., 2009; Slovic, 2010). This perspective recognizes that risk perception is not a universal and homogeneous process, but rather, it is shaped by a variety of contextual factors.

To protect homes and ways of life within communities, leaders are actively engaged in coastal management and urban political agendas, collaborating on various activities to facilitate organization and collective action, promoting intercultural knowledge exchanges, and building narratives that support their ongoing pursuit of territorial demarcation, food and nutritional sovereignty, and quality of life (De Freitas et al., 2016; Araos et al., 2019; OTSS, 2022).

Despite their distinct identities, the formulated hypothesis adopts this conceptual framework, which is inseparable from the broader context of coastal management conflicts and the literature on traditional knowledge that emphasizes its adaptive and problem-solving nature (Berkes, 2007; Brondízio and Moran, 2008; Naess, 2013; Reyes-García et al., 2016, 2019; Brondízio et al., 2021). Thus, the hypothesis formulated *a priori* by the scientific researchers was as follows:

(H_1) There is no significant difference in perceptions of climate-related disaster impacts between traditional communities (Caiçaras and Quilombolas);

(H_2) Communities possess their own adaptation strategies and local solutions to cope with the effects of climate change.

The statistical test used to analyze the data was the Kolmogorov–Smirnov (KS) correlation measure. The KS test aims to determine whether two samples originate from the same probability distribution by calculating the maximum difference between the empirical distribution functions of the two compared samples (Siegel, 1977).

The KS test was used to investigate whether there is a significant difference between the two population samples regarding local observations of climate change impacts: one from the Quilombola community (Paraty municipality) and the other from artisanal fishers (Ubatuba municipality).

The second hypothesis was evaluated through interviews conducted with community leaders and the administration of surveys.

3.5 Interviews with community leaders

To complement the quantitative data collection, five community leaders were interviewed by academic researchers

using a semi-structured questionnaire. The toolkit used included a paper-based questionnaire, digital camera, voice recorders, lapel microphone, notebook, and pen. The audio was transcribed to enable documentary analysis, and the videos were edited to create materials for disseminating research results. The interviews aimed to:

(a) Identify mentions of climate-related disaster impacts;
(b) Map adaptation strategies and spontaneous local solutions used to cope with climate change; and
(c) Promote a collective evaluation of the research and its main products. Additionally, the team exchanged messages remotely throughout the research process.

When analyzing the interviews, we extracted excerpts in which the leaders described climate change impacts, either directly or indirectly. These descriptions were counted as mentions of LICCI classification system variables—see Table 1. Repeated mentions of the same variable by the same interviewee were excluded. Each excerpt was converted and counted as a mention of a variable.

When presenting excerpts from the interviews in full, the names of the leaders were replaced with codes, which are actually cultural heritage elements of the communities and also the names of the principal rivers of the hydrographic basins in which the traditional coastal territories are located. Each leader was assigned a unique codename, such as "Abayomi," "Carapitanga," "Iriri-onça," "Pedras azuis," and "Tangará." The codification aimed to anonymize their names, in accordance with the ethical terms and conditions applied in the study.

4 Results

This section presents the results collected through the Survey123 App, semi-structured interviews, and an overview of the social and political organization.

4.1 Local-scale observations of climate-related disaster impacts

Local observations of climate-related disaster impacts were co-produced by integrating data from surveys, guided by community researchers, and interviews, guided by academic researchers. The Survey123 App was used to register 21 observations, each investigating the occurrence of 22 perception variables adapted from the LICCI classification system. The collections indicated the occurrence of 280 impacts, which were added to the 86 impact records mentioned by leaders in sections of the five interviews. Thus, the dataset analyzed in this topic consists of 366 climate-related disaster impacts reported (Figure 3).

Figure 3 shows the climate-related disaster impacts identified by this study ($n = 366$). More perception variables were mentioned in the physical system and climate system categories, with seven variables each. The impacts mentioned in the Cultural/Socioeconomic System were grouped into five variables, and impacts on the biological system were distributed in three variables. The impacts associated with the cultural system (36.34%) stood out compared to the others, with the physical (27.87%) and climate (26.23%) systems presenting similar values, and the biological system category (9.56%) appearing last, with the perception of biological impacts being less frequent than all the others.

Figure 4 illustrates the cumulative distribution curve that was generated to measure the theoretical distance between two samples categorized according to the LICCI tree. By analyzing the accumulated frequencies, D_{max} was calculated from the difference between the values obtained for each community. Figure 4 presents a comparison between D_{cal} and D_{crit} ($\alpha = 0.01$) for each system category. Note that D_{max} represents the largest observed difference between the two samples, while D_{crit} is the critical value that defines the threshold for rejecting H_1.

The test results show that the D_{max} value obtained corresponds to the socioeconomic/cultural system. After conducting the test for the significance level $\alpha = 0.01$, it was found that $D_{max} < D_{crit}$, which validates the hypothesis (H_1) that there is no significant difference between the perception of the two communities, at least for this dataset.

The distribution also demonstrates that there were fewer observations in Ubatumirim and more in Campinho territory. Some variables were particularly relevant to each community, and there are significant variables in both territories. In both communities, subsistence practices and climate variability variables (cold and heat waves) stand out. In Ubatumirim, the most mentioned impacts are associated with floods and landslides, while in the Campinho territory, water outages, epidemics, coastal erosion, and river sedimentation stand out.

4.2 Community-based strategies for climate change adaptation

4.2.1 The importance of traditional and local knowledge

The traditional and local knowledge about climate conditions is a longstanding tradition in both communities. Interviewed leaders engage with both older and younger community members to share the stories of those who experienced floods, landslides, droughts, and the strategies employed to mitigate and prevent damages and losses. The interviewees emphasize the deep connection with their community's ancestral heritage, providing valuable insights into the experiences of their forebears and the recent impacts of climate change:

> *"I've learned everything our ancestors did, and to carry on their legacy, I need this [territory] of fishing and the woods to sustain myself and others. This is what nourishes me... the reason is that my family is deeply rooted in this culture, in this place" (Tangará, leader of Ubatumirim, interview conducted in October 2022, Ubatuba, São Paulo).*

Regarding adaptation strategies to address the ongoing transformations and challenges they face, they mentioned:

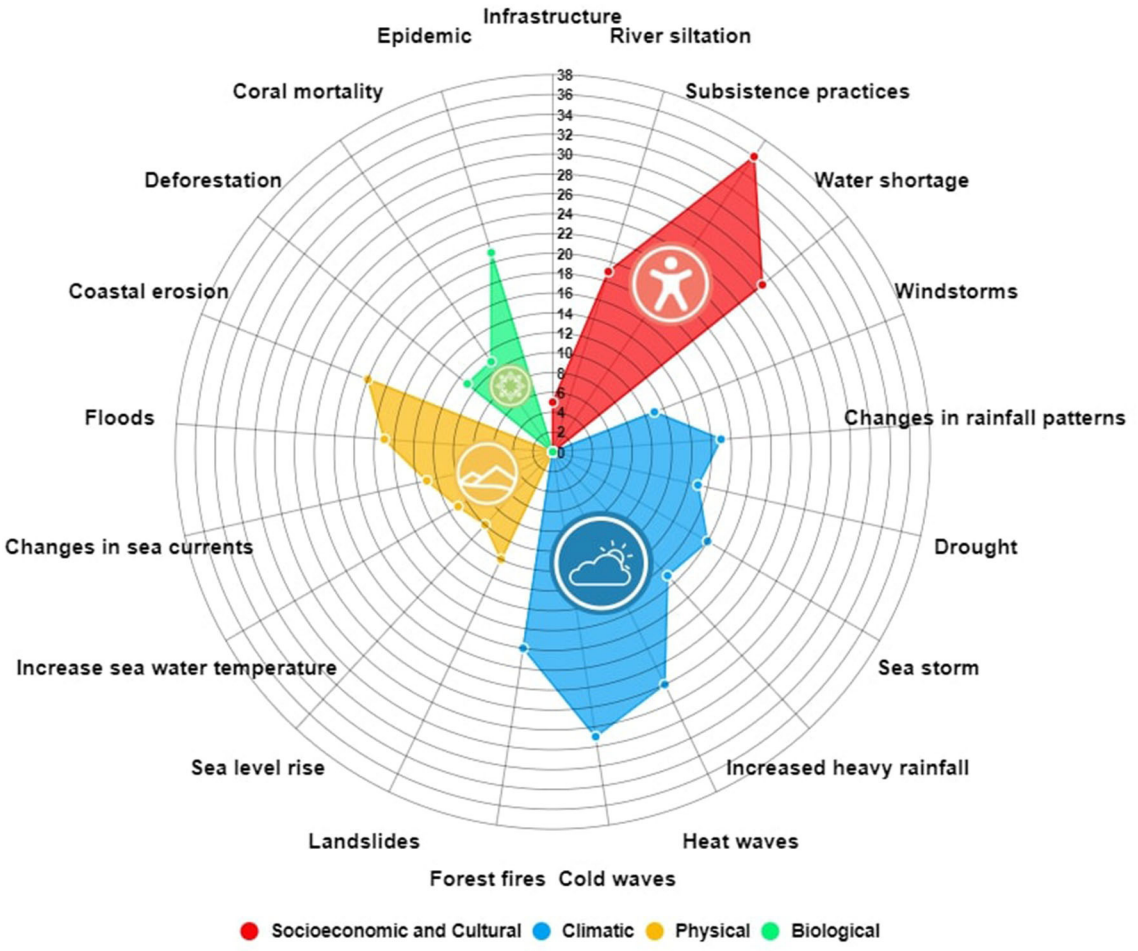

FIGURE 3
Climate-related disaster impacts identified by community researchers at the traditional coastal territories ($n = 366$).

> *"One strategy is to halt land surrender! People are still giving up their lands! People continue to relinquish their territory, right? And those occupying this land possess no knowledge whatsoever... I believe they should show more reverence for the land where our ancestors lived... and which they preserved for centuries, right?" (Tangará, leader of Ubatumirim, interview conducted in October 2022, Ubatuba, São Paulo).*

In this statement, the Caiçara leader of Ubatumirim expresses concern about the increasing pressure from real estate interests on Caiçara communities, compelling them to cede their lands to strangers who lack a connection and understanding of the territory. Prioritizing and safeguarding Caiçara cultural and environmental heritage becomes crucial in the face of economic pressures on the territory's integrity.

Testimonies from the Campinho and Ubatumirim communities shed light on the changes that have occurred over the last 30 years and the challenges posed by their geographical locations, which require river and stream navigation to access essential services and facilities. For instance,

> *"In some communities, children can't attend school during heavy rainfall" (Pedras Azuis, leader of Campinho, interview conducted in October 2022, Paraty, Rio de Janeiro).*

Despite these challenges, community members possess an intimate understanding of their local environmental conditions, enabling them to predict rising river levels and warn downstream residents or those in isolated areas vulnerable to flooding. Communication is often facilitated through portable radios, providing advance notice of incoming rainfall and potential home-endangering risks, while also assessing family preparedness. In the past, when technology was less advanced, communication and transportation proved more arduous, leading to the common use of "bamboo rafts" to ferry supplies downstream to these families.

The interviewees' motivations are linked to their attachment to the territory and nature. Their narratives converge on issues of land rights, ancestral roots, cultural and subsistence practices, and the transmission of ancestral knowledge, all playing a vital role in addressing the challenges that emerged during the interviews.

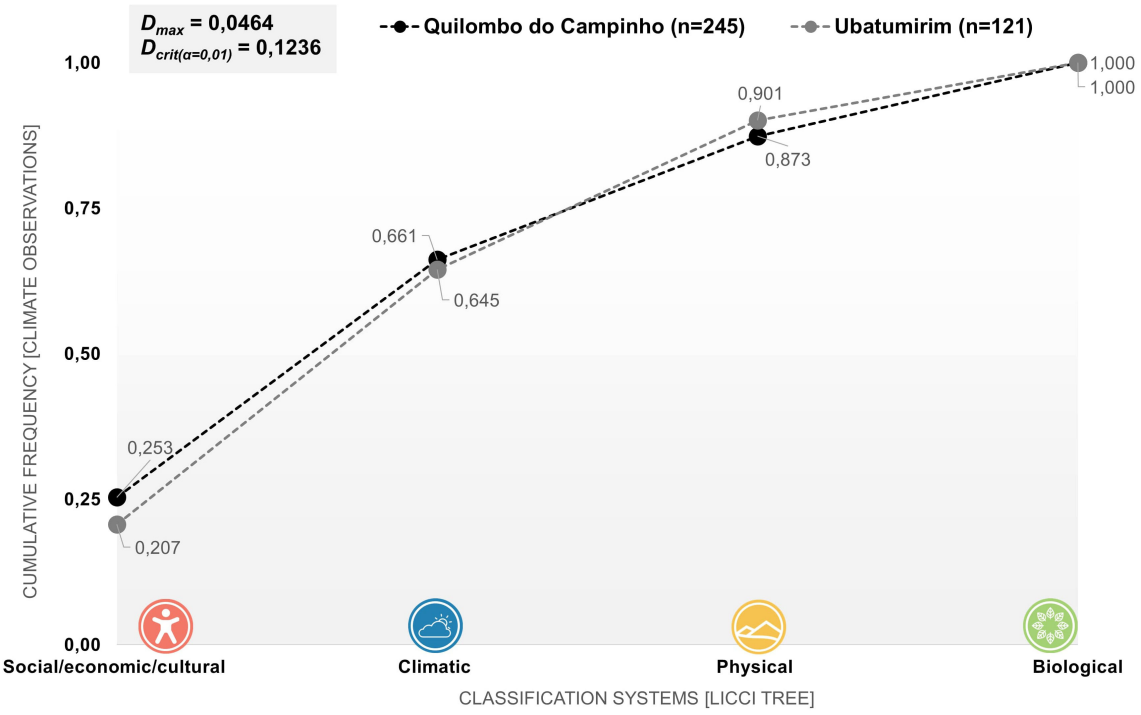

FIGURE 4
Cumulative distribution curve for the Kolmogorov-Smirnov (KS) test of two samples categorized by LICCI tree.

4.2.2 Collective action based on self-organization

Community leaders involved in the research have a long history of activism within social movements advocating for the rights of traditional peoples. They emphasize the significance of ancestral ties to traditional coastal territories, possessing a deep understanding of community members and the ability to engage them in collective actions aligned with the community's objectives. These leaders actively represent their community's interests and engage in organizations and social movements of local, regional, national, and international political significance (see Table 1).

The presence of influential figures from their respective communities is indicated by "(Q)" or "(C)" in this representation, highlighting their active participation in each organization. Note that community members may also partake in other initiatives.

This leadership capacity was recognized as essential for disseminating knowledge and the collaborative efforts required by this study. Furthermore, the academic researcher team led the preparation of surveys and workshops, which in turn facilitated a new arrangement and distribution of responsibilities, elevating community researchers to more prominent roles. These community researchers oversaw data collection evaluation, recruited new community researchers, and led the project's final sprint on evaluation of the role process. Consequently, the initial coordination efforts of the project brought young researchers from both communities and academia closer to experts and local leaders, fostering new relationships and bonds that did not exist before and expanding the possibilities for coordinated collective action.

> *"This community mobilization is not limited to one region but involves several areas, engaging more people in a communal sense and demanding public policies" (Tangará, leader of Ubatumirim, interview conducted in October 2022, Ubatuba, São Paulo).*

Our fieldwork and interviews reveal that, in both territories, self-organization is a fundamental principle of collective and coordinated action in social mobilization and political advocacy to safeguard social rights. This is intricately linked with the wellbeing of these communities, encompassing access to healthcare, education, infrastructure, adequate housing, and other fundamental human rights that are strained by the absence of public policies and/or territorial conflicts, as detailed in Section 2.

Preserving culture and territory is seen as a shared responsibility between community members and the government. In their view, the concept of adaptation strategy is constructed in line with the social movement narrative of traditional communities:

> *"I still believe that the struggles of the people, the struggles of social movements, are what maintain a minimal balance in this equation" (Carapitanga, leader of Campinho, interview conducted in October 2022, Ubatuba, São Paulo).*

As climate change exerts pressure on subsistence practices, its effects are perceived fundamentally as socio-economic and cultural issues that require strategic political action.

> *"I think the way of life of these communities has historically had a direct relationship with sustainability. I believe that if the State had understood and treated this strategically from the beginning, it would be an excellent alliance for conservation and addressing the climate issue" (Carapitanga, Campinho Leadership, interview conducted in October 2022, Ubatuba, São Paulo).*

Both communities understand that adaptation occurs within a context of territorial and social conflict. Their strategies address climate change as a social issue, anchoring their actions in policies that seek to ensure fundamental human rights. In their perception, Climate Adaptation is a political action that demands prioritizing collective action aimed at reducing vulnerability and enhancing access to basic rights, thereby combating inequality.

5 Discussion

The findings regarding the research questions pointed out:

(a) Communities primarily perceive the impacts of climate change in relation to their subsistence practices and variations in climate conditions.
(b) Community-based adaptation strategies to reduce the effects of climate change are mainly based on the transmission of ancestral knowledge, the preservation of cultural heritage, the collective and coordinated efforts guided by community leadership, and advocacy on social rights that may mitigate vulnerability.
(c) A shared perspective prevails among the two communities—Quilombolas and artisanal fishermen—about climate-related crises. They view climate adaptation as a political action intertwined with policies that prioritize socioeconomic impacts endured by these communities, ensuring their wellbeing and access to social rights.

5.1 Advances on risk knowledge through "similar but different" experiences

Local communities are experiencing a wide range of disaster impacts associated with climate change. When it comes to the public sphere, climate variability, especially associated with extreme events of temperature, is not unilaterally understood as evidence that reinforces anthropogenic climate change (Finnis et al., 2015). Reports of individual experiences related to climate variability are often used both to affirm and deny climate change (Di Giulio and Vasconcellos, 2014). In both communities, it is evident that climate change is real and is affecting subsistence practices, which demonstrates that communities understand the anthropogenic nature of climate change and the inherent uncertainty of this issue. This documentation of climate-related disaster impacts is a first step to strengthen communities' capacities to engage the DRM public policies. It also paves the way for a deeper exploration of community-based risk monitoring, communication, and building disaster response capabilities.

It is important to highlight that the Caiçara and Quilombola identity groups have unique ways of life and culturally differentiated realms, rich with knowledge, beliefs, values, and practices. While their perceptions of risks and climate change impacts show certain distinctions, they also exhibit points of convergence.

We argue that shared experiences of regional climate variability may have contributed to the convergence of community perceptions regarding specific documented climate change impacts. For instance, according to Marengo J. et al. (2023), São Paulo and Rio de Janeiro both experienced cold spells and cold waves during the winter of 2021, while the southeastern region faced extreme drought conditions. Furthermore, between 2015 and 2019, states in southeastern Brazil witnessed 1,373 instances of extreme rainfall, with precipitation exceeding 50 mm/h (Marengo J. A. et al., 2023). The Intergovernmental Panel on Climate Change (2023) also showed an increase in the number of additional days of heatwave exposure in several South American countries. In Brazil, between 2016 and 2020, there were 3.1 additional days of heatwave exposure compared to the period between 1986 and 2005 (Intergovernmental Panel on Climate Change, 2023).

Nevertheless, two distinct factors that the communities experienced individually played crucial roles in their perception, influencing the outcomes of our study. The first factor is the landslides and floods in Ubatumirim during the research period. Previous studies on vulnerability have provided evidence of such events in Ubatuba and neighboring municipalities (Iwama et al., 2014). These recurring disasters impacted the local communities, disrupting our data collection phase and sometimes leading to the suspension of data gathering activities.

The second factor is the water shortage in Campinho. The water crisis in the region in January 2014 was primarily caused by an anomalously intense and prolonged high-pressure system over the Atlantic Ocean, which affected the Southeast Region (Marengo J. et al., 2023). Factors such as inadequate water supply planning for Brazilian megacities (Fracalanza and Freire, 2015) and prolonged drought periods associated with changes in rainfall distribution also contributed to these events (Marengo J. A. et al., 2023). Despite these slight differences, it was evident that both communities understand climate change and the interactions between the climate system and their ways of life and culture. These impacts are an integral part of their daily lives.

The communities mentioned the biological systems category less frequently, even though it is directly related to the current issues they have been facing, often associated with pressures for land use, deforestation, and urban expansion (Inouye et al., 2015; Daunt and Silva, 2019; Daunt et al., 2021), as well as land use conflicts due to overlaps with protected areas (Simões, 2015; Maretti and Simões, 2020). Initially, the problems that emerge are associated with social infrastructure. Indeed, although biological and climatic effects are recognized, they are not prioritized. Therefore, engaging with the impacts that will arise from climate effects and disasters remains a challenge that is still evolving.

The use of the LICCI classification system offered an opportunity to deepen our knowledge of local impacts and for the locals to further understand the associated risks. The categories allowed us to identify specific concerns of each community on

both slow-onset and sudden-onset events. This approach not only identifies impacts but also enables integrated analyses to be extended to other territories that have similar experiences yet different identities and local concerns. Expanding the scope of data collection and monitoring these impacts is paramount to advance our understanding, and to sustain ongoing actions, it is essential to allocate technological, financial, and human resources that ensure the implementation of regional-local actions.

5.2 A comprehensive adaptation strategy is beyond isolated efforts

In a broader context, our findings regarding adaptation strategies, in conjunction with various other studies (Sato et al., forthcoming; Cajigal-Molina et al., 2017; González-Gaudiano and Maldonado-González, 2017; Olivato et al., 2017; Simões et al., 2017; Matsuo et al., 2019; Albagli and Iwama, 2022; Pereira et al., 2022b), underscore the pivotal role of collective action in addressing the climate crisis. Traditional leaders hold a central position in mobilizing communities socially, and their strategies for mitigating the impacts of climate change predominantly hinge on the transmission of ancestral wisdom, preservation of cultural heritage, coordinated and collective efforts through community leadership, and advocacy for social rights aimed at reducing vulnerability. As evidenced in Table 1, these leaders extend their influence beyond local political realms onto regional, national, and international levels (Pereira et al., 2022a). They maintain strong ties with fellow community members and collaborate with other territories through cultural events and festivals (OTSS, 2022). Their views on adaptation strategies are intricately linked with territorial disputes and the pressing need for mechanisms and legal instruments to govern the demarcation of their lands (De Freitas et al., 2016).

The organizations and alliances forged by traditional communities also play a significant indirect role in climate adaptation. They consistently advocate for resolving issues related to land rights, improving the quality of life for traditional communities, advancing understanding of climate impacts, safeguarding cultural heritage, and establishing governance structures for coastal areas (Simões et al., 2017).

Nevertheless, these efforts alone do not ensure safety when the next storm strikes. The documented perceptions in this study provide insights into priority impacts and factors that could promote effective adaptation strategies. Yet it is widely acknowledged that global guidelines on disaster risk reduction and climate adaptation stress the importance of laws securing the sustainable use of resources and the land rights essential for the security of traditional communities (Birkmann et al., 2009; Diaz et al., 2019).

As with many other studies (Schumann, 2007; Kronik and Verner, 2010; Cains and Henshel, 2019), our research offers a potential pathway for these public policies to operate at the local-regional scale by employing community-based strategies to gather information about local risks and impacts. It is already evident from numerous studies that, when guided by community perceptions, progress can be made in activities dedicated to disaster risk reduction (Chari et al., 2019; Hicks et al., 2019), the development of warning systems (Marchezini et al., 2018), participatory monitoring of environmental conditions (Bañales-Seguel et al., 2020), participatory mapping (Olivato et al., 2017), and even the co-designing of people-centered strategies in disaster risk management (Erisman et al., 2015). Recognizing the significance of documented perceptions and historical communication strategies, it becomes evident that ancestral knowledge can play a crucial role in fostering people-centered early warning systems (PCEWS). By doing so, these public policies can transcend the traditional "last mile approach" that prioritizes response over prevention (Marchezini and Londe, 2018), instead empowering coastal communities to actively engage with the EWS as key actors in enhancing their resilience to future disasters.

5.3 Citizen science collaboration bridging local knowledge in climate-related disasters

In addition to the need for more public policies supporting the involvement of traditional communities in DRM, our study's findings, rooted in the shared perception of community leaders, highlight that local observations align with scientific findings. The absence of significant differences in perception suggests that interventions and strategies developed based on this collective understanding can effectively benefit both communities. This emphasizes the importance of inclusive and participatory approaches that combine local knowledge with scientific data (Simões et al., 2017), fostering a dialogue rooted in shared comprehension of impacts within the community.

Citizen science collaboration between researchers and local communities can provide access to research as a fundamental right, using data collection actions on risk perception and adaptation measures (Albagli and Iwama, 2022). This research favors the expansion of possibilities for reflection on practice, self-criticism, and the development of solutions to redirect the actions of the research project while it is still ongoing. Building bonds of trust built between traditional and local communities and scientists (Iwama et al., 2016; Albagli and Iwama, 2022) is crucial in order to increase the community participation in the research phases.

Although our research outlines collaborative participation in the citizen science approach to climate change research, it is still necessary to: (1) build medium-term and long-term agendas that allow communities to effectively have more autonomy in the use of digital technologies for data collection; (2) advance in capacity building for analyzing the collected data. This involves creating conditions for the right to research that citizen science (Appadurai, 2006; Albagli and Iwama, 2022) or community science (Charles et al., 2020) has sought to advance in climate-related disaster research.

De Mello-Théry (2020) remarks that this type of field research has the potential to realize the scientist's social function through applied research. Building a dialogical form of communication continuously throughout the research process allows for a constant exercise of mutual learning and knowledge integration (Tengö et al., 2014; Albagli and Iwama, 2022).

Furthermore, our findings reveal that the more community engagement is built, the more local observations will be generated as a result. This engagement must take place in all phases

of the research, and the pre-research phase is fundamental to start building this participation in the research. This underscores the value of involving multiple, diverse stakeholders in climate action (Marchezini, 2020; Norstrom et al., 2020; Serrao-Neumann et al., 2020). The extent of this engagement is influenced by various factors, including individual profiles (Lee et al., 2015), as well as collective actions and cultural factors, which significantly shape community perspectives, especially regarding the impact of climate-related disasters on subsistence practices (Wannewitz and Garschagen, 2023).

The demands expressed by leaders in Ubatumirim and Campinho are closely related to fundamental human rights rather than specific instruments for DRM. They advocate for the protection of their social rights, including education, health, safety, land rights, and cultural heritage (Simões et al., 2017; Araos et al., 2019; Bruno et al., 2020). These aspects are integral to the capacity to adapt, encompassing social rights that can reduce vulnerability more broadly (Eakin et al., 2014).

In this context, going beyond acknowledging local perspectives as relevant and translating this knowledge into action requires addressing climate-related challenges identified through their perceptions. Empowering vulnerable communities and promoting cognitive justice means recognizing the validity and value of their memories, perceptions, and knowledge (Santos, 2007, 2018). It is essential that climate research agendas incorporate traditional communities' perceptions, integrate multiple evidence-based observations, and facilitate the scaling up of localized and spontaneous solutions developed with key actors from traditional communities. Additionally, it involves supporting them to lead their own climate adaptation efforts.

6 Conclusion

The climate crisis urges engagement from all stakeholders in reducing and adapting to climate-related disasters. Our findings support that both traditional communities—artisanal fishers and Quilombolas—share similar views on climate change impacts, considering a connection with their community's ancestral heritage. The citizen science approach utilizing technologies for data collection, has not only expanded knowledge and perception, but also the potential for collective action. This enhances their capacity to engage in fruitful dialogues with other stakeholders, facilitating data collection and monitoring of local impacts on their own.

Our main contribution is documenting their perceptions of daily exposure to the effects of the climate crisis through a collaborative effort. It highlights that their voices are vital in shaping responses to these impacts. Consequently, there is a need to deepen our understanding of long-term strategies for reducing vulnerability, including education, health, wellbeing, and efforts to mitigate impacts, particularly in more immediately sensitive areas, such as subsistence practices.

However, the observations produced offer only a preliminary glimpse into the reality of climate-related disaster impacts. Continuous monitoring is imperative as the communities' response capacity to these events is limited due to the fact that a comprehensive adaptation strategy is beyond isolated community efforts, thus escalating risks. Empowering them and promoting cognitive justice calls for recognizing the validity and value of their memories, perceptions, and knowledge within climate research agendas.

Future research should investigate the effectiveness and coverage of public policies focused on Disaster Risk Management (DRM) in traditional territories, Research should also explore alternative financing options for local solutions and community projects to maintain the impact monitoring and progress from risk knowledge toward other Early Warning System (EWS) components. This advancement requires public policies that recognize the potential of inclusive approaches integrating local and scientific knowledge. Also, it reinforces the importance of recognizing the role of engagement by traditional and coastal communities as key actors, while supporting their autonomy to lead community-based adaptation efforts.

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 humans were approved by Comitê de Ética em Pesquisa com Seres Humanos (CEP)—Universidade do Sul de Santa Catarina—UNISUL. The studies were conducted in accordance with the local legislation and institutional requirements. Written informed consent for participation in this study was provided by the participants' legal guardians/next of kin. Written informed consent was obtained from the individual(s) for the publication of any potentially identifiable images or data included in this article.

Author contributions

RP, LB, and AI contributed to the conception and design of the study. RP took the lead in writing the first draft of the manuscript. LB and AI conducted the statistical analysis. MT-R and MD conducted interviews with community leaders. MT-R provided valuable critical feedback on the study. MD specifically reviewed the discussion section. DS reviewed the references. LB and DS were responsible for writing the Section 2 and conducted the spatial analysis for susceptibility mapping. LSo, AB, MO, and RS contributed to data collection in traditional coastal territories, actively mobilized their communities, and administered survey questionnaires to identify climate-related disaster impacts. All authors actively participated in manuscript revision, thoroughly read the content, 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.

Publisher's note

Supplementary material

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fclim.2023.1243008/full#supplementary-material

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