frontiers | Frontiers in Ecology and Evolution

ORIGINAL RESEARCH
published: 20 April 2022
doi: 10.3389/fevo.2022.788879

Octopus Fishing and New Information on Ecology and Fishing of the Shallow-Water Octopus *Callistoctopus furvus* (Gould, 1852) Based on the Local Ecological Knowledge of Octopus Fishers in the Marine Ecoregions of Brazil

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Specialty section:
This article was submitted to Conservation and Restoration Ecology, a section of the journal Frontiers in Ecology and Evolution

Received: *03 October 2021*
Accepted: *09 March 2022*
Published: *20 April 2022*

Citation:
Jesus MD, Zapelini C, Santana ROd and Schiavetti A (2022) Octopus Fishing and New Information on Ecology and Fishing of the Shallow-Water Octopus Callistoctopus furvus (Gould, 1852) Based on the Local Ecological Knowledge of Octopus Fishers in the Marine Ecoregions of Brazil. Front. Ecol. Evol. 10:788879. doi: 10.3389/fevo.2022.788879

Studies that compile local ecological knowledge (LEK) on some of the various species of living beings observe biological data and are notably fundamental for effectively managing fisheries, supporting management strategies for protected areas, species conservation, and other factors. In this study, ethnoecological approaches were used to focus on the octopus *Callistoctopus furvus* (Gould, 1852), recently re-described and re-presented to the academic community more than a century after its discovery. The LEK of octopus fishers from different marine ecoregions of Brazil was compared to identify the distribution limits of the species along the Brazilian coast. Semi-structured interviews were conducted in 16 municipalities across four marine ecoregions located between the states of Ceará (northern limit) and Santa Catarina (southern limit), between March 2018 and August 2019. The results of the 187 interviews indicated a traditionality of fishing among artisanal octopus fishers, who are mostly men, although some are women who also share information on the fishing of *C. furvus* and hold leadership positions in the fishing colony. Cronbach's alpha was used to analyze reliability of the form used in the interviews. A logistic regression model with binomial distribution was used to assess whether the probability of capturing the "eastern octopus" was associated with some of the interview variables. A cluster analysis based only on the respondents who caught the "eastern octopus" indicated the formation of groups and revealed greater dissimilarities among the fishers from the southeastern marine ecoregion of Brazil due to the fishing method used in the region. Heat maps showed that most of the information on the

species was obtained in the eastern marine ecoregion of Brazil. The occurrence of the "eastern octopus" was recorded in all the studied Brazilian marine ecoregions. Moreover, this study revealed the relevant contribution of fishers' knowledge to the distribution diagnosis of species with scarce scientific information.

Keywords: ethnoknowledge, marine protected areas, reef environments, artisanal fishing, Western Atlantic Ocean

INTRODUCTION

The Indo-Pacific "spotted octopuses" were originally classified as *Octopus macropus* (Risso, 1826), but from 2005 after taxonomic revision (Norman and Hochberg, 2005), they were reclassified in another genus and became scientifically known as *Callistoctopus macropus* (Risso, 1826). Among the characteristics that allowed its reclassification, the one that stands out the most is its "reddish brownish" chromatic pattern, displaying, when disturbed, the characteristic white spots (Jereb et al., 2014). There are several very similar species in the Indian Ocean and the western Pacific Ocean. The most recent reviews consider that the species *C. macropus* lives in the Mediterranean and the northeast coast of the Atlantic (NW Africa), with some presence on the American and Caribbean coast (Jereb et al., 2014). According to Norman (2000), it is a complex of very similar species, where probably the true identity of American populations needs to be clarified.

In a study carried out by Jesus et al. (2015) a specimen of this other genus of octopus was captured in the region of southern Bahia (Brazil), *Callistoctopus* sp., the "eastern octopus." Given this, and the need to clarify the taxonomic status of the species known locally (South of Bahia state) as "eastern octopus" (*Callistoctopus* sp.), Jesus et al. (2021a,b) presented a neotype and redescribed the octopus species *Callistoctopus furvus* (Gould, 1852), along with morphological and genetic characteristics, after more than 150 years without any scientific publications about it. Despite the recent taxonomic confirmation of *C. furvus*, there are still gaps in information regarding the species.

It is a fact that the worldwide interest in adopting interdisciplinary approaches in the study of the multifaceted relationships between society and its landscapes is increasing every day. In this sense, studies with ethnoecological approaches have been gaining great notoriety. In general, the concept of Ethnoecology can be understood as a branch of ethnoscience related to the study of the knowledge of human groups in relation to their practices about something, as well as about their beliefs and interactions with the environment and its ecosystems (Barrera-Bassols and Toledo, 2005; Zappes et al., 2018). Studies compiling the local ecological knowledge (LEK) on the different species of living beings, complement the biological data and have been fundamental for the effective management of fisheries, strengthening of strategies for the management of protected areas, species conservation, nutritional importance and medicinal use (Begossi and Silvano, 2008; Prabhakar and Roy, 2009; Castilho et al., 2013; Chakraborty et al., 2015; Nascimento et al., 2020).

Mollusks are poorly studied ethnoecologically. Although there is still little information about this group, most are related to management strategies for their artisanal fisheries (Cidreira-Neto et al., 2019). Some ethnoecology works involving bivalve mollusks focus on their medicinal use to cure a number of diseases, such as rheumatism, calcium metabolism, heart disease, conjunctivitis, dizziness, nervousness, dehydration, and various gastrointestinal disorders (Prabhakar and Roy, 2009), as well as the its nutritional importance (Chakraborty et al., 2015). However, regarding ethnoknowledge about cephalopod mollusks, there are information gaps (e.g., distribution, habitat, availability, and socioeconomic importance), which need to be filled. In a study with ethnoecological approaches to the octopus *Octopus insularis* (Leite and Haimovici, 2006) in southern Bahia, Martins et al. (2011) suggested the need for further studies of the octopus species that occurred in that region. This is because in their work on the ethnoecological aspects of octopus fishing in the community of Coroa Vermelha—Santa Cruz Cabrália, Bahia (Brazil), these same authors indicated that octopus fishers reported that in that region there was also another species of octopus that was not commercialized. In this regard, the use of traditional knowledge of extractive communities associated with data collected through scientific methodology can help create management plans and programs to support artisanal fishing (Freitas et al., 2012), as well as characterize a species with limited scientific records of its capture. The local knowledge of fishers, here understood as synonymous with the term ethnoecology (Hanazaki, 2003) can contribute to scientific knowledge and promote cooperation and dialogue between fishers and scientists (Silvano and Begossi, 2005).

It is currently known that the octopus species *C. furvus* occurs along the Brazilian coast, with records of its occurrence in Colombia and Mexico (Cedillo-Robles and Pliego-Cardenas, 2018). Thus, our objective was to analyze the ethnoknowledge of fishermen about octopus fishing, focusing on the species *C. furvus*. In this way, we present initial ethnoecological information on the fishing of the "eastern octopus" species *Callistoctopus furvus*, which has recently been re-described (Jesus et al., 2021b), and compare the LEK of artisanal octopus fishers in four Brazilian marine ecoregions.

MATERIALS AND METHODS

Study Area

The study was carried out in reef environments in the coastal marine zone of Brazil, between the states of Ceará—CE (northeast region) and Santa Catarina—SC (southern region) and the island of Fernando de Noronha—PE (northeast region). According to Spalding et al. (2007), the Brazilian coast comprises

the biogeographic domains known as Tropical Atlantic and Temperate South America. The Fernando de Noronha and Atol das Rocas ecoregion is characterized by volcanic islands. The emerged portion of Fernando de Noronha is represented by 21 islands, islets and rocks, featuring algal and coral reefs (Mohr et al., 2009). Atoll das Rocas is a region bathed by the south equatorial current, originating on the coast of Africa. Its formation predominates calcareous algae and colonial mollusks, associated with true corals and foraminifera (Mohr et al., 2009). Northeast Brazil is characterized by dunes, estuaries and reefs in fringing and coral reefs (Leão, 1996). In the Eastern ecoregion of Brazil, there is the Banco dos Abrolhos, an extension of the continental shelf with waters rarely greater than 30 m in depth, representing the largest and richest area of coral reef in the South Atlantic (Moura et al., 2013). It is the most oligotrophic of Brazilian coastal waters (Ekau and Knoppers, 1999). Finally, the Southeastern Brazil ecoregion has colder waters and upwellings, being a region with higher primary productivity (Coelho-Souza et al., 2012).

Considering the need for criteria, requirements, and other conditions to obtain information on ethnoconservation and the occurrence of the octopus *C. furvus* along the Brazilian coast, collection points were established in six marine protected areas (MPAs) and 16 municipalities surrounding these MPAs located in four Brazilian marine ecoregions (BME) (Spalding et al., 2007), as shown in **Figure 1**.

The definition of collection points in the MPA is due to the fact that, as it is a species with few records, the MPAs, theoretically, could harbor some population of the species. Therefore, MPAs with different types of uses were chosen, as well as areas without protection. The North limit was defined because there was a record in Fernando de Noronha (Leite and Haimovici, 2006) and the South limit because one of the divers consulted in the first phase of the study (*ad hoc*) confirmed the presence of the species in the State of Santa Catarina.

The study area was defined after the initial phase of research through expert consultations (see more in Jesus et al., 2021a), by which marine protected areas (MPAs) were defined with different use types and surrounding areas located in distinct marine ecoregions (**Table 1**). These locations were included because they are potential occurrence sites of the species *C. furvus* (**Figure 2**).

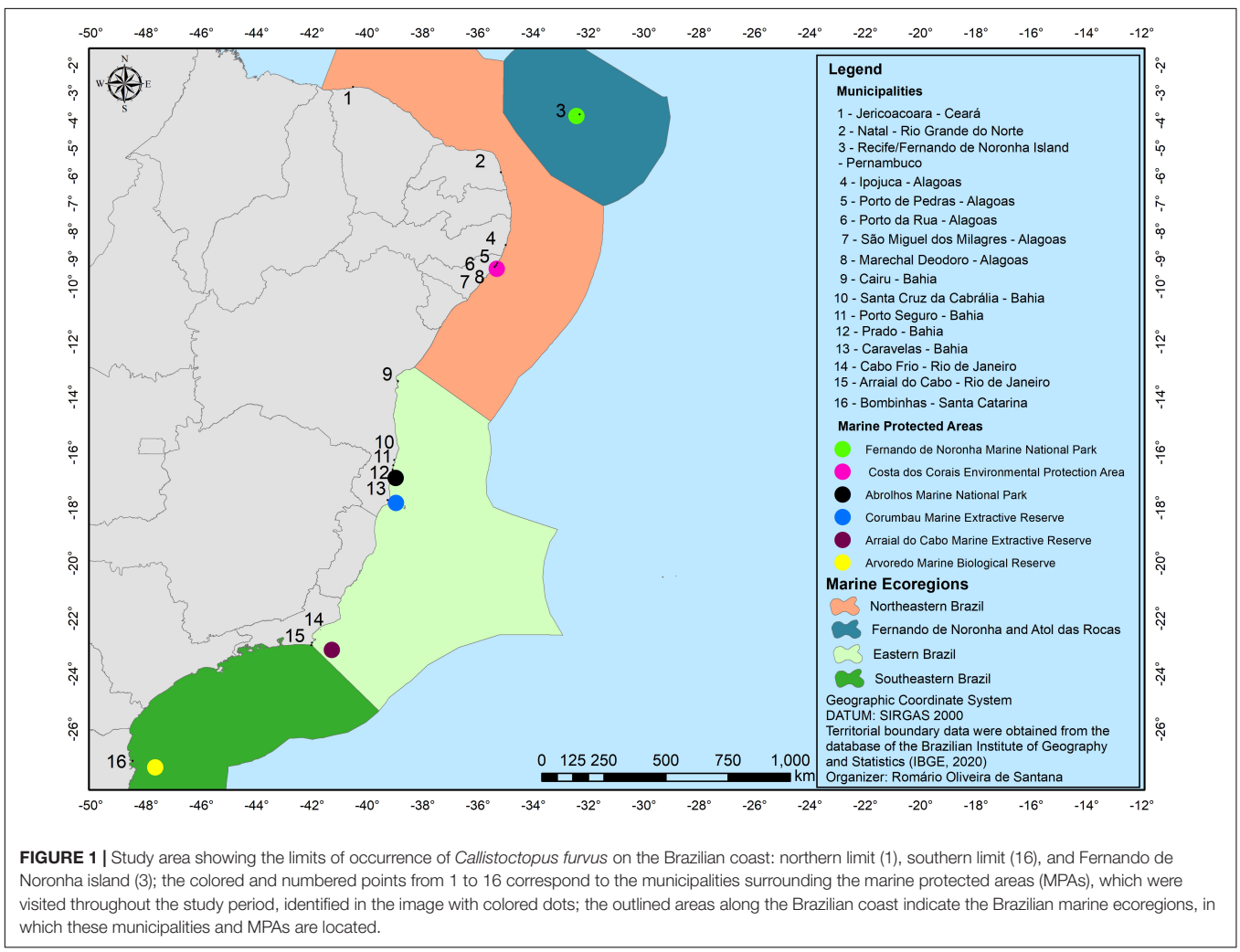

FIGURE 1 | Study area showing the limits of occurrence of *Callistoctopus furvus* on the Brazilian coast: northern limit (1), southern limit (16), and Fernando de Noronha island (3); the colored and numbered points from 1 to 16 correspond to the municipalities surrounding the marine protected areas (MPAs), which were visited throughout the study period, identified in the image with colored dots; the outlined areas along the Brazilian coast indicate the Brazilian marine ecoregions, in which these municipalities and MPAs are located.

TABLE 1 | Marine protected areas in which the study was developed, comprising the marine ecoregions of Fernando de Noronha and Atol das Rocas, northeastern Brazil, eastern Brazil, and southeastern Brazil.

Marine protected area	Legal diploma of creation	MPA class (SNUC/IUCN)	Marine ecoregions
Costa dos Corais Environmental Protected Areas	Decree of October 23, 1997	Sustainable use/V	Northeastern Brazil
Fernando de Noronha Marine National Park	Decree n° 96,693 of September 14, 1988	Full protection/II	Fernando de Noronha and Atol das Rocas
Abrolhos Marine National Park	Decree n° 88,218 of April 6, 1983	Full Protection/II	Eastern Brazil
Arraial do Cabo Marine Extractive Reserve	Decree of January 3, 1997	Sustainable use/V	Eastern Brazil
Corumbau Marine Extractive Reserve	Decree of September 21, 2000	Sustainable Use/VI	Eastern Brazil
Arvoredo Marine Biological Reserve	Decree n° 99,142 of March 12, 1990	Full protection/I	Southeastern Brazil

SNUC, National System of Conservation Units; IUCN, International Union for Conservation of Nature.

Data Collection

Data were collected between March 2018 and August 2019, initially by using behavioral components such as Rapport (Petit, 1987) in the previously delimited areas to establish a relationship of trust and respect between the researcher and the interviewed fishers, thus facilitating the exchange of information. Techniques used in social research were also applied, such as simple observation and semi-structured interviews (Minayo, 2016) with a script of closed-ended questions, and visual stimulation through photographs (Garcia, 2006; Monteiro et al., 2006a,b) and guided tours (Petit, 1987).

The semi-structured interviews were conducted to obtain all the details on the method of catching the octopus, the period during which fishing occurs (day/night), length of fishing activities, tide regimes, fishing gear used, fishing frequency, frequency of occurrence of the "eastern octopus" in the fishing region, consumption, trade, knowledge of the species that occur in the location, differences between males and females (sexual dimorphism), color pattern, size and weight requirements for capture/consumption, and sale (see **Supplementary Material 1**). During the interviews, the respondent had access to a set of 12 photographs (with images of *O. insularis*, *O. vulgaris* and *Callistoctopus* spp.), and the interviewer asked the respondent to inform which octopuses occurred in that region and how they differentiated them. The interview involved the use of fishers' LEK to discover, define distribution, and characterize the species of octopus *Callistoctopus furvus* on the Brazilian coast. Participant anonymity and confidentiality of information were guaranteed and specified in informed consent form No. 2,593,218 approved by the Research Ethics Committee of the Universidade Estadual de Santa Cruz.

The fishers who participated in the form-based interviews were initially contacted through fishing associations and colonies.

FIGURE 2 | "Eastern octopus" (*Callistoctopus furvus* Gould, 1852) found in the coastal reef of Cairu, Bahia, Brazil, photograph (Jesus et al., 2021b).

Permission to carry out this study in Protected Areas was obtained from the Sistema de Autorização e Informação em Biodiversidade (Biodiversity Authorization and Information system) ("SISBio"), under Protocol No. 60468-2.

Data Analysis

First, general octopus fishing data were analyzed (n = 187). The internal consistency (reliability) of the form questions was verified using Cronbach's alpha coefficient (Cronbach, 1951). This coefficient verifies the interrelationship of form items and varies from 0 to 1; the closer to the unit, the better the consistency of the form. Form questions with little variance are removed from the analysis since they decrease the value of the coefficient. According to the literature, values above 0.70 are considered appropriate (Cortina, 1993; Tavakol and Dennick, 2011), while values above 0.90 may suggest redundancy (Streiner, 2003).

Based on the coefficient alpha, the variables that remained and contributed to the alpha result were considered. These variables were used for principal component analysis (PCA) to

verify the response pattern of respondents considering the marine ecoregions of their municipalities, namely (i) northeastern Brazil, (ii) Fernando de Noronha and Atol das Rocas, (iii) eastern Brazil, or (iv) southeastern Brazil, according to the classification of Spalding et al. (2007). This analysis was carried out to verify which octopus fishing variables (in general) are associated with which Brazilian marine ecoregion.

A logistic regression model (LRM) was used to evaluate whether the probability (1 = yes; 0 = no) of catching the "eastern octopus" is associated with some of the interview variables. A binomial model with logit link was used.

A second set of analyses was performed considering only the respondents who captured the "eastern octopus" (n = 50). Since not all respondents answered all the questions, the data matrix was incomplete. To circumvent this problem, an imputation method was used for missing data. The *mice* package was used to implement a method for handling missing data. The function creates multiple imputations (substitution values) for missing multivariate data. The algorithm can impute combinations of continuous categorical, binary, unordered categorical, and ordered categorical data (for more information, see van Buuren and Groothuis-Oudshoorn, 2019). Specifically in this study, the values are unordered categorical values.

Once the new matrix was complete (with imputed data), a Cronbach's analysis was performed again, as described above. Subsequently, the dissimilarity pattern of the respondent answers in the different locations was verified using cluster analysis (dendrogram) with the *hclust* function and the "average" method. This analysis was used to verify if the formation of groups of respondents occurs within the Brazilian marine ecoregions, considering all the information from fishers about the species *C. furvus*. The optimal number of clusters was verified using the *NbClust* function. The cophenetic correlation coefficient (CCC; Rohlf, 1970) was used to verify the extent to which the observed dendrogram appropriately represented the data. This correlation ranges from 0 to 1; the closer to the unit value, the more fitting the dendrogram. All these analyses were performed in R software (R Core Team, 2020) with the packages *psych*, *MASS*, *cluster*, *vegan*, *labdsv*, *BiodiversityR*, *ggplot2*, *NbClust*, *FactoMineR*, *missMDA*, and *ggfortify*.

The data obtained from the interviews were also the basis for generating heat maps using kernel density estimation, in ArcGIS 10.5 software (Environmental Systems Research Institute [ESRI], 2016). This tool was used to identify the concentration of information on the artisanal fishing of octopus and fishers' LEK on the species *C. furvus* by marine ecoregion. This concentration of information was categorized into three classes, namely low (green), medium (yellow), high (red).

RESULTS

In all, 187 interviews were conducted with questions about octopus fishing traditionality, fishing effort, and sale (**Supplementary Material 1**). Ecological factors of fishing the octopus *C. furvus* were only presented considering the answers of fishers (n = 50) who, at some point in their fishing activity, caught one or more specimens of the octopus *C. furvus* since its capture is not frequent.

General Factors of Octopus Fishing

Cronbach's alpha was 0.81 [alpha = 0.81; confidence interval (95%) = 0.78–0.85; n = 187; mean inter-item correlation = 0.21]. Only one variable was removed ("consumes"), as there was no response variation. **Table 2** shows the test statistics and alpha value for the case of the individual removal of each variable. Some of the variables were negatively correlated with the total scale.

As shown in **Table 2**, the second column indicates the behavior of Cronbach's alpha in response to the removal of each variable from the analysis. The individual removal of the variables did not produce any significant increases in the alpha value. Therefore, Cronbach's alpha value is satisfactory, the variables are adequate, and the consistency indicator is reliable. As such, the form questions are reliable for assessing fishers' knowledge about octopus fishing.

The first axis of the PCA accounts for more than 36% of the data variation, while the second axis accounts for more than 11% (**Figure 3**). The variables "instrument," "level_tide," "moon_interferes," "phase," "hours," and "kilos" characterized the fishers of the southeastern Brazilian marine ecoregion and reflected the fishing system developed in the region, which is

TABLE 2 | Cronbach's alpha statistics for the form applied to octopus fishers (n = 187) along the Brazilian coast (standardized alpha = 0.81).

Variable	Correlation (+ or –)	Alpha when item is removed	Mean inter-item correlation	Correlation of the item with total value
Learned	+	0.83	0.23	0.38
Instrument	+	0.78	0.19	0.86
Dimorphism	+	0.82	0.23	0.23
Frequency	–	0.82	0.23	0.23
Period	–	0.82	0.23	0.16
Influence_tide	+	0.81	0.22	0.48
Level_tide	+	0.79	0.19	0.83
Moon_interferes	+	0.79	0.19	0.81
Phase	+	0.79	0.19	0.83
Alone	–	0.83	0.24	0.20
Hours	+	0.78	0.19	0.82
Kilos	+	0.78	0.20	0.77
Smallest	+	0.78	0.20	0.75
Largest	+	0.80	0.21	0.57
Member	+	0.82	0.23	0.17
Main_income	+	0.82	0.23	0.23
Sale	–	0.82	0.23	0.22

Learned, with whom the fisher learned to fish; instrument, fishing gear used; sex, differentiation between male and female; frequency, frequency of octopus fishing; period, the fishing period; influence_tide, whether fishing is influenced by the tide; level_tide, fishing tide level; moon_interferes, whether the moon interferes with fishing; phase, fishing moon phase; alone, whether he or she fishes alone; hours, fishing times; kilos, amount of fish; smallest, smallest captured octopus; largest, largest captured octopus; member, whether member of a fishing colony or association; main_income, whether octopus is the main source of income; sale, whether all octopuses captured are sold.

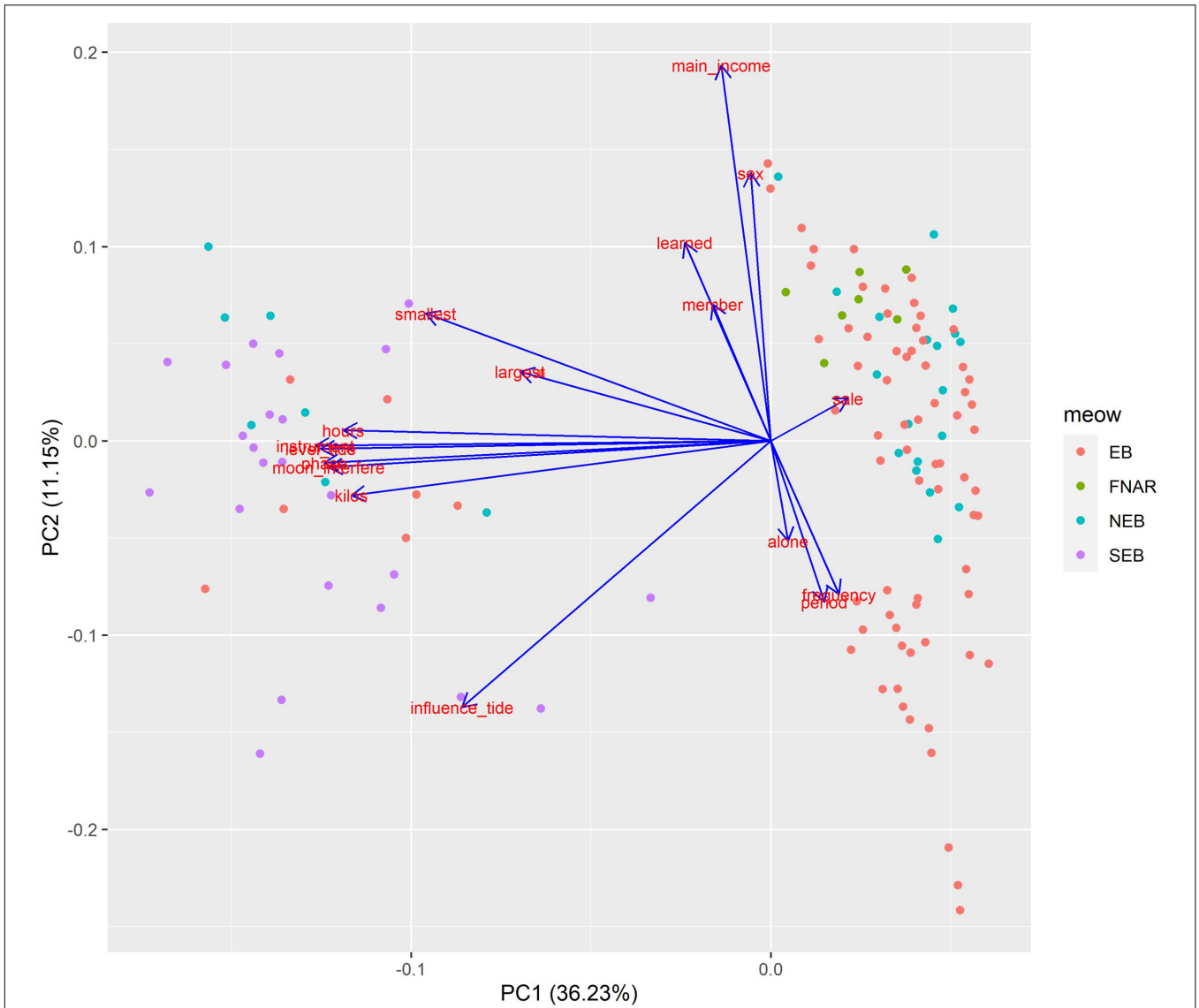

FIGURE 3 | Principal component analysis illustrating the pattern of octopus fishers interviewed along the Brazilian coast, considering the marine ecoregions of the Brazilian coast, according to Spalding et al. (2007): EB, eastern Brazil; FNAR, Fernando de Noronha and Atol das Rocas; NEB, northeastern Brazil; SEB, southeastern Brazil. Description of variables, as in **Table 2**.

predominantly industrial, in contrast to the system in the other national regions (notably artisanal).

Fishing along the coast of Brazil has traditional characteristics since around 45% of the interviewed octopus fishers learned to fish with their parents and/or grandparents. This inherited ecological knowledge was predominantly observed in the northeastern and eastern ecoregions of Brazil, where the artisanal mode of octopus fishing is adopted by 69% of the interviewed fishers.

In all the interviews, the respondents reported that octopuses are captured using a trap ("covo" or pot—industrial fishing) or instrument ("bicheiro" or hook—artisanal fishing). The capture of octopuses using longline pots submerged in water attached to ropes was reported by approximately 27% of fishers.

Notably, this type of fishing was mentioned during the interviews conducted in the localities surrounding the Arraial do Cabo Marine Extractive Reserve (RJ) and the Arvoredo Marine Biological Reserve (SC), located in the southeastern marine ecoregion of Brazil, where octopus fishing takes place at an industrial scale using longline pots (**Supplementary Figure 1**).

Octopus fishing with a hook ("bicheiro," **Supplementary Figure 2**), which is like an iron rebar with a hook at the end, was reported by 79% of respondents. This is the main form of octopus fishing in the other localities, distributed across the three marine ecoregions, Fernando de Noronha and Atol das Rocas, northeastern Brazil, and eastern Brazil. Around 60% of respondents do not consider sexual dimorphism a relevant characteristic for octopus fishing. Among the fishers who have

already caught the "eastern octopus" at some point in their fishing activity, around 49.7% said that their fishing region has more than one species of octopus. In general, the fishers mentioned that they can differentiate the species by observing the size and thickness of the arms (longer and thinner for *C. furvus*), smaller head size, body color and type of substrate in which the species is found, namely the stone octopus (*O. insularis*) and sand octopus (*C. furvus*).

In the regions of industrial octopus fishing using longline pots, the tide regime, moon phase, or any traditionality characteristics do not influence the activity. In contrast, artisanal octopus fishing, which is carried out by around 87.16% of the respondents, is directly influenced by the tide regime and moon phases. Fishing occurs fortnightly, at low spring tides and during the "full moon" and "new moon" phases.

Although none of the interviewed fishers catch octopuses exclusively, around 97.3% fish during the day. However, the respondents who fish octopuses at night reported that both the stone octopus and the sand octopus ("eastern octopus") are captured "opportunistically," that is, occasionally, when they are trying to capture another type of fish, usually during lobster fishing.

In regions where octopuses are caught using longline pots, the pots are placed 1–2 km away from the shores of the Marine Extractive Reserve of Arraial do Cabo (RJ), and most of the fishers (65%) do not fish alone. Similarly, artisanal fishers go out in pairs or trios to fish octopuses and optimize foraging time.

According to 57.75% of these artisanal fishers, each fishing session lasts around 3 h and occurs on the reef plateau of coastal reef environments. To maximize the productivity of this activity, 59.4% of fishers go out in search of octopuses with at least one fishing partner. In this joint fishing effort, 78% of fishers catch, on average, 10 kg of octopuses per session.

This number increases considerably (two to four tons) in industrial-scale fishing with longline pots (**Figure 4**), in which around 20 thousand pots (per vessel) are thrown in the sea to capture octopuses, as reported by fishers working in the regions surrounding the Arvoredo Marine Biological Reserve (SC) and the Arraial do Cabo Marine Extractive Reserve (RJ). Regarding average catch size/weight, most of the fishers (64%) generally catch octopuses weighing more than 500 g.

Based on the data obtained from the interviews conducted in the states of Ceará (CE), Rio de Janeiro (RJ), and Santa Catarina (SC), the octopuses caught with longline pots are larger than the octopuses caught in artisanal fishing, although they never exceed 4 kg/individual. This includes the southeastern marine ecoregion of Brazil, where the species of octopus captured is *O. vulgaris* (Cuvier, 1797), which can reach a body weight of 5 kg (Perales-Raya et al., 2014). According to these fishers, the largest octopus they ever captured weighed around 3 kg. Approximately 50.3% of artisanal octopus fishers reported that the largest specimen they caught themselves weighed around 1.9 kg.

Although 90.4% of respondents are members of a fishing colony or association, 79% reported that not every octopus is sold or consumed; when the captured animal is considered small, fishers use it as bait. Part of what is caught is consumed by the fishers or sold by intermediaries, directly to businesses (restaurants, inns, hotels, and beach stands), or final consumers. However, for 96.26% of these fishers, octopus fishing is not their main source of income.

Fishing and Ecology of *Callistoctopus furvus*

Although the octopus *C. furvus* is part of a cryptic species complex, its morphological characteristics are unique and specific when compared to the other two octopus species, namely *Octopus vulgaris* and *O. insularis*, which are common on the Brazilian coast. In this regard, data on the ecological factors of the species *C. furvus* were collected only from octopus fishers, divers, and underwater fishers, who reported having sighted or fished this species at some point during their fishing activity in the region where they operate. Thus, fishers working in localities in the states of CE, SC, and RN did not answer these specific questions, as the species *C. furvus* was not recognized in those regions.

When asked about the capture of *C. furvus,* 67.1% of the respondents answered that, although they were familiar with the octopus species due to sightings of some specimen during underwater activities, they had never caught any individuals. Therefore, the interviews on the ecological factors and fishing of *C. furvus* were conducted with 32.9% of the fishers (n = 50), who had already caught this octopus at some point during their fishing activity.

The LRM indicated that the variables "learned" (the person with whom the fishers learned to catch octopus) and "alone" (if

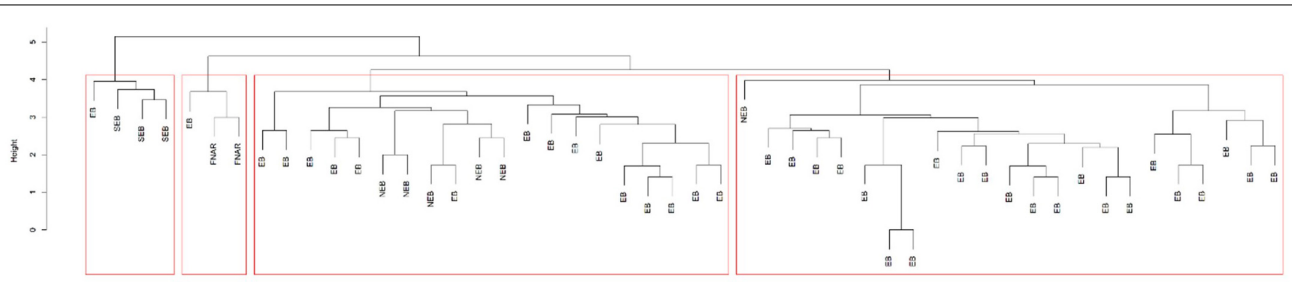

FIGURE 4 | Dendrogram showing dissimilarity among fishers of the "eastern octopus" *Callistoctopus furvus* in the marine ecoregions of the Brazilian coast. EB, eastern Brazil; FNAR, Fernando de Noronha and Atol das Rocas; NEB, northeastern Brazil; SEB, southeastern Brazil.

they fish alone) are associated with "eastern octopus" fishing. That is, fishers who learned to fish with their parents or grandparents are more likely to fish this species than fishers who learned with friends or alone. Similarly, fishers who fish with a fishing partner are more likely to catch the species than if they were alone (**Table 3**).

Cronbach's alpha for data of the "eastern octopus" fisher was 0.75 (alpha = 0.75; confidence interval (95%) = 0.66–0.85; n = 50; mean inter-item correlation = 0.14). Two variables were removed ("consumption" and "arms") because the answers did not change in relation to consumption or the size and thickness of the arms, which hold the greatest commercial interest. **Table 4** shows the test statistics and alpha value for the case of the individual removal of each variable. As in the previous analysis, some of the variables were negatively correlated with the total scale. The individual removal of the variables did not produce any significant increases in the alpha value. Therefore, Cronbach's alpha value is satisfactory.

The dendrogram with the dissimilarities among the "eastern octopus" fishers shows the formation of four groups (**Figure 4**). Fishers from the southeastern ecoregion of Brazil "SEB" differed and formed a group. The second group was formed by fishers from the Fernando de Noronha and Atol das Rocas ecoregion "FNAR." Both groups are accompanied by an individual from the eastern ecoregion of Brazil "EB." The third group was formed by individuals from the eastern ecoregion of Brazil "EB" and northeastern ecoregion of Brazil "NEB." Finally, the fourth group was formed almost exclusively by individuals from the "EB" ecoregion, and only one fisher from the "NEB" fell into this group. This result highlights the different fishing characteristics along the coast, such as the predominance of "SEB" fishers involved in industrial fishing and the predominance of small-scale fishers in the other ecoregions. The CCC showed a good fit (0.78), which indicates the consistency of the clustering pattern of these characteristics.

According to 70% of respondents, *C. furvus* is a large octopus when compared to the other octopus species they capture (*Octopus insularis* Leite et al., 2008 and *O. vulgaris*), and may even reach a total length of 3 m, according to some fishers. The presentation of images during the interview (**Supplementary Figure 3**) revealed that the fishers of the eastern ecoregion of Brazil use the term "common octopus" to refer to both the species *O. insularis* and *O. vulgaris*; moreover, they differentiate them as female octopuses (wider animal with short arms) and male octopuses (slimmer animal with long, robust arms), respectively.

For 100% of respondents, *C. furvus* has no commercial value since the most widely commercialized part of this fish are the arms. Although *C. furvus* is larger and heavier than the common octopus, it can have long and very thin, fragile arms that often break with simple handling. The maximum weight reported by fishers was about 1.5 kg.

According to 76% of respondents, *C. furvus* is commonly found in shallow water less than 5 m deep. However, the largest specimens are usually found during the night. *C. furvus* has an orange-red coloration (**Figure 2**) with white spots scattered throughout its body. Although these white spots are common characteristics of species in the cryptic species complex, this feature does not particularly draw the attention of the fishers since they believe "all octopuses change color when they want to flee." For all the interviewed fishers, the length and thickness of the arms are considered when they determine whether it belongs to another octopus species. For 90.9% of the fishers, "habitat" is the main difference between the species of that region, that is, they believe there are two species of octopus, namely the stone octopus or common octopus, which is *O. insularis*, and the sand octopus, which is *C. furvus*.

TABLE 3 | Result of the logistic regression model with the variables that may be associated with fishing of the "eastern Octopus" (*C. furvus*).

Coefficients	Estimate	Standard error	*z*-value	P
MunicipalityBombinhas	1.149e + 01	1.590e + 04	0.001	0.99
MunicipalityCabo Frio	–4.895e + 00	1.236e + 04	0.000	0.99
MunicipalityCairu	–4.205e + 01	9.456e + 03	–0.004	0.99
MunicipalityCaravelas	–5.308e + 01	1.860e + 04	–0.003	0.99
MunicipalityNoronha	–5.328e + 01	1.860e + 04	–0.003	0.99
Municipalitylpojuca	–5.412e + 01	1.860e + 04	–0.003	0.99
MunicipalityJericoacoara	–1.851e + 00	1.526e + 04	0.000	0.99
MunicipalityMarechal Deodoro	–5.290e + 01	1.860e + 04	–0.003	0.99
MunicipalityNatal	–7.222e + 01	1.914e + 04	–0.004	0.99
MunicipalityPorto da Rua	–5.465e + 01	1.860e + 04	–0.003	0.99
MunicipalityPorto de Pedras	–7.476e + 01	2.243e + 04	–0.003	0.99
MunicipalityPorto Seguro	–5.412e + 01	1.860e + 04	–0.003	0.99
MunicipalityPrado	–5.511e + 01	1.860e + 04	–0.003	0.99
MunicipalitySão Miguel dos Milagres	–5.428e + 01	1.860e + 04	–0.003	0.99
Learned2	–3.183e + 00	9.556e-01	–3.331	0.00***
Learned3	–3.435e + 00	9.630e-01	–3.568	0.00***
Instrument2	6.428e + 00	9.454e + 03	0.001	0.99
Sex2	1.659e-01	6.729e-01	0.247	0.80
Frequency2	1.752e-02	2.657e + 00	0.007	0.99
Frequency3	2.118e + 00	7.083e + 03	0.000	0.99
Period2	1.365e + 00	2.027e + 00	0.673	0.50
Influence_tide2	1.394e + 00	1.360e + 00	1.025	0.30
Level_tide2	–3.875e + 01	9.161e + 03	–0.004	0.99
Moon_interferes2	–1.039e + 00	6.511e + 03	0.000	0.99
Phase2	–3.748e + 01	8.171e + 03	–0.005	0.99
Alone2	2.440e + 00	1.127e + 00	2.165	0.03*
Alone3	2.638e + 00	1.220e + 00	2.162	0.03*
Hours2	1.082e + 00	1.863e + 00	0.581	0.56
Hours3	9.506e-02	9.099e + 03	0.000	0.99
Kilos2	–7.848e-01	1.067e + 04	0.000	0.99
Kilos3	1.772e + 00	1.287e + 04	0.000	0.99
Smallest2	–7.147e-01	9.373e-01	–0.763	0.44
Smallest3	–7.587e-01	2.216e + 00	–0.342	0.73
Largest2	1.072e + 00	6.903e-01	1.553	0.12
Largest3	4.896e-01	8.783e-01	0.557	0.58
Member2	4.915e-02	1.776e + 00	0.028	0.98
Main_income2	3.960e + 01	9.239e + 03	0.004	0.99
Sale2	4.750e-01	7.470e-01	0.636	0.52

The variable "learned" indicate that the levels "learned2" (= friends) and "learned3" (= alone) are negatively associated with fishing of the "eastern octopus," based on level 1 (parent/grandparents) as reference. The variable "alone" indicates that the levels "alone2" (= no) and "alone3" (sometimes) are negatively related to fishing the species, based on level 1 (= yes) as reference. These results can be interpreted as a possible consequence of the LEK passed from generation to generation (parents/grandparents to children/grandchildren) and the sharing of this knowledge with the fishing partner.

**Significance < 0.05; ***significance < 0.001.*

TABLE 4 | Cronbach's alpha statistics for the questionnaire applied to the fishers of the "eastern octopus" (n = 50) along the Brazilian coast (standardized alpha = 0.75).

Variable	Correlation (+ or -)	Alpha when item is removed	Mean inter-item correlation	Correlation of item with total value
Learned	+	0.77	0.15	0.05
Instrument	+	0.75	0.13	0.51
Sex	+	0.76	0.15	0.09
Frequence	+	0.76	0.15	0.09
Period	–	0.75	0.14	0.33
Influence_tide	–	0.73	0.14	0.61
Level_tide	+	0.75	0.14	0.30
Moon_interferes	+	0.75	0.13	0.41
Phase	+	0.75	0.14	0.25
Alone	–	0.74	0.14	0.48
Hours	+	0.74	0.13	0.56
Kilos	+	0.74	0.13	0.48
Smallest	+	0.73	0.13	0.60
Largest	+	0.74	0.14	0.48
Member	+	0.75	0.15	0.29
Main_income	+	0.72	0.13	0.79
Sale	+	0.76	0.15	0.09
Where	+	0.75	0.14	0.40
Depth	+	0.73	0.13	0.63
Largest_furvus	–	0.76	0.15	0.20
When	+	0.71	0.13	0.75
How_many_furvus	–	0.73	0.13	0.68
Season	–	0.79	0.15	0.20
Factor	+	0.75	0.14	0.33
Habitat	+	0.75	0.14	0.49
Color	+	0.77	0.15	0.32

Learned, with whom the fisher learned to fish; instrument, fishing gear used; sex, differentiation between male and female; frequency, frequency of octopus fishing; period, the fishing period; influence_tide, whether fishing is influenced by tide; level_tide, fishing tide level; moon_interferes, whether the moon intereferes with fishing; phase, fishing moon phase; alone, whether he or she fishes alone; hours, fishing times; kilos, amount of fish; smallest, smallest captured octopus; largest, largest captured octopus; member, whether member of a fishing colony or association; main_income, whether octopus is the main source of income; sale, whether all octopuses captured are sold; where, fishing location; depth: fishing depth; largest_furvus, largest captured "eastern octopus"; when, capture season; how_many_furvus, number of "eastern octopus" captured on the best day; season, season of the year of catches; factor, factor considered to differentiate "eastern octopus" from common octopus; habitat, habitat of the "eastern octopus"; color, difference in color between the "eastern octopus" and the common octopus.

In the region of Cairu, (BA) this octopus occurs throughout the year, regardless of season or wind regime, and is often spotted by fishers who catch lobster at night. In the town of Garapuá, near Morro de São Paulo (Cairu district), fishers reported that the species *C. furvus* is very difficult to find and has not been captured for more than 5/10 years. However, recently (November 2020), one specimen was captured in the Garapuá reef environments. This indicates the species also occurs in this region and the possible reason for the absence of records is that the fishers catch octopus during the day, and they do not have the habit of catching lobsters.

In the eastern ecoregion, the Corumbau Extractive Marine Reserve, the species is known although it is infrequent and rarely caught. As in the region of Porto Seguro, it is associated with the "eastern" wind regime that usually occurs between May and August. In contrast, in the Lagos region (Rio de Janeiro), sightings, when they occur, are usually in the summer.

Compared to the common octopus, the "eastern octopus" is apparently less abundant since approximately 62% of the fishers caught less than three specimens in their best fishing sessions. The same species was also caught in coastal reefs less than 5 nautical miles from the coast, according to 74% of the respondents.

Based on the classification of Marine Ecoregions of the World (Spalding et al., 2007), it was also observed that the LEK of artisanal octopus fishers in eastern Brazil is more varied in terms of information than that of the fishers in the southern limit of the eastern ecoregion of Brazil and the southeastern ecoregion of Brazil, who use longline pots. All the information obtained through interviews was organized according to the marine ecoregion in which it was collected, as shown in **Figure 5**.

DISCUSSION

Studies addressing ethnoknowledge and LEK have been essential to aggregate information about resources that have often not been identified by researchers (Neis et al., 1999; Jesus et al., 2021a,b). Traditional communities, such as artisanal fishers, have comprehensive knowledge of the different resources they exploit and can provide valuable information in management scenarios with data-poor fisheries (Sáenz-Arroyo et al., 2005; Ramires et al., 2007; Leeney and Poncelet, 2015; Bezerra et al., 2021). In the present study, the knowledge of the fishers was used to investigate their historical perceptions of octopus fishing, complemented with information on the species *C. furvus*, and, consequently, obtain data to characterize ethnoecologically this octopus species in the different marine ecoregions of Brazil.

The classification of Marine Ecoregions of the World was based on taxonomic configurations of various marine groups, influenced by evolutionary history and geographical isolation (Spalding et al., 2007), resulting in three levels of organization: realms, provinces, and ecoregions. Each ecoregion has a relatively homogeneous species composition, which differs from adjacent systems. This condition would theoretically explain the possibility that Mexico, Colombia, and Brazil share the same genetic lineage of the octopus *C. furvus* (Jesus et al., 2021b) since they are in the same realm (Tropical Atlantic). Following this same line of reasoning, the MPA and surrounding localities from which most of the information was obtained on general octopus fishing and ecological factors of the octopus *C. furvus*, are in the same marine ecoregion (eastern Brazil), as shown in the heat maps.

Although they have distinct geographical characteristics, the species *C. furvus* was reported in all ecoregions; moreover, its occurrence in the southern limit of the Eastern Brazil marine ecoregion was associated with the phenomenon of upwelling (Jesus et al., 2021a). These observations also involved analyzing the dendrogram with the dissimilarities among fishers of the eastern octopus (*C. furvus*), which revealed different fishing characteristics along the coast, namely the predominance of

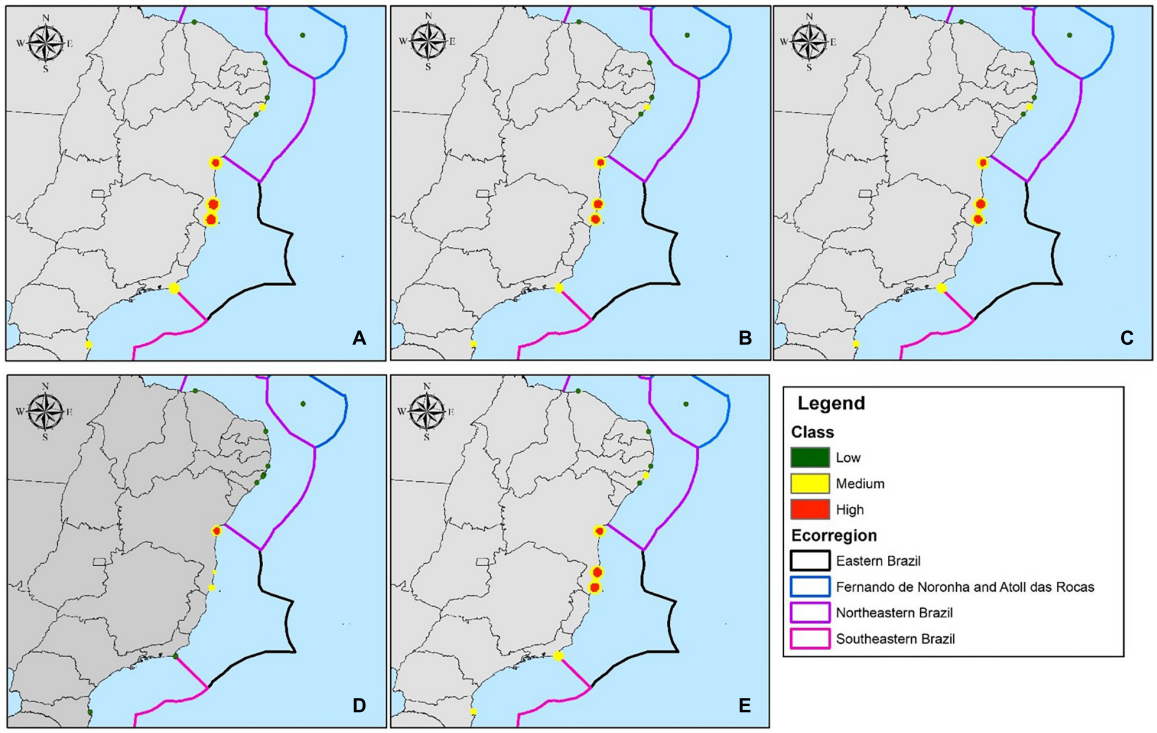

FIGURE 5 | Heat maps indicating the concentration of information obtained on octopus fishing and the ecological factors of *Callistoctopus furvus*, in each of the four Brazilian marine ecoregions included in this study. The information is presented in five categories: **(A)** general factors of octopus fishing; **(B)** seasonality; **(C)** fishing effort; **(D)** sale; and **(E)** factors of *C. furvus* fishing. The marine ecoregion with the highest concentration of information in the five categories was eastern Brazil, high class, in red.

"SEB" fishers in industrial fishing and the predominance of small-scale fishers in the other ecoregions.

Some gaps regarding the fishers of the Southeastern marine ecoregion indicate the need for more research to clarify the possible occurrence of *C. furvus* in this region, especially considering that this species was only recorded once outside the Atlantic Tropical realm (Jesus et al., 2021a,b), which starts in Florida (United States) and extends up to a part of southeastern Brazil. The upwelling phenomenon in the southern limit of the Tropical Atlantic realm (Spalding et al., 2007), associated with the movement of marine currents (Brazil current), can theoretically explain the occurrence of the species *C. furvus* in the realm and adjacent ecoregion (Temperate South America realm and the Southeastern ecoregion of Brazil, respectively).

Notably, fishers have detailed ecological knowledge about resources on a local geographical scale (Johannes, 1998). For example, they may remember particularly good catches from a productive day (Daw, 2010). According to the artisanal fishers, the average amount of common octopuses caught at the end of each fishing session is currently around 10 kg even when they fish in pairs or trios to optimize fishing effort. Therefore, the fishing of this resource is a secondary source of income since it does not meet the demands of the fishing market, as also reported by Jesus et al. (2015).

In the Northeastern and Eastern marine ecoregions of Brazil, the octopus *O. insularis* is predominantly captured by artisanal fishers, as reported by 79% of the respondents; moreover, fishing is directly influenced by the tidal regime and moon phases and occurs fortnightly at low spring tides and during the "full moon" and "new moon" phases, as previously reported by other researchers (Mendes, 2002; Martins et al., 2011; Haimovici et al., 2014; Jesus et al., 2015). Although *O. vulgaris* occurs in all the studied marine ecoregions, since it is commonly found in deeper waters, it is predominantly captured on an industrial scale with longline pots in the southern limit of the Eastern and Southeastern marine ecoregions of Brazil.

Notably, the eastern octopus, also known as "sand octopus" or "cheetah octopus" (*chita,* in Portuguese; Jesus et al., 2021a) *C. furvus*, is difficult to find; moreover, scientific reports of its capture are scarce (Leite and Haimovici, 2006; Jesus et al., 2015, 2021a,b; Cedillo-Robles and Pliego-Cardenas, 2018). It has long, thin arms and apparently inhabits shallow waters with higher temperatures when compared to *O. vulgaris*. Although its occurrence has been recorded, niche overlap was not observed in areas predominantly close to reef environments with the species *O. insularis*, which also occurs in the studied reef environments. *C. furvus* is an octopus with reportedly nocturnal habits and a different escape strategy than that of the two other species mentioned above.

According to the fishers' LEK in Eastern ecoregion of Brazil, when *C. furvus* feel threatened, they bury themselves in the sand rather than "release" ink to "throw off the predator." This is a

common behavior among octopus species, including *O. insularis* and *O. vulgaris*. This behavior helps them distinguish these two other species, which are also called "stone octopus" by the fishers of this same ecoregion since they are commonly caught in existing burrows in reef environments.

Traditionality in relation to octopus fishing in general and the fishing of *C. furvus* was analyzed using the logistic regression model. Among other factors, this analysis revealed that the "eastern octopus" was more commonly captured among the fishers who learned to fish from their parents or grandparents than among those who were taught by friends or who learned alone. This finding reinforces the idea that the information shared between different generations can provide reliable data on occurrence sites (Reis-Filho et al., 2016); moreover, this LEK may play an important role in the development of measures to protect vulnerable stages of life history (Herbst and Hanazaki, 2014).

Interviews using quantitative methodological approaches can contribute to the available data by providing insight into the decline of some species over time (Santos et al., 2016) and accurate capture data even after decades (e.g., Sáenz-Arroyo and Revollo-Fernández, 2016; Thurstan et al., 2016). However, survey strategies that target the conservation of endangered and widely distributed species can be challenging and costly to develop and require long-lasting research programs (Wiley and Simpfendorfer, 2010). In this regard, unconventional data sources are convenient to infer, for example, long-term abundance trends for target species (Pitcher and Lam, 2010), as in the case of alternative approaches, namely LEK and citizen science (Jesus et al., 2021a), which generate results in a short period.

Despite their remarkable economic importance and although the phylum Mollusca, which includes octopuses, is the second-largest group of invertebrate animals (Haszprunar, 2001), these representatives are not among the groups of aquatic invertebrate animals on the list of endangered species (ICMBio, 2018). As a result, studies conducted on the ecology and artisanal fishing of octopus in Brazil indicate that the standardization goal of this type of fishing in the northeast region, for example, should be to protect the species and its environment and make it compatible with a small-scale fishing modality for recreational purposes (Leite et al., 2008). Thus, some conservationist measures, such as establishing standard measures for making and using hooks (used for octopus fishing), prohibiting, and supervising the use of chemicals for removing octopuses from burrows, establishing minimum catch size and weight, and curbing trap fishing (Leite et al., 2008; Haimovici et al., 2014), can support the management of octopus fishing.

Given the absence of a global and/or national regulation for artisanal octopus fishing, the species *Octopus* spp. are being commercially exploited according to normative instructions that regulate octopus fishing with long-line pots in the northeastern, southeastern, and southern regions of Brazil. In this regard, Ordinance SAP/MAP N° 328, of December 31, 2020, proposes a public consultation to change the minimum permitted depth and disposal of octopus (*Octopus* spp.) fishing gear. These guidelines were originally established in the normative instruction of the Special Secretariat for Aquaculture and Fisheries of the Presidency of the Republic No. 26 of December 19, 2008, by means of criteria and procedures for managing operations related to octopus (*Octopus* spp.) fishing in the marine waters of the southeastern and southern Brazil.

However, fisheries involving the capture of species of the genus *Callistoctopus* have been reported as exceptional (Leite and Haimovici, 2006) or sporadic (Haimovici et al., 2014), which exempts them from any use and management rules applicable to the capture and conservation of the species *Octopus* spp. In this context and based on the ethnoecological information about the octopus species *C. furvus* obtained in this study, the species may not be suffering fishing pressure since it has no commercial value and is rarely used in the sampled area, even for subsistence consumption.

However, the scarce occurrence of *C. furvus* on the Brazilian coast may be related to species recolonization as it was first recorded in Brazil in the nineteenth century, followed by new records in the twenty-first century (Mendes, 2002; Martins et al., 2011; Jesus et al., 2015), resulting in its redescription (Jesus et al., 2021b).

CONCLUSION

Although data obtained from LEK and the perception of fishers require careful analysis, these data proved efficient and reiterated their value as a source of information. Grouped data obtained through interviews and presented in heat maps indicated that most of the answers on the ecological factors of *C. furvus* were provided by artisanal fishers in the Eastern marine ecoregion of Brazil who learned their craft from parents and/or grandparents. A comparison of the frequency of occurrence of *C. furvus* in relation to *O. insularis* and *O. vulgaris* (species also occurring in the study area) showed that *C. furvus* was less abundant than the other two species, although it has different habits.

Based on the information presented here, studies with behavioral approaches should be carried out to complement current data and adapt conservation strategies for the species *Callistoctopus furvus.*

DATA AVAILABILITY STATEMENT

Copies of the interviews were deposited in the collection of the Laboratório de Etnoconservação e Áreas Protegidas of the Universidade Estadual de Santa Cruz (BA), Ilhéus, Brazil. Any requests to access the datasets for this article should be directed towards the corresponding author(s).

ETHICS STATEMENT

The studies involving human participants were reviewed and approved by the Research Ethics Committee of the Universidade Estadual de Santa Cruz Authorization No. 2,593,218. The patients/participants provided their written informed consent to participate in this study. The animal study was reviewed

and approved by Sistema de Autorização e Informação em Biodiversidade (SISBIO) Protocol No. 60468-2.

AUTHOR CONTRIBUTIONS

MJ and AS conceived of the presented idea. MJ carried out the data collection and wrote the first draft of the manuscript. MJ, CZ, and RS carried out the data analysis. MJ, CZ, RS, and AS reviewed and final wrote of the manuscript. AS supervised. All authors contributed to the article and approved the submitted version.

FUNDING

The Coordenação de Aperfeiçoamento de Pessoal de Nível Superior (CAPES) for the funding support—Funding Code 001, and CNPq for the productivity grant awarded to the last author (process 310464/2020-0).

ACKNOWLEDGMENTS

We would like to thank the Universidade Estadual de Santa Cruz (UESC), the graduate program in development and environment of the UESC. George Olavo at the Universidade Estadual de Feira de Santana (UEFS). To the fisherman and friend Braz de Oliveira.

SUPPLEMENTARY MATERIAL

The Supplementary Material for this article can be found online at: https://www.frontiersin.org/articles/10.3389/fevo.2022.788879/full#supplementary-material

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