Local Ecological Knowledge Networks in Tropical Artisanal Shrimp Fisheries

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Research

Keywords: socio-ecological systems, common-pool resources, conservation, social network analysis, co-management, local/traditional/fisheries ecological knowledge

Posted Date: December 14th, 2020

DOI: <https://doi.org/10.21203/rs.3.rs-125962/v1>

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Abstract

Background

Local ecological knowledge (LEK) in fishing communities is generated through interactions between fishers and the exploited resources. It is transmitted through social networks, interdisciplinary structures that drives the dynamics of socio-ecological systems (SES). LEK variability is supposed to depend on the quality and quantity of ecological information flow among different stakeholders. To assess what is driving LEK themes, we hypothesized that the formation of LEK clusters among fishers is determined by network articulation, fisher experience and the commercial value of the exploited species.

Methods

The study area comprises three fishing communities in the Western South Atlantic, in the tropical coastal zone of Brazil where artisanal shrimp fisheries (on *Penaeus schmitti*, *P. subtilis* and *Xiphopenaeus kroyeri*) are a major activity. Data collection took place between March, April, and November 2019. To test our hypothesis, linear regression and bipartite network analyses were performed to visualize the interactions between fishermen groups and LEK themes. The connectivity, nesting, modularity, and centrality parameters in this social network were calculated to test the hypothesis.

Results

Our results indicate that experienced fishers enhance LEK in their networks on the themes of food, mortality, and growth. Furthermore, there are subgroups of fishers with dissimilar knowledge about the exploited shrimp species, one old on the fishery with wide knowledge, other less experienced, just knowing about reproduction and migration themes.

Conclusion

We conclude that there is a spatial similarity in the connectivity of fisher's LEK, mainly concerning the reproductive and migratory dynamics of the target species, but also differences permeated by fishers' experience and local interests. Managers initiating co-management agreements using reproduction and migration referential variables as benchmarks will be more successful if they incorporate LEK into decision-making. Regional knowledge similarities favor the implementation of management policies at a regional scale potentially reducing conflicts within fishing communities and increasing resource use efficiency.

Highlights

- Fishers' knowledge connectivity is high and driven by common interests.
- Experienced fishers' deal better than younger with hard to observe themes, as growth, mortality or feeding. Conversely, reproduction and migration are widely known.

- Similarities in regional knowledge favor the implementation of regional-scale management policies

Introduction

The interaction between fishers and resources generates individual ecological knowledge that is redistributed throughout the community depending on the system of relationships [1, 2]. Redistribution influences social functions, with individual characteristics determining the quality and quantity of knowledge in a society and, consequently, affecting social group structure [3]. Several individual characteristics are known to influence local ecological knowledge (LEK), such as gender [4], demography [5, 6], or formal education [7]. Beyond the individual level, social organization has a strong influence on local knowledge [8], which is of fundamental importance for the efficient exploitation of uncertain natural systems [9, 10]. Thus, a community's local ecological knowledge profile is expected to be associated with the quality and quantity of information on the bioecological aspects of their target resources which are useful to improve fisheries yield.

Cultural knowledge (including LEK) is transmitted or dispersed through social networks. Such networks are interdisciplinary structures that play a key role in the dynamics and structure of socio-ecological systems [11]. The social network profile defines social groups most connected by sharing and information flow [12, 13]. Social connectivity among fishers influences artisanal fisheries management, usually involving a large variety of stakeholders [14]. These agents are inserted in various fishing and interagency institutions at different scales and in heterogeneous ways [3], comprising complex socio-ecological systems. In this context, apart from the relationship between the fishers and LEK, the quality of the connections among agents from the fisheries sector is essential in knowledge dissemination, as well as in the generation of the world view of those actors involved directly in fishing.

Knowledge network strength is also an essential feature of complex SES, considering that the ability of social actors to use and spread information is key in structuring an equitable social structure to support participatory deliberative processes [15], promoting a qualitatively critical basis for management initiatives [16, 17]. Collaborative networks are potential multipliers of information relevant to decision-making by social groups [13, 18], including those related to artisanal fishing [19, 20]. Specifically, multiplication potential can be influenced by attributes such as the amount of interactions and the degree of cohesion of the network [21], the position of individuals in the network [22], and the presence of central informants [23, 24] and subgroups in a community [25]. In this way, the quality and quantity of ecological information circulating in a traditional community can indicate the ability of that community to adapt management in a viable socio-ecological arrangement.

Management arrangements facilitate conflict management among stakeholders, where the inclusion of all social actors is an essential feature [9, 26]. Artisanal fishing is the predominant activity in traditional coastal communities in the tropics, being characterized by low investment in external technologies, the use of small vessels that limit the extent of fishing and the extensive use of LEK (see Batista et al., 2014). However, the supposed simplicity of artisanal fishing contains a variety of competing interests and

complex knowledge that may, depending on social context, contribute to conflicts and/or solutions [28–31]. Therefore, analyzing the structuring of LEK through mapping flows between existing relationships can generate positive externalities in fisheries management, enhancing its effectiveness.

Artisanal shrimp fisheries in the tropics are environments where LEK is mainly enhanced by the relationships between fishers [32]. In tropical coastal ecosystems of the tropical South Western Atlantic, shrimp fishing is mainly undertaken by artisanal fleets [33] at small and medium scales [27, 34, 35]. Of the marine shrimp species that co-occur in coastal waters there are three mainly targeted by these fisheries: i) the white shrimp *Penaeus schmitti* – high commercial value; ii) the pink shrimp *Penaeus subtilis*, and; iii) the seabob shrimp *Xiphopenaeus kroyeri* (Heller, 1862) – the most abundant, all from the family Penaeidae [36, 37]. These shrimps are resources of considerable socioeconomic importance, exploited in the region with beam trawls since 1969 [36]. There are indications that this fishery is close to recruitment overfishing [38–40] creating typical fisheries conflicts with distinct socioeconomic, political [41], and environmental dimensions [42, 43]. In short, these tropical shrimp fisheries are socio-ecological systems are culturally interrelated by patterns of competitive use of species of high economic interest with low effort regulation, where segments with higher LEK and active perception of environmental changes should be more efficient.

Based on the assumption that there is a relationship between LEK diversity and the local social network in socio-ecological systems [3], we aimed to evaluate the existence of fisher groups in traditional artisanal fisheries with differentiated capacity for LEK about the main co-occurring target shrimp species. We hypothesized that the LEK domain of information is affected by fishing experience, by the locally articulated social networks, and by interests related to the commercial value of the shrimp species, delimiting social network groups of fishers with differentiated knowledge.

The integration of local social networks at regional scales, identified by traditional knowledge in the patterns of use of species of high commercial value, can generate subsidies for integrative and sustainable management as well as co-management tools. Therefore, we have a bridge to fishers' communication with managers, enabling the productive conservation of target species and their associated socio-ecological systems.

Material And Methods

Study area

This study was conducted in three fishing communities in Northeast Brazil: (1) Pontal do Peba (10 ° 21'14.92"S 36 ° 17'53.76"W); (2) Barra de Sirinhaem (8 ° 36'50.99"S 35 ° 03'10.94"W); (3) Baía Formosa (6 ° 22'05.52"S 35 ° 00'14.56"W). Artisanal shrimp fishing is the main local fishing activities [44–46] (Fig. 1).

The main fishery is located in Pontal do Peba associated with the São Francisco River discharge enriching coastal waters [47]. There are 65 motorized wooden boats, with a length between 8 and 12 meters [48]. The trawls are usually in mud bottoms between 10 and 20 meters deep [48]. Further north,

there is the most traditional shrimp fishery in Pernambuco at Barra de Sirinhaém associated with the Sirinhaém river. Local fishing fleet is smaller in size than that of Peba, 12 vessels [40], the average length of the boats is 9 meters that exploits mud fisheries at depths between 10 and 20 meters. Baía Formosa is the third fishing ground located at the north end of the northeast Brazilian coast, mainly associated to the flow of small rivers, mainly rivers Guaju and Curimataú. The exploitation of marine shrimp in Baía Formosa occurs with large beach seines, following the levels of seasonal productivity, with 12 vessels operating locally, with an average length of 9 meters [36]. These vessels are equipped with a net (single drag), or two nets (double drag) which are paired and act simultaneously trawling at an average depth of 20 meters [33, 37]. Most fishers fish daily (locally termed 'come-and-go'). Each vessel usually supports two or three fishers, including the skipper [49].

Data collection

Field interviews were carried out in March, April, and November 2019. Random sampling was carried out in blocks (the three fishing communities) according to opportunistic meetings with artisanal shrimp fishers at each location [50], seeking to interview the maximum number of fishers during the time on field, covering at least 30% of the total number of fishers per fishing community [51, 52]. In each community, the number of shrimp fishers who use bottom-trawls was estimated based on the testimonies of the most experienced fishers indicated by communitarians at each location. Only resident shrimp fishers that fish for the three main Penaeidae species (white, pink and seabob shrimps) were interviewed at each location (following Silvano and Begossi, 2010). To avoid pseudoreplication, we did not interview more than one fisher per boat [54].

In Pontal do Peba we conducted 42 interviews (representing 59% of shrimp fishers), 19 interviews were conducted in Barra de Sirinhaém (27% of fishers) and 10 interviews were conducted in Baía Formosa (14% of fishers). All interviews took place after a meeting held with the local fishers organization to present the objectives of the study.

A semi-structured questionnaire was prepared containing questions that referred to five LEK topics related to the bioecology of the shrimp species: I- feeding, II- reproduction, III- predation, IV- migration and V- growth (Table 1) (questionnaire structure in supplementary material). To all questionnaires applied, the themes with more answers by fishers were counted.

Table 1
Relationship between LEK themes and bioecological knowledge of shrimp

LEK topics	Questionnaire themes
Reproduction	Breeding month
	Seasonal breeding period
	Breeding location
Migration	What migration do shrimps perform
	Purpose of migration
Food items	Feeding in the dry season
	Feeding in the rainy season
Predation	What are the shrimp predators
	What location predation occurs
Growth	Size that shrimps are ripe
	Age that shrimps are ripe
	Longevity

Data analysis

Considering that the age of the fisherman and the time working in the fishery are collinear ($r > 0.7$; $p > 0.001$), the age of the fishers was considered as a proxy for their experience in the activity. In order to verify if the domain of the LEK of shrimp fishers by bioecological theme are explained by the experience in fishing, a model was adjusted between the proportion of fishers by age group to those declared knowledge about the themes asked.

The fishers' local ecological knowledge network was represented on two worksheets, one defining the "Nodes" and the other the "Edges". Fishers and their local ecological knowledge are the nodes, meanwhile Edges are the connections between fisherman and LEK. The nodes' spreadsheet is characterized by two columns, one with the ID and the other label. In this spreadsheet, the ID is classified into an ordinal number, defined by the number of nodes. The "Label" column is designated by the names that will determine each node in the network. The edges worksheet is described by four columns, "Origin", "Destination", "Connection type" and "Weight". The first column contains the source ID, followed by the "Destination" column with the record of the occurrence of responses for each knowledge. The "Connection type" column defines the connection type of the interaction, whether directed or not directed. The "Weight" is defined in Gephi [55] for each ID. Gephi is an open source program that is used for graph

analysis that provides easy and wide access to network data and allows users to spatialize, filter, navigate, manipulate and group data. The nodes (fisherman and LEK) of the graphs can be generalists, with many interactions, or they can be considered specialists, with few interactions [56].

To test our hypothesis, a modularity metric was applied. This metric identifies cohesive groups, in this case between fishers and LEK who are highly connected, and thus, interact more with each other than with other nodes in the network [25, 57].

$$Q = \frac{1}{2m} \sum_{C \in P} \sum_{i,j \in C} \left[A_{ij} - \frac{K_i K_j}{2m} \right]$$

The analysis is developed using an adjacent matrix A, where A_{ij} is equal to 1 if there is a connection between node i and node j, and zero otherwise; the degree of node i is defined as $k_i \equiv \sum_j A_{ij}$; and $m \equiv \sum_{i,j} A_{ij} / 2$ is the total number of connections on the network. The sum is performed on all pairs of nodes belonging to the same C community of partition P [58]. The null model $A_{ij} = k_i k_j / 2m$ is usually preferred because it captures the degree of network heterogeneity [12].

Intermediate centrality is a global measure of network centrality to analyze which LEK themes are central to a network [23]. The measure considers the number of times that a specific node is among the various other nodes in the network. The intermediate centrality of a node is defined as the number of shortest paths (among all pairs of nodes) that pass through the specified node divided by the number of the shortest path between any pair of nodes (regardless of passing through the given node) [59]. It is calculated by the formula:

$$C_B(V) = \sum_{s \neq v \neq t \in V} \frac{\sigma_{st}(V)}{\sigma_{st}}$$

Where V represents nodes, representing fishers and ecological information. A path from $s \in V$ to $t \in V$ is defined as an alternating sequence of nodes and edges, starting with s and ending with t, so that each edge connects its anterior node with its posterior node [60]. Here, edges are understood as the links between fishers and bioecological information.

In addition to these metrics, (i) degree of nesting (nesting) and (ii) degree of network connection, that is, the fraction of all possible connections between nodes that are made in the network, were calculated [61]. The connection metric of a network is to check the complexity of the network, being given by:

$$C = \frac{2L}{S(S-1)}$$

Where C is the connection; L, total number of observed interactions; S, number of possible interactions.

The degree of nesting was calculated using the nesting metric based on overlap and decreasing fill (NODF). Nesting can vary on a scale from 0 to 100, with 100 being perfect nesting, that is, when 50% of columns are filled from left to right and top to bottom in the rows [62]. To test the significance of the NODF, random matrices ($n = 1000$) were generated from the original binary matrix, in which the probability of interactions between fishers and CEL was proportional to the total number of interactions [63]. The proportion of random matrices with NODF values equal to or greater than the observed values indicated a degree (significantly) greater than the expected nested pattern [64]. Observed and null NODF values the matrices were calculated using the software Aninhado v.3.0 [63].

The visualizations of the bipartite networks and the analysis of modularity and intermediate centrality were performed in the Gephi program [55]. The connection and nesting dimension metrics were analyzed in the R program (R Development Core Team, 2017) with the Bipartite package [66] which has the purpose of visualizing bipartite networks and calculate metrics.

Results

Knowledge about reproduction and migration of the three shrimp species are the most dominant among fishers, regardless of the age of the fisherman. LEK on breeding is related to the season and month of breeding, indicated by fishers as the time when shrimp reproductive activity is most intense. However, spawning behavior is less known among fishers. The second domain is LEK about migration and is relates to the migration route and the purpose of migration (Fig. 2). The remaining themes of the LEK (food, mortality and growth) were less developed among younger fishers (20–30 and 31–40 age classes). The results indicate that the more detailed the aspects of the shrimp life cycle (food, mortality and growth) the greater the effect of experience (Fig. 2).

The conformation of the associative networks for *P. schmitti* (Fig. 3), *P. subtilis* (Fig. 4) and *X. kroyeri* (Fig. 5), shows different modularity classes of social groups with specific knowledge by location. The differentiated distribution on the number of modularity classes is related to the LEKs of greater dominance among fishers, such as reproduction and migration, as indicated by the centrality metric that varied between 0.054 and 0.126. Moreover, in Baía Formosa the knowledge networks differ from others with a smaller number of modularity classes for the white shrimp.

It should be noted that the metrics of connectivity and nesting are similar between species and locations. A degree of nesting greater than 70 indicates the interaction of knowledge between groups of fishers generated by local knowledge of other topics, such as food, mortality and growth (Table 2).

Table 2
Metrics of the fisherman-information interaction networks
of the three species

Species	Connectivity	Nesting	Modularity
White shrimp	0.542	77.09	0.109
Pink shrimp	0.531	78.09	0.098
Seabob shrimp	0.557	79.01	0.102

Discussion

Artisanal shrimp fishers' local ecological knowledge is a largely social construct, reinforcing the importance of well-crafted public policies for efficient and socially equitable fisheries management. This calls for the incorporation of LEK as an important supporting information for conservation and sustainable use of socio-ecological systems [67, 68]. Our results also show that, as anticipated, LEK is greater among experienced prawn fishers, though this difference is less for directly applied themes as reproduction and migration, and greater for less applied themes such as feeding, growth and mortality. Another important consideration is the aggregating power of fishers' specific local knowledge, generating connectivity linked to the sharing of similar bioecological knowledge about the exploited species.

LEK is known to be influenced by several factors, including fishers age [6]. However, in the context of small-scale artisanal shrimp fisheries, fishers were relatively knowledgeable about shrimp reproduction and migration, regardless how old they were. The fact that these species have a continuous reproductive cycle allow fishers to follow the species reproductive cycles during the year, mainly for white and pink shrimps that migrate into estuarine environments to reproduce [69–71]. The acquisition and evolution of LEK is expected to progress through passive adaptive processes according to the cumulative experiences in the environment [72, 73]. Our study suggests this only occurs for lower rated topic themes (feeding, mortality and growth) and older fishers (≥ 41 years). Thus, the experience acquired over the years by older fishers is mainly manifested in knowledge of more refined and difficult to observe bioecological topics.

The similarity in the quality of ecological information on exploited species indicates that there is considerable information sharing or homology of interests. The themes most often cited as part of LEK were similar across species, contrary to expectations due to known interspecific bioecological differences (e.g., Dall et al. 1990) and attention bias toward higher revenues [74], e.g., the higher priced shrimp species. The main bioecological difference between species, discriminated by hypothetical-deductive knowledge, is related to migration. White shrimp (*P. schmitti*) and pink shrimp (*P. subtilis*) need the estuary to complete the life cycle [38, 39, 75, 76], while the seabob shrimp (*X. kroyeri*) completes its life cycle exclusively at sea [33, 40, 77]. Another difference between species is the age at first maturation. Pink shrimps mature in 2 to 3 months [78]; white shrimp from 6 to 7 months [36], and the seabob shrimp in 12 months [79, 80]. Notwithstanding these bioecological differences, thematic knowledge was similar

for all species as shrimp fisheries are multispecific allowing similar connection of fishers to all species life cycles. Thus, neither abundance nor sales value is as important as fishers interest and the frequency and constancy of observation.

There was high similarity in LEK between informants from different locations, consolidated in information networks on bioecological themes. This indicates that similar environmental conditions and experiences lived by fishers drive similarities in the acquisition, retention and sharing of knowledge (Berkes et al., 1993; Ruddle and Ruddle, 1991). Social actors involved in sharing ecological information interact at different scales [3], mainly at fishing harbors and fishers centers – called colonies or “colônias” in local language [83]. The intragroup similarity of fishers on bioecological information on species is consequently determined by the operational fisheries affinity. The fishing gear with greater power to catch shrimp is regionally similar, usually single or double bottom trawls [36, 37], not differing by species. The LEK similarity shows that the connection of knowledge between fishers is anchored in bioecological issues relevant to independent social groups, generating similarity of knowledge even though there is social and cultural heterogeneity between communities. Moreover, the fact that the seabob shrimp life cycle is specific, involving movements between estuaries and the open sea, does not apparently affect LEK about the species. This may be related to the lower interest in this species due to its lower economic value.

It is also noteworthy that these species are close to the limits of overfishing [38–40], and thus need to be effectively monitored. According to our findings, artisanal fishers’ LEK is focused on the themes on reproduction and migration. However, information on growth and mortality is more restricted to more experienced fishers. Older fishers are typically less active, but have high status within the community, providing inputs to other fishers and acting as important nodes in local network.

Information sharing is essential in natural resource management processes that contain a wide variety of social actors, such as artisanal fishers. This sector is essential for coastal food security, using common resources that require participatory fisheries management [14] planned at local, and even regional, scales [84–86]. Possible reduction in the flow of ecological information could limit the wider dissemination of LEK [12, 13], generating subgroups affected by local species importance. Differences on species importance among harbors, e.g., white shrimp at Baía Formosa responding to 35,1% of shrimp yields; against 29,4% at Pontal do Peba and 25% at Sirinhaém [36], may generate differences on local community learning. Therefore, social networks feed by common needs potentially affect productivity and their social survival with high connectivity among the networks nodes. Facing results, reproduction and migration themes were considered essential in promoting intercommunity dialogue and with other decision makers aiming at participatory and effective fisheries management.

With respect to the main themes covered by the social networks, the intermediate centrality metric indicates information exchange in networks [23, 24]. Such exchange is essential for success in natural resource management planning and execution. The most relevant intermediate centrality metrics were on the themes of reproduction and species migration, and these themes could therefore be used to leverage

collaboration among stakeholders. Networks must consider all existing knowledge, no matter coming from hypothetical-deductive methods or from LEK, either to improve fisher communities well-being, attending yield targets but also to conserve coastal biodiversity [72] that is essential to biological production. Therefore, for efficient management in the future, the themes of reproduction and migration could be considered as bridges for dialogue and decision-making, reconciling conservation of populations with sustainable economic revenues for the fishing communities.

The bioecological similarity in the LEK of the species evaluated in different areas suggests that regional level planning of resource management could be effectively implemented. Current legal determinations include different no-take reproductive periods on the Northeast coast during the last 20 years (e.g., Dias-Neto 2011; Santos et al. 2013). These clearly lack justification and must be concluded, reducing conflict due to the displacement of fleets between fishing grounds. A fisheries agreement validated by government authorities based mainly on experienced fishers LEK and supplemented by scientific advice will reduce conflicts and safeguard fisher communities. In addition, scientific research on topics where LEK is weak (e.g., growth and mortality), with participative dissemination of results to all stakeholders may improve management efficiency and the communication quality among networkers.

Ecological information provided by the fishers can and should be combined with that generated by experimental science to better support the assessment of fisheries [88] and even to predict changes in the spatial distribution of species [89] with positive social, economic and environmental outputs. Such co-production of research [90] can improve dialogue and the effectiveness of fisheries management. Following common-pool resources principles, mainly collective choice arrangements monitoring methods and eventual sanctions to illegal actions [91] are facilitated when managers value the knowledge of fishers [26, 92]. Researcher-manager-fisher cooperation should be used to make LEK and ecological science a basis for social and environmental sustainability, providing a robust information-driven platform to respond to challenges of climate change and other anthropogenic impacts.

Declarations

Ethics approval and consent to participate

This research was registered with the Brazilian System of Genetic Resource Management and Associated Traditional Knowledge (SisGen) and approved by the Research Ethics Committee (CEP) at UFAL (approval code 2.970.521).

Consent for publication

Not applicable

Availability of data and materials

The datasets used and/or analyzed during the current study are available from the corresponding author on reasonable request.

Competing interests

The authors declare that they have no competing interests.

Funding

The Fundação de Amparo à Pesquisa do Estado de Alagoas- FAPEAL for graduate fellowship to RBC (#60030.001068/2018). The Coordenação de Aperfeiçoamento do Pessoal de Ensino Superior – CAPES for graduate fellowship to ASO. The Conselho Nacional de Desenvolvimento Científico e Tecnológico - CNPq for grants (VSB #311038/2017-4, and NNF #311785/2018-2), and to CNPq in partnership with the Brazilian Ministry of Aquaculture and Fisheries - MPA for research funding.

Authors' contributions

RBC and VSB conceived of the idea for the paper and outlined and structured its content. RBC and JGCOJ analyzed the data. All authors interpreted the data. RBC wrote the first draft of the manuscript with additional edits from VSB, JGCOJ, ASO and NNF. The authors read and approved the final manuscript.

Acknowledgements

We are grateful for comments on an earlier version of the manuscript from Alexandre Schiavetti, Adriana Carvalho, and all fellows from the Management and Conservation of Renewable Resources Lab that continuously contributed to the data collection and analysis. We thank the fishers from Pontal do Peba, Sirinhaem and Baía Formosa for their kind collaboration and support.

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Figures

Figure 1

Fishing communities in the Northeast region of Brazil where interviews were performed. Note: The designations employed and the presentation of the material on this map do not imply the expression of any opinion whatsoever on the part of Research Square concerning the legal status of any country, territory, city or area or of its authorities, or concerning the delimitation of its frontiers or boundaries. This map has been provided by the authors.

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Figure 2

Local ecological knowledge and fishing experience. (BM: Breeding month, SB: Seasonal breeding period, BL: Breeding location, MP: What migration do shrimps perform, PM: Purpose of migration, DF: Dry feeding, RF: Rainy feeding, SP: What are the shrimp predators, LP: What location predation occurs, SS: Size that shrimps are ripe, AS: Age that shrimps are ripe, LO: Longevity).

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Figure 3

Ecological information network shared about *Penaeus schmitti* (white shrimp) for fishers from Pontal do Peba (P), Barra de Sirinhaém (S) and Baía Formosa (F). White shrimp associative network (*Penaeus schmitti*)

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Ecological information network shared about *Penaeus schmitti* (white shrimp) for fishers from Pontal do Peba (P), Barra de Sirinhaém (S) and Baía Formosa (F). White shrimp associative network (*Penaeus schmitti*)

Figure 4

Ecological information network shared about *Penaeus subtilis* (pink shrimp) for fishers from Ponta do Peba (P), Barra de Sirinhaém (S) and Baía Formosa (F). Pink shrimp associative network (*Penaeus subtilis*)

Figure 4

Ecological information network shared about *Penaeus subtilis* (pink shrimp) for fishers from Pontal do Peba (P), Barra de Sirinhaém (S) and Baía Formosa (F). Pink shrimp associative network (*Penaeus subtilis*)

Figure 5

Ecological information network shared about *Xiphopenaeus kroyeri* (seabob shrimp) for fishers from Pontal do Peba (P), Barra de Sirinhaém (S) and Baía Formosa (F). Seabob shrimp associative network (*Xiphopenaeus kroyeri*)

Figure 5

Ecological information network shared about *Xiphopenaeus kroyeri* (seabob shrimp) for fishers from Pontal do Peba (P), Barra de Sirinhaém (S) and Baía Formosa (F). Seabob shrimp associative network (*Xiphopenaeus kroyeri*)

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