

Local Ecological Knowledge as a Quantifiable Attribute: Variation Among Small-Scale Fishers in Southeastern Brazil

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LOCAL ECOLOGICAL KNOWLEDGE AS A QUANTIFIABLE ATTRIBUTE: VARIATION AMONG SMALL-SCALE FISHERS IN SOUTHEASTERN BRAZIL

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ABSTRACT

Coastal communities are increasingly vulnerable to environmental change, facing ecological, economic, and social uncertainties. This study investigates how local ecological knowledge (LEK) contributes to the adaptive capacity of small-scale fisheries. Research was conducted in four coastal communities in SE Brazil using semi-structured questionnaires with open and closed questions. Fishers' perceptions of environmental change were explored through scenario-based questions, and LEK was quantified using biological and ecological indicators. Results reveal significant differences in LEK among communities ($p < 0.0001$), strongly influenced by fishing experience and species knowledge. LEK varied widely across communities and was associated with adaptive responses such as changes in fishing areas and gear use. Our findings indicate that LEK plays a fundamental role in enhancing adaptive capacity in small-scale fisheries facing socio-environmental change.

Keywords: Socio-environmental vulnerability; environmental change; local ecological knowledge; SE Brazil.

1. INTRODUCTION

Small-scale fisheries are fundamental components of coastal social-ecological systems, providing food, income, employment, and cultural identity for millions of people worldwide. However, their strong dependence on natural resources and environmental conditions makes them particularly sensitive to ecological variability and long-term environmental change. Limited technological capacity, spatial dependence on fishing grounds, and restricted access to institutional support may further constrain the ability of small-scale fishers to respond to environmental disturbances (Allison et al., 2009; Allison & Ellis, 2001; Allison et al., 2012; Bene et al., 2016).

In coastal environments, fishers interact continuously with species, habitats, environmental conditions, and seasonal processes. Through continuous observation and practical experience, these interactions generate a body of knowledge about the ecological characteristics and dynamics of the resources on which fishing depends. This knowledge is commonly referred to as local ecological knowledge (LEK) and encompasses empirically acquired information about species distribution, habitat use, feeding, reproduction, life cycles, predators, and behavioral patterns, as well as the environmental conditions associated with their occurrence (Berkes et al., 2000; Silvano & Begossi, 2012).

LEK is not a static or homogeneous body of information. Rather, it is continuously constructed, tested, refined, and transmitted through interactions between people and their environment. Fishers may therefore differ considerably not only in the number of species they recognize, but also in the breadth and specificity of their knowledge about those species. In this sense, the level of LEK can be understood as an indicator of the extent to which a fisher is able to identify and describe multiple ecological attributes of the resources with which they interact. Greater knowledge of a species, for example, involves more than recognizing its name or occurrence; it may include understanding where and when it occurs, what it feeds on, how it reproduces, its life-history stages, its predators, and its social or schooling behavior.

Importantly, LEK also incorporates a temporal dimension, as fishers accumulate information through repeated interactions with resources and environmental conditions throughout their fishing careers. This accumulated knowledge can enable fishers to recognize and describe changes in exploited resources over time. Studies suggest that fishers' knowledge can be used to reconstruct historical changes in catches and perceived resource abundance, particularly in contexts where systematic historical datasets are limited (Martins et al., 2018). Similarly, comparisons between LEK and scientific data have demonstrated that fishers can identify long-term changes in resource abundance, catch patterns, and exploitation that are consistent with independently collected ecological and fisheries data (Bender et al., 2014). Thus, LEK can provide not only information about the current ecological characteristics of species, but also experiential records of environmental and fisheries changes accumulated across generations and throughout fishing careers.

The accumulation of LEK is expected to be closely associated with the duration and intensity of interactions with the environment. Fishing experience provides repeated opportunities to observe ecological variation across seasons, fishing grounds, species, and environmental conditions. Consequently, more experienced fishers may possess a broader and more detailed ecological repertoire than individuals with shorter fishing histories. Evidence from small-scale fisheries supports this expectation, showing that more experienced fishers may retain greater knowledge of historical changes in fish abundance and environmental conditions than less experienced fishers (Bender et al., 2014). At the same time, knowledge is socially embedded and may vary among communities according to differences in environmental context, access to fishing grounds, livelihood dependence, cultural transmission, and the degree of interaction with protected or

urbanized landscapes (Berkes et al., 2000; Silvano & Begossi, 2012; Begossi et al., 2017; Aswani et al., 2018).

This distinction between the breadth and depth of knowledge is particularly relevant when LEK is considered in relation to adaptive capacity (Adger et al., 2005). Fishers are often among the first observers of ecological change because their livelihoods depend directly on the temporal and spatial dynamics of marine resources (Allison & Bassett, 2015). Changes in species occurrence, catch composition, seasonality, fishing grounds, and environmental conditions can therefore become incorporated into practical knowledge through continuous observation (Daw et al., 2009; Begossi, 2014; Martins et al., 2018). However, possessing a high level of LEK should not necessarily be interpreted as producing a specific adaptive response. Rather, LEK may provide an experiential and cognitive foundation through which environmental changes are recognized, interpreted, and incorporated into decision-making processes.

Environmental change further complicates this process because fishers from different generations may experience different ecological baselines. Younger or less experienced fishers may begin their fishing careers in ecosystems that have already undergone substantial ecological transformation, whereas older fishers may retain memories of previous ecological conditions (Adger, 2006). This phenomenon is consistent with the shifting baseline syndrome, whereby perceptions of environmental conditions are progressively established relative to the conditions experienced by each generation rather than necessarily against historical ecological states (Pauly, 1995). Thus, differences in the knowledge accumulated by fishers may reflect not only variation in individual experience but also differences in the ecological conditions encountered throughout their fishing careers.

Despite the growing recognition of LEK as a valuable source of ecological information, relatively little attention has been given to quantifying variation in the level of ecological knowledge among fishers and examining how this variation is structured across different fishing communities. Much of the literature has focused on documenting what fishers know, reconstructing historical environmental changes, or validating local observations using scientific data. A complementary approach is to investigate the level of LEK itself as an individual- and community-level characteristic, considering whether fishers with different levels of experience and from different socio-ecological contexts exhibit different degrees of ecological knowledge. Such an approach may provide a deeper

understanding of how ecological knowledge is accumulated, maintained, and differentiated among small-scale fishing communities.

In this study, we investigated how local ecological knowledge (LEK) varies among small-scale fishers in coastal communities of southeastern Brazil and examined its relationship with fishing experience, species knowledge, fishing practices, and community context. Specifically, we asked: (1) Do fishers perceive environmental changes affecting fishing activities? (2) Have fishing practices changed in response to these perceived changes? (3) Does the level of LEK vary among fishers and communities? and (4) Which factors are associated with higher levels of LEK? By conceptualizing LEK as a measurable gradient of ecological knowledge rather than as a binary attribute, we aimed to clarify how experiential and social contexts contribute to the development of knowledge that may underpin adaptive capacity in small-scale fisheries.

2. MATERIAL & METHODS

Study Area

The study was conducted in four small-scale fishing communities located between Peruíbe and Iguape, southern São Paulo State, Brazil (Figure 1): Portinho de Pesca de Peruíbe, Barra do Una Sustainable Development Reserve, Rio Verde, and Prelado. These communities differ in population size, degree of urbanization, and proximity to protected areas, providing a gradient of socio-environmental contexts.

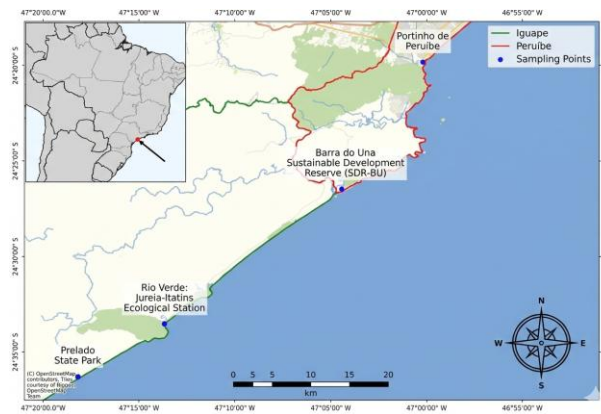


Figure 1. Study area, outlined in red, and the communities located between Peruíbe and Iguape marked in green.

Data Collection

Between 2023 and 2025, a mixed participatory approach was employed. The lead author resided in the field for three years, conducting participative observation to build up trust and gain contextual understanding (Goodman, 1961; Bernard, 2011). Fieldwork

duration was proportional to each community's size, integrating qualitative and quantitative techniques to analyze fishing dynamics.

Semi-structured interviews were conducted with 46 active gillnet fishers using snowball sampling strategy (Vieira, 2009; Biernacki & Waldorf, 1981). Interviews alternated between experienced (≥ 20 years) and less experienced fishers to reduce selection bias, in no case exhausting the target population.

Each interview consisted of approximately 150 questions. For this study, 28 questions were selected, comprising 19 closed-ended and nine open-ended questions addressing environmental change perception, fishing practices, and LEK.

Vulnerability Framework

Vulnerability was assessed following the framework proposed by Turner et al. (2003); Aswani et al. (2018), incorporating exposure, sensitivity, and adaptive capacity (Table 1).

Exposure was evaluated through fishers' perceptions of environmental and fishery-related changes.

Sensitivity was assessed through reported changes in gillnet dimensions (length and height) over the past 20 years.

Adaptive capacity was evaluated using a quantitative index of LEK.

Local Ecological Knowledge

LEK was quantified based on fishers' knowledge of six biological and ecological attributes: feeding, habitat, predators, reproduction, life cycle, and schooling behavior (Table 2), following Silvano and Begossi (2012).

For each species cited by a fisher, answers were coded as known (1) or unknown (0). Scores ranged from 0 to 7 and were classified into three ordered categories: incipient (0–2), intermediate (3–5), and substantial (6–7).

Table 1. Structure combining vulnerability descriptors for assessment, showing the relationship between the three components of vulnerability and the indicators used in the research.

Component	Indicator	Dimension
Exposure to risk	Environmental changes	Perceptual
Sensitivity	Changes in gear dimensions	Technological
Adaptive capacity	Level of local ecological knowledge	Biological

Table 2. Description of the variables explored in local ecological knowledge (LEK).

Variable	Description	Details
Feeding	Types of food consumed	Plankton (phytoplankton and zooplankton), crustaceans, other fish.
Habitat	Environments where the species is found	Coastal oceanic waters, estuaries, rivers, and lakes.
Predators	Main predators of the species	Large fish (mackerel, sharks, snapper, croaker, snook), seabirds, marine mammals.
Life Cycle	Development stages and occurrence areas	Eggs, larvae, juveniles, and adults; with variations among estuarine, marine, and freshwater environments.
Reproduction	Reproductive strategies and characteristics	Type of fertilization (external or internal), spawning site, parental care (when applicable).
Schooling	Social behavior regarding schooling	Formation of large schools, small groups, or solitary behavior.

Data Analysis

Because several variables violated normality assumptions, non-parametric methods were applied (Zar, 2010). Differences between past and current gillnet dimensions were evaluated using paired Wilcoxon signed-rank tests (Zar, 2010).

To jointly assess changes in gillnet length and height, a Bray–Curtis dissimilarity index was calculated (Bray & Curtis, 1957):

$$d_i(a, d) = \frac{|hf_{i,d} - hf_{i,a}| + |hs_{i,d} - hs_{i,a}| + |c_{i,d} - c_{i,a}|}{|hf_{i,d} + hf_{i,a}| + |hs_{i,d} + hs_{i,a}| + |c_{i,d} + c_{i,a}|}$$

where $d_i(a, d)$ is the Bray–Curtis distance for the i – th fisher between the time points a (before, 20 years ago) and d (after, currently); hf . is the bottom depth; hs . is the surface height; and c . is the reported gear length. Thus, $d_i(a, d)$ was used as the response variable in a classical linear ANCOVA model, with the initial predictor composed of the community location factor (with four levels) and the covariates: average LEK score, years of experience, and number of fishing techniques known.

Lastly, to evaluate variables that potentially impact LEK, a mixed ordinal logistic model with proportional odds (Hartzel; Agresti; Caffo, 2001) was employed. In this case,

the response variable was the r -th level of LEK specificity ($r = 1, 2$) for the j -th species mentioned by the i -th fisher, and the linear predictor included:

$$\eta_{ijr} = \alpha_r + \mathbf{x}'_{ij}\boldsymbol{\beta} + \mathbf{z}'_{ij}\mathbf{u}_i,$$

where α_r (satisfying $\alpha_1 < \alpha_2$) are intercept parameters; $\mathbf{x}'_{ij}$ is the column vector of fixed-effect covariates, and $\boldsymbol{\beta}$ is the corresponding vector of coefficients; $\mathbf{z}'_{ij}$ is the column vector of random-effect covariates, and $\mathbf{u}_i \sim MVN(\mathbf{0}, \boldsymbol{\Sigma})$.

The fixed-effect covariates considered were the fisher's community of origin (a factor with four levels), years of experience as a fisher, the number of species known, and the number of fishing techniques used. It is important to note that the response categories refer to the cited species, which are naturally grouped by fisher. Therefore, the random-effect covariate is the fisher, providing in $\mathbf{u}_i$ a block-diagonal covariance matrix $\boldsymbol{\Sigma}$, with typical elements σ_{pesc}^2 .

Model selection was performed using likelihood ratio tests at a 5% significance level, first for the random effect, then for the fixed effects. Post hoc multiple comparisons procedures were carried out at a 5% significance level based on marginal means and the final model, communities with statistically significant differences were denoted by distinct lowercase superscript letters.

All statistical analyses were conducted in R (R Core Team, 2024), using the packages *emmeans* (Lenth, 2025), *hnp* (Moral, Hinde & Demétrio, 2017), *Mass* (Venables & Ripley, 2002), *ordinal* (Christensen, 2023), and *vegan* (Oksanen et al., 2025).

3. RESULTS

A total of 46 active fishers were interviewed in the municipalities of Peruíbe and Iguape, ranging in age from 20 to 75 years (mean $\pm$ SD = 46.3 ± 14.8 years), with professional experience ranging from 5 to 57 years (mean $\pm$ SD = 29.1 ± 16.0), all using gillnets.

The fishers mentioned 25 commercially important species, with special emphasis on snooks (*Centropomus paralellus* and *Centropomus undecimalis*), acoupa weakfish (*Cynoscion acoupa*), Argentine croaker (*Macrodon atricauda*), smalltooth weakfish (*Nebris microps*), Serra mackerel (*Scomberomorus brasiliensis*), bluefish (*Pomatomus saltatrix*), and mullet (*Mugil liza*) as the most economically important fishery resources in the region. These species are not only highly valued in the local market but also play a

fundamental role in maintaining the economic and sociocultural fabric of the local fishing communities.

The distribution of responses to items 1, 2, 3, and 4 (Figure 2), 5, 6, 7, and 8 (Figure 3), and 9 (Figure 4) across different levels of agreement, according to the adopted perception scale, allowed for the identification of varying response patterns among the communities.

Item 1 (Figure 2): The Barra do Una community showed the highest proportion of responses at the “strongly disagree” level (1), with 44%. Agreement increased progressively in subsequent levels, reaching 13% at level 4 and 44% at the “partially agree” level (5). In Peruíbe, no responses were recorded at levels 1 or 2 (0%). Agreement increased progressively, with 22% at level 4 and 79% at level 5. In Prelado, the highest frequency occurred at level 2 (“partially disagree”), with 40%, followed by 40% at level 4 and 20% at level 5. In Rio Verde, there were no responses at disagreement levels (1 and 2) or at the neutral level (3). However, 40% responded at level 4 and 100% at level 5. Considering all communities, overall percentages for Item 1 were: 22% at level 1, 4% at level 2, none at level 3, 17% at level 4, and 57% at level 5.

Item 2 (Figure 2B): In Barra do Una, 31% of respondents expressed total disagreement (level 1), 13% selected level 3, 31% level 4, and 26% partial agreement (level 5); no responses were recorded at level 2. In Peruíbe, a small percentage responded at level 1 (7%), followed by 15% at level 3, 22% at level 4, and 58% at level 5; again, no responses were recorded at level 2. In Prelado, all responses (100%) were at level 1, indicating complete disagreement with the statement, and no responses were registered in any other category. In Rio Verde, no responses were recorded at levels 1, 2, 3, or 4, with all responses concentrated at level 5 (100%). Across all communities, overall percentages for Item 2 were: 28% at level 1, none at level 2, 11% at level 3, 22% at level 4, and 39% at level 5.

Item 3 (Figure 2C): At the “strongly disagree” level (1), Prelado recorded 100% of responses, while Barra do Una, Peruíbe, and Rio Verde showed lower rates: 9%, 29%, and 24%, respectively. Overall, 24% of responses were concentrated at this level. No responses were recorded at the “partially disagree” (2) or “neutral” (3) levels in any community. At the “moderately agree” level (4), Rio Verde stood out with 75% of responses, while Barra do Una (5%), Peruíbe (7%), and Prelado (0%) showed lower rates, totaling 11% of responses at this level. The “partially agree” level (5) concentrated most

responses in Barra do Una (86%) and Peruíbe (64%), while Prelado and Rio Verde had no responses in this category. In total, 65% of responses fell within level 5.

Item 4 (Figure 2D): Analysis of the responses revealed variable distributions across agreement levels in the four communities. At the “strongly disagree” level (1), the highest concentration of responses occurred in Barra do Una (40%), followed by Peruíbe (7%); Prelado and Rio Verde showed no responses at this level, resulting in an overall rate of 22%. No responses were recorded at levels 2 (“partially disagree”) or 3 (“neutral”) in any of the communities. At the “moderately agree” level (4), low percentages were identified in Barra do Una (9%) and Peruíbe (14%), with no responses in Prelado or Rio Verde, totaling 9% at this level. The majority of responses were concentrated at the “partially agree” level (5), with high percentages across all communities: Barra do Una (52%), Peruíbe (79%), and 100% in both Prelado and Rio Verde. Overall, 70% of responses fell within level 5.

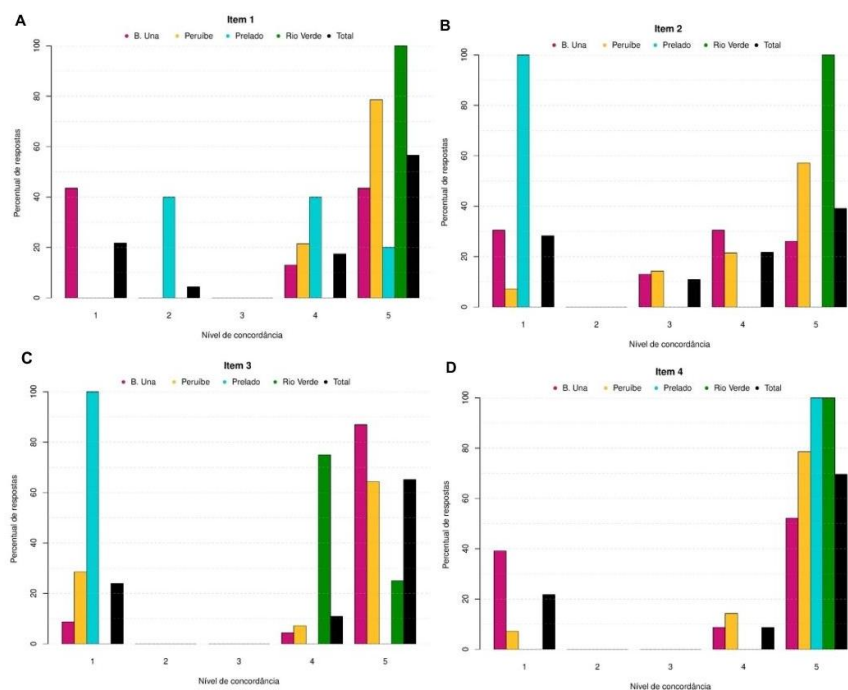


Figure 2. Percentage of agreement with the statements corresponding to items 5 to 8, with response distribution by community (Peruíbe, Barra do Una, Rio Verde) and overall total. The perception scale consisted of five levels: 1 – strongly disagree; 2 – partially disagree; 3 – undecided; 4 – strongly agree; 5 – partially agree. (A) Resources occurring in fishing areas with greater depths. (B) Perception of the relationship between the decrease in catches over the years and the increase in gillnet height. (C) Capture of commercially important fish such as *Robalo peba*, *Corvina*, *Tainha*, and *Sororoca* was not carried out using the same type of gear currently used. (D) Fishing grounds located farther offshore.

The results for items 5, 6, 7, and 8 (Figure 3), based on the perception scale, show the distribution of responses across different Levels of Agreement in the evaluated communities.

Item 5. Seasonal unpredictability of fishery resources: perception assessment (Figure 3): Level 1: In the community of Barra do Una, 26% of fishers reported not observing the occurrence of seasonal species at different times of the year, followed by 22% in Peruíbe, 21% in Prelado, and 20% in Rio Verde. The overall percentage was 22%. Levels 2 and 3: No responses were recorded. Level 4: In Barra do Una, 9% agreed that commercially important fish species are occurring at different times of the year, compared to 14% in Peruíbe, 40% in Prelado, and 11% in Rio Verde. The overall percentage across all communities was 13%. Level 5: Partial agreement was observed in 65% of respondents from Barra do Una, 64% in Peruíbe, 40% in Prelado, and 100% in Rio Verde. The total percentage at this level was 65%.

Item 6. Perception of fishing effort over the last 20 years (Figure 3F): The results show considerable variation among communities regarding the perception of increased fishing effort over the past two decades. Level 1 (total disagreement): The highest percentages were recorded in Prelado (60%), followed by Rio Verde (25%), Peruíbe (21%), and Barra do Una (13%), with an overall total disagreement percentage of 22%. Level 2 (partial disagreement): No responses were recorded in any of the communities. Level 3 (undecided): Peruíbe reported 7% undecided responses, while Barra do Una and Rio Verde each had 4%. No undecided responses were recorded in Prelado. Level 4 (total agreement): No responses were recorded. Level 5 (partial agreement): This level concentrated the majority of responses, indicating a clear pattern of perceived increase in fishing effort. The highest percentages were observed in Barra do Una (83%), Rio Verde (75%), Peruíbe (71%), and Prelado (40%), totaling 74% of general responses at this level.

Item 7. Perception of fish stock decline and loss of traditional knowledge (Figure 3G): Responses reveal a marked pattern of agreement with the statement across communities. Level 1: 22% of responses came from Barra do Una and 14% from Peruíbe, while no responses were recorded at this level in Prelado and Rio Verde. The overall percentage was 15%. Level 2: No responses were recorded. Level 3: Responses were recorded in Barra do Una (22%) and Peruíbe (20%), with no entries from Prelado or Rio Verde, resulting in an overall percentage of 13%. Level 4: No responses were observed.

Level 5 (partial agreement): The majority of responses were concentrated here, with high percentages in all communities: Barra do Una (57%), Peruíbe (86%), Prelado (80%), and Rio Verde (100%). The overall percentage at this level was 72%.

Item 8. Levels of agreement with the influence of environmental changes on fisheries (Figure 3): Level 1 (total disagreement): Percentages of 22% in Barra do Una and 14% in Peruíbe were observed, with no responses from Prelado or Rio Verde. The overall percentage was 15%. Level 2 (partial disagreement): No responses were recorded in any of the communities. Level 3 (undecided): Similar percentages were found in Barra do Una (22%) and Peruíbe (20%), with no responses from Prelado or Rio Verde. The overall undecided rate was 13%. Level 4 (total agreement): No responses were observed. Level 5 (partial agreement): The majority of responses were concentrated here, indicating a broad perception of the influence of environmental changes on fisheries: Rio Verde (100%), Peruíbe (86%), Prelado (80%), and Barra do Una (57%). The overall percentage at this level was 72%.

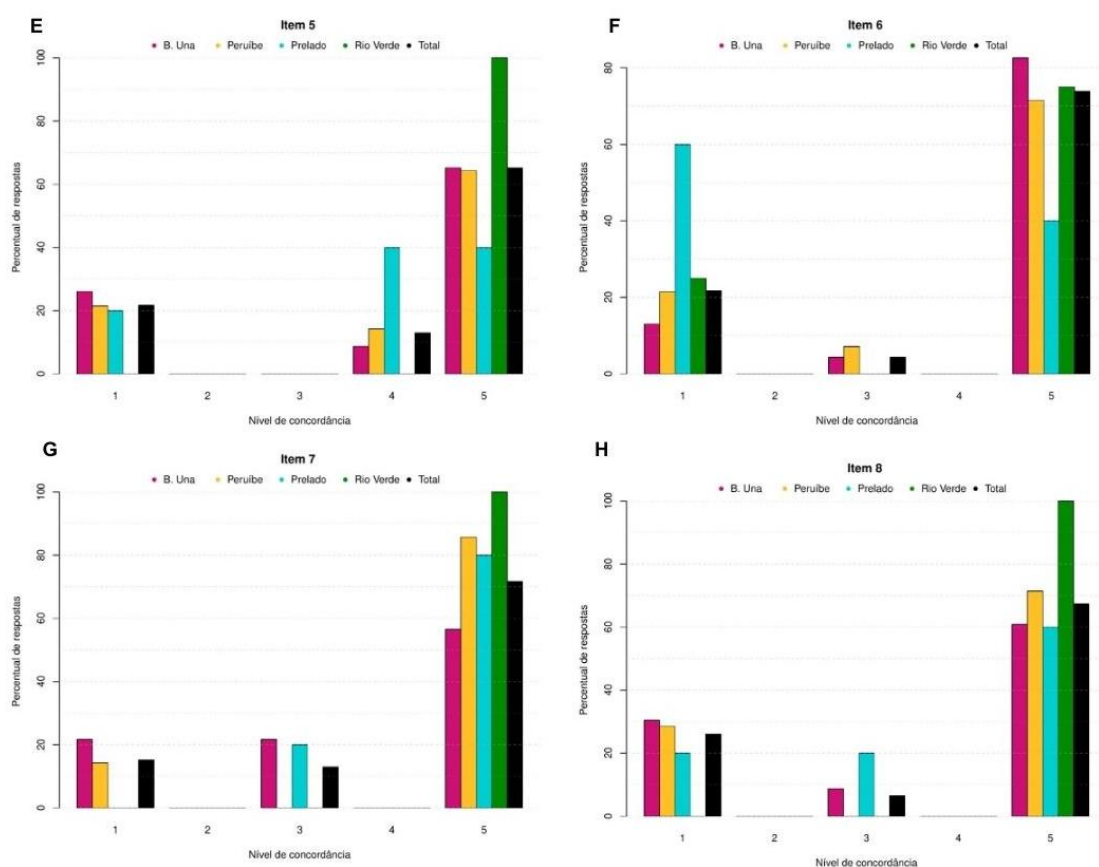


Figure 3. Distribution of responses for items 5 to 8. Percentage distribution among Peruíbe, Barra do Una, Rio Verde, and the total across the variables, where: 1 = totally disagree; 2 = partially disagree; 3 = undecided; 4 = totally agree; 5 = partially agree. Figure E. Perception of the unpredictability of seasonal fishery resource occurrence. Figure F. Perception of fishing effort over the past 20 years. Figure G.

Perception and level of agreement regarding the decline of fish stocks and the loss of traditional knowledge. Figure H. Perception of the influence of environmental changes on fisheries.

Item 9 (Figure 4). Fishing in areas different from traditional fishing sites (Figure 4): At level 1, the highest percentages were observed in Barra do Una (13%) and Peruíbe (6%), with no responses recorded in the communities of Prelado and Rio Verde. The overall percentage was 8%. Level 2 had no responses in any of the communities. At level 3, Barra do Una (26%) and Rio Verde (25%) stood out, while Peruíbe and Prelado had no responses. The overall percentage of indecision was 15%. Level 4 also had no recorded responses. Level 5 concentrated the majority of responses, indicating a widespread perception of changes in fishing locations: Prelado (100%), Peruíbe (94%), Rio Verde (75%), and Barra do Una (61%). The overall percentage was 76%.

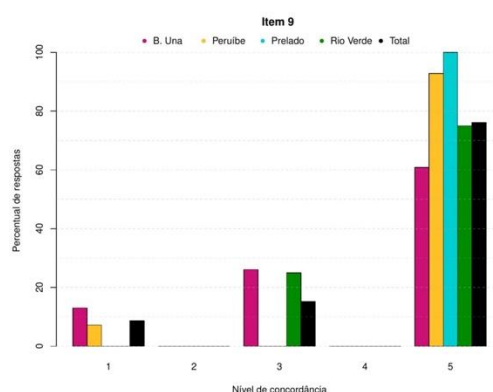


Figure 4. Perception of the capture of commercially important species in different fishing areas. Percentage distribution of responses among the communities of Peruíbe, Barra do Una, Rio Verde, and overall Total according to the levels of agreement on the scale used: 1 totally disagree; 2 partially disagree; 3 undecided; 4 totally agree; 5 partially agree.

According to the fishers, catches in nearby locations are decreasing, forcing them to fish in more distant areas. They also reported catching uncommon species in surface and bottom gillnet fisheries, such as the snook *Centropomus paralellus* in surf zones, which had not been observed before.

The use of gear with greater height enables the simultaneous capture of both bottom and surface fish. Table 3 details the responses and absolute frequency among the communities..

Table 3. Consolidated perceptions of artisanal fishers regarding observed changes in fishing gear across different communities. Ft: absolute frequency; Fr: relative frequency (relative to the total number of interviews per site).

Location	Responses	Ft	Fr
Peruíbe	<i>"Catches are decreasing"</i> <i>"Fishing areas farther away"</i> <i>"Capture of resources not previously caught in surface and bottom gillnets"</i>	7	7/14

Barra do Una	<i>"We did not previously catch snook in surf zones" "Tall gear captures bottom and surface species simultaneously"</i>	5	5/23
Rio Verde	<i>"Catches are decreasing" "We did not previously catch snook in surf zones" "Tall gear captures bottom and surface species simultaneously"</i>	4	4/4
Prelado	<i>"Catches are decreasing" "We did not previously catch snook in surf zones" "Tall gear captures bottom and surface species simultaneously"</i>	2	2/5
Total		18	18/46

Statistical analysis of changes in gear length, comparing 20 years ago and the present, showed that the correlation between the variables A_{before} (previous length) and B_{after} (current length) is not significant ($r^2 = 0.023$, $n = 46$; $p = 2.58E-08$), indicating no direct relationship between lengths in the two periods. However, comparison of group medians ($medC_{before}$ — previous median; $medC_{after}$ — current median) revealed a significant difference, with the population median of the first group being lower than the second, according to the Wilcoxon test ($W = 933.5$, $p < 2.58E-08$).

Correlation analysis indicated a positive association between variables ($r^2 = 0.18$; $n=46$; $p = 0.003$), showing a significant relationship between both periods. The Wilcoxon test ($W = 49$, $p = 0.017$) compared the distributions of variables related to bottom gillnets in the previous and current periods ($medAF_{before}$ is statistically different from $medAF_{after}$). Although the medians $medAF_{before}$ and $medAF_{after}$ are equal, the Wilcoxon test revealed significant differences between groups for bottom gillnets. This seemingly counterintuitive result can be explained by the nature of the test, which evaluates not only the central tendency (median) but also data distribution and uncertainty in estimates. When comparing two paired samples, it is common to find numerically identical medians. However, the Wilcoxon test can detect statistically significant differences by considering the sign and magnitude of differences between observation pairs and the overall distribution shape. Thus, significant differences can be found despite identical medians if distributions differ in shape, asymmetry, or presence of outliers. This underscores that the term “distribution-free methods” for nonparametric statistics is misleading (SPRENT & SMEETON, 2001).

Correlation analysis showed no significant linear relationship between $medAS_{before}$ and $medAS_{after}$ ($r^2 = 0.0006$; $p = 0.863$). However, comparison of medians between groups $medAS_{before}$ and $medAS_{after}$ identified a significant difference, with the median of the first group lower than the second ($W = 861$, $p < 2.14E-08$).

Table 4 presents ANCOVA results, which did not find statistically significant covariates for the three combined dimensions of gear size measured by Bray-Curtis distance. Therefore, by cross-referencing paired tests and ANCOVA results, it can be concluded that fishers are striving to adapt to perceived environmental changes. However, the potential factors influencing the metric used to quantify this effort remain unclear.

Table 4. Analysis of covariance for the Bray-Curtis distance data. Where: Local Ecological Knowledge (LEK), Fishing Experience (E), Number of fishing techniques known by the fisher (T).

Source	DF	SS	MS	F	<i>p</i> -value
Local	3	0.06887	0.022956	0.6161	0.6095
LEK	1	0.00732	0.007316	0.1963	0.6606
E	1	0.00703	0.007027	0.1886	0.6669
T	1	0.00129	0.001289	0.0346	0.8536
L:C	3	0.07850	0.026167	0.7023	0.5575
L:E	2	0.08841	0.044203	1.1863	0.3180
L:T	1	0.00279	0.002786	0.0748	0.7862
Residual	33	1.22959	0.037260		

The likelihood ratio test for the presence of a random effect ($\hat{\sigma}_{\text{fisherman}}^2=16,09$) of the fisher was highly significant ($\chi^2=154,998$, $DF=1$, $p < 0,0001$), reinforcing the existence of high variability in responses among interviewees. Regarding the selection of fixed effects, only the number of techniques known by the fishers was not statistically significant (Table 5).

The final predictor for the LEK level included the fisher's place of origin (community), the number of species known by the fisher, and fishing experience time. The estimated coefficients and their respective standard errors are presented in Table 4. The results indicate that for each additional species known, the odds of the fisher being in the higher LEK categories increase more than threefold ($\exp\{1,19\} \approx 3,29$). Additionally, each extra year of experience contributes to an approximate 20% increase ($\exp\{0,83\} \approx 1,20$) in the probability of the fisher moving from a lower to a higher LEK category (either from incipient to intermediate, or from intermediate to substantial).

Although the coefficients are presented in Table 4, the comparison (contrasts) of LEK among communities is better shown in Table 5. It is observed that Barra do Una^(a) and Rio Verde^(ab) did not differ significantly regarding fishers' LEK, but fishers from Barra do Una showed significantly higher LEK than Prelado^(b) and Peruíbe^(c). Meanwhile, Rio Verde^(ab) and Prelado^(b) did not differ significantly between each other, whereas fishers from Peruíbe (c) exhibited the lowest LEK among the communities studied.

Table 5. Likelihood ratio tests for fixed effects in the fitted predictors of Local Ecological Knowledge level. L: fisher's place/community of origin; E: experience time (years); T: number of fishing techniques known by the fisher; B: biodiversity/number of species cited by the fisher. k: number of model parameters; AIC: Akaike Information Criterion; DF: degrees of freedom of the test statistic; χ^2 : chi-square statistic.

Effect	k	AIC	χ^2	DF	p-value
Intercept only	3	382,81		-	-
L	6	368,58	20.2352	3	0,0002
L + E	7	348,67	21.9661	1	< 0,0001
L + E + B	8	339,95	10.6658	1	0,0011
L + E + B + T	9	341,55	0.3959	1	0,5292

Table 6. Parameter estimates (coefficients) of the final proportional odds model with logistic link function for the response variable *local ecological knowledge level*, ordinal with three levels (1: incipient knowledge, 2: intermediate, and 3: substantial), and random effect of fisherman. SE: standard error. $|Z|$: absolute value of the asymptotic Z statistic. $\alpha_{1|2}$: threshold coefficient between levels 1 and 2 (intercept of the first category); $\alpha_{2|3}$: threshold coefficient between levels 2 and 3 (intercept of the second category). β_{11} : effect of Peruibe relative to Barra do Una; β_{12} : effect of Prelado relative to Barra do Una; β_{13} effect of Rio Verde relative to Barra do Una; β_2 : coefficient associated with the fisherman's experience (years); β_3 : coefficient associated with the number of species cited by the fisherman; $\sigma_{fisherman}^2$: variance of the random effect.

Parameter	Estimate	SE	$ Z $	p-value
$\alpha_{1 2}$	4.344301	0.002684	-	-
$\alpha_{2 3}$	15.834481	0.921231	-	-
β_{11}	-12.956134	0.002684	4827.449	< 0,0001
β_{12}	-7.267931	1.877132	3.872	0,0001
β_{13}	-1.632426	1.801378	0.906	0,3648
β_2	0.182991	0.005164	35.436	< 0,0001
β_3	1.193179	0.005184	230.171	< 0,0001
$\sigma_{fisherman}^2$	341,55	-	-	-

Table 7. Tukey-type multiple comparisons to assess differences between locations in terms of the level of local ecological knowledge.

Null hypothesis of contrast	Estimate	SE	$ Z $	p-value
Barra do Una - Peruibe = 0	10,44	1,47	7,085	< 0,0001
Barra doUna - Prelado = 0	4,84	1,28	3,786	0,0009
Barra do Una - Rio Verde = 0	2,38	1,27	1,868	0,2417
Peruibe - Prelado = 0	-5,60	1,59	3,518	0,0025
Peruibe - Rio Verde = 0	-8,06	1,66	4,845	0,0001
Prelado - Rio Verde = 0	-2,46	1,47	1,671	0,3389

4. DISCUSSION

LEK serves as a fundamental tool for understanding resilience in social-ecological systems, as the adaptive capacity of small-scale fisheries is intrinsically linked to the dynamics of natural ecosystems. The findings of this study show that fishers manage

environmental uncertainties through continuous adjustments to their fishing practices, grounded in a body of knowledge built through direct interaction with the environment.

However, a temporal and generational gradient was observed in the perception of these transformations. While novice fishers interact with a biophysical landscape that has already been altered a phenomenon known as shifting baseline syndrome (Pauly, 1995) accumulated experience allows for a more refined interpretation of ecological trajectories. As years in the profession progress, LEK levels increments, enabling more experienced fishers to describe and contextualize environmental changes occurring over decades. This transmission and accumulation of knowledge are what allow the community to not only react to changes but to anticipate responses to new environmental stressors.

This study shows that fishers perceive environmental change and respond through adaptive strategies, supporting previous findings that fishers act as early observers of ecological change (Daw et al., 2009; Begossi, 2014; Martins & Gasalla, 2018). Our results extend this premise by showing that such perceptions act as catalysts for purposeful technical modifications to fishing effort, rather than remaining passive observations."

Perceptions of change were generally nuanced, with most responses clustering around partial agreement rather than extreme positions (Figures 2–4). This pattern suggests that fishers recognize gradual and cumulative environmental shifts rather than abrupt changes, reflecting the complexity of socio-environmental dynamics and reinforcing the value of perception-based approaches in fisheries research.

Fishers reported changes in fishing grounds, seasonality, and species occurrence, including the capture of species in habitats where they were previously uncommon (Table 3). Such observations are consistent with documented shifts in species distribution associated with environmental variability and climate change (Perry et al., 2005; IPCC, 2014; Worm & Lotze, 2021).

Adaptation was evident through modifications in fishing gear, particularly increases in gillnet length and height over time. These changes likely reflect attempts to compensate for declining catch rates and altered resource availability, a pattern commonly reported in small-scale fisheries (Silvano & Begossi, 2012). However, the absence of significant predictors for the magnitude of gear changes (Table 4) suggests that adaptation emerges from multiple interacting factors, including ecological conditions, regulatory constraints, and individual decision-making, rather than from LEK alone.

Local ecological knowledge emerged as a central component of adaptive capacity. LEK varied significantly among communities and was strongly influenced by fishing experience and the number of species cited (Tables 5 and 6), reinforcing the view that ecological knowledge accumulates through long-term interaction with diverse resources (Berkes et al., 2000; Silvano & Begossi, 2012). The strong random effect of fisher identity further highlights the individualized nature of knowledge construction.

Community context also played a significant role. Fishers from Barra do Una exhibited higher LEK levels than those from more urbanized communities such as Peruíbe (Table 7). Greater isolation, proximity to protected areas, and continued reliance on fishing as a primary livelihood may favor the maintenance and transmission of ecological knowledge, whereas urbanization and livelihood diversification may erode it.

Overall, the results indicate that LEK does not act as a direct driver of specific adaptive responses, such as gear modification, but instead provides a cognitive and experiential foundation that enables fishers to perceive change and explore adaptive strategies. This distinction is important, as it positions LEK as an enabling condition for adaptation rather than a deterministic predictor. This trend corroborates the premise that socioeconomic modernization and integration into global markets often act as drivers of acculturation, resulting in the loss of traditional knowledge related to resource management (Aswani et al., 2018). In increasingly urbanized contexts, the transition toward occupations that are less directly dependent on biological seasonality disrupts mechanisms of intergenerational oral transmission. This, in turn, fragments the ecological repertoire that underpins the community's adaptive capacity (Gomez-Baggethun & Reyes-García, 2013).

Recognizing and incorporating LEK into fisheries management may therefore enhance the resilience of small-scale fisheries, particularly in regions experiencing rapid socio-environmental change. Policies that overlook this knowledge risk undermining locally grounded adaptive strategies that have developed over generations.

5. CONCLUSION

The results demonstrate that small-scale fishers are active agents in perceiving and responding to environmental change. Local ecological knowledge (LEK) constitutes an important foundation of adaptive capacity, enabling fishers to recognize changes in species distribution, seasonality, fishing grounds, and resource availability.

Accumulated experience was one of the main factors associated with LEK levels, indicating that knowledge is developed and refined through continuous interaction with

the environment and intergenerational transmission. Differences among communities also indicate that the maintenance of this knowledge is related to socio-environmental context, dependence on fishing, and the intensity of urbanization processes.

However, LEK was not directly associated with specific changes in fishing gear, indicating that adaptation results from the interaction among ecological knowledge, environmental conditions, economic factors, regulations, and individual decision-making. Thus, LEK should be understood as an enabling condition for adaptation, rather than as an isolated determinant.

Therefore, the systematic incorporation of local ecological knowledge into fisheries management, monitoring, and conservation strategies can strengthen communities' capacity to respond to environmental change. Valuing, documenting, and promoting the transmission of this knowledge are therefore essential for strengthening the resilience of small-scale fisheries and the social-ecological systems on which they depend.

Declarations

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The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

Ethics approval

This research was conducted in accordance with the ethical guidelines established by the Brazilian National Health Council, specifically Resolution CNS No. 466/2012 and Operational Norm CNS No. 001/2013, which regulate research involving human beings in Brazil through the CEP/CONEP system. The methodological procedures were approved by the Ethics Committee for Research Involving Human Beings at Universidade Santa Cecília (Opinion No. 6.580.809).

Declaration regarding the use of generative AI and AI-assisted technologies in the writing process. During the preparation of this work, the authors used Google's Gemini AI to translate the text into English. After using this tool/service, the authors reviewed and edited the content as necessary and assume full responsibility for the content of the publication.

Clinical trial registration

Not applicable.

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