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Local ecological knowledge indicates: There is another breeding period in the summer for the mullet *Mugil liza* in a Brazilian tropical bay

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ABSTRACT

Local Ecological Knowledge (LEK) is based on the knowledge that a community has about the organisms that occur in the place where people has lived for generations and can be useful to complement biological knowledge. The LEK of artisanal fishermen in the Sepetiba Bay (coast of the State of Rio de Janeiro) on the reproduction, migration and interactions (feeding and parasitism) of the mullet *Mugil liza* was analyzed. Semi-structured interviews were conducted with 40 informants (24–79 years old), from November 2017 to January 2019, considering the emic (fisherman's perception) and ethic (scientist's perception) aspects. Fishermen's information coincided with the literature for aspects of the species' biology, such as reproductive period, feeding patterns and parasitic relationships. However, new patterns have been described by the fishermen. These new patterns pointed to a probable reduction in the fish maximum body size and first maturation size. In addition, LEK also points to an additional period of reproduction in the summer, and the presence of north and east winds favoring the appearance of individuals in the bay. The summer spawning, already reported in other areas, was not foreseen in the biological literature for the Sepetiba Bay, and the LEK associated this spawning season to a possible resident population that stay most of the time under structures formed by wharfs of mega-enterprises in the area. Also, the mullet could be forming different metapopulations on the Southeast-South coast of Brazil with part of these populations entering into the Sepetiba Bay. These points raised by LEK need to be tested by biological studies, which could help to a rational management and conservation of this important fishery resource in the southeastern and southern Brazil.

1. Introduction

People from traditional local communities have knowledge on nature and ecological processes, such as perceptions and understanding of ecological dynamics and functions (ethnoecology), as well as beliefs on how patterns are influenced by processes in several natural issues (Berkes et al., 2000). Such knowledge can facilitate the rapid exchange of information that may not be possible by scientific routes, thus complementing biological knowledge (Neis et al., 1999; Aswani and Hamilton, 2004; Albuquerque et al., 2020). Methodologically, ethnobiology uses both emic information (concepts specific to local populations) and ethical information (empirical and scientific values, specific to the researcher). Such concepts, suggested by Pike (1954), were analyzed in detail by Harris (1976) and Shagrir (2017). The Local Ecological Knowledge (LEK) has the potential to fill gaps in the biological knowledge and has been increasingly used in several regions (Johannes et al., 2000; Silvano et al., 2008).

The artisanal fisheries for mullets *Mugil liza* Valenciennes, 1836 are culturally and historically important along the southern and southeastern Brazilian coast (Vieira, 1991). The "caiçaras" are the rural native inhabitants of the SE Atlantic Forest coast, descendants of native Indians and Portuguese. They are artisanal fishermen that have provided important information for various studies on fish biology and ecology in southeastern Brazil (Begossi, 2006; Begossi et al., 2016, 2017; Silvano et al., 2006, 2017; Silvano and Begossi, 2012). Even though it is an important fishery resource and relatively well studied (Fig. 1), there are still gaps in relation to some ecological questions about mullets (Herbst and Hanazaki, 2014). In this specific case, we believe that the knowledge of fishers (caiçaras) can add knowledge to what is already known on the species or could be used as a contribution for designing testable hypotheses about migration, reproduction and interactions with other species in the Sepetiba Bay region.

The objective of this study was to analyze the LEK of "caiçaras" artisanal fishermen on the mullet *Mugil liza*, regarding reproduction,

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Fig. 1. Traditional artisanal fisheries of the mullet *M. liza* in the Sepetiba Bay, southeastern Brazil.

migration and interactions (feeding and parasitism). Considering artisanal fishing as a system of predator-prey, in which the skill of the predator is decisive for the success of fishing, this article describes the ecological knowledge of artisanal fishermen in Sepetiba Bay. In addition, we compare the LEK with biological knowledge, and present indications of how this knowledge can be used to benefit the conservation of mullets.

1.1. Synthesis of mullet biological knowledge

The mullet *Mugil liza* Valenciennes 1836 is a widely distributed species along the western Atlantic coast of South America, occurring from the Caribbean Sea to Argentina (Menezes et al., 2010; Sicha-Ramirez et al., 2014). Recent studies suggest the existence of two genetically distinct populations in the southeastern-southern Brazilian coast: the "southern" population, that occur from the São Paulo (24°S) to Chuí (34°S) coast in the southern Brazilian border, and the "northern" population, in the coast of Rio de Janeiro state (22-23°S) (Mai et al., 2014; Lemos et al., 2017). However, due to the wide distribution, migration capacity and plasticity of this species in the uses of different types of semi-closed coastal environments, there are still many concerns about this pattern (Herbst and Hanazaki, 2014).

Fishes of the family Mugilidae are iteroparous (Brusle, 1981; Andrade-Talmelli et al., 1994) and highly fecund (Okumuş and Başçnar, 1997; Albieri and Araújo, 2010; González-Castro and Minos, 2016). Males testes are classified as the unrestricted spermatogonial type with cystic spermatogenesis, according to the description of Lemos et al. (2014). *Mugil liza* exhibits synchronous group oocyte development with two oocytes populations distinguished in the ovary (Wallace and Selman, 1981). The mullet *Mugil liza* from the Sepetiba Bay is a total spawner, with high fecundity, short reproductive season ranging from May to August (Albieri and Araújo, 2010). Mullets grow rapidly and can reach up to 10 years (González-Castro et al., 2009a) and reach up to 1 m in length and 6 kg (De Abreu-Mota et al., 2018); feed and grow inside lagoons and estuaries, migrating to the sea in schools to spawn (Fraga et al., 2007; González-Castro et al., 2009b). After spawning, they may return to the lagoon-estuarine environment, as well as the larvae and juveniles (González-Castro et al., 2009a). Apparently, they are well adapted to a wide range of temperature and salinity (Vieira, 1991), although these factors interfere in the survival and growth of juveniles (Vieira et al., 2008; Lisboa et al., 2015; Garcia et al., 2018).

The species is often classified as semi-catadromous owing to its predictable migrations from freshwater and estuarine habitats to marine spawning areas (Vieira et al., 2008; Fontoura et al., 2018). It is believed that the mullet must move to salty waters, leaving the estuary and going to the ocean in large schools to reach the gonadal maturation (Lemos et al., 2014). The Patos Lagoon estuary, located in the state of Rio Grande do Sul, is the main *Mugil liza* nursery area in Brazil (De Abreu-Mota et al., 2018). The "trigger" for the exit of the mullets from the estuaries towards the ocean are climatic changes typical of autumn and winter, when there is a drop in the water temperature, between 19° and 21 °C, associated with changes of winds direction, from predominantly northeast, to southwest winds, locally known as "rebojo". The flow of surface water on the platform is inverted and becomes towards the coast, pushing salty and cold water into the estuary, thus causing the mullet to exit in counterflow (Lemos et al., 2014). This period, called by fishermen "running for the corso", was used as a synonym for reproductive migration or to define when fish leave the semi closed areas where they grow (Herbst and Hanazaki, 2014). It is believed that part of the mullet population in Sepetiba Bay comes from the southern coast of Brazil during the period of reproductive migration that occurs between May and August (Lemos et al., 2014; Fontoura et al., 2018).

Most mullet species feed on large amounts mud and detritus, being classified as iliophagous that use the organic matter present in the sediment, although they can also exploit benthic invertebrates, green filamentous macroalgae, periphytic microalgae, plankton and other suspended organic matter of detritus (Odum, 1970; Cardona, 2015) mostly on microalgae (Odum, 1970; Cardona, 2001; Mai et al., 2018). Mugilidae may rely on different food sources within the microphytobenthos or organic detrital matter pools (Le Loc'h et al., 2015; Carassou et al., 2017). They are also one of the most important forage fishes in the estuarine areas and represent a significant food source for upper-level piscivores (Mcdonough and Wenner, 2003). Mullets represent a significant food source for upper-level piscivores (Mcdonough and Wenner, 2003).

Another important aspect of mullet interaction is the parasitism. The presence of metacercarias *Ascocotyle (Phagicola) longa* Ramsom, 1920 (Digenea: Heterophyidae) was recorded in *Mugil platanus* (= *M. liza*) from "mullet festivities" in the State of São Paulo (Rodrigues et al., 2015), which can be transmitted to human population as recorded by Chieffi (1990) and Chieffi et al. (1992). Digenean parasites *Ascocotyle (Phagicola) longa* is a common mullet parasite known by its potentially zoonotic capacity. The natural first intermediate host of *A. (P.) longa*, an agent of human heterophyiasis in Brazil, is the cochliopid snail *Heleobia australis* (new first intermediate host) (Simões et al., 2010). Metacercariae were found encysted in the body musculature, heart, stomach, liver, kidney, spleen, gonads and mesentery of mullets *Mugil liza* (Simões et al., 2010). In addition, four species of *Ligophorus* (Monogenea: Dactylogyridae), were described parasitizing the gills of *Mugil liza* (Mugilidae) from the Guandu River (Abdallah et al., 2009).

2. Material and methods

2.1. Study area

The Sepetiba Bay (Fig. 2) (22°55′-23°49′S; 43°35′-44°11′W) is one of the largest semi-enclosed coastal ecosystems in the state of Rio de Janeiro covering a wide range of habitats, including mangroves, sand beaches and small estuarine areas (Leal Neto et al., 2006). The tidal amplitude is about 1 m, and the southwest and northeast predominating winds contribute to moving the waters, into and out of the bay, respectively (Signorini, 1980). The average temperature ranges from 20 to 25 °C in the winter, and 26–30 °C in the summer. The waters are rich in organic nutrients from continental drainage, has a mean depth of about 8 m (Borges and Nittrouer, 2016).

The climate is characterized by a well-defined wet season during the austral summer (December to March) and a dry season in the winter (June to August). The Guandu River is the main source of freshwater into the bay, with an average flow of 150m^3/s (SEMADS, 2001). The bay has two different zones (Fig. 2) that are geographically continuous but differ in depth, salinity and in the degree of human influences (Araújo

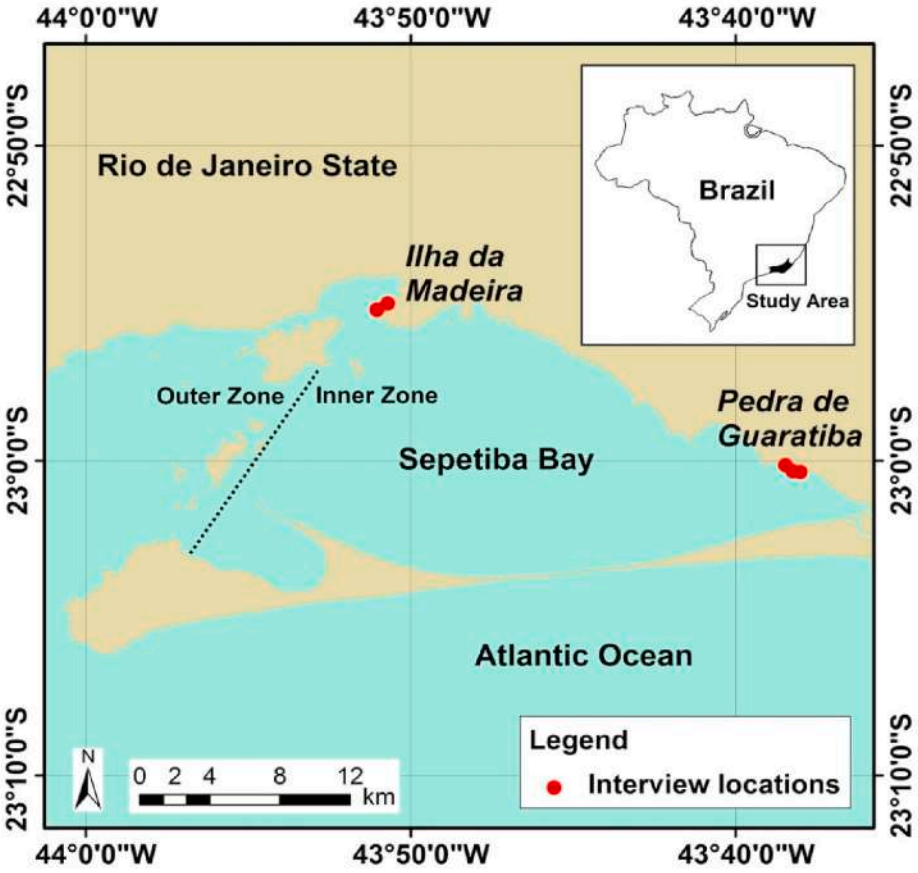

Fig. 2. Study area, the Sepetiba Bay in southeastern Brazil, with indication of the two locations (Ilha da Madeira and Pedra de Guaratiba) of the interviewers with artisanal fishermen and the bay zones.

et al., 2002; Azevedo et al., 2006). The inner zone is influenced by discharges of perennial small rivers that contribute to increase turbidity and temperature and to decrease salinity; the substratum is mainly muddy with depths that are mostly <5 m. The water salinity averages 28 ± 1.1. s.d. This zone is the most altered because of the nearby industrial development (Cunha et al., 2009; Leal Neto et al., 2006). The outer zone, located near the sea, has comparatively lesser influence on anthropogenic activities and exhibits contrasting environmental conditions: the substratum is predominantly sandy, the water temperature is comparatively lower, and the salinity and transparency are comparatively higher; the maximum depth is ca. 30 m, and the average salinity is 33 ± 0.9.

The bay supports rich and diversified fauna, mainly mollusks, crustaceans and fishes of the families Sciaenidae, Ariidae, Engraulidae, Mugilidae and Carangidae that use the bay in great abundances, as grounds for growth, reproduction, and feeding (Cardoso et al., 2011; Araújo et al., 2002, 2016). Despite its great ecological importance, an increased degradation by organic and industrial pollution is occurring in the bay shoreline, altering habitat structure and the water quality. Such alterations beginning in the 1960s, expanding during the 1970s, mainly because of new industrial development in chemical and metallurgical factories (Lacerda et al., 1987; Molisani et al., 2004, 2006). More recently, areas nearby the bay shoreline are target of economic, strategic and geopolitics that are reflected in a complex entanglement of mega-projects with high potential of social and environmental impact (Araújo et al., 2016; Pinto et al., 2019). Recent human interferences in the bay were the enlargement of the Sepetiba Port, including dredging of the access channel to 20 m depth, and the construction of a large steel factory in 2010, and a terminal for building submarines in 2013 (Araújo et al., 2016). Such activities contribute to shoreline degradation, impoverishing of natural habitats, and increasing pollutants loads into the bay (Carneiro et al., 2013; Ribeiro et al., 2013).

The fishing gear used by artisanal fishermen from the Sepetiba Bay for the mullet fishery is the gillnet, which can be used as an active siege technique or "caceio". In the siege technique, fishermen cast the vessel's net around the visually identified school, closing the siege and throwing the weight (poita) in the centre, trapping the fish, thus carrying out the fishing. In the "caceio" technique, fishermen attach one end of the net to the boat and release the other end that is adrift to cause the gill of the fish. In both techniques, fishermen produce sound stimuli by means of the motor or by hitting the paddle in the water (Brasil, 2015). The siege technique is much more usual than the "caceio". Although without an official statistic, the majority of artisanal fisheries in Sepetiba Bay are trawls, sieges and "caceio" on fisheries resources such as mullets, whitemouth croaker *Micropogonias furnieri* (Desmarest, 1823), Brazilian flounder *Paralichthys brasiliensis* (Ranzani, 1842), black drum *Pogonias cromis* (Linnaeus, 1766) Atlantic anchoveta *Cetengraulis eduntulus* (Cuvier, 1829) and weakfish (*Cynoscion* spp).

2.2. Data collection

Informants from two traditional fisheries localities (Ilha da Madeira and Pedra de Guaratiba) that have the largest number of fishers that catch different fisheries resources in the Sepetiba Bay (Fig. 2) were intentionally chosen using the snowball method (Bernard, 2006; Albuquerque et al., 2014a), including the following criteria: 1) to have participated in the mullet fishery throughout his life; 2) to be an artisanal fisherman and; 3) to be available and willing to participate

voluntarily in the research. In each community, 20 fishermen were interviewed through a semi-structured questionnaire (Huntington, 2000). The interviews were conducted only after consulting the informants, that is, signing a consent form. The interviews addressed questions about reproduction, migration and interactions (food and parasitism) (Table 1). All interviews were audio recorded and occurred between November 2017 and January 2019. Ethical procedures followed the protocol of the National Research Ethics Commission (CONEP) and ethics approval was granted by the Human Research Ethics Committee of Castelo Branco University (Number 3,089,110).

2.3. Data analyses

The interview data were selected and analyzed semi-quantitatively with the calculation of the percentages of the responses to understand the trends given by the highest frequency of interviewed. The analysis aims, whenever possible, to compare descriptively local knowledge with biological knowledge. The method of comparison and contrast of the data was used in the analysis to form categories, establish limits, synthesize contents and find negative evidences (Albuquerque et al., 2014b). We compared the answers given by the fishermen and calculated the frequencies and proportions of the fishermen who cited equivalent answers. Response patterns (highest frequencies) express knowledge because the information can be considered more reliable (Silvano and Begossi, 2005). Some quotes from the informants were used to illustrate the answers given.

3. Results

Forty fishermen (39 men and 1 woman) were interviewed, with ages ranging from 24 to 79 years (average = 52 years; standard deviation - sd = 13 years); and with the time of mullet fishing in Sepetiba Bay ranging between 5 and 69 years (average = 38 years; sd = 14 years).

The nets used in the mullet's fisheries are between 600 and 2500 m in length (average = 1193 m; sd = 565 m). Most fishermen said they use nets 1000 m long: (57%), between 2 and 12 m in height (average = 4; sd = 3); and with mesh varying between 50, 55 or 60 mm between opposite knots. These values were very consistent among the respondents.

The vessel of the great majority of fishermen (75%) is a caique, a light rowboat. Some use both a caique and a canoe (10%); others use a small trawler (approximately 7 m long) (10%), and still others use only a canoe (5%). Artisanal fishing in the Sepetiba Bay is carried out for both trade and consumption.

3.1. Reproduction

Based on the fishermen's reports, the average maximum size reached by the species is 91.3 cm Total Length - TL (±27.8 cm); and the minimum size in which the mullets are already ripe for breeding in the Sepetiba Bay averages 47 cm TL (±19 cm) (Table 2). The mullet is indicated by artisanal fishermen as having a preference for breeding in the colder months (June and July), but with indications suggesting tendencies to expressive reproduction also in the summer (Table 2). Most of the interviewees pointed out the innermost part of the bay, mangroves and even lower rivers reaches as the preferred spawning grounds for the species (Table 2). The patterns pointed out by fishermen for the reproductive process were to enter the rivers and mangroves areas to carry out the reproductive process (Fig. 3; Table 2).

Table 1
Questions of the semi-structured protocol with the main points of investigation.

Ecological aspects addressed	Questions
Size	How big does the mullet reach?
Reproduction	When does the mullet spawn? And what is the approximate size it has at this moment? What are the mullet spawning sites? How do mullets reproduce?
Migration	What is the ideal condition for the mullet to migrate?
Feeding	What does the mullet feed on?
Interactions	How do mullets interact (behavior with the group)? Is there any kind of mullet interaction with other species? Do you know any type of parasite or mullet disease?

Table 2
Reproductive indicators of the mullet by Local Ecological Knowledge (LEK). N, number of times the feature was cited. 40 fishermen were interviewed.

Size (cm)	N	Mean ± standard deviation
Maximum size	35	91.3 ± 27.8
Minimum spawning size	31	47 ± 19
Reproductive period		**Detailed description**
Winter	18	June and July. (Fisherman from Pedra de Guaratiba, 64 years old)
Summer	10	Fisherman from Ilha da Madeira, 52 years old
Whole year	03	Fisherman from Pedra de Guaratiba, 66 years old
Spawning Location		
Mangroves	14	Nearby mangroves, close to grass substrate. (Fisherman from Pedra de Guaratiba, 64 years old)
Rivers	14	"Mouth" of the São Francisco River, Guandu River, Itaguaí rivers, enter to spawn. (Fisherman from Ilha da Madeira, 65 years old)
Marambaia Restinga	07	Restinga, near to mangroves. (Fisherman from Pedra de Guaratiba, 38 years old)
Open ocean	02	Fisherman from Pedra de Guratiba, 42 years old
How is the reproductive process		
Enter the river to spawn	06	They go to the river margins, now silted up, or probably to the piers of harbors and enterprises, because this is a private area. (Fisherman from Pedra de Guaratiba, 65 years old)
Enter the mangroves	05	Looking for mangroves, rivers are silted, shallow, making reproduction difficult. Fisherman from Pedra de Guaratiba", 66 years old)
In warmer waters	03	Looking for shallow and warm waters. (Fisherman from Pedra de Guaratiba, 64 years old).
When spawning capable goes to port	01	Fisherman from Ilha da Madeira, 54 years old
Near the islands	01	Spawning capable individuals move toward the islands. (Fisherman from Ilha da Madeira, 58 years old)

3.2. Migration

Fishermen related the great mullet abundances to the presence of northeast winds, associated with warmer waters (Table 3). The most recorded behavior by the fishermen of the Sepetiba Bay for mullets was jumping and staying near the surface "in the full moon" (Table 3). Fishermen indicated that the largest mullet catches occur in the coldest months (June and July), but with a tendency to increase also in the summer (Table 3).

3.3. Biotic interactions

The dolphin (*Sotalia guianenses* (Van Bénédén, 1864)) (=*S. fluviatilis*) is the species that most prey on mullets and on other fish species (e.g., the whitemouth croaker *Micropogonias furnieri* (Desmarest, 1823), the jack *Caranx crysus* (Mitchill, 1815) and the common snook *Centropomus undecimalis* (Bloch, 1792)) according to the fishermen (Table 4). On the other hand, the mullet feeds mainly on silt, algae, slime and mud (Table 4). The changes in the health status of the mullet most cited by fishermen were the presence of a fungus and an organism that they call "busano", which they say makes the fish very thin. This "disease" is reported as a recent phenomenon (Table 4). Only few fishers mentioned interactions (occurrence together with other species) and parasitism in mullets.

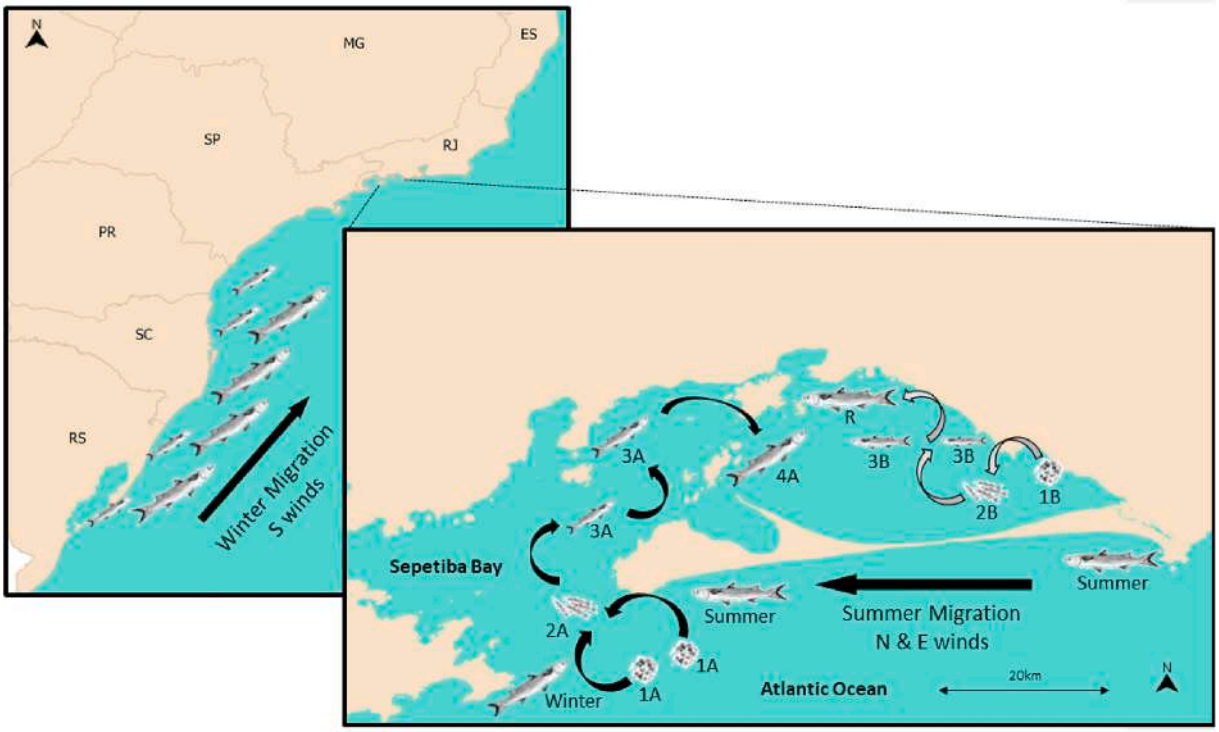

Fig. 3. The reproduction of the mullet *Mugil liza* following Local Ecological Knowledge of fishers from the Sepetiba Bay. Black arrows indicate the cycle of the migrant mullet **Population A**: spawning occurs in the ocean, between autumn and winter; adults and juveniles migrate northward; adults from South (Winter migration) spawning near Sepetiba Bay (1A); (2A) juveniles penetrate into the bay where they develop; (3A) growth of juveniles and (4A) individuals start maturation toward to the ocean to spawn. When North and East winds predominate in the summer (Summer migration), adults are able to spawn in the ocean. Gray arrows show the cycle of a likely **resident population (B)** in the estuarine system: adults (R) spawn in the mangroves and in lower rivers reaches (1B); juveniles develop in the innermost area of the Sepetiba bay (2B and 3B), as well as adults (R), who are resident in areas next to industrial structures.

4. Discussion

4.1. Size

In this study we find that LEK information on aspects of the biology and ecology of the mullet *Mugil liza* in Sepetiba Bay coincided with the biological literature in many aspects, however, new patterns have been described by fishermen. These new patterns indicate a likely reduction in the maximum size reached by the mullets. The maximum size that the mullet reaches reported by the fishermen (average of 91.3 cm TL) is well above that recorded by Albieri and Araújo (2010) of 70 cm TL. However, it is important to point out that when fishermen respond about the maximum size of a given fish species, they consider the largest size that they have ever fished in their life, and they pointed out that currently they no longer fish mullet of that size, and that the fish are now smaller than used to be in previous times. Bender et al. (2013) found that it is usual that fishermen over 50 years old not only caught larger individual fish, and they always say that large fish occurred four decades ago, suggesting that fish size are declining, a general trend also recorded in the biological literature (Jackson, 2010; Gardner et al., 2011; Sheridan and Bickford, 2011).

Since 2004, mullets have been ranked among the most overexploited fish resources by the Brazilian authorities (Brasil, 2015) and there is strong evidence that the southern population is overfished, particularly due to fishing pressure during the reproductive migration period (Lemos et al., 2014; Santos et al., 2018). Artisanal fishermen complain that industrial fisheries performed by large vessels impairs artisanal fisheries in the Sepetiba Bay, which are practiced when mullets move to the coast. According to respondents, the abundance of mullet in the Sepetiba Bay has decreased over the last decades. Such perception is in accordance with the recorded data of mullets' abundance in the southern region, where this species has been ranked as overexploited, with strong evidence of overfishing, particularly because the high fishing pressure during the period of reproductive migration (Brasil, 2015). The exploitation of marine ecosystems has already caused structural and functional changes in many fish populations that are part of fishery resources, such as reductions in the average size of individual fish and some species extinctions (Jackson, 2010). However, others studies attributed to climate changes as the main causes of reduction in fish size (Gardner et al., 2011; Sheridan and Bickford, 2011).

The minimum average size for the mullet breeding pointed out by fishermen was 47 cm TL (Table 2). Albieri e Araújo (2010) reported that size at first maturity (LT_{50}) is 35 cm TL for females of *M. liza* and that 100% of the individuals reach gonadal maturity (LT_{100}) with 55 and 57 cm TL for males and females, respectively. This difference in size at first maturation (Lm) from biological knowledge and the minimum spawning size reported by fishermen may be suggesting a possible trend towards a reduction in the first maturation size of mullet in the Sepetiba Bay, coinciding with decreasing in the maximum size reported for this species in this area.

4.2. Reproduction

It is likely that part of the mullet population in the Sepetiba Bay come from the southern Brazilian coast during the period of the reproductive migration that occurs between the months of May and August (Lemos et al., 2014; Fontoura et al., 2018). This period, named by fishermen as "running to the 'corso'" was used as a synonym for reproductive migration of schools, or as a synonym to define when the fish leave the areas where they grow to perform reproductive migration (Herbst and Hanazaki, 2014).

The period reported by fishermen as the preferred breeding season was the winter. Such perception is in agreement with the biological literature (see Albieri and Araújo, 2010) based on the gonadosomatic

Table 3
Environmental conditions and mullet behavior associated with breeding according to Local Ecological Knowledge (LEK). 40 fishermen were interviewed.

Environmental condition	Citations	Detailed description
Conditions to spawn		
North and east winds	12	East wind is paramount, because the mullet "jumps" against the wind: when the wind decreases the fish comes into the bay (Fisherman from Pedra de Guaratiba, 58 years old). With the north wind the fish appears, the water is hot; with the south wind, the water is cold, the mullet is scarce (Fisherman from Pedra de Guaratiba, 66 years old). The mullet swims against the wind: the more east the more fish into the bay; with southwest winds it returns to their "shelter" (structures formed by mega-enterprises developed in the region and used as shelter by the mullets) (Fisherman from Ilha da Madeira, 67 years old).
High tide	01	Fisherman from Ilha da Madeira, 43 years old
High tide	01	Fisherman from Ilha da Madeira, 33 years old
How do you know when schools are coming?		
See jumping	20	The mullet "kept calm" and occasionally jumps one in the middle of the school (Fisherman from Pedra de Guaratiba, 51 years old). 'The mullet can be seen, because it jumps out. The mullet is a more "call with voice" fish, it is more in the water column (in the "upper layers") (Fisherman from Ilha da Madeira, 51 years old)
Stay on the surface	12	Float in the "water surface"' (Fisherman from Ilha da Madeira, 53 years old). 'One can see, "reboja", "runs" on the surface (Fisherman from Pedra de Guaratiba, 64 years old)
Season	01	In the past I knew that in June/July the mullets would arrive into the bay, today one no longer has that certainty (Fisherman from Ilha da Madeira, 49 years old)
Interactions (behavior with the group)		
Jump	19	Jump and 'run on the surface southwards (Fisherman from Ilha da Madeira, 43 years old)
Stay on the surface	15	The school is in the surface, against the tide, moving the mouth, it is easy to see. (Fisherman of Pedra de Guaratiba, 58 years old)
Catch Period		
Winter	17	In the cold weather (Fisherman from Pedra de Guaratiba, 79 years old)
Summer	10	Summer with a thunderstorm (Fisherman from Ilha da Madeira, 33 years old)
Whole year	07	The whole year (Fisherman from Pedra de Guaratiba, 58 years old)

Table 4
Mullet interactions with other species (food and parasitism) in the Sepetiba Bay according to LEK. 40 fishermen were interviewed.

Feed on mullet and interaction with other species	Citations	Detailed description
Prey on mullet		
Dolphin (*Sotalia guianenses, S. fluviatilis*)	08	Dolphins feed on mullets (Fisherman from Ilha da Madeira, 49 years old)
Sharks	01	Shark, and dolphin feed on mullets (Fisherman from Ilha da Madeira, 52 years old)
Interaction with other species (mullets + other species)		
Marine catfish (Ariidae)	03	Usually catches common snook and marine catfish together (Fisherman from Pedra de Guaratiba, 24 years old)
Common snook (*Centropomus undecimalis, C. parallelus*)	03	. Marine catfish, whitemouth croaker, horse-eye jack and common snook interacts with mullet (Fisherman from Pedra de Guaratiba, 34 years old)
Horse-eye jack (*Caranx crysos*)/(*C. latus*)	02	Jacks, catfish, snook (Fisherman from Ilha da Madeira, 43 years old)
White mullet (*Mugil curema*)	01	Occur together with white mullet (Fisherman of Pedra de Guaratiba, 51 years old)
Whitemouth croaker (*Microponias furnieri*)	01	Marine catfish, whitemouth croaker, horse-eye jack, common snook interacts with mullet (Fisherman from Pedra de Guaratiba, 34 years old)
"Enxada" (Perciformes), "Carapau" (Carangidae), and "espada" Largehead hairtail (*Trichiurus lepturus*)	01	"Enxada", "carapau" and "espada" interact with mullet (Fisherman of Pedra de Guaratiba, 57 years old)
"Xareu" (Carangidae)	01	"Xareu" interacts with mullet (Fisherman of Ilha da Madeira, 53 years old)
Food		
Sludge/Algae/Slime/Mud	37	Sludge (Fisherman from Pedra de Guaratiba, 38 years old); Algae and silt (Fisherman from Pedra de Guaratiba, 51 years old); Lime and algae (Fisherman, Pedra de Guaratiba, 53 years old); Mullets feed on mud (Fisherman from Ilha da Madeira, 58 years old) Sludge (Fisherman from Pedra de Guaratiba, 38 years old); Algae and lime (Fisherman from Pedra de Guaratiba, 60 years old); Lime e algae (Fisherman from Pedra de Guaratiba, 53 years old); Mullets feed on mud (Fisherman from Ilha da Madeira, 58 years old)
"Earthworm" (polychaetes)	05	Mud, lime, and earthworm (polychaetes) that occur in the mangrove (Fisherman from Ilha da Madeira, 47 years old)
Barnacle/Shrimp/Crustaceans/fish	05	Barnacles and lime (Fisherman from Ilha da Madeira, 26 years old); shrimp, herring and anchovies (Fisherman from Ilha da Madeira, 50 years old); crustaceans, "foam" and Crustaceans, "foam" and green lettuce (green algae) (Fisherman from Ilha da Madeira, 33 years old)
Hering	02	Sardine (Fisherman from Pedra de Guaratiba, 66 years old)
Anchovies	01	Shrimp, sardine and piquitinga anchovy (Fisherman from Ilha da Madeira, 50 years old)
Shellfish	01	Lime and shellfish (gnaw) (Fisherman from Ilha da Madeira, 38 years old)
"Foam"	01	Crustacean, "foam", green lettuce (green algae) Fisherman from Ilha da Madeira, 33 years old)
Parasitism		
Fungi	02	Fungi in the fish scales; the fish became thinner and skinny (Fisherman from Pedra de Guaratiba, 65 years old)
"Busano"	02	'Busano': like termites, inside the fish - it looks like a cockroach - isopods (Fisherman from Ilha da Madeira, 33 years old)
"Aphid" (Isopoda)	01	Aphid that penetrates through the fish body surface and feeds on muscle (parasite mainly flatfish and sole); very small, yellow bug, eats the fish muscles and keeps sucking - isopods (Fisherman from Ilha da Madeira, 52 years old)
Slime	01	It's happening now to be just skin and bone, like the whitemouth croaker (Fisherman from Pedra de Guaratiba, 58 years old)

index values and macroscopic and microscopy stages of gonads. *Mugil liza* spawning occurs between May and August, whereas the congeneric *Mugil curema* Valenciennes 1836 spawns between August and January, just before the rainy season (Albieri et al., 2010). According to these authors such temporal segregation of the spawning season between *M. curema* and *M. liza* may be a mechanism to avoid interspecific competition between offspring that recruits in inner bay areas. Silva and Araújo (2000) reported that the *M. liza* recruitment period in Sepetiba Bay range from May to October. In this period the water column and environmental conditions are stable in the Sepetiba Bay. Early juveniles could take advantage of the stable water conditions and abundant food resources that are available in semi-enclosed areas, such as coastal lagoons, estuaries and embayments, all year round (Macgregor and Houde, 1996).

However, it is important to note that fishermen also pointed to a tendency for the species to reproduce during the summer period. According to them, the reproductive period of the mullet was regularly occurring in the cold months (June–July) for decades, but in recent years they have observed this species, although still preferring this period to reproduce, also to spawn in other periods of the year, such as the summer. Although there are no records in the biological literature on mullet reproduction in summer in the Sepetiba Bay, a second advanced maturity mullet group in November–December was reported for the Mar Chiquita coastal lagoon, northern of the Argentinean coastal (González-Castro, 2007; González-Castro et al., 2011). This secondary spawning event cannot be disregarded, because females in advanced sexual maturity during November–December were observed uninterruptedly over several years (González-Castro, 2011). There was also a strong recruitment of early juveniles in summer (Acha 1990; Castellini et al., 2019) in this coastal lagoon. Therefore, the second breeding period indicated by LEK in the present study, is not something new in the biology of mullets, since it had been detected by biological studies in the coast of Argentina. Some fishermen believe that the individuals that spawns in the summer in the Sepetiba Bay are those that come from the Southern Brazilian coast, whereas others fishermen think that, differently from the population from the south, they belong to another population from Cabo Frio in north of the Rio de Janeiro State. This population, reported by the fisherman, stay under the wharfs of the mega-enterprises that were constructed in the last decades, such as, the expansion of the Sepetiba Port, a large shipyard for the construction of submarines, and piers of a large steel company.

Many fishermen claimed that spawning of mullets occur in lower river reaches or near to the edges of mangroves, which is the opposite of most fishes that take advantage of the high productivity of estuaries that exhibit offshore spawning, produce great numbers of small pelagic eggs and recruit to estuaries as larvae or juveniles (Lefeuvre et al., 1999; Costa and Araújo, 2002). It is likely that spawning areas of the mullet are deeper areas in the inner shelf, which have more favorable and stable environmental conditions for the development of eggs before being transported by currents to more unstable, eutrophic and rich semi-enclosed coastal systems (Costa and Araújo, 2002; Albieri and Araújo, 2010).

These species have offshore reproduction, using the inner bay areas as rearing grounds (Silva and Araújo, 2000; Lemos et al., 2014; Froese and Pauly, 2019). Nevertheless, due to intraspecific and interspecific variation in spawning behavior (e.g., timing and duration), there is considerable variation in life history characteristics of mugilids that inhabit similar environments (Brusle, 1981). The possibility of mullets enter coastal rivers and estuaries to spawn has low likelihood (Silvano e Valbo-Jørgensen, 2008). Such hypothesis deserves further investigation in order to be properly rejected, because exact spawning locations of this fish have not been found yet. Although some coastal fish populations may vary in their spawning behavior and finding new spawning areas, the hypothesis of spawning in rivers might be based on an inaccurate LEK, for example because the fishermen confounded spawning and nursery grounds.

4.3. Migration

Migration and recruitment processes of fishes are more complex than once thought as revealed by chemical analysis of fish otoliths (Chapman et al., 2012). There is a known general mugilid behavior of spawning offshore and their larvae migrating from the sea to estuarine or freshwater areas (González-Castro et al., 2011; Whitfield et al., 2012; González-Castro and Minos, 2016). Fortunato et al. (2017) observed that the mullets do not follow exactly this well described pattern, with migration between estuaries and sea of only some individuals (contingents), with part of the population staying permanently in the estuarine areas. This latter study, based on otolith chemistry have suggested the occurrence of three movement patterns throughout its life history: type I, the most frequent use of estuarine environments; type II, fluctuating behavior between estuarine and the sea; and type III, most frequent use of sea high salinity habitats (Fortunato et al., 2017). These findings cannot assure that there is more than one stock in the studied region (Southern Brazil and North of Argentinean coast). However, this study revealed that *Mugil liza* have different environmental migratory behavior showing a facultative use of estuarine waters, as indicated by Sr/Ca concentrations in otoliths, thus differing from the general mugilid behavior previously described. Mai et al. (2018), also using Sr: Ca and Ba: Ca concentrations in otoliths, has shown high variability in migratory patterns of mullets and that intra-specific variation in estuarine habitat use indicates that the migratory behavior in mullets is far more complex than previously known. These recent findings of the biological knowledge suggest intraspecific variation behavior of this species.

Mullets stocks assessment is another important issue in this area that have varied fisheries exploitation. Heras et al. (2016), using mitochondrial techniques, found two highly divergent mullet stocks throughout their distribution range, one in the north of Rio de Janeiro and the other south of this region. Mai et al. (2014) using microsatellite markers presented molecular evidence of the existence of different mullet populations throughout South America Atlantic coast: one represented by samples from Niterói (latitude 22.8°S), and another including samples from the southern Brazil (Ubatuba, Laguna and Rio Grande, latitudes: 23.4–32.0°S) and Argentine (Lavalle, Buenos Province of Aires, latitude: 33.8°S).

According to fishermen's reports, the mullet approaches the Sepetiba Bay mainly with north and east winds, which are associated with warmer waters. Herbst and Hanazaki (2014) reported, based on LEK that the necessary conditions for mullet shoals to approach the semi closed systems in southern Brazil are the absence of winds or the presence of a weak north/northeast winds, calm sea and warmer coastal waters, which coincides with the reported by LEK in the Sepetiba Bay.

The most common group behavior recorded by the fishermen for the mullet was that it jumped. Such behavior is well known to mugilids (Devos et al., 2019). "Jumping fish" was the ethno-category with the highest number of ethological terms (reproductive, attack and escape behaviors) among fishers (Costa-Neto, 2000). Overall, general biological knowledge corroborates that jumping is related to several behaviors in fishes (Mann and Lobel, 1997). Studies on animal behavior are often overlooked by conservation biologists (Sutherland, 1998). However, information on the behavior of animals (and fishes in particular) is essential for their conservation, to: a) to understand and manage the responses of species to anthropogenic environmental stresses such as fishing; b) to reduce by catch and improve the selectivity of fishing techniques to mitigate the decline of some endangered species; and, c) to survey and monitor populations (Shumway, 1999). Therefore, the knowledge of fish behavior is an important tool through which fishers can develop strategies and fishing techniques; it can also help them in management and conservation planning (Morril, 1967; Devos et al., 2019).

4.4. Fishing season

Industrial mullet fisheries in the south of the country occur in winter, during the period of reproductive migration of the species. The winter is the period of greatest mullet catches, reported by artisanal fishermen in the Sepetiba Bay, but a significant number of fishers also points to the summer. Disagreements between fishermen's LEK and biological data may reveal new biological information (Johannes et al., 2000; Silvano and Valbo-Jorgensen, 2008), or the necessity to perform new biological assessments on this issue. Considering that mullet is a migratory species, data on its capture patterns can help in understanding the fluctuation of its abundance throughout the year. Here, this pattern coincides with the pattern of reproductive periods indicated by the interviewees for this species in this region, reinforcing their perception of the possibility of the existence of two populations, with one of them living under the structures formed by mega-enterprises in the Sepetiba Bay region, differently from the population that arrives at the bay in the cold period (June–July), which has been regular for a long time that migrate from the south of the country. Therefore, the individuals captured in the summer are either those who came in the winter and remained in the bay, or have different origins, such as Cabo Frio, in the north of the state of Rio de Janeiro, as reported by some interviewers.

4.5. Trophic relationships

Most of the fish feeding habits mentioned by the fishermen corresponded to the fish diet according to the literature. Abundances of mullets increased from 1983 to 1985 to 1999–2001, in the inner zone of the Sepetiba Bay (Araújo et al., 2016). The eutrophication process that the Sepetiba Bay has been going through with the consequent increase in microalgae (Magalhães et al., 2003) may favor increases in the abundance of this species in the area. Fishermen pointed out that the main food items of mullet were mud, algae, slime and sludge. This species feeds on cyanobacteria, algae, protozoa, metazoans and debris (Oliveira and Soares, 1996). Mullets have thick-walled gizzard-like segments in their stomach along with a long gastrointestinal tract that enables them to feed on detritus (Herbst and Hanazaki, 2014). Detritivores fishes transform the environment they inhabit, so knowledge of their feeding habits and the interrelation of this species with the environment is essential for the management of this cross-border resource (Thompsom et al., 2015). In this sense, it is important to highlight that Mugilids contribute significantly to the ecological functioning of estuaries and storage areas using organic matter and primary production, accelerating the turnover of microalgae communities. In addition, this species has an important role in the energy flow within and between marine ecosystems (Odum, 1970; Lefeuvre et al., 1999; Laffaille et al., 2002).

Some respondents reported that this species also feeds on what they call "foam" or "turbidity" (foam that stays on the water's surface). Mourão and Nordi (2003) recorded this phenomenon from fishermen of the estuary of the Mamanguape River, in Pernambuco, who refer to the mullet as a fish that "drinks foam". Mullets feed on shrimp and on a yellowish foam that floats, named "turvança", according to fishery knowledge of a traditional community in the Ecological Station of Juréia-Itatins, in Peruibe coast, São Paulo (Souza and Barrella, 2001). This "turvança" could be phytoplankton blooms, but we cannot be sure because we have no objective indication for this possibility. In a study on the local knowledge of two "caiçaras" populations on the coast of São Paulo, Clauzet et al. (2005) also recorded that some interviewers said that the mullet feeds on "turbidity". This "turbidity" is, according to these fishermen, a yellowish foam that covers the surface of the sea, estuaries and mangroves, composed of silt, sand and seaweed. Garcia et al. (2018) analysing spatial diet overlap and food resource between *M. liza* and *M. curema*, found that *M. liza* explores a wider range of microalgae in the estuary, and the number of food items in the diet of *M. liza* was more than two-folds higher than those of *M. curema* (71 vs. 30 items). It is possible, therefore, that for subtropical estuaries *M. liza* is better adapted than *M. curema* to explore different microhabitats and a great variety of food resources. *Mugil liza* occurs all year-round in subtropical estuaries of the Southwestern Atlantic (Mai et al., 2018). The residence time into estuarine areas of *M. liza* seem to be larger than *M. curema* that has a more tropical distribution and peaks in abundance in these areas only during the warmest season.

Predation on mullets by dolphins were very common in the area according to fishermen, and this is in accordance with the literature. Marine tucuxi dolphins (*Sotalia guianensis*) prey chiefly on bottom-dwelling sciaenid fish found in coastal and estuarine waters, as well as on seasonal schooling fish such as mullets (*Mugil* spp.) and sardines (*Sardinella brasiliensis*) (Santos et al., 2000, 2002; Cardoso et al., 2011). In the Sepetiba Bay the second largest concentration of estuarine dolphins (Flach et al., 2008), suggested that resources are plentiful here. Nery et al. (2010) identified and catalogued 217 individuals of this species in this bay, with 186 re-sightings.

4.6. Parasites

The main health change in mullets pointed out by fishermen was the presence of fungus that make the fish "thinner and skinny'. We cannot accurately evaluate this information, however, because the poor description of the bed characteristics, we speculate that it may be the Metacercariae of the digenetic trematode, that have worldwide distribution. This parasite named *Ascocotyle (Phagicola) longa* Ransom, 1920 belongs to the family Heterophyidae, the causative agent of heterophyiasis (Citti et al., 2014). *Ascocotyle (Phagicola) longa* is a cosmopolitan species recorded from the Americas, Europe, Africa and the Middle East (Simões et al., 2010), and is considered an emerging fish-borne, zoonotic disease for humans (Brazil, 2010). In Brazil, studies have identified a high prevalence of *A. (P.) metacercariae* parasitizing *M. platanus* (=*M. liza*) (Knoff et al., 1997; Citti et al., 2014; Rodrigues et al., 2015), with prevalence of this parasite reaching 100% of the specimens evaluated (Citti et al., 2014). *Ascocotyle* (*Phagicola*) *longa* has a complex life cycle with two intermediate hosts, the snail *Heleobia australis* (d'Orbigny, 1835) and mullets *Mugil* spp. with adult parasites being found in the intestine of piscivorous birds and mammals (Simões et al., 2010).

The extensive geographical distribution of A. (*P.*) *longa* and its intermediate hosts along with the increasing consumption of raw or undercooked fish increase the risk of human infection (Pontes Santos et al., 2013). The humans develop typical symptoms of parasitosis, such as colic, flatulence, diarrhoea and other events characteristic of worms in general (Chieffi et al., 1990), including weight loss (Toledo et al., 2019). Cheng (1973) reported that there is no doubt that the transmission of phagicolose to humans occurs through the consumption of raw mullet, in the form of "sushi" and "sashimi", so that this fish represents a reservoir of infection for man and for other animal species, since the long *A.* (*P.*) does not seem to require high host specificity. Specialized studies should be carried out to detect the species of mite parasites in the Sepetiba Bay and their consequences of the species for humans. However, as a prophylactic measure in relation to long *A.* (*P.*), we do not recommend the consumption of raw mullet, in the form of "sushi" and "sashimi". The parasite "busano" that makes the fish very thin, is possibly an isopod ectoparasite that occur mainly on the body, oral cavity or in fish gills, however this parasite identification was not yet confirmed. We also should bear in mind that few fishers respond on parasitism. It is likely that the fishers have difficult to recognize, or may be the prevalence of parasitism is not so high to be recognized by them.

In conclusion, the present study showed the contributions of local ecological knowledge that identified new patterns as a result of their knowledge of the natural history of the species in the region. Respondents showed a perception of a new mullet population in the Sepetiba Bay and a new spawning season. The predominant reproductive period pointed out by the interviewees was the winter, in agreement with the biological knowledge. However, they also suggest a tendency

for the species to reproduce in the summer, and this pattern would be associated to the resident population that occur under the piers of the structures formed by the mega enterprises in the bay. Mullets spawning in summer was reported for the first time for the Sepetiba Bay by the LEK. However, biological studies on the coast of Argentina, already detect the summer as spawning period for this species González-Castro (2007); González-Castro et al. (2011). This new pattern raised by the LEK in the Sepetiba Bay needs confirmation in the biological knowledge. Answers to these issues will help management and conservation policies for the rational exploitation of this important fishery resource from the southern and south-eastern Brazilian coast.

Declaration of competing interest

The authors declare no conflicts of interest.

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