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How disasters and crises reshape economic vulnerability among small-scale fishers in Brazil

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Small-scale fishers worldwide face compounded crises, yet vulnerability manifests differently across disruption types. Using 402 fishers' surveys from Brazil, we contrast economic vulnerability pathways during an ecological disaster (oil spill) and a social crisis (COVID-19 pandemic), by combining income data with adaptation and perceived risk. Intersectional identities, not crisis type alone, determined vulnerability: gender drove disparities during the oil spill (women lost 2 times more income due to reliance on contaminated and low-value nearshore species). At the same time, age shaped pandemic impacts: while younger fishers incurred slightly larger proportional losses, older fishers maintained lower incomes and showed limited adaptative capacity. Pre-existing place-based inequities amplified both crises, accelerating entry into and intensification of hardship. We argue that equitable resilience requires crisis-tailored policies (e.g., gender-responsive support for ecological disasters; age-inclusive adaptation for health crises). Ignoring these intersectional pathways risks reinforcing marginalization in an era of compounding shocks.

Complex socio-ecological systems (SES) are characterized by interdependencies between social and ecological components, shaping community resilience and vulnerability[1,2]. SES are particularly susceptible to disruptions from environmental shocks (e.g., natural disasters) or social crises (e.g., economic downturns)[3,4]. The frequency and intensity of such disruptions have increased in recent decades, driven by global environmental change, urbanization, and interconnected socio-economic pressures[5,6]. In SES, these disruptions have profound and cascading effects, threatening livelihoods, food security, and cultural practices[7,8]. Understanding how communities experience and respond to such challenges is critical for their well-being and may help guide SES resilience policies amid unprecedented change[9,10].

Communities highly dependent on nature have historically grappled with disruptions that trigger cascading effects throughout the system[1,11]. Their responses are shaped by a complex interplay of social, economic, and ecological factors[3,4]. Research on disaster response highlights that communities often rely on adaptive strategies to mitigate crises, such as livelihood diversification, migration, and collective action[12,13]. In fisheries, for example, fishers may shift target species, modify fishing grounds, or adopt new technologies in response to ecological disturbances like coral bleaching or overfishing[3,14]. Similarly, during social disruptions such as economic recessions, communities may turn to informal networks, government assistance, or alternative income sources[15,16]. However, the effectiveness of these responses depends on access to resources, institutional support, and pre-existing social and economic capital at the community and household levels[10,17]. Yet, while studies have documented these responses, few have compared how economic security is shaped by distinct types of crises within the same SES context.

A major debate in SES research concerns whether the pathways communities are affected by and respond to disruptions differ by whether the disturbance is ecological or social[3,15]. Ecological disruptions, such as habitat degradation, typically affect resource availability, forcing communities to adapt harvesting practices, shift target species, or relocate fishing grounds[18,19]. In contrast, social disruptions, such as economic crises, may

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disrupt market access, labor availability, or institutional support, requiring broader livelihood adjustments that extend beyond resource use[15,16]. While both types of disruptions can lead to economic losses, the mechanisms through which they affect economic security may be fundamentally distinct.

Despite growing interest in how communities respond to disruptions, comparative studies on economic vulnerability across social and ecological disturbances within SES remain limited[15,19]. This study addresses this gap by asking whether and how certain fishers (e.g., women, specialists, users of particular fishing environments) face greater economic insecurity, regardless of disturbance type. While both types of disruptions can lead to economic losses, we hypothesize that the pathways through which economic vulnerability emerges will differ. For example, ecological disruptions (e.g., oil spills) can reduce resource availability, disproportionately affecting fishers who specialize in certain habitats or species[3,18]. In contrast, social disruptions (e.g., pandemics) can limit market access, disrupt labor dynamics, and worsen gendered access and decision-making, increasing vulnerabilities for groups like women or small-scale fishers who rely on informal networks[20–22].

To test these hypotheses, we examine the economic impacts of two crises that struck Brazilian fishing communities in quick succession: the 2019 oil spill, the largest in the South Atlantic, and the COVID-19 pandemic, which emerged while spill effects persisted. By representing ecological and social disruptions, respectively, these events provide a unique opportunity to compare their effects on coastal livelihoods. The oil spill contaminated coastal ecosystems and disrupted fishing activities, directly affecting resource availability and livelihoods[23,24]. In contrast, the COVID-19 pandemic led to market closures, restricted mobility, and reduced demand for fish, exemplifying a social disruption with indirect but profound economic effects[15,19]. Some evidence suggests that men and women experienced COVID-19's impacts differently[22], but the magnitude, underlying causes (e.g., type of habitat exploited, target species), and comparison with ecological impacts remain unresolved. Our findings inform SES theory and highlight the need for policies that address immediate shocks and structural inequalities shaping resilience in resource-dependent communities.

Results

Fishing aspects

Out of the 402 respondents, only 88 were women, with the majority living in Alagoas – AL state (N = 46), followed by Rio Grande do Norte – RN state (N = 30) and Bahia – BA state (N = 12) (Fig. 1a and b). In general, fishers were on average 50 (± 12) years old, with the highest average age in BA (54 ± 13 y), followed by AL (47 ± 9 y) and RN (45 ± 10 y). Fisherwomen tended to be younger, with an average age of 46 y (±10), compared to 50 y (±13) for fishermen. The average time of schooling among fishers was approximately 7 years, with BA showing the highest average (7.6 years), followed by AL (6.2 years) and RN (5.8 years). The lower average schooling time in RN was associated with fishermen, who averaged 5.4 years of schooling, compared to 7.6 years for fisherwomen.

Over half of the fishers (64%) conducted their activities in coastal environments, while the remaining 36% operated in open waters (Fig. 1c). Fisherwomen exclusively worked in coastal areas, with 75% relying on benthic and benthopelagic species (e.g., shellfish), compared to only 28% of fishermen. This reliance on shellfisheries was particularly pronounced in AL, where 69% of fisherwomen depended on these species. Across the three states, most fishers (N = 272, 68%) reported using hand-based methods, nets, and traps for fishing. In AL, fisherwomen were especially reliant on hand gleaning, with 83% (out of 46) identifying it as their primary method.

On average, fishermen consistently earned three times more than fisherwomen before, during, and after the events (Fig. 2a; Mann-Whitney U test: all periods/p-value = 0.000). In the five years preceding the oil spill, fishermen earned an average of R$ 1406 (US$ PPP 583.4) compared to R$ 485 (US$ 201.2) for fisherwomen. The oil spill disaster drastically reduced average incomes for both groups, with fishermen's earnings dropping to R$ 743 (US$ PPP 308.3) and fisherwomen's to R$ 228 (US$ PPP 94.6), nearly half their previous levels. During the pandemic, however, fisherwomen managed to increase their average income by 14%, reaching R$ 259 (US$ PPP 107.5), while fishermen showed a slight decline of 1%, bringing their average income to R$ 734 (US$ PPP 304.6). Despite the relatively better recovery for fisherwomen during the pandemic, the income disparity persisted after the events, with fishermen earning around R$1249 (US$ PPP 518.3) and fisherwomen earning R$ 361 (US$ PPP 149.8). Regarding the group of fishers based on age, fishers under 50 years old consistently earned higher incomes (avg R$986.6/US$ PPP 409.4) than those over 50 (avg R $767.4/US$ PPP 318.4) across all observed periods (Fig. 2b; Mann-Whitney U test: pre-crisis and during oil spill/p-value = 0.02, during pandemic/p-value = 0.123, pots-crisis/p-value = 0.002). However, the pandemic reduced earnings by nearly half for both age groups. Additionally, weekly average income varied sharply by state, with fishers in Rio Grande do Norte (RN) earning substantially more (avg R$1308 / US$ PPP 542.7) than those in Bahia (BA, avg R$693/ US$ PPP 287.6) and Alagoas (AL, avg R$449.7/ US$ PPP 186.6). This pattern with fishers in RN earning more than their counterparts in the other states persisted throughout the study period, with the largest income gaps emerging after the disruptive events (Fig. 2c; Kruskal-Wallis test: all periods/p-value = 0.000).

When analyzing the income change per state, BA emerged with the largest proportion of fishers experiencing very high income loss (>80% of loss), accounting for 67% of this group, followed by AL at 17% and RN at 16%. Conversely, most fishers (93 out of 402) with stable or some gain in incomes were from RN (50%), followed by BA (38%) and AL (12%). Specifically, out of 402 fishers surveyed, only 17 reported income gains during the oil spill and 23 during the COVID-19 pandemic, while 12 reported gains in both events. When analyzing the income change by gender, 30% of fisherwomen fell into the highest category of income loss, compared to 22% of fishermen. The worst situation was in AL, where 74% of those experiencing very high income loss were fisherwomen. RN and BA followed, with 17% and 9% of the affected fisherwomen, respectively. Only 14% (out of 88) of fisherwomen maintained a stable economic situation, compared to 26% (out of 314) of fishermen.

In terms of trade, fishers in Rio Grande do Norte (RN) exhibited greater reliance on middlemen than fishers in Bahia (BA) and Alagoas (AL), who were more engaged in direct sales. Specifically, more than half (66%) of RN fishers depended on fixed buyers (middlemen), while only 22% sold directly to consumers. This contrasts with AL, where 40% engaged in direct sales (versus 28% relying on fixed buyers), and BA, where 29% sold directly (compared to 27% relying on fixed buyers).

What drivers underlie the economic vulnerability of fishers during crisis events

Several factors contributed to changes, primarily losses, in fishers' income during the oil spill and the COVID-19 pandemic (Table 1). Yet, the only common predictor of income change across both events was the geographic location of the fishers.

During the oil spill, income change was significantly associated with gender and the coastal state where fishing activities were conducted (Fig. 3a and b). Specifically, fishermen had 57% lower odds of falling into a higher income loss category compared to fisherwomen (p = 0.001), indicating that being male was associated with a lower probability of experiencing severe income change. Additionally, fishers from Bahia (BA) were found to be twice (odds of 110%) more likely to experience income change than those from Alagoas (AL) (p = 0.015). The number of fishing environments used was not a significant predictor of income change (p > 0.05).

During the COVID-19 pandemic, the most significant predictors of income loss were fishers' age and again their state of residence (Fig. 3c and d). Older fishers were slightly less likely to experience income loss compared to younger counterparts (p = 0.055), with each additional year of age associated with a 1.6% reduction in the odds of falling into a higher income loss category. In terms of geographic differences, fishers from Rio Grande do Norte (RN) had 75% lower odds of experiencing greater income loss compared to those from Alagoas (AL) (p = 0.000). Neither the number

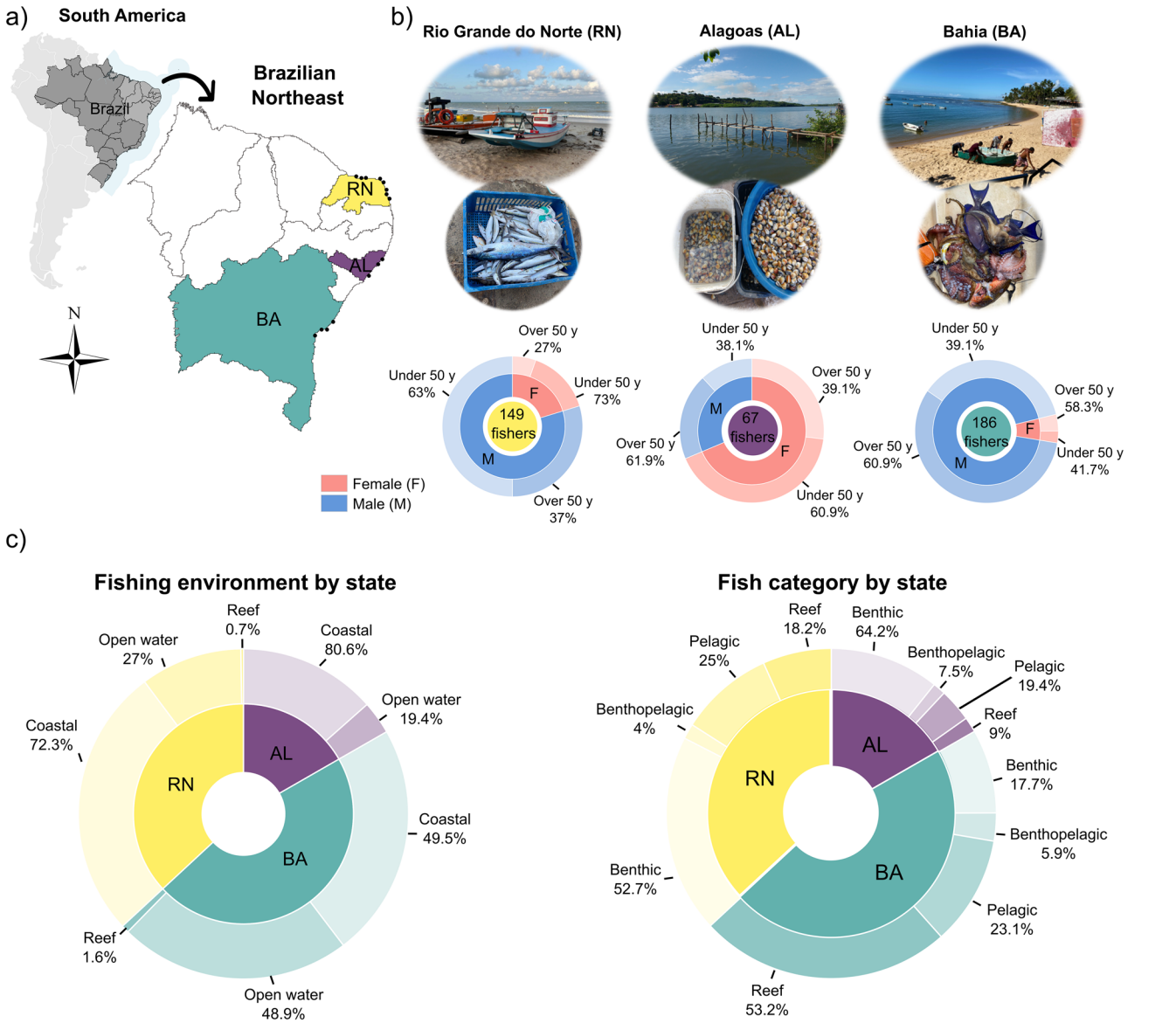

Fig. 1 | Study area, sample, and fishing profiles. a Study area located on the Northeast coast of Brazil, covering three coastal states: Rio Grande do Norte (RN), Alagoas (AL), and Bahia (BA); Light blue shows the Brazilian Exclusive Economic Zone (EEZ) in Brazil's coastline; Black dots represent the coastal municipalities sampled (N = 15) in the Brazilian Northeast. **b** Photos illustrate the coastal environment and typical marine resources from each state (Photos by Gabriel Costa and Evelynne Barros); Circles show the total number of fishers, and by gender and age group, interviewed in each state. **c** The percentage of fishers by fishing environment (coastal, open water, and reef) (left) and by target fish category (benthic, benthopelagic, pelagic, and reef) (right), displayed in donut charts for each state.

of fishing environments used nor the category of target fish species significantly influenced income variation during the pandemic (all $p > 0.05$).

Fishers' perceptions of environmental and health-related disruptions to their livelihoods

To ensure comparability across events, we focused on fishers' perceptions of how each event affected their community, profession, and income. Unlike the previous regression-based analysis, which estimated income loss based on reported fishing earnings, this section explores perceived impacts, i.e., how fishers subjectively experienced the consequences of each event, including on income itself. For the oil spill, we compared perceptions by gender (fishermen vs. fisherwomen) and across the three coastal states (AL, BA, and RN). For the COVID-19 pandemic, we focused on age differences (under 50 y vs. over 50 y), while also conducting the same regional comparison. These variables, gender (oil spill), age (COVID-19), and coastal state (both events) were those shown to be significantly affecting income during each event.

During the oil spill, perceptions of its impact on community, profession, income, sales, and fishing activities differed significantly between fishermen and fisherwomen ($t = 3.154$, $df = 172$, $p = 0.002$). For instance, 83% of fisherwomen reported perceiving greater income impacts, compared to 61% of fishermen (Fig. 4a). Moreover, 56% of fisherwomen reported interruptions to their activities due to the oil spill, whereas only 26% of fishermen experienced similar disruptions; and 83% of fisherwomen perceived a greater impact on seafood sales compared to 69% of fishermen (Figure S1a, Supplementary Materials). Perceptions of the oil spill also varied significantly across coastal states ($KW = 63.641$, $df = 2$, $p < 0.001$). Fishers from Rio Grande do Norte (RN) reported significantly lower perceived impacts than those from Alagoas (AL) and Bahia (BA), where the majority experienced very high levels of impact (Fig. 4a). In particular, the number of beaches perceived as affected by the oil spill was greatest in BA and AL, with 92% of fishers in BA reporting that at least half of the beaches were impacted, followed

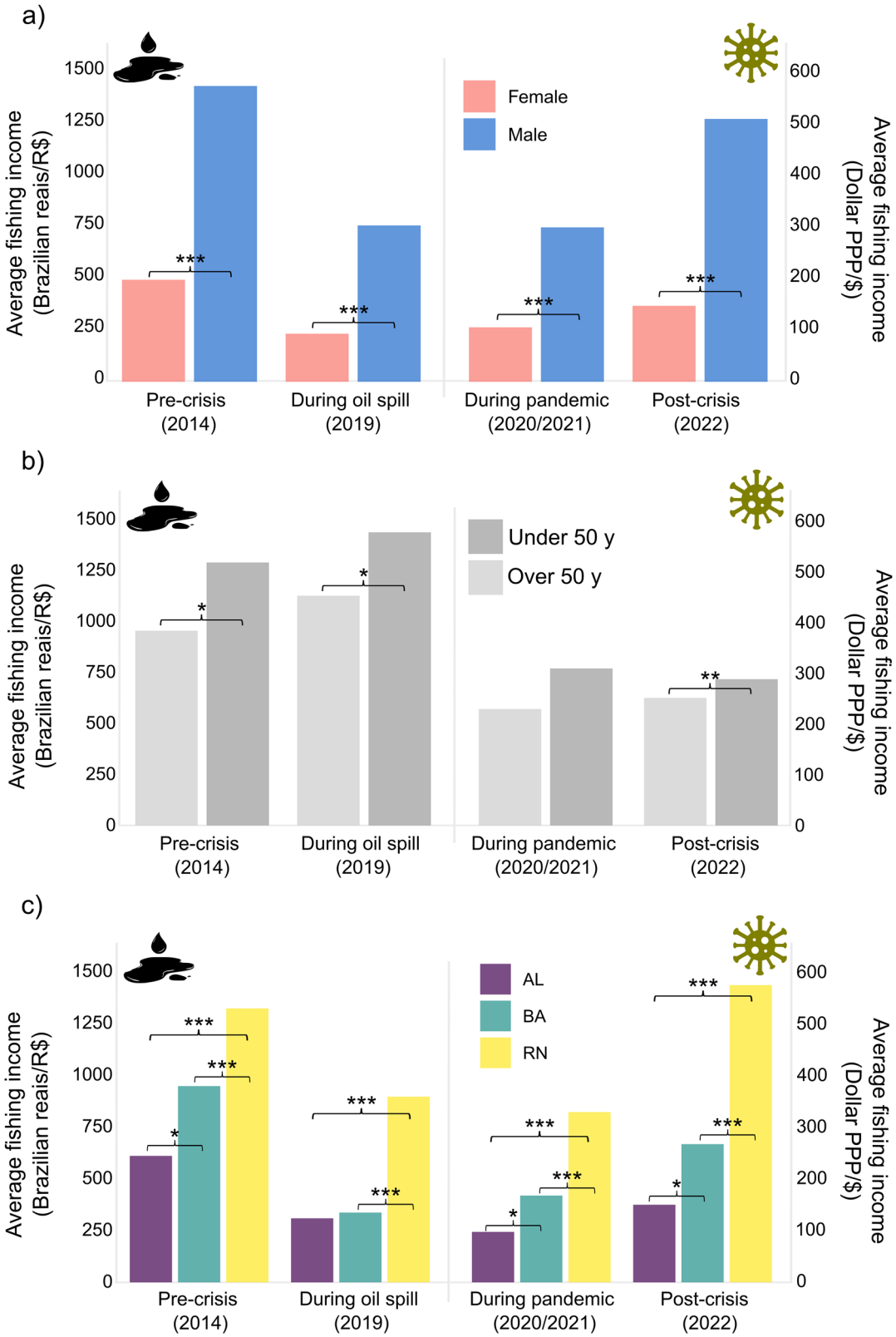

Fig. 2 | Fishing income trends across crises. Weekly average fishing income before disruptions (2014), during the ecological (2019 oil spill) and social (COVID-19 pandemic) disruptions for (**a**) gender (female and male), (**b**) age group (under 50 y and over 50 y), and (**c**) coastal states (AL, BA, and RN). Income average values are presented in Brazilian reais (left y-axis) and dollar PPP (right y-axis). Significant codes: 0 = ***, 0.001 = **, 0.01 = *.

by 78% in AL and 59% in RN (Figure S2a, Supplementary Materials). The perceived duration of oil presence on the beaches varied significantly across the coastal states (KW = 37.706, df = 2, $p = 0.000$; Figure S2b, Supplementary Materials), with BA experiencing the longest average duration (97 days), significantly longer than in AL (66 days, $p = 0.001$) and RN (55 days, $p < 0.001$).

Most people mentioned their perceptions of the impacts of the COVID-19 pandemic as moderate, high, and very high impact categories

Table 1 | The most relevant and significant predictors explaining income change resulting from the final best model for each event

Event	Predictors	Estimates	Std. Error	z-value	Pr (>|z|)
Oil spill	*Gender (Male)*	-0.854	0.260	-3.286	*0.001***
	State (BA)	0.742	0.305	2.428	*0.015**
	State (RN)	-0.340	0.293	-1.159	0.246
	Number of environments	0.280	0.159	1.761	0.078
COVID-19 pandemic	State (BA)	-0.480	0.302	-1.588	0.112
	State (RN)	-1.389	0.291	-4.767	*0.000****
	Age	-0.016	0.008	-1.912	*0.055**
	Number of environments	0.230	0.160	1.437	0.151
	Category of fish (Benthopelagic)	0.270	0.414	0.654	0.513
	Category of fish (Pelagic)	-0.464	0.254	-1.826	0.068
	Category of fish (Reef)	-0.044	0.250	-0.176	0.860

Oil spill model: Income change ~ gender + state + number of environments; COVID-19 model: Income change ~ gender + state + age + number of environments + category of fish; Significant codes: 0 = ***, 0.001 = **, 0.01 = *.

(Fig. 4b, bars in shades of green). Fishers across coastal states once again showed differing perceptions (KW = 30.249, df = 2, $p = 0.000$). Fishers from AL had distinct perceptions compared to those from BA (p = 0.001) and RN ($p = 0.000$), while fishers from BA also differed from those in RN ($p = 0.003$). Fishers from AL reported very high impacts on their profession (91%) and income (92%), compared to fishers from BA (66% and 76%, respectively) and those from RN (56% and 71%, respectively) (Fig. 4b). Additionally, it is worth noting that fishers from AL reported a lower average value per kilogram (R$15,97/ US$ PPP 6.6) for the main fish sold during the COVID-19 pandemic, compared to the averages for BA (R$ 22,00/ US$ PPP 9.1) and RN (R$44,69/ US$ PPP 18.5). Fishers under 50 y reported higher overall impacts, particularly regarding losses in fishing income (82% of fishers), than those over 50 y (t = -2.187, df = 376, $p = 0.02$) (Fig. 3b). Despite these challenges, these younger fishers were more likely to secure additional income sources (37%) and employed more effective adaptation strategies (26%) during the pandemic compared to their older counterparts (Figure S1b, Supplementary Materials).

Discussion

This study bridges a critical gap by comparing economic vulnerability across distinct ecological and social crises within a fisheries-dependent social-ecological system. Our findings show that vulnerability is not uniform; rather, it materializes through intersecting, context-specific pathways shaped by gender, age, and geography.

Gender played a decisive role in shaping economic impacts during the oil spill. Fisherwomen experienced significantly greater income losses than fishermen, a disparity rooted in both the ecological characteristics of the event and the gendered division of labor in fisheries[25]. Coastal areas, which were among the most visibly contaminated, are frequently accessed by women for fishing and gleaning[26]. Benthic species such as bivalves, primarily targeted by women, are especially vulnerable to oil pollution due to their filter-feeding behavior[27,28]. In our study, 75% of fisherwomen harvested benthic resources, compared to only 28% of fishermen, who focused more on pelagic species like dolphinfish and mackerel in offshore zones, areas that were less affected by the spill[29].

This pattern reflects broader global trends. In small-scale fisheries worldwide, women often harvest nearshore and intertidal species without the need for boats, enabling them to reconcile income generation with caregiving responsibilities, the so-called "double shift" [30,31]. Yet these same environments also function as ecological sinks, accumulating pollutants such as oil, sewage, and industrial runoff[32]. As a result, fisherwomen face disproportionate risks, including health hazards[33] and economic instability[34], during environmental disasters.

Fisherwomen's vulnerability was further compounded by pre-existing economic disparities. In the study region, shellfish sold by women fetched just R$12.50/ US$ PPP 5.2 kg, less than half the price of finfish sold by men (R$32.40/ US$ PPP 13.4 kg). While shellfish can command premium prices elsewhere[35,36], in Northeast Brazil, they remain undervalued due to limited demand and poor infrastructure for sanitary processing. This reflects broader neglect of female-dominated sectors in fisheries economies[37,38].

These disparities echoed in fishers' perceptions. A higher proportion of women reported severe income losses (83% vs. 61% of men) and fishing interruptions (56% vs. 28%). Such findings align with post-disaster studies showing women's slower recovery due to peripheral roles in value chains, caregiving burdens, and dependence on degraded ecosystems in comparison to men[20,39–41]. Furthermore, 21% of fisherwomen felt less adapted to the crisis compared to others in their community, versus only 13% of men, indicating lower adaptive capacity, likely linked to reduced access to markets and alternative fishing grounds. While women often exhibit stronger risk perception and responsiveness to warnings[22], these strengths are undercut by structural vulnerability.

In contrast, the COVID-19 pandemic revealed a different vulnerability profile. Older fishers (50+ y) maintained lower income levels than younger counterparts, reflecting both higher health risks[42] and reduced adaptability to rapid socioeconomic changes[43]. Only 30% of older fishers were able to secure alternative income sources during the crisis. Moreover, previous research indicates that the rapid digitalization of fisheries, through online marketing and coordination, can exacerbate existing inequalities, as older fishers are less likely to use digital tools[44]. While we did not directly measure digital tool use, these documented dynamics help contextualize the age-specific patterns of exclusion and precarity observed in our results.

The impact of both the oil spill and the pandemic was deeply shaped by geography. In Bahia (BA), the most severely affected state, fishers reported the highest income losses. BA accounted for 44% of all oil occurrences in the Northeast, far more than Alagoas (AL, 14%) or Rio Grande do Norte (RN, 10%)[45]. Its economy is heavily coastal-dependent, and its fishing population is older, exacerbating risk. RN, by contrast, had the youngest fishing population and reported the lowest income losses, illustrating how age and geography intersect to shape vulnerability. In fact, RN's relative resilience can be traced to three key factors. First, RN experienced limited exposure to the oil spill, avoiding or limiting the consequences of back-to-back economic shocks[45,46]. Second, its coastal communities are geographically more isolated in comparison to the communities in the other two states, which may have reduced exposure to the virus and loosened enforcement of mobility restrictions[47]. Third, RN's reliance on middlemen helped maintain product distribution during lockdown. While the role of intermediaries remains contested[48], similar studies show that they may serve as informal safety nets during crises by expanding commercial opportunities through their extended market reach and logistical networks[49]. These findings highlight that market structure, like ecological exposure, mediates resilience.

During the pandemic, AL fishers reported the highest professional (91%) and income (92%) losses. This again may have stemmed from both occupational and demographic factors. Shellfish harvesting is a labor-intensive activity that is typically performed in groups[35,38]. As this was the dominant activity in AL, involving mostly women, it is possible that fishers in this region likely faced an increased exposure risk to COVID-19. The state also had a higher proportion of fisherwomen. While gender was a clearer vulnerability driver during the oil spill, in this case, demographic and occupational variables at the state level seemed to have masked gender patterns. These dynamics mirror global findings that women and older workers face intensified hardship in the wake of socio-environmental disruptions due to their marginal roles in governance and market access[37].

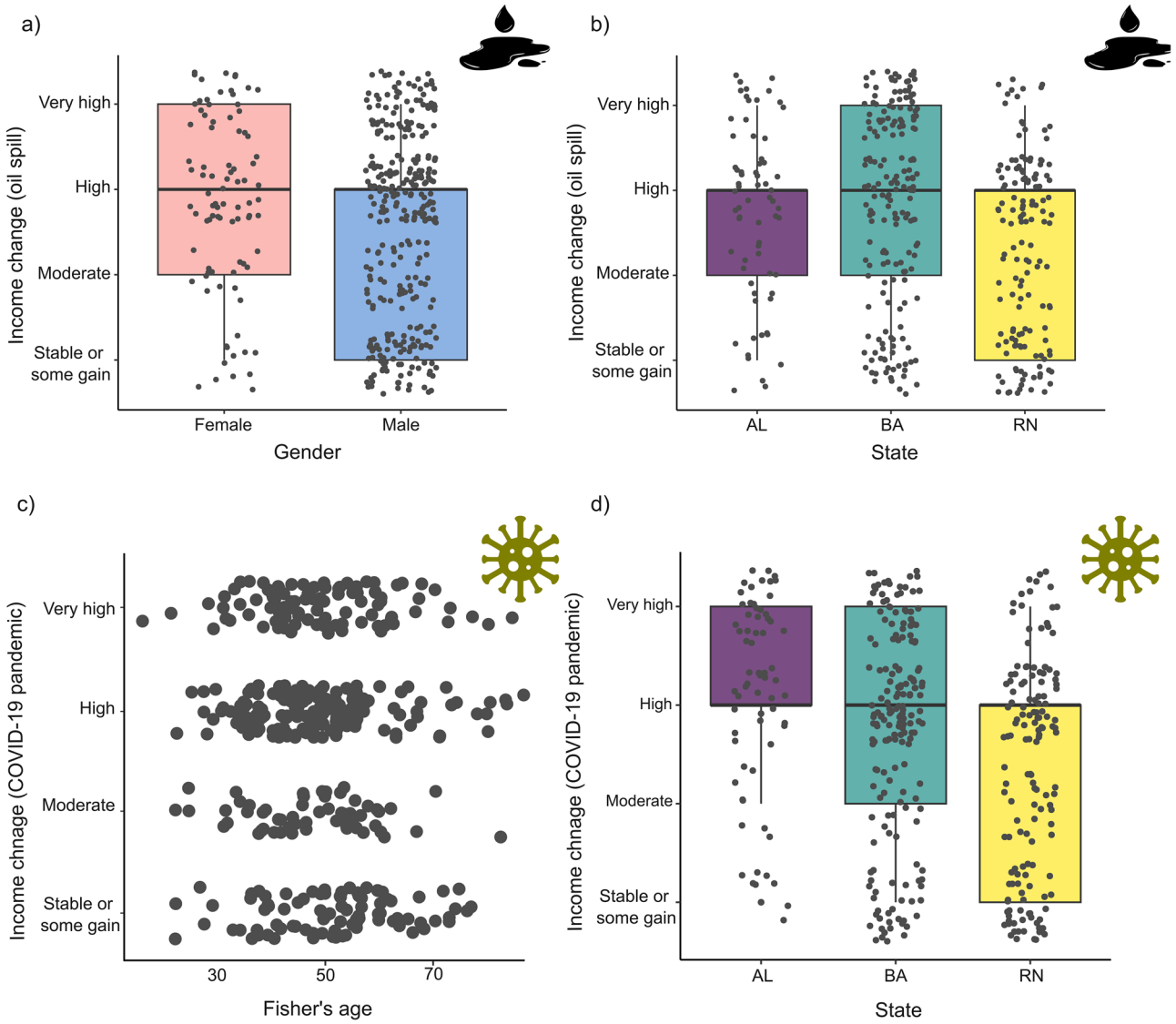

Fig. 3 | Economic impact by crisis and group of fishers. Categories of income change (very high income loss, high income loss, moderate income loss, and stable or some gain) in the oil spill model (upper plots) comparing (**a**) gender categories (female and male) and (**b**) coastal states (AL, BA, and RN), and in the COVID-19 model (lower plots) comparing (**c**) fisher's age and (**d**) coastal states (AL, BA, and RN).

By integrating social-ecological and crisis vulnerability frameworks, this study shows how economic vulnerability in fisheries-dependent systems varies across crises. Economic disruption emerges through different pathways depending on whether the shock is ecological (e.g., ecosystem degradation) or social (e.g., health or mobility restrictions). In this Brazilian case study, the 2019 oil spill disproportionately affected women who rely on benthic, low-value, contamination-prone nearshore resources, while the COVID-19 pandemic deepened age-based inequalities, with older fishers facing compounded health, mobility, and likely digital barriers. These patterns reinforce that vulnerability is unevenly distributed, shaped by intersecting factors such as gender, age, socio-ecological dependence, geography, and state-level infrastructure. Perhaps most importantly, crises often build on pre-existing inequalities[50], exposing structural, spatial, institutional, and demographic disparities that amplify risks for marginalized fishers. Ultimately, fishing communities remain in chronic precarity, lacking the institutional, economic, and social buffers against new shocks, conditions that both magnify crisis impacts and weaken long-term adaptive capacity.

Given this state of chronic precarity in many coastal areas, particularly in the global south, building resilience requires fisheries governance to proactively embed equity into both emergency response and long-term adaptation. Our findings point to three critical priorities: 1) implementing gender-responsive policies supported by sex-disaggregated data to recognize women's labor, 2) developing age-inclusive adaptation tools, and 3) advancing intersectional research to guide targeted interventions. Without such measures, recovery efforts risk reinforcing structural inequities, such as the invisibility of caregiving burdens. As global disruptions escalate, resilience will depend on designing policies that address differentiated risks and enable all fishers—not just the most visible—to thrive. These efforts are essential not only for disaster preparedness but also for supporting the United Nations Ocean Decade goals for sustainable and equitable small-scale fisheries.

Methods

Study area context

The Brazilian coastline spans over 7400 km along the Atlantic Ocean and includes diverse ecosystems such as the Atlantic Forest and mangroves, offering critical ecosystem services and cultural value (Fig. 1a). Approximately 55% of Brazil's population lives within 150 km of the coast[51], and coastal cities serve as key centers for fisheries, tourism, trade, and industry.

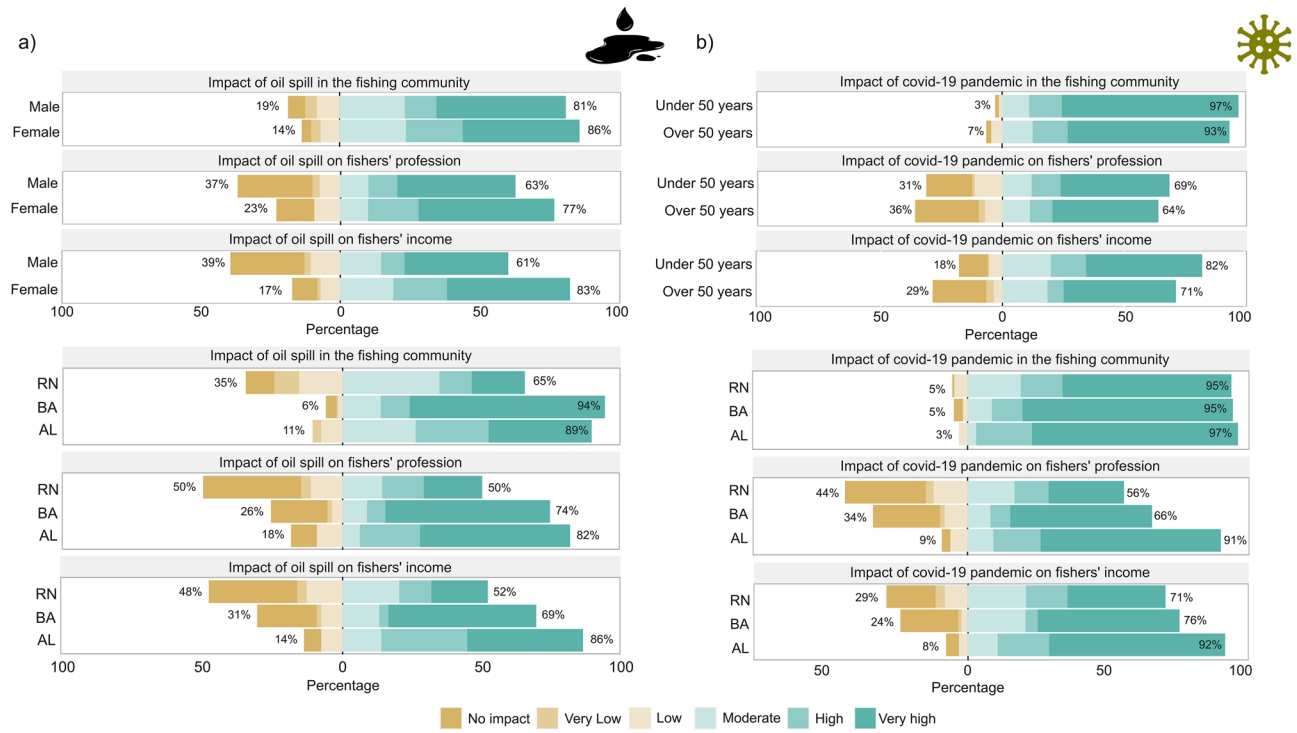

Fig. 4 | Perceived impacts of oil spill and COVID-19. Perception of the impacts of oil spill (**a**) and COVID-19 pandemic (**b**) on the fishing community, fishers' profession, and fishers' income by gender categories (male and female), coastal states (AL, BA, and RN), and fishers' age (under 50 years and over 50 years). Fishers' perceptions categories: no impact, very low impact, low impact, moderate impact, high impact, and very high impact.

In August 2019, a large-scale oil spill affected 15–20% of Brazil's coastline, severely impacting the Northeast region[24]. States such as Bahia, Pernambuco, Sergipe, Alagoas, and Rio Grande do Norte reported widespread contamination of beaches, mangroves, and coral reefs, disrupting marine ecosystems and coastal livelihoods. Tourism and fishing, primary economic activities in the region, were hit hard by beach closures and growing concerns over seafood safety[42].

These challenges were further compounded by the COVID-19 pandemic (2020–2022), deepening socio-economic vulnerabilities across affected communities. Travel restrictions, market disruptions, and limited access to healthcare, particularly in the historically under-resourced northeastern coastal areas, amplified the crisis. Small-scale fishers, already struggling, faced severe impacts from lower demand and mobility constraints. Meanwhile, environmental recovery efforts from the oil spill were delayed or suspended as public resources shifted to the health emergency.

Data collection

The data used in this study were collected through a survey conducted between 2021 and 2022. This two-year period enabled broad spatial coverage of the study area and captured temporal variations in fishing productivity and fishers' income during and following major socio-ecological disruptions, namely, the 2019 oil spill and the COVID-19 pandemic, which peaked in 2021 and continued to affect communities into 2022. To establish a pre-disturbance baseline, we also included retrospective data on fishers' income from 2014, representing conditions approximately five years before these disruptions began.

Data were collected through interviews with fishermen and fisherwomen using a semi-structured questionnaire (Supplementary Materials). A total of 424 [402 used for analysis] interviews were conducted across 15 coastal municipalities (towns and cities) (22% out of 68 in total), located in three coastal states of Brazil's Northeast region: Rio Grande do Norte (RN; 8 towns), Alagoas (AL; 3 towns), and Bahia (BA; 2 towns and 2 cities/large urban centers). Within these 15 coastal municipalities, we worked in 31 fishing communities, defined here as locally recognized socio-organizational units. In Salvador, a megacity and the capital of Bahia, fishing communities were defined as neighborhoods or as conglomerations of sites, such as fishing colonies, where geographically dispersed fishers regularly gather. Study sites varied in their degree of urbanization, ranging from communities embedded in metropolitan areas (as in Bahia) to more remote coastal settlements (as in Rio Grande do Norte). The full list of coastal towns and fishing communities by state with the number of interviews conducted at each site is available in the supplementary material (Table S1).

Initially, we aimed to interview all fishers in key fishing communities across the three states, selected based on our long-term field experience and prior engagement. However, due to the absence of reliable data on the total number of local fishers, we prioritized broader geographic coverage instead. Fishers were identified through snowball sampling, a necessary adjustment given the context[52]. Data collection occurred primarily during the COVID-19 pandemic, which imposed significant logistical and safety constraints. Most interviews were conducted remotely, using phone calls or messaging platforms (e.g., WhatsApp), depending on participants' accessibility and digital connectivity. As a result, the sampling strategy also incorporated opportunistic sampling[53] due to practical challenges like contact availability and digital access.

The survey captured information on fishing practices, socioeconomic characteristics, and environmental aspects through online and in-person interviews. All field activities followed approved safety protocols and ethical standards, as authorized by the Ethics Committee of the Federal University of Rio Grande do Norte (CAAE #40054920.7.0000.5537). Participants were informed about the voluntary nature of their participation, the confidentiality of their responses, and their right to withdraw at any time. Informed consent was obtained from all participants.

The semi-structured questionnaire (Supplementary Materials) included questions on fishing characteristics (target species, gear type, fishers' income, and years of experience), demographic attributes (age, gender, state, and self-declared ethnicity), and environmental variables related to fishing activities (type of fishing environment and type of fish habitat). Fishing gear

was later recategorized into hand-dependent gear, nets, and traps, with hand-dependent gear being the most commonly used (68%, or 272 out of 402 respondents). Environmental aspects encompassed the type of fishing environment (coastal, open water, or reef), the number of environments exploited by each fisher, and the category of fish targeted (benthic, benthopelagic, pelagic, or reef-associated). Fishing income was reported for four time periods: before the crises (2014), during the oil spill (second half of 2019), during the COVID-19 pandemic (2020-2021), and after both crises (2022).

Finally, gender was defined based on sociocultural aspects rather than biological attributes, in accordance with the Sex and Gender Equity in Research (SAGER) guidelines[54,55], which advocate for the systematic integration of sex and gender considerations in research.

Data analysis

Before modeling the factors affecting income, we prepared the dataset through cleaning and organization, addressing missing values, outliers, and inconsistencies. Details of methods for handling missing data and imputation are provided in the supplementary material. The final dataset comprised 402 interviews: 149 from Rio Grande do Norte (RN), 67 from Alagoas (AL), and 186 from Bahia (BA). The dataset included both continuous variables (e.g., fishers' age and fishing experience) and categorical variables (e.g., gender and state). The 22 excluded interviews (from an initial N = 424) lacked critical variable combinations (e.g., missing income data concurrent with fishing gear type and fishing environment), which prevented reliable imputation.

To investigate how fishers' income was affected during the oil spill and the COVID-19 crises, and how socioeconomic, demographic, and fishing-related factors influenced this variation, we conducted regression analyses and assessed perceived impacts at the individual, community, and environmental levels.

We began by estimating the weekly income for each time period. This was calculated using the number of fishing days per week, the amount of fish caught per trip (in kilograms), and the price per kilogram of fish. Catch quantity was based on respondents' reports of a "good day" of fishing, defined during interviews as a fishing trip with catches higher than typical trips, but not representing the best catch ever achieved. This concept was used because both "good day" and "typical day" catches have been shown to be consistently recalled by active fishers, with "good day" estimates providing stable reference points when time since recall is short and respondents remain active in the fishery[56]. It is important to note that this income estimate does not reflect total household income, but rather income from the main target species, which constituted the primary source of fishing earnings. All income values were adjusted for inflation and converted to international dollars (See Supplementary Materials for details).

Following the income estimation, we calculated the percentage of income change for each event. This percentage was derived by dividing the difference between income during the crisis and pre-crisis income by the pre-crisis income, then multiplying the result by 100. The resulting values were used to construct an ordinal response variable representing levels of income change based on the data distribution. Income change was categorized into: very high income loss (>80%), high income loss (40–80%), moderate income loss (<40%), and stable or some gain (less than 1% of income loss or some income gain). For the last category, we grouped fishers with minimal income losses together with the minority reporting income gains during either or both events. This grouping ensured a more balanced distribution across income loss categories, improving model fit in the next step.

Next, we employed Cumulative Link Mixed Models (CLMMs) to model income change as a function of socioecological independent variables. This type of regression is specifically designed for ordinal response data and is particularly appropriate when observations are not independent but clustered within groups or subjects[57]. CLMMs estimate the probability of the ordinal response variable falling into or below a given category based on predictor variables. We computed the standard errors of the model coefficients using the diagonal of the Hessian matrix, with larger values suggesting greater curvature in the likelihood surface, which may indicate overparameterization[57]. The inclusion of random effects allows the model to account for hierarchical structures or grouped data, thus capturing both fixed and random effects[57]. In our analysis, a random effect was included to account for the clustering of respondents within fishing communities.

For each event (the oil spill and the COVID-19 pandemic), we fitted a full model using the percentage change in income as the response variable. Fixed effects included gender (male, female), age (continuous), ethnicity (white, Black, and *pardo*/mixed), state (RN, AL, BA), fishing environment (coastal, open water, reef), number of environments used (continuous), and fish target category (benthic, benthopelagic, pelagic, reef).

We conducted a variable selection process to exclude non-significant predictors from the full model and used Akaike's Information Criterion (AIC) to compare model performance[58]. We adopted a significance threshold of $p < 0.05$ and discussed only predictors meeting this criterion in the final model (Table S2, Supplementary Materials). The best-fitting model for each event is provided in the supplementary material (Table S3). Finally, to improve interpretability, we exponentiated the model coefficients using the 'exp' function to obtain odds ratios (See Supplementary Materials for details).

To assess the perceived impacts of the oil spill and the COVID-19 pandemic at individual, community, and environmental levels, we conducted a Likert-scale analysis focusing on how groups of fishers, categorized by the predictors identified in the regression models, perceived the effects of both events on their socio-ecological systems. Perceived impact was measured on a 6-point scale: no impact, very low impact, low impact, moderate impact, high impact, and very high impact. Specifically, we analyzed perceptions of the impact on fishing communities (e.g., collective well-being), fishers' income (e.g., economic repercussions), and fishing as a profession (e.g., changes to daily fishing practices). Additional aspects included the oil spill's effects on fishing activities, seafood sales, the number of contaminated beaches, and fishers' adaptation strategies during the pandemic.

To identify differences in perceptions, we used Welch's *t*-tests to compare responses by gender (male vs. female) and age group (under 50 vs. over 50 years). The age cutoff of 50 was selected based on the sample's average age and evidence suggesting that older fishers may experience reduced physical capacity and adaptability, making them more vulnerable to disruptions[59]. Prior studies also indicate that older fishers (e.g., >40 years) often face difficulties in adopting new technologies or adjusting to environmental changes[43,44].

We applied Kruskal-Wallis tests followed by Dunn's post hoc tests to evaluate differences among states (AL, BA, and RN), accounting for regional variability not captured by gender or socioeconomic factors alone. Regional differences, such as environmental degradation, local infrastructure, or access to support networks, may influence vulnerability and adaptive capacity. For example, fishers in more polluted regions may face greater hardships than those in less affected areas[60]. To explore these contextual differences, we analyzed mean Likert responses related to the duration of oil presence on beaches and the average market value of the main target species.

All analyses were performed in RStudio[61]. The "mice" package[62] was used for multivariate imputation, the "ordinal" package[63] for fitting cumulative link mixed models, and the "Likert" package[64] for visualizing Likert-scale responses.

Data Availability

The datasets analyzed during the current study are available from the corresponding author on request. The data are not publicly available because they are part of an ongoing, multi-institutional data collection effort by the Pacto Futuro Network.

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References

1. Folke, C. et al. Resilience thinking: integrating resilience, adaptability and transformability. *Ecology and Society* **15**, 20 (2010).
2. Biggs, R. et al. 2021. What are social-ecological systems and social-ecological systems research? In: *The Routledge handbook of research methods for social-ecological systems*, 3-26. Routledge.
3. Cinner, J. E. et al. Building adaptive capacity to climate change in tropical coastal communities. *Nature Climate Change* **8**, 117–123 (2018).
4. Folke, C. et al. Our future in the Anthropocene biosphere. *Ambio* **50**, 834–869 (2021).
5. Halpern, B. S. et al. Recent pace of change in human impact on the world's ocean. *Scientific Reports* **9**, 1–8 (2019).
6. Pecl, G. T. et al. Climate change and marine ecosystems: Impacts, adaptation, and vulnerability. *Annual Review of Marine Science* **15**, 1–28 (2023).
7. Allison, E. H. et al. Vulnerability of national economies to the impacts of climate change on fisheries. *Fish and Fisheries* **10**, 173–196 (2009).
8. Béné, C. et al. Contribution of fisheries and aquaculture to food security and poverty reduction: Assessing the current evidence. *World Development* **79**, 177–196 (2016).
9. Folke, C., Biggs, R., Norström, A. V., Reyers, B. & Rockström, J. 2016. Social-ecological resilience and biosphere-based sustainability science. *Ecology and Society*, 21.
10. Cinner, J. E. et al. Meeting fisheries, ecosystem function, and biodiversity goals in a human-dominated world. *Science* **368**, 307–311 (2020).
11. Biggs, R., Schlüter, M. & Schoon, M. L. 2015. Principles for Building Resilience: Sustaining Ecosystem Services in Social-Ecological Systems. *Cambridge University Press*.
12. Adger, W. N. et al. Focus on environmental risks and migration: causes and consequences. *Environmental Research Letters* **10**, 60201 (2015).
13. Sina, D., Chang-Richards, A. Y., Wilkinson, S. & Potangaroa, R. What does the future hold for relocated communities post-disaster? Factors affecting livelihood resilience. *International journal of disaster risk reduction* **34**, 173–183 (2019).
14. Silva, M. R., Pennino, M. G. & Lopes, P. F. M. Predicting potential compliance of small-scale fishers in Brazil: The need to increase trust to achieve fisheries management goals. *Journal of Environmental Management* **288**, 112372 (2021).
15. Béné, C. et al. Resilience of local food systems and links to food security – A review of some important concepts in the context of COVID-19 and other shocks. *Food Security* **12**, 805–822 (2020).
16. Coulthard, S. et al. Crisis, change, and adaptation in small-scale fisheries: A comparative analysis of challenges and opportunities. *Marine Policy* **120**, 104145 (2020).
17. Adger, W. N. Social capital, collective action, and adaptation to climate change. *Economic Geography* **79**, 387–404 (2003).
18. Daw, T. M. et al. Applying the ecosystem services concept to poverty alleviation: The need to disaggregate human well-being. *Environmental Conservation* **39**, 370–379 (2012).
19. Bennett, N. J. et al. The COVID-19 pandemic, small-scale fisheries, and coastal fishing communities. *Coastal Management* **49**, 1–14 (2021).
20. Fröcklin, S. et al. Towards improved management of tropical invertebrate fisheries: including time series and gender. *PLoS One* **9**, e91161 (2014).
21. Harper, S. et al. Gender and small-scale fisheries: A case for counting women and beyond. *Fish and Fisheries* **21**, 940–955 (2020a).
22. Silva, M. R., Silva, A. B., Barbosa, J. C., Amaral, C. & Lopes, P. F. Empowering fisherwomen leaders helped reduce the effects of the COVID-19 pandemic on fishing communities: Insights from Brazil. *Marine Policy* **135**, 104842 (2022).
23. Magris, R. A. et al. A blueprint for securing Brazil's marine biodiversity and supporting the achievement of global conservation goals. *Diversity and Distributions* **27**, 198–215 (2020).
24. Soares, M. O. et al. Oil spill in South Atlantic (Brazil): environmental and governmental disaster. *Marine Policy* **125**, 104387 (2020).
25. Cavole, L. M. et al. Unveiling Gender Disparities: The Role of Women in Transforming Small-Scale Fisheries. *Fish Fish* **26**, 1146–1163, https://doi.org/10.1111/faf.70023 (2025).
26. Arce-Ibarra, A. M. & Charles, A. T. Inland fisheries of the Mayan Zone in Quintana Roo, Mexico: Using a combined approach to fishery assessment for data-sparse fisheries. *Fisheries Research* **91**, 151–159 (2008).
27. Nunes, B. Z., Ribeiro, V. V., Garcia, Y., Lourenço, R. A. & Castro, ÍB. Chemical contamination affecting filter-feeding bivalves in no-take marine protected areas from Brazil. *Journal of Environmental Management* **360**, 121102 (2024).
28. Mello, L. C. et al. Oil spill effects in biota and traditional populations from protected areas of Brazil's Northeast. *Human and Ecological Risk Assessment: An International Journal* **31**, 563–586 (2025).
29. Magalhães, K. M. et al. Polycyclic aromatic hydrocarbons (PAHs) in fishery resources affected by the 2019 oil spill in Brazil: Short-term environmental health and seafood safety. *Marine Pollution Bulletin* **175**, 113334 (2022).
30. Harper, S., Zeller, D., Hauzer, M., Pauly, D. & Sumaila, U. R. Women and fisheries: Contribution to food security and local economies. *Marine policy* **39**, 56–63 (2013).
31. Kleiber, D., Harris, L. M. & Vincent, A. C. Gender and small-scale fisheries: a case for counting women and beyond. *Fish and Fisheries* **16**, 547–562 (2015).
32. Morin-Crini, N. et al. Worldwide cases of water pollution by emerging contaminants: a review. *Environmental Chemistry Letters* **20**, 2311–2338 (2022).
33. Flores, M. G. et al. The protective and destructive critical processes of female labor in small-scale fishing in coast Pernambuco, Brazil. *Ciência & Saúde Coletiva* **29**, e03612024 (2024).
34. Estevo, M. O. et al. Immediate social and economic impacts of a major oil spill on Brazilian coastal fishing communities. *Marine Pollution Bulletin* **164**, 111984 (2021).
35. Chuku, E. O. et al. Spotlighting women-led fisheries livelihoods toward sustainable coastal governance: The estuarine and mangrove ecosystem shellfisheries of West Africa. *Frontiers in Marine Science* **9**, 884715 (2022).
36. Piñeiro-Antelo, M. D. L. Á. & Santos, X. M. Shellfishing on foot and the road to defeminization in Galicia (Spain). *Maritime Studies* **20**, 341–354 (2021).
37. S. Harper, et al. 2023. Towards gender inclusivity and equality in smallscale fisheries. In: FAO, Duke University & WorldFish. 2023. *Illuminating Hidden Harvests: the contributions of small-scale fisheries to sustainable development*. Rome, FAO; Durham, USA, Duke University; Penang, Malaysia, WorldFish.
38. Reis-Filho, J. A. et al. Fisherwomen's activities are as complex, salient, and profitable as those performed by fishermen: A study from vulnerable traditional fishery communities. *Fisheries Research* **286**, 107380 (2025).
39. Aguilera, F., Méndez, J., Pásaro, E. & Laffon, B. Review on the effects of exposure to spilled oils on human health. *Journal of Applied Toxicology* **30**, 291–301 (2010).
40. Harper, S., Adshade, M., Lam, V.W., Pauly, D. & Sumaila, U.R. 2020b. Valuing invisible catches: estimating the global contribution by women to small-scale marine capture fisheries production. *PLoS One* 15.
41. Bari, A. M. et al. Gender-based vulnerability and adaptive capacity in the disaster-prone coastal areas from an intersectionality perspective. *Climate Risk Management* **43**, 100581 (2024).

42. Neis, B. et al. Fishing safely during COVID-19 in Newfoundland and Labrador, Canada: Making it happen. *Marine Policy* **145**, 105281 (2022).
43. Villasante, S. et al. Resilience and social adaptation to climate change impacts in small-scale fisheries. *Frontiers in Marine Science* **9**, 802762 (2022).
44. Lopez-Ercilla, I. et al. The voice of Mexican small-scale fishers in times of COVID-19: Impacts, responses, and digital divide. *Marine Policy* **131**, 104606 (2021).
45. Câmara, S. F., Pinto, F. R., Silva, F. R., Soares, M. O. & De Paula, T. M. 2021. Socioeconomic vulnerability of communities on the Brazilian coast to the largest oil spill (2019–2020) in tropical oceans, *Ocean & Coastal Management*, 202.
46. Soares, M. O. et al. The most extensive oil spill registered in tropical oceans (Brazil): the balance sheet of a disaster. *Environmental Science and Pollution Research* **29**, 19869–19877 (2022).
47. Kung, S., Doppen, M., Black, M., Hills, T. & Kearns, N. Reduced mortality in New Zealand during the COVID-19 pandemic. *The Lancet* **397**, 25 (2021).
48. Nuraini, S. et al. 2024. Dual Role of Middlemen: An Opportunity or Exploitation for Fisherman? In *Proceedings of the 6th Open Society Conference (OSC 2024)*, 45. Springer Nature.
49. D'agata, S. et al. Multiscale determinants of social adaptive capacity in small-scale fishing communities. *Environmental Science & Policy* **108**, 56–66 (2020).
50. Wang, C. & Yarnal, B. The vulnerability of the elderly to hurricane hazards in Sarasota, Florida. *Natural hazards* **63**, 349–373 (2012).
51. IBGE – Instituto Brasileiro de Geografia e Estatística. *Censo Brasileiro de 2022*. Rio de Janeiro: IBGE, 2022. Available in: https://cidades.ibge.gov.br/brasil/panorama.
52. Biernarcki, P. & Waldorf, D. Snowball sampling problems and techniques of chain referral sampling. *Sociological Methods & Research* **10**, 141–163 (1981).
53. Howarth, A. et al. Non-probabilistic surveys and sampling in the human dimensions of fisheries. *Rev Fish Biol Fisheries* **34**, 597–622, https://doi.org/10.1007/s11160-023-09831-1 (2024).
54. Heidari, S., Babor, T. F., De Castro, P., Tort, S. & Curno, M. Sex and gender equity in research: rationale for the SAGER guidelines and recommended use. *Research integrity and peer review* **1**, 1–9 (2016).
55. Van Epps, H., Astudillo, O., Martin, Y. D. P. & Marsh, J. The Sex and Gender Equity in Research (SAGER) guidelines: Implementation and checklist development. *European Science Editing* **48**, e86910 (2022).
56. Castello, L. et al. Local knowledge reconstructs historical resource use. *Front Ecol Environ* **22**, e2726. https://doi.org/10.1002/fee.2726 (2024).
57. Christensen, R. H. B. 2019. Ordinal - Regression Models for Ordinal Data. R package version 2019.12-10. Available at: https://CRAN.R-project.org/package=ordinal.
58. Zuur, A. F., Ieno, E. N., Walker, N., Saveliev, A. A. & Smith, G. M. 2009. *Mixed effects models and extensions in ecology with R*. Springer.
59. del Valle, E. et al. Fishing in turbulent waters: resilience, risk, and trust in British Columbia's declining commercial salmon fishery. *FACETS* **9**, 1–17 (2024).
60. Halpern, B. S. et al. Spatial and temporal changes in cumulative human impacts on the world's ocean. *Nature communications* **6**, 7615 (2015).
61. R Core Team. 2022. R: A Language and Environment for Statistical Computing. R Foundation for Statistical Computing, Vienna, Austria. URL https://www.R-project.org/.
62. Van Buuren, S. & Groothuis-Oudshoorn, K. mice: Multivariate Imputation by Chained Equations in R. *Journal of statistical software* **45**, 1–67 (2011).
63. Christensen, R. H. B. 2015. Ordinal: Regression Models for Ordinal Data. R package version X.X-X. Retrieved from https://CRAN.R-project.org/package=ordinal.
64. Speerschneider, K. K. & Bryer, J. M. 2013. Likert: An r package for visualizing and analyzing likert-based items. In Proceedings of the The R User Conference, UseR, 120.

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Competing interests

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Additional information

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