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SUSTAINABILITY OF Skipjack Tuna FISHERY IN BRAZIL

Paco Editorial

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SKIPJACK TUNA PROJECT

The “Skipjack Tuna Project: ecology and socioeconomics of *Katsuwonus pelamis* fishing off the coast of Rio de Janeiro aiming at stock assessment, sustainable management and its use in school feeding” received support from the Marine and Fisheries Research Project in Rio de Janeiro, a compensatory measure established by the Chevron Responsibility Conduct Adjustment Term, conducted by the Federal Public Ministry - MPF / RJ, with implementation of the Brazilian Fund for Biodiversity - FUNBIO.

SKIPJACK TUNA PROJECT

FUNBIO - Brazilian Fund for Biodiversity

FAURG - Foundation to Support Universidade Rio Grande

IO - Instituto de Oceanografia da Universidade Federal do Rio Grande – FURG

Laboratório ECOPESCA - Department of Marine Biology, Institute of Biology of the Universidade Federal Fluminense – UFF

NUPEM - Instituto de Biodiversidade e Sustentabilidade da Universidade Federal do Rio de Janeiro, Macaé *Campus*

NITEC - Center for Innovation Studies at the Universidade Federal do Rio Grande do Sul - UFRGS

NEPAM - Center for Environmental Studies and Research at the Universidade Estadual de Campinas-UNICAMP

FIPERJ – Rio de Janeiro State Fisheries Institute Foundation

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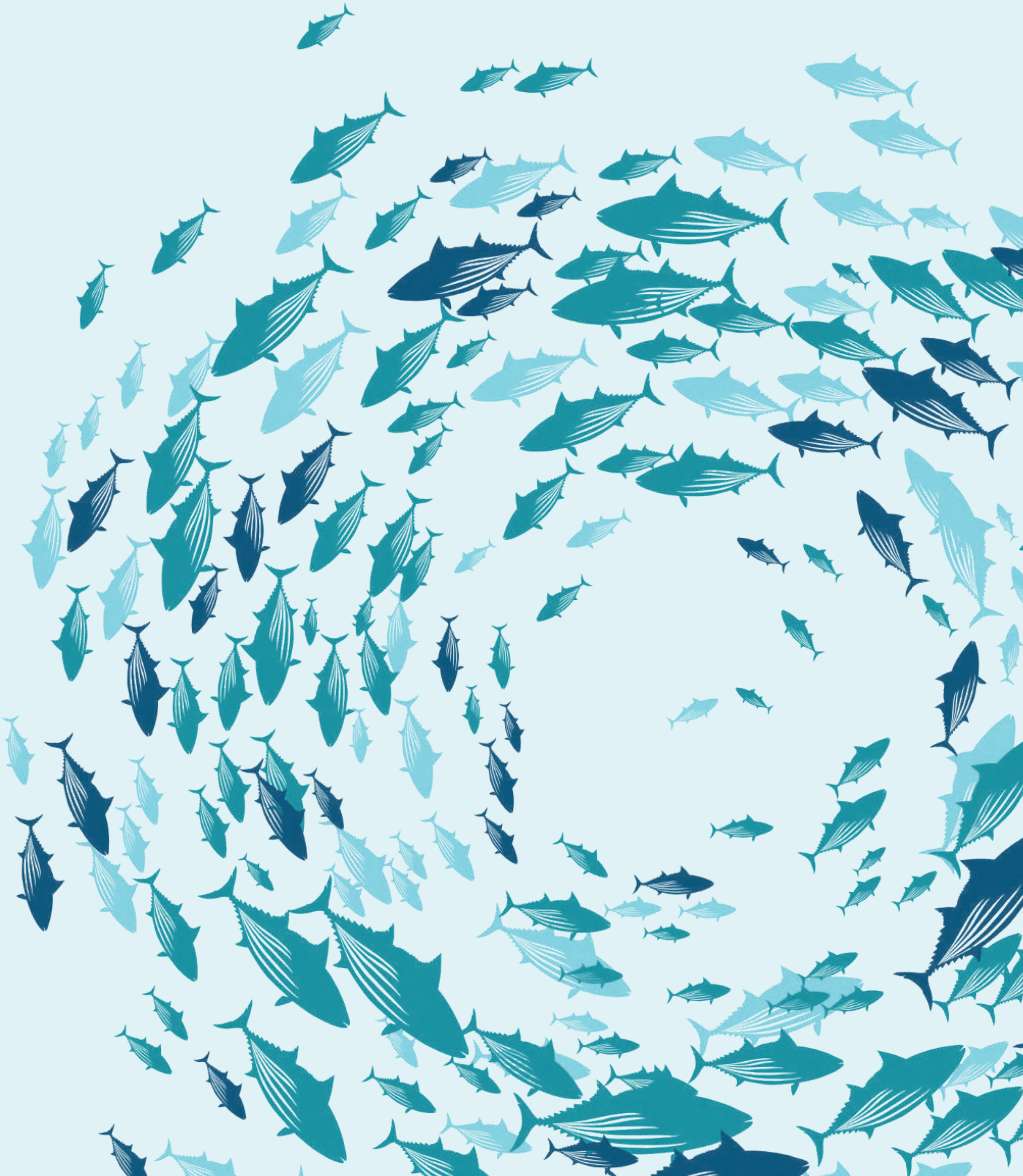
SUMMARY



PRESENTATION

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We present the *Sustainability of Skipjack Tuna Fishery in Brazil*, containing 13 unpublished chapters authored by about 45 researchers, who for three years worked to improve data on the species *Katsuwonus pelamis*, the skipjack tuna, one of the most important marine resources and a valuable commodity for the Brazilian fishing industry.

The research was part of an initiative created by FUNBIO[1] for a Project to Support Marine and Fisheries Research in Rio de Janeiro, to meet a compensatory measure of the Conduct Adjustment Term, conducted by the Federal Public Ministry – MPF/RJ, in partnership with Ibama, related to oil spills in Campo do Frade, in the Campos Basin, under the responsibility of Chevron. In this project, 16 study projects on the marine environment were approved, such as the ecology of threatened species or of fisheries importance; coral and rocky shore ecosystems; invasive marine species; social impacts of oil exploration on traditional communities; female participation in artisanal fishing; monitoring of fishing landings in Rio de Janeiro; and nutritional importance of the main targets of fishing.

The Skipjack tuna Project was one of them, having started its activities in 2016 and concluded in 2020, with the institutional name of "Skipjack Tuna Project: ecology and socioeconomics of *Katsuwonus pelamis* fishing on the coast of Rio de Janeiro aiming at stock assessment, sustainable management and its use in school meals". This project's main objective was to expand knowledge about the species and its habitat in Brazil, with special attention to the state of Rio de Janeiro, and to improve the understanding of the socio-economic dynamics related to the productive sectors of this fish. The information produced by the project, organized in this book, aims to contribute to public policies for the sustainability of the species, connected to the recommendations of international agendas and the commitments reiterated in the report from The Ocean Conference (2017)[2], which aim at the conservation of the biodiversity of the marine environment to promote sustainable development.

In order to address this thematic scope, work was carried out in partnership with institutes, study centers, research laboratories of five universities[3] and the regional research institute of fisheries activities[4], which jointly defined the specific objectives of the project. In this way, the different fields of different institutions characterize the Skipjack tuna Project as a multi-disciplinary research.

The multi-disciplinary characteristic occurs in the "participation of different areas of knowledge, with individualized goals under the same unifying theme"[5]. But the approach, in the knowledge production process, was interdisciplinary. Because, in addition to analyze the socioeconomic issues of the productive sectors in line with the recommendations of the Sustainable Development Goals (SDG – UN)[6], "interdisciplinarity creates new knowledge that simply adds the knowledge of the areas involved", which "goes beyond the limits of each

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[1] Available at: http://www.funbio.org.br/programas_e_projetos/pesquisa-marinha-e-pesqueira/. Accessed on: 20 Apr. 2020.

[2] Item 8 of the UN's Ocean Conference (2017) report highlights "[…] the need for an integrated, interdisciplinary and cross-sectoral approach, as well as enhanced cooperation, coordination and policy coherence, at all levels.". Available at: https://www.un.org/ga/search/view_doc.asp?symbol=A/CONF.230/14&Lang=E. Accessed on: Aug. 8. 2020.

[3] Universidade Federal do Rio Grande – FURG; Universidade Federal Fluminense – UFF; Universidade Federal do Rio de Janeiro – UFRJ; Universidade Estadual de Campinas – UNICAMP; and Universidade Federal do Rio Grande do Sul – UFRGS.

[4] FIPERJ – Rio de Janeiro State Fisheries Institute Foundation Research institution for fishing and aquaculture activities in the state of Rio de Janeiro.

[5] TOLEDO, P. M. Interdisciplinaridade: aspectos teóricos e questões práticas. *In:* VIEIRA, I. C.; TOLEDO, P. M.; SANTOS JUNIOR, R. A. *Ambiente e Sociedade na Amazônia*: uma abordagem interdisciplinar. Rio de Janeiro: Editora Garamond, 2014, p. 30.

[6] Available at: https://sdgs.un.org/. Accessed on: May 18. 2020.

discipline through the adoption of a common goal to be achieved "[7], and allows new issues to emerge.

To make interdisciplinary practice in the project feasible, special meetings, workshops (ws), were organized to provoke debate, encourage dialogue and promote interaction. Annually, the researchers met and presented partial results, while the others were able to question and debate. This interaction allowed us to broaden the issues, so that they could be more comprehensive and more enlightening. In addition, together, they solved problems that arose during the activities, and, finally, they were able to plan more direct partnerships for the production of articles and other studies.

In this process, many social issues were considered from observations in the field of human sciences; on the other hand, it was possible to get in touch with the language and perspectives of topics investigated by the specialties of marine biology and ocean sciences. The skipjack tuna was the key to improve the understanding of the connection of climatic phenomena in the marine environment that affect the dynamics of ocean currents, influencing the behavior of the species, which impact the various sectors in the production chain. These factors are examples that reveal that the intertwining between the researched objects can be reinforced with the interdisciplinary approach, above all, because it broadens the perspectives in the thematic development.

Over the course of three years, three workshops were held: (i) the first, on November 11, 2016, aimed to share the perspectives of each specific objective, to envision opportunities for cooperation and, mainly, to institutionalize relational spaces, seeking consonance in the production of knowledge; (ii) the second, on September 15, 2018, aimed to share the results obtained from the beginning to that moment, to evaluate the difficulties and to reprogram some specific objectives, but mainly for the planning of the production of articles and studies, as well as assessing ways to share the knowledge produced to a wider audience; (iii) the third took place in August 2019, when more conclusive results from some studies were presented, partial in others, but together they managed to agree on the possibility of publishing a book on the researched topics.

Sustainability of Skipjack Tuna Fishery in Brazil is, therefore, the result of the commitment established between researchers to produce texts that represent the three years of research, organized into four thematic units, with the purpose of grouping chapters with perspectives that dialogue with each other. The first unit deals with *The skipjack tuna habitat in the Southwest Atlantic*, and consists of two chapters: the first, *The oceanographic dynamics of the skipjack tuna fishing area in the Southwest Atlantic*, describes the behavior of marine currents related to topography of the Southern and Southeastern Continental Shelf, which influence the schools' preferred locations. The intensification of climatic phenomena is one of the main elements of analysis presented in one of the case studies, correlated to the modernization process aiming the sustainability of an important company in the industrial sector. The study highlights the results of the partnership between a private company and a research institute. The second, the *Use of electronic tags to identify movement patterns of skipjack tuna*, presents an unprecedented experience in Brazil, tagging specimens of skipjack tuna in order to refine data and confirm assumptions about the movement of the species in the Ocean. This experiment, within the scope of the Skipjack tuna Project, showed that, in order to improve information, it will be necessary to develop more research, incentives and stimuli, both to experiment with new technologies and to improve current ones.

The theme of the second unit is the *Life story* of the species, presented in five chapters. The first describes the *Early stages of the skipjack tuna life cycle on the Brazilian coast* and their distribution, at this stage, in the region. The chapter draws attention to the need for further studies on the initial phase in order to better understand the factors that "affect the distribution and survival of the species in this phase", given the commercial importance of

[7] TOLEDO, op. cit., p. 30.

the skipjack tuna. The second chapter, *Knowledge about the skipjack tuna life cycle in the Southwest Atlantic*, presents a study about the species in the adult phase, from samples obtained from fishing boats. The analyzes relate fish sizes, in weight and length, to geographic areas and seasons. They also present data that characterize the fish in the reproduction phase, which can guide actions aiming sustainability in fisheries management, considering that fishing individuals in the reproductive phase represents a risk for the future. The third chapter, *Genetics of the skipjack tuna on the Brazilian coast*: connectivity and demographic aspects, is a genetic and genomic approach to population and phylogeographic analyzes of the skipjack tuna from samples from the South, Southeast and Northeast regions. The objective was to verify the connectivity and genetic diversity of the species, through DNA sequencing of samples collected in these different locations. The verified data demonstrate that there is still no indicative of population decline, but the researchers draw attention to the need for further studies to improve these data. The fourth chapter, *Trophic ecology of the skipjack tuna in the southeastern and southern regions of Brazil*, analyzes the stomach contents of fish caught in different regions. According to what was found, the researchers characterized the feeding behavior of the species by correlating it with marine biological diversity by region. From the information available in the databases on the fish diet, it was possible, for example, to assess environmental changes.

The fifth chapter, *Contribution to the study of parasitism by helminths in skipjack tuna* in the Southwest Atlantic, presents data that draw attention to the number of occurrences of parasites found in relation to the number of fish analyzed. Considering the high commercial value in the skipjack tuna chain, the data presented point to the need for more research, especially on the marine environment, the fish habitat, and on the possible causes of the verified occurrence rates.

The third thematic unit is on *Fishing and sustainability*, and is composed of three chapters that present approaches that aim at the sustainability of skipjack tuna fishing from available data. The chapters reaffirm the need for further research and emphasize the importance of policies for systematizing data on fishing activity. The first, *Dynamics of the pole and live bait fleet in the Southwest Atlantic*, analyzes the sustainability of fishing through the dynamics of the fleets, taken as a tool, and identifies the differences in the fishing strategies adopted by the fleets of Rio de Janeiro and the Rio Grande do Sul, such as fishing technology, movement patterns between fishing areas and catch position. The second, *Stock assessment of skipjack tuna in the Southwest Atlantic*, presents the construction of scenarios, based on a mathematical model, aimed at the sustainability of the species. They are constructions based on data and scientific information, whose projections provide fundamental information to see the situation of this natural resource. The third chapter, *Overview of the pole-and-line bait fishing in the Southwest Atlantic* results from a search for information about this fishing gear, from the year 1979 to 2018. It is an angled approach to the fishing production statistical data, available in the reports of several fishing management institutions in Brazil. In addition to tables on scientific production during the periods, the text suggests the correlation of research with the expansion of activity. The analyzes generated by the researchers reinforce the need to establish a public policy to improve data collection with more research, in addition to efficient management strategies, which guarantee the sustainability of this fishing.

The fourth unit, *Socioeconomy in skipjack tuna fishing*, has three chapters that highlight the social issue. The first, *Socioeconomic dynamics and social conflicts in the production chain of the skipjack tuna in the state of Rio de Janeiro*, seeks to identify the profile of the workers that make up the production chain in the state of Rio de Janeiro. After verifying that information from some official databases does not reflect the category, the researchers went to the field to collect direct information, accompanied industrial and artisanal landings, and interviewed people involved in the chain. The experience of direct contact with people, added to the analysis of the content of the collected interviews, allowed to identify the types of problems that the sector faces, such as, for example, the restrictive aspects of rules and laws, from an environmental and of security; factors related to seasonality in the availability of live bait, the moments of scarcity of fish; difficulties in modernizing vessels; and "instability and gaps in management and policies to promote the fishing sector". The case study on the skipjack tuna fishing in the state of Rio de Janeiro reaffirms the importance of interdisciplinary research to see the elements that configure the arenas of social conflicts of one of the most coveted marine resources of high industrial value.

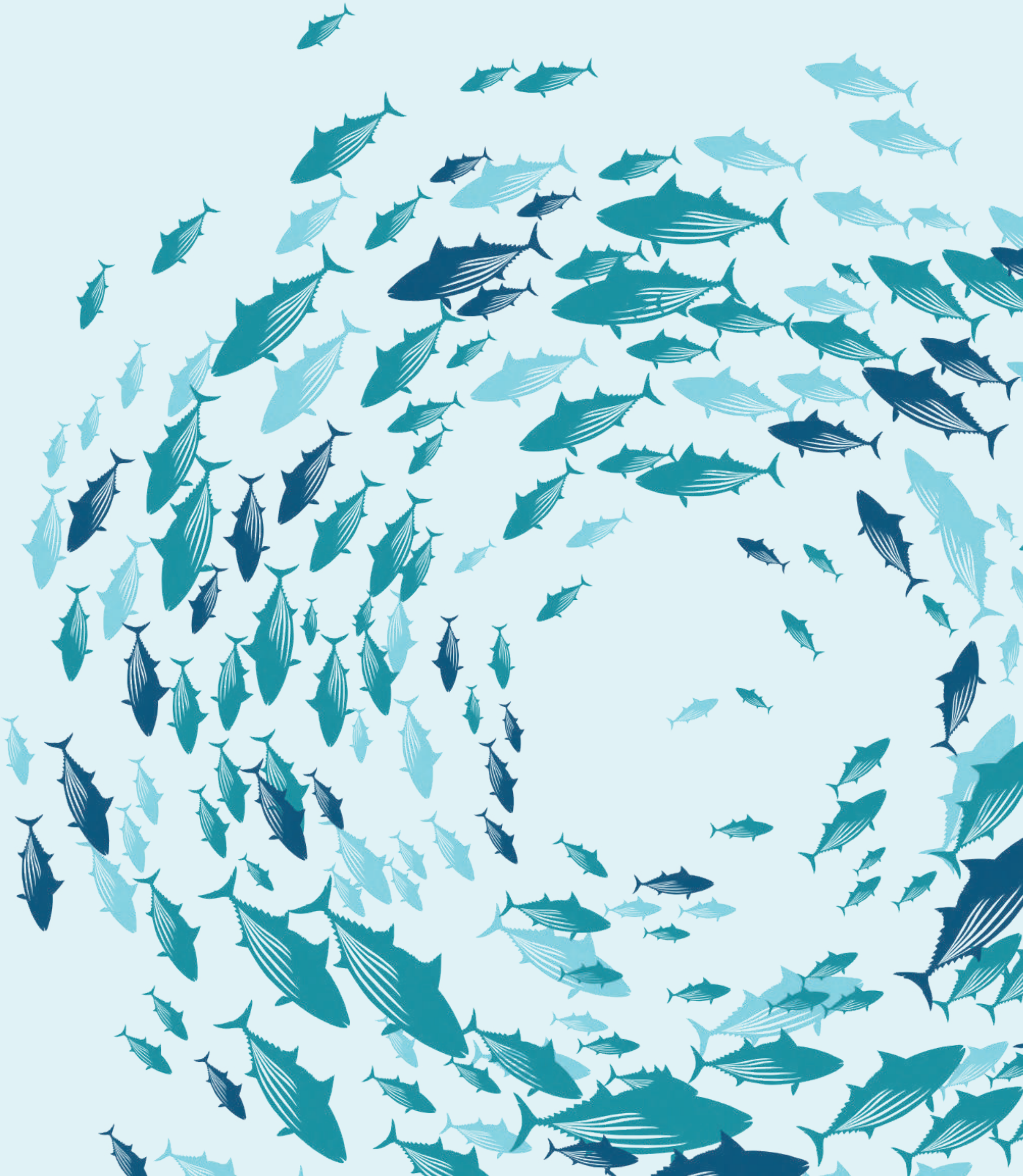
The second, *Analysis of the acceptability of skipjack tuna by public school students in the municipality of Macaé*, brings an indirect social approach, considering that it is a natural resource extracted from Brazilian waters, of high nutritional value, which could contribute to complement poor diets in proteins across the country. Within the scope of the Skipjack Tuna Project, this research object specifically aimed at providing data to suggest to the agents of the National School Feeding Program (PNAE) the adoption of fish in school meals, with the purpose of enriching the lunch with high quality protein.

The third, *Development and prospects for the marine-fishing activity of skipjack tuna*, also aims at the social and economic aspect. The researchers present data on the low consumption of fish in the country, and, in view of this, make a broad diagnosis of the fishing activity, analyzing in detail the structure of the skipjack tuna productive chain, "highlighting its market sizes", comparing it to the historical process of structuring and modernizing the chicken and pork production chain over the past 50 years. The objective is to exemplify and illustrate the complexity of processes necessary to foster the development of the sector, aiming at increasing the social reach in the consumption of skipjack tuna. The chapter offers a Development Plan with detailed analysis of the dimensions: institutional, technical-operational and market. Based on these analyzes, the chapter presents perspectives for the development of the marine-fishing activity in Brazil, organized into four focuses: costs, consumption, sustainability and value generation.

The chapters that comprise *the Sustainability of Skipjack Tuna Fishery in Brazil*, are studies that aim to improve the understanding of this important marine natural resource and the aspects related to socioeconomic activities. The objective is that the information presented here can contribute for sustainability in all its fishing scope to be effective. The book is part of the interdisciplinary process of sharing knowledge, making available the information produced, facilitating access to those who seek to broaden their understanding of the topic. But, above all, to reinforce the value of multidisciplinary scientific research.

Unit I

THE SKIPJACK TUNA HABITAT IN THE SOUTHWEST ATLANTIC



The oceanographic dynamics of the fishing area of the skipjack tuna in the Southeast Atlantic

2

Lauro A. Saint Pastous Madureira,
José Luiz L. Azevedo,
André L. Brum, Juliano L. Coletto,
Marcelo P. Pinho, Caroline M. Varela

Introduction and Background

The southern and southeastern regions of Brazil include the coastal zone, the continental shelf and the embankment between Cabo de São Tomé-RJ (22°00' S and 41°30' W), at its northern limit, and an imaginary oceanic line between Brazil and Uruguay, in the position of Chuí-RS (33°44' S and 53°16' W), at its southern limit.

Rossi-Wongtschowski & Madureira (2006) organized an extensive work with different authors on the oceanographic environment of this region, including: a) thermohaline structure and ocean circulation; b) climatology and fishing resources; c) composition of water bodies and their productive potential; d) primary production of phytoplankton in the region between the Cape of São Tomé (RJ) and Chuí (RS); e) distribution of marine zooplankton and ichthyoplankton; f) production of demersal fish, in addition to its hydrography and biological production. The knowledge gathered in the referred study is fundamental for the understanding of the oceanographic environment of the southeastern and southern regions and its fishing production. A significant portion of the chapter developed and presented below has evolved based on this work.

Madureira & Rossi-Wongtschowski (2005), in a study in the southeast-south region of Brazil (SE/S), between Cabo de São Tomé (RJ) and Chuí (RS), focusing on bait species, evaluated the distribution, abundance and environmental interactions of small to medium-sized pelagic species. The study was divided into two parts where, in the first, we have the results on the distribution, abundance and environmental interactions of these pelagic species on the platform, slope and oceanic region. Two aspects then caught the attention of the authors of this study. Firstly, the enormous diversity found, the majority of which are formed by forage species and which are the food for larger species, including the skipjack tuna. Second, but no less relevant, is the fact that forages play an important role in the transfer of energy in the ecosystem, and this study was the first to show its ecological importance on the Brazilian coast. In the second part, the authors evaluate the biomass of the species under analysis. This study was complemented with the important contribution of the edition of the book by Rossi-Wongtschowski & Madureira (2006), which had ocean fishing and the biodiversity of the Southeast/South region as objects of analysis.

However, the two works mentioned did not address the issue of top predators, such as, for example, tuna. Thus, to partially fill this gap, this chapter will continue studies that involve fishing resources and the oceanographic environment, in this case, focusing on the skipjack tuna species (*Katsuwonus pelamis*).

It is interesting to note that this species moves throughout the SE/S region of Brazil, as described in Chapters 9, 10 and 11. In this sense, the aforementioned past studies, in particular that of Madureira & Rossi-Wongtschowski (2005), complement the most recent observations on the skipjack tuna diet and, together, allow to expand the knowledge about the bioecology of this species, including new information about the forages themselves (see Chapter 7). In addition to updates on diet and bio-ecology, this book contains descriptions of fishing (Chapter 9, 10 and 11), the production chain (Chapter 14) and socioeconomic aspects associated with skipjack tuna (Chapter 12).

According to Matsuura & Andrade (1999) and Andrade (1996), the areas with concentrations of skipjack tuna move from the smallest to the largest latitudes according to the progress of the seasons, reaching the southern end of the Brazilian coast in the summer, where areas of higher concentrations can be found close to the Subtropical Convergence Zone (ZCST).

The Ministry of the Environment (MMA, 2006), in a review on the fishing resources of Brazil, confirms that the skipjack tuna is the most abundant species of tuna in the country, occurring in higher densities in the intermediate platform and on the higher slope. Vilela & Castello (1993) illustrated the area of distribution of the species in Brazilian waters according to the onboard maps of the commercial fleet and with the results of exploratory fishing cruises with fishnets in the southern region (HABIAGA *et al.*, 1986; CASTELLO & HABIAGA, 1989). These authors indicated that the distribution of the species depended on the temperature distribution in the surface layer of the sea (SST) and, in addition, they reported that the average temperature of the highest occurrence of the species was 23.3° C, in a range of 17.8° to 26.2° C.

Skipjack tuna Fishing Area in the Southeast and South Regions of Brazil

The sector of the Brazilian coast formally called the Southeast-South Region has an extensive continental platform that can be divided into the Southeast Continental Platform (PCSE) and the South Continental Platform (PCS), based on its geomorphological characteristics (ROSSI-WONGTSCHOWSKI & MADUREIRA, 2006).

The PCSE extends from Cabo de São Tomé-RJ (22°02’ S and 041°03’ W) to Cabo de Santa Marta Grande-SC (28°36’ S and 48°48’ W), with its share more extensive (~ 230 km) located in front of the city of Santos. Its narrowest stretches are located in the vicinity of Cabo Frio (~ 50 km) and Cabo de Santa Marta Grande (~ 70 km) (CASTRO *et al.*, 2003), as can be seen in figure 1.

The topography of the PCSE is smooth on the continental shelf, with the isobates being arranged practically parallel to the coastline and where the depth of the platform break varies between 120 m and 180 m. The total estimated area of the PCSE is approximately 150,000 km^2 (e.g., ZEMBRUSKI, 1979; PINHO *et al.*, 2011).

The South Continental Platform (PCS), in turn, is located between the Cape of Santa Marta Grande and the ocean border Brazil-Uruguay (Arroio Chuí-RS – 34°44’ S and 53°22’ W). It is interesting to note that fishermen refer to this motto as “the stripe”, in analogy to a layout that was made in the old paper nautical charts, published by the Brazilian Navy. This is a purely geopolitical division (REVIZEE, 2006).

The northern sector of the PCS is narrower, with approximately 110 km, extending to the south until reaching 170 km in the region of the Cone of Rio Grande (see figure 1). The coastal boundary and topography of the underwater bottom are relatively uniform (FIGUEIREDO & TESSLER, 2004; FIGUEIREDO & MADUREIRA, 2004; COOKE *et al.*, 2007; LUMI COSTA *et al.*, 2013).

The coastal and ocean waters that flow in the southeastern and southern regions are under the dynamic action of the convergence of the Currents of Brazil (CB) and the Malvinas (CM), forming the western border of the Subtropical Convergence (CS) (CASTRO *et al.*, 2003; CASTRO & MIRANDA, 1998; PIOLA *et al.*, 2000), sector where Matsuura & Andrade (1999), Andrade (1996), Lima *et al.* (1996) and Andrade (2003) indicated high concentrations of skipjack tuna, based on the onboard maps of the fishing fleet of this species.

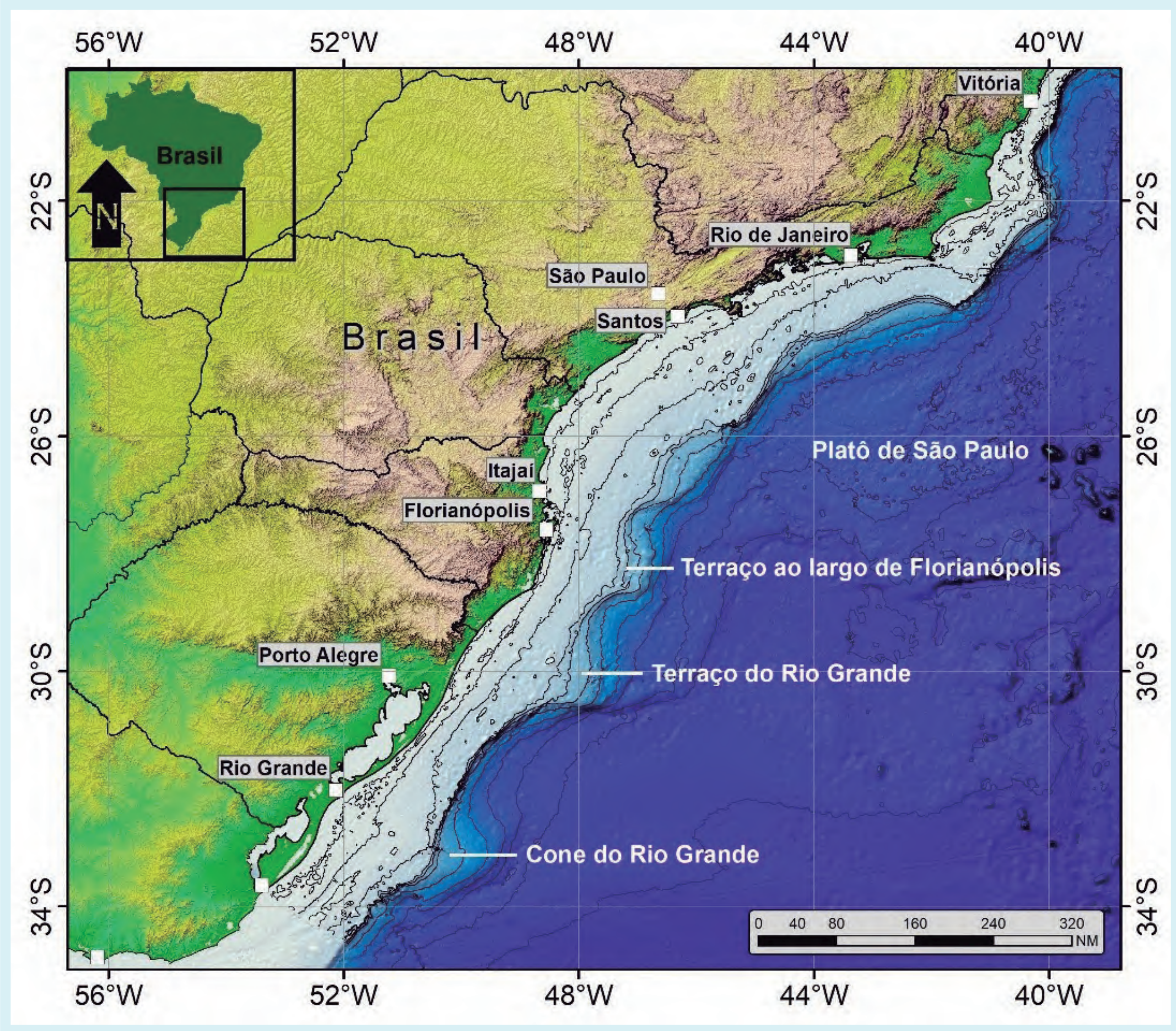


Figure 1. Continental Southeast-South margin of Brazil and its main features.

In the South Atlantic, the Brazilian Current is the contour current that forms the western arm of the Subtropical rotation. West contour currents are characterized by intense, narrow and well-defined flows, flowing off continental margins or from the embankment (e.g., CASTRO *et al.*, 2003). It is important to highlight that the Brazilian Current advances, frequently, on the continental shelf and causes impacts on the distribution of ichthyofauna, forage species and predators, as the fishing data will show next.

The Brazilian current flows south and is formed by the stacking of water bodies characteristic of the South Atlantic, that is, Tropical Water (AT), Central Water of the South Atlantic (ACAS) and Coastal Water (AC). The thermohaline structure and circulation in the SE/S region, between Cabo de São Tomé (RJ) and Chuí (RS), are extensively described in Belmiro *et al.* (2006), in chapter 2 of Rossi-Wongtschowski & Madureira (2006), among countless other works.

In the PCSE, the Cabo Frio region is characterized by the occurrence of resurgences due to the NE incident wind regime, which results in a transport of coastal waters towards the shelf, as a consequence of the Ekman transport. Figure 2 illustrates a resurgence event in Cabo Frio, which developed mainly between 12/26/2019 and 1/3/2020, when continuous NE wind days caused a gradual cooling in the area, which accentuates to the west.

The resurgences of shelf breaks observed in the region are determined by the meandering pattern of the Brazilian Current and the vortices formed by this current (e.g., CAMPOS *et al.*, 1995). Probably, one of the sources of disruption that can lead to generation of vortices in this area is the effect of the local topography on the basic flow (VELHOTE, 1998) and the change in the orientation of the coastline in the Cabo Frio region (CAMPOS *et al.*,1995). Figure 3a illustrates a series of cyclonic and anticyclonic vortices, approximately aligned with the embankment, generated by the meandering of the Brazilian Current in its movement to the south. Figure 3b shows the respective distribution of chlorophyll concentration on the surface, resulting from the action of cyclonic gyrations that pump cold waters and rich in nutrients from deeper regions of the water column to more superficial regions towards the action of sunlight (KLEMAS, 2013).

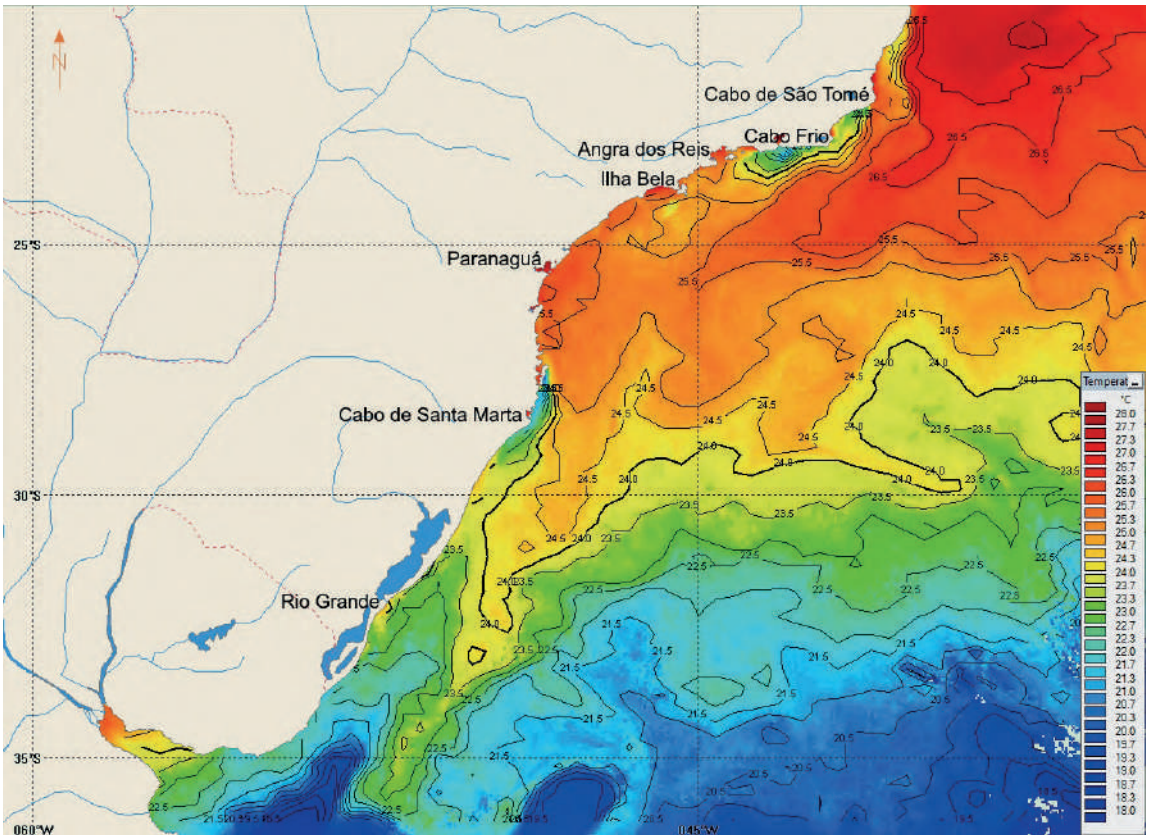


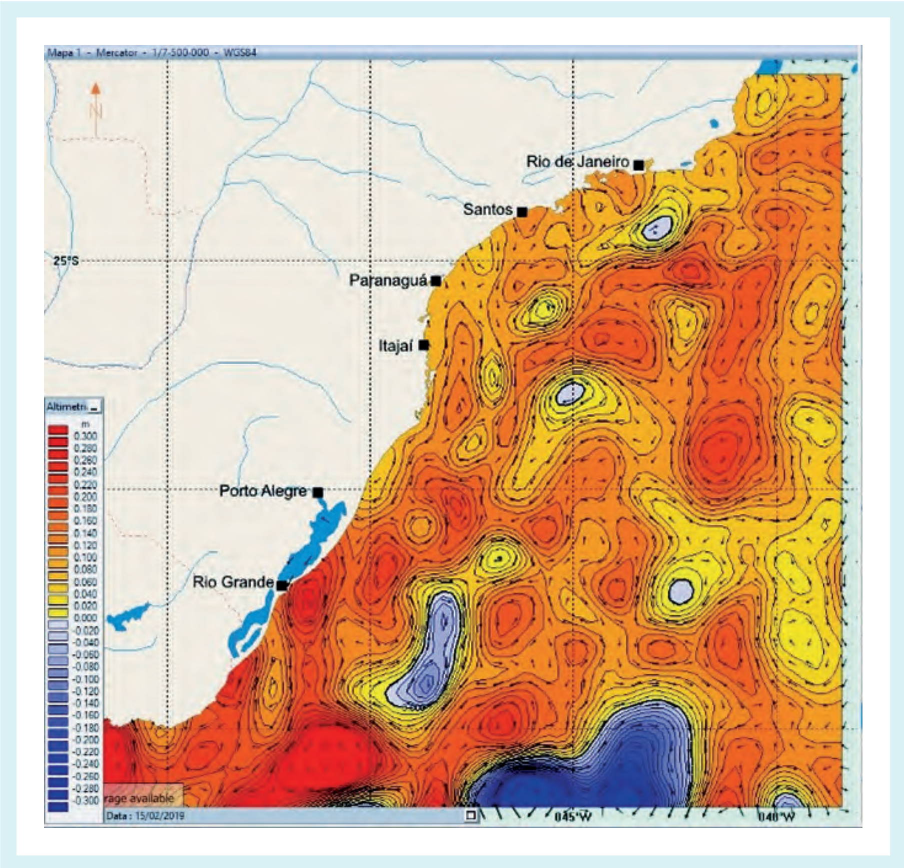
Figure 2. SST image of 1/3/2020 (color scale covering temperature values between 19.4° C and 28.4° C). There is a resurgence in the area between Cabo de São Tomé and Cabo Frio, close to Angra dos Reis (in blue). To the south/southwest of Ilha Bela to the vicinity of Paranaguá (PR), there is an area with an orange color, or a less intense red than that of the other sectors of the Brazilian Current. The embankment is located in this area and is indicative of the proximity of the ACAS to the surface. In the southern region of Cabo de Santa Marta there is also a resurgence zone.

In summer, the predominance of winds from the north quadrant, especially from the northeast, favors the incidence of resurgence of platform breaks in the northern and central region of the PCSE, the intrusion of ACAS on the internal shelf and the presence of a seasonal thermocline.

In figure 2, mentioned above, there is a resurgence in the area between Cabo de São Tomé, passing through Cabo Frio, to the vicinity of Angra dos Reis. To the south/southwest of Ilha Bela to the vicinity of Paranaguá (PR), there is an area with an orange color, or a less intense red than that of the other sectors of the Brazilian Current. The embankment is located in this area and is indicative of the proximity of the ACAS to the surface. In the southern region of Cabo de Santa Marta there is also a resurgence zone.

During winter periods, winds from the south quadrant can induce conditions of water subsidence, weakening the thermocline and forcing ACAS towards the platform break (CASTRO & MIRANDA, 1998).

(a)



(b)

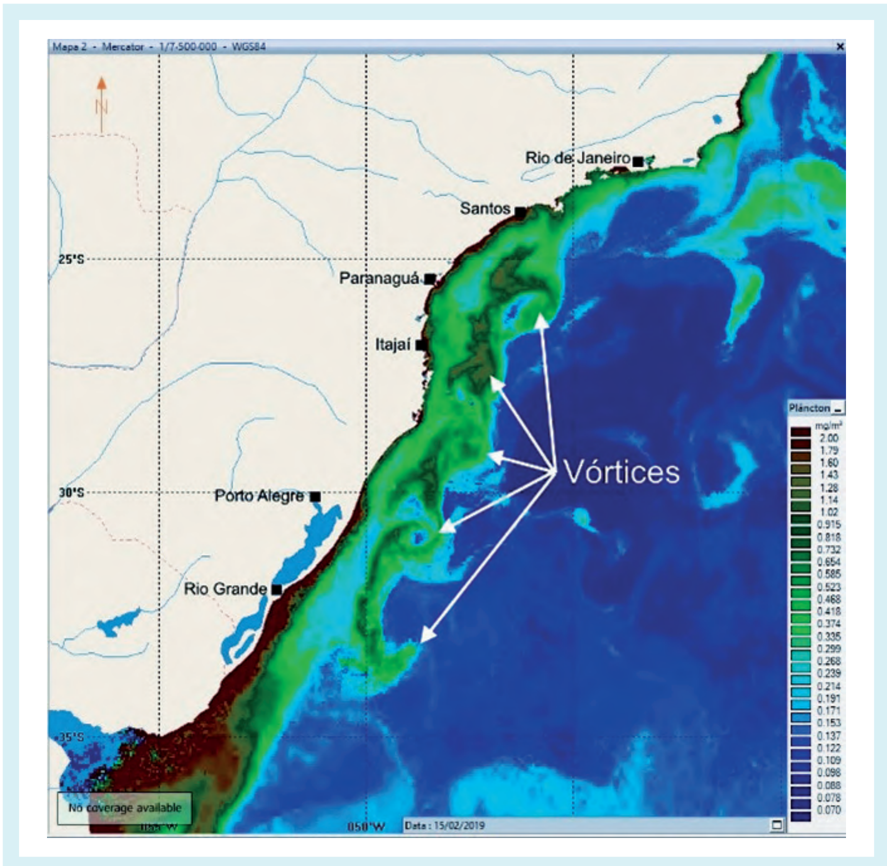


Figure 3. (a) Altimetry of the SE/S region showing vortices generated by the meandering of the Brazilian current, where warm colors (orange) are associated with anticyclonic vortexes, of warm core, which present elevation of the sea surface, while cold colors (bluish) are associated with cyclonic vortexes of cold cores, with lowering of the surface. (b) Chlorophyll concentration showing the impact of cyclonic vortexes (Vótices) for the same region.

Figure 4 shows a sequence of 8 days of N/NE wind in Cabo Frio, starting on 12/26/2019 and extending until 02/01/2020, and shows the intensification of a process of surface waters cooling westwards, especially on 01/01/2020.

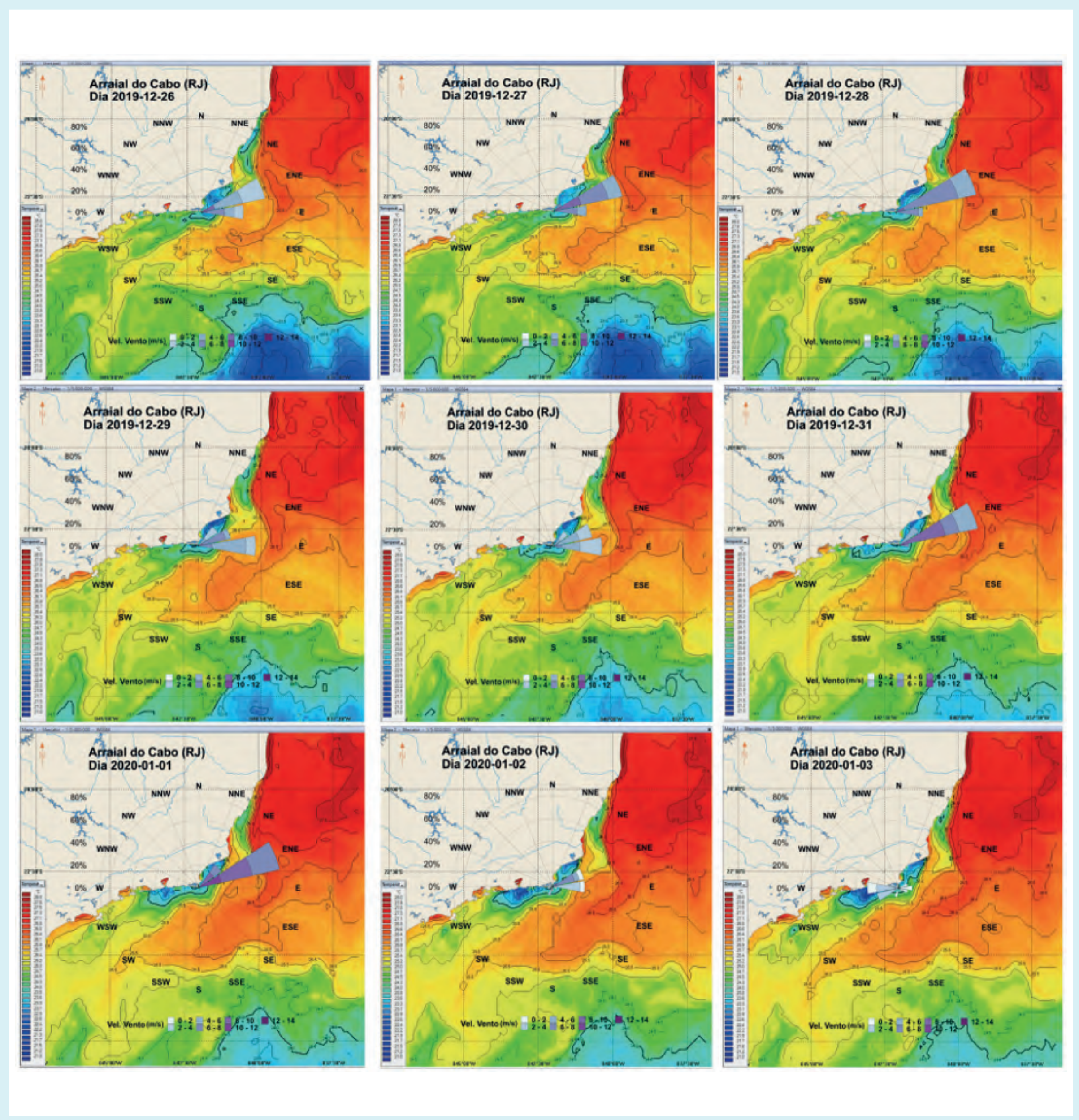


Figure 4. Dynamics of SST in the Cabo Frio region between 12/26/2019 and 1/3/2020, under different wind systems.

In the same figure, there is also the turn of the wind to the west on 03/01/2020 and the gradual warming of the waters of the region, with the CB overlapping the ACAS, which retreats. The oceanic dynamics around Cabo Frio and Cabo de São Tomé will be better detailed at the end of this chapter.

Studies of coastal and ocean waters off the continental shelf and offshore, covering the Exclusive Economic Zone (EEZ) of the PCSE and PCS of Brazil, suggest that the distribution of the hydrographic properties of the water bodies and their circulation are conditioned by meteorological forces, by the western contour currents of tropical and subtropical origin, as well as by the direct or remote influence of river discharge of estuarine and lagoon systems (GARCIA *et al.*, 1998; CASTRO *et al.*, 2003; BELMIRO *et al.*, 2006).

The distribution of temperature and salinity in winter and summer confirms the idea that the meandering induced by resurgence of shelf breaks plays an important role in pumping ACAS from the embankment region to the continental shelf (CAMPOS *et al.*, 2000).

In the PCS, the resurgence region of Cabo de Santa Marta Grande is characterized by frequently stratified shelf water, with warm and salty water on the surface, originating in the CB, and cold, less saline and nutrient-rich waters, from ACAS (e.g., CASTRO *et al.*, 2003).

Skipjack Tuna Fishing

We will use the mention of ACAS and its rise to the surface to open a window that allows us to put ourselves in contact, at least theoretically, with fishing boats working in the sea, fishing the skipjack tuna. These boats, generic for the time being, operate over 90% of their time without having visual contact with land. In fact, until not too long ago, 20 years, contact with land was restricted to communications via SSB radio (Single Side Band), which required a large amount of time to establish communication, which was of low quality and restricted only to voice, at least until the FAX phase, when the weather charts started to arrive on board.

The giant technological advance, which has been developed since those times (1980s, 1990s), allowed any tool that could connect and establish communication via the internet to be able to arrive on board. From a situation where there was an almost complete ignorance of what was happening on land, it moved to another, in which there is nothing that happens on the planet that is not immediately known on board.

Back to the rise of ACAS, if this body of water rises towards the surface and differs thermally from CB, and knowing that artificial satellites capture these thermal differences, as well as the color of the oceans, and still measure other variables remotely of the marine environment and commercialize them, then, those boats that moved on gigantic volumes with very low information now have the opportunity to put themselves in another level. The science called Operational Oceanography (ARVIDSON *et al.*, 2000; KLEMAS, 2013) has been associated with fishing and has shown surprising results that will be explored in the sequence.

The connection between satellite images and skipjack tuna fishing off the coast of Brazil is not new, Andrade & Garcia (1999) and Andrade (2003), already dealt with the relationship between SST, thermal fronts and skipjack tuna. Between the period of those studies and the current one, the development of Operational Oceanography was immense, but, in Brazil, little has arrived to fisheries. Some aspects of this topic are discussed in Chapter 3. However, there was a situation in which the technology arrived on the skipjack tuna fishing boats, and it will be described throughout this chapter.

At the beginning of 2013, Indústrias Alimentícias Leal Santos Ltda., a company that owns 6 skipjack tuna fishing boats, with 25 years of tradition in this activity and 130 years since its creation, established contact with the Federal University of Rio Grande (FURG) research group, which presents this chapter. The company had acquired 7 licenses of the CATSAT[1] Software, 6 for installation on board the company's 6 fishing boats and 1 license for an onshore operational base. CATSAT is a software to assist in the decisions that must be taken to optimize the operation of vessels that act in the fishing of pelagic resources (CATSAT, 2015).

[1] CATSAT (www.catsat.com) is an Oceanographic service for fishermen developed by CLS company. CLS (https://www.cls.fr/en/), a subsidiary of CNES and CNP, is a worldwide company and pioneer provider of monitoring and surveillance solutions for Earth since 1986. The company is exclusive provider of ARGOS environmental data. CATSAT service is the result of CLS 'expertise in satellite technology and Oceanography. It is an integrated solution with the highest resolution available oceanographic maps, meteorological products and fishing oriented tools, all in a user friendly GIS software. CATSAT also offers the support of a team of oceanographers, helping in oceanographic interpretation and decision making to captains while at sea. As a consequence of all the mentioned, it is currently used by the most modern fishing vessels in the three oceans, being nowadays the leader in ocean-graphic services in the fishing industry.

As is known, pelagic fish species are not randomly distributed, but conditioned by certain environmental variables that define their habitats (AGENBAG *et al.*, 2003; ACHA *et al.*, 2004; MUGO *et al.*, 2010).

The problem that Leal Santos was facing, however, was that they encountered difficulties in operating the software, interpreting the satellite images, as well as taking advantage of the potential of the information available through global oceanographic models, accessible through the software. In addition to this situation, there was the question of how to proceed so that this package of technology and data interpretation was in fact assimilated by the masters of the boats, all experienced professionals on the skipjack tuna fishing.

In the following text, we try to explain and exemplify how the work between the University and the Company was developed, in an interactive way between teachers, technicians, undergraduate and graduate students, directors, fishing experts and fishermen, in a continuous learning. Regular meetings made it possible to update and level the group, and the know-how reached the crews whenever the majority of the boats were on land.

Work Development

Formally, from 2013 to the present, FURG's Institute of Oceanography (IO) maintains an active agreement[2] with Indústrias Alimentícias Leal Santos Ltda. (LS). If, on the one hand, IO-FURG has a 40-year tradition of science applied to fisheries, on the other hand, LS has a pole-and-line/bait boat skipjack tuna fishing operation for 25 years, as already mentioned. The results of this public-private partnership emerged gradually, evolving with the theory being confronted with the practice, effectively on a daily basis, as will be analyzed below. From the beginning, there was integration and direct participation of undergraduate, master and doctoral students and of fishing masters.

In 2016, already as an outcome of partial results of this work, the IO-FURG research team joined researchers from four more public universities, namely: UFRGS, UFF, UFRJ and UNICAMP, in addition to FIPERJ (Foundation for the Fisheries Institute of the State of Rio de Janeiro), for the development of the research project entitled: "Skipjack Tuna Project: ecology and socioeconomics of *Katsuwonus pelamis* fishing off the coast of Rio de Janeiro", aiming at stock assessment, sustainable management and its use in school food, approved in the project call 02/2016 (Project to Support Marine Research in Rio de Janeiro) of FUNBIO, which this book is about. The knowledge generated in the work started in 2016 will be adequately addressed in the different chapters that integrate this book.

At this point, it is important to highlight the fact that the call for projects 02/2016, mentioned above, was induced by a TAC (Term of Adjustment of Conduct) to subsidize the sustainable use of fishing resources in Rio de Janeiro. On the one hand, as part of a federation, Rio de Janeiro has no fishing resources of its own and, on the other, the fishing resources that frequent the coast of Rio de Janeiro also frequent other Brazilian coasts. We believe that, at the time the TAC was formatted, the reading would have been that Rio de Janeiro's fishing resources intended to include those landed in Rio de Janeiro, that establish a production chain in that state. Chapters 12 and 14 will cover these aspects in detail.

The fishing for skipjack tuna really started in Rio de Janeiro, in 1965, and continues today. However, there was the emergence of fleets from other states that fish in Rio de Janeiro, as well as on the coast of São Paulo, Paraná, Santa Catarina and Rio Grande do Sul. The Rio de Janeiro fleet, its dynamics over time and performance are discussed in detail in Chapter 9.

[2] Agreement No. 021/2013.

The results presented below are the outcome of the work started in 2013 with Leal Santos and which continues today. In fact, the structuring of this chapter associated with this fleet is due to the fact that while assessing boat movements, the team was inevitably included in the oceanography of the SE/S region. In addition, two short cruises (one week each) were carried out around Cabo Frio, within the scope of the Skipjack tuna Project - FUNBIO.

The results were organized into three Case Studies, based on three time scales on the variability of SST, for the data that incorporate this chapter. Case Study 1 deals with the variability of SST in the order of days, recorded in fieldwork, Case Study 2 expands the time scale between years, with analyzes linked to the Leal Santos fleet, and Case Study 3 assesses the variability of SST between decades, with the expansion of research covering the national fleet.

Case Study 1: SST variability on a daily scale

In this case study we will explore data obtained during the Skipjack tuna-FUNBIO 2018 Oceanographic Cruise, which, in the development of this text, will be briefly treated as Skipjack tuna Cruise 2018.

The region prospected during the cruise was originally established with the objective of evaluating the sector of the southeastern coast, where the specimen of skipjack tuna should be tagged. This tagging, in turn, aimed to study the movements of the species in the South Atlantic Ocean (OAS), which are processed in Chapter 3.

The tagging would have to be carried out on large skipjack tuna (greater than 65 cm) that, historically, are captured in the region east of Cabo de São Tomé, as well as in the surroundings of Cabo Frio. In fact, the tagging took place in the south of Cabo Frio.

The assessment of the area included hydroacoustic prospecting with a scientific echo sounder (SIMRAD, model EY60), operating at a frequency of 120 kHz, over 649 nautical miles (1,202 km). In situ environmental data were obtained with 46 launches of the CTD equipment (SEABIRD, model SBE 25 Plus), with coupled sensors for temperature, conductivity, pressure, dissolved oxygen and fluorescence.

In the conception of the sampling design, the first step was to pre-plan the extension of the profiles to be prospected, in order to distribute the sea time, or sampling effort, in the most homogeneous way possible between the limits of the study area. The sweep should cover the middle shelf, extending to the embankment. Figure 5 shows the sample design on a bathymetric map.

The second aspect aimed to distribute the sampling effort over sectors with colder waters and greater potential for the location of skipjack tuna prey, based on Madureira *et al.* (2005). In this sense, SST images were used to identify the distribution of this parameter in the work area. Figure 6 shows the sample design, projected on the SST image on the day the work started.

During the development of the Skipjack Tuna Cruise 2018, there was a variability in SST in the order of days, which impacted the results of the work and generated the notes that follow.

The SST images shown in figure 7 refer to the beginning (09/18/2018), middle (09/22/2018) and end (09/25/2018) of the cruise under analysis, and show a considerable variation in SST, especially between the beginning and the end of the cruise, within an interval of 8 days. In fact, the SST values observed in the image of the fifth day of work already indicate surface heating (Fig. 7b), in relation to the previous 4 days. Therefore, the oceanographic structure observed based on the SST images between the half and the end of the cruise (Fig. 7b and 7c) was quickly changed. This dynamic drew attention because the scenario, or the “SST landscape” on which the sample design was projected, with the expectation of prospecting more intensively the sectors with lower surface temperature waters, was modified.

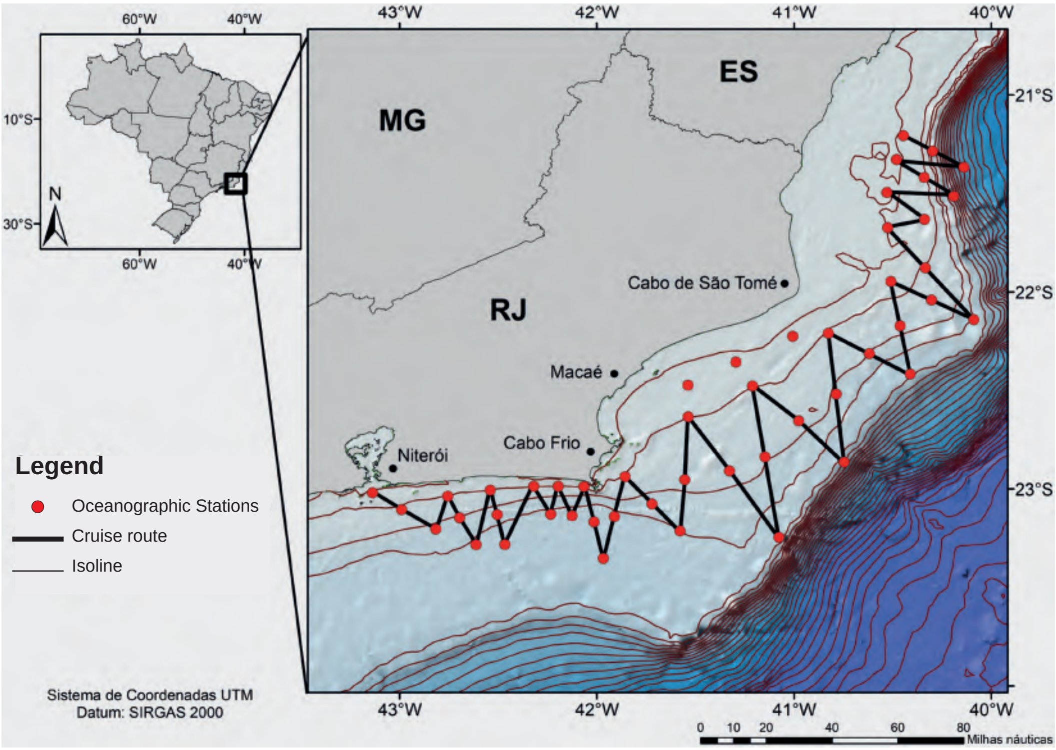


Figure 5. Oceanographic cruise performed in the northern sector of the area of occurrence of skipjack tuna.

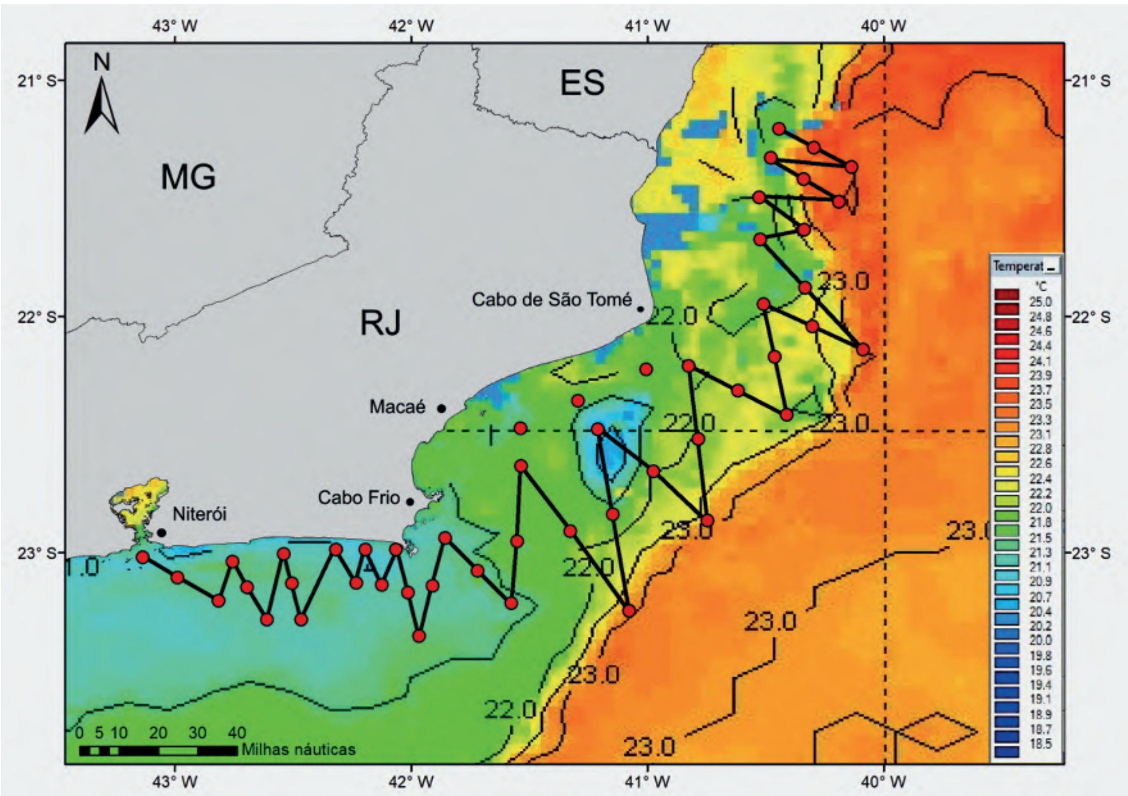


Figure 6. Sample diagram projected on the SST image of the 2018 Skipjack tuna cruise start day.

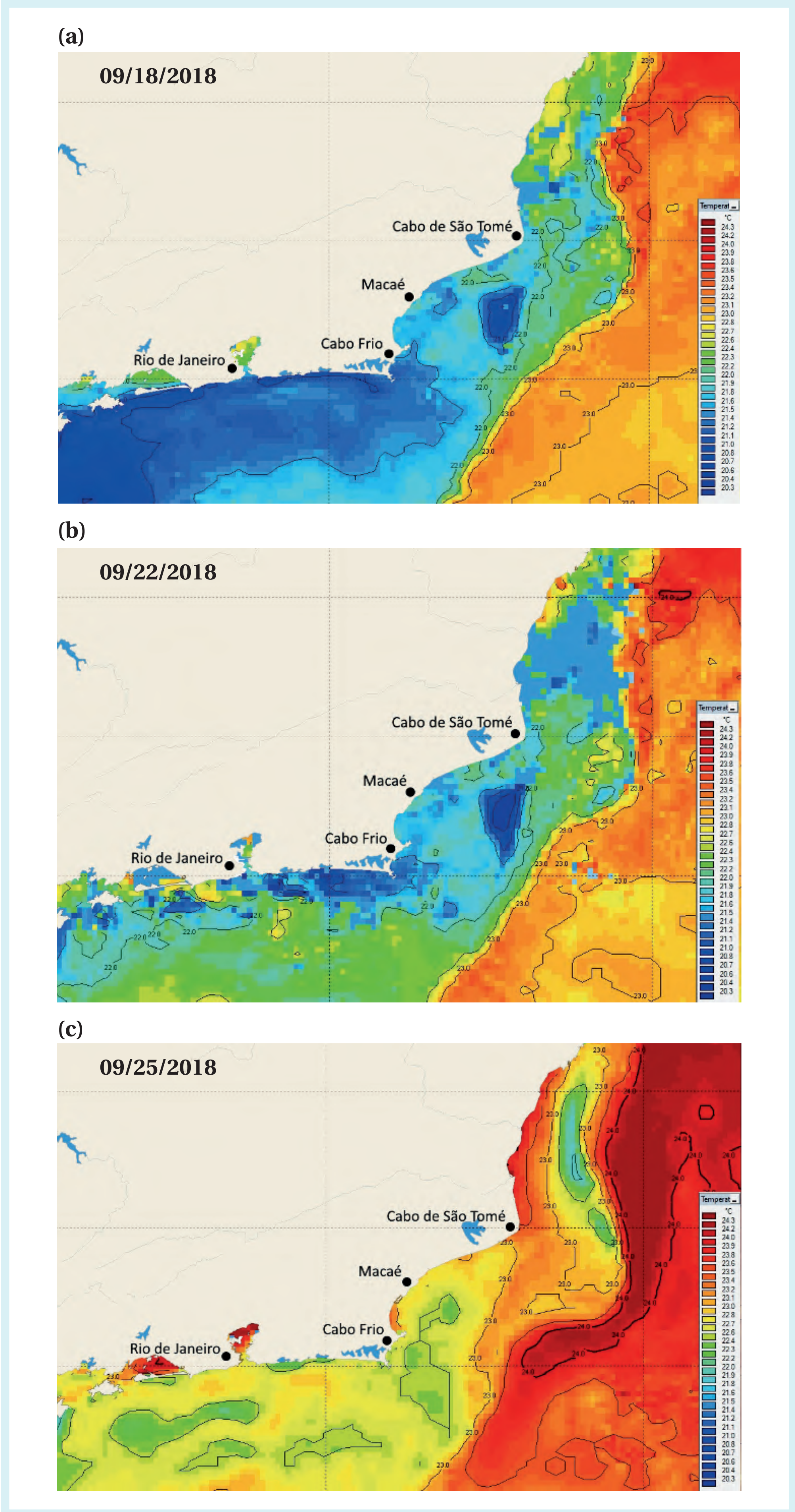


Figure 7. SST images of the beginning (a), middle (b) and end (c) of Skipjack tuna cruise 2018.

In the hope of better understanding the SST variability, the wind system was analyzed, pre-cruise and during the cruise. In the previous period, the work was carried out with a predominance of NE winds, according to data from the Macaé Meteorological Station (Fig. 8a). Winds from this quadrant favor the resurgence process in the region, as reviewed at the beginning of this chapter and also shown in figure 2.

In the period between September 18 and 20 2018, the wind direction changed, moving to southwest/west (Fig. 8b and 8c), common during the passage of cold fronts through the region. Winds remained in the south quadrant after the 20th.

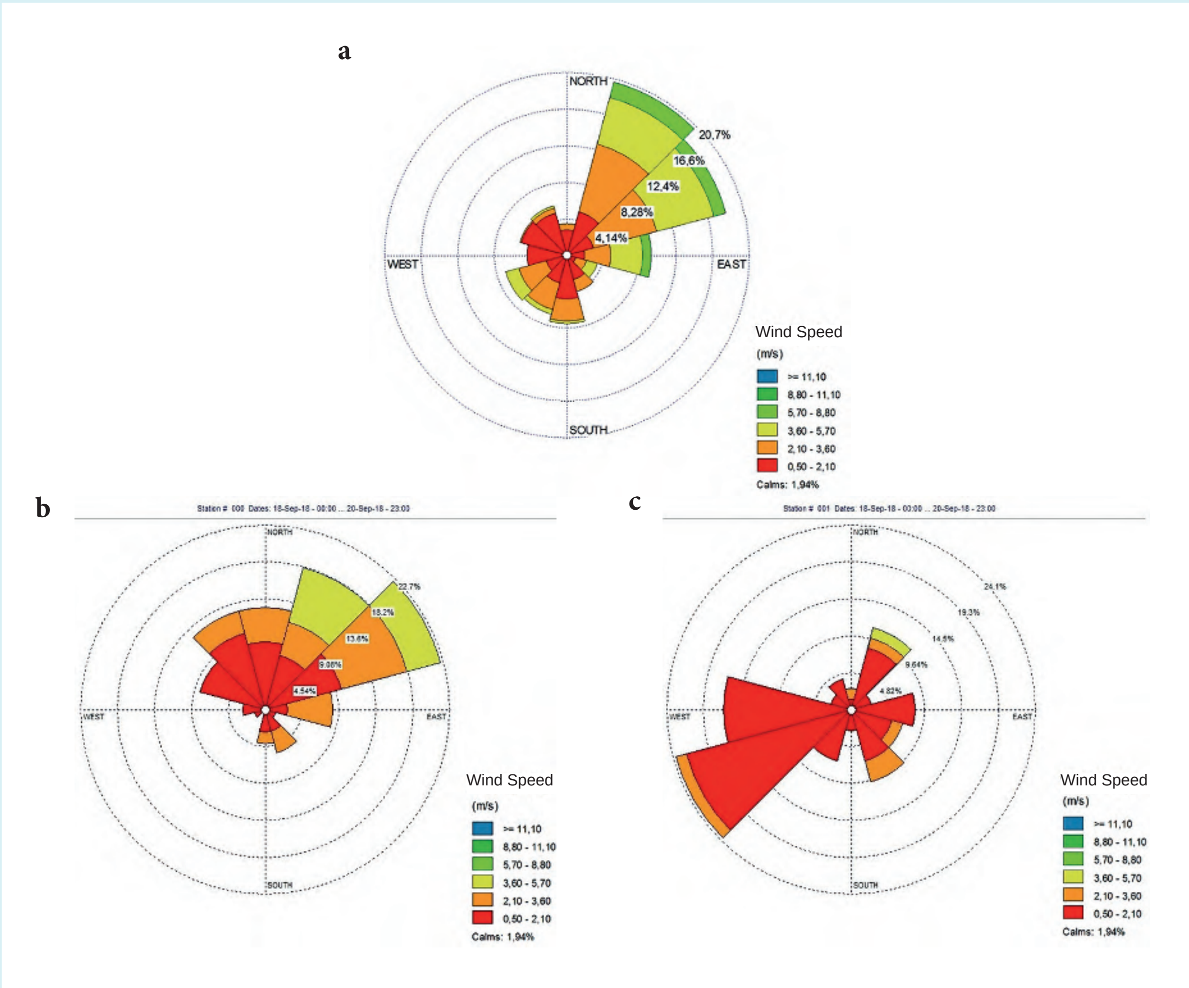


Figure 8. Compass rose for: (a) the month of September in Macaé (RJ); (b) the period between September 18 and 20 in Macaé (RJ); (c) the period between September 18 and 20 in Saquarema (RJ).

The change in the wind system allowed water to be transported off the shelf towards the coast, warming the region and weakening the resurgence process and characteristics, as can be seen in the SST images between the 18th and 20th of September (Fig. 9). The final result, from the point of view of the sample design of the cruise, can be seen in figure 10, which presents the original design on the dynamics imposed by the variability of the SST, throughout the execution of the work.

In hydroacoustic prospecting cruises, the acoustic data is collected while the observer (ship) moves along the profiles and, later, correlated to the environmental data from the oceanographic stations. The dynamics presented draws attention to the difficulty, which can be anticipated, in an attempt to associate the occurrences of organisms with the environmental conditions that define their habitats. Simmonds & MacLennam (2005) make an important review of sample designs on hydroacoustic cruises.

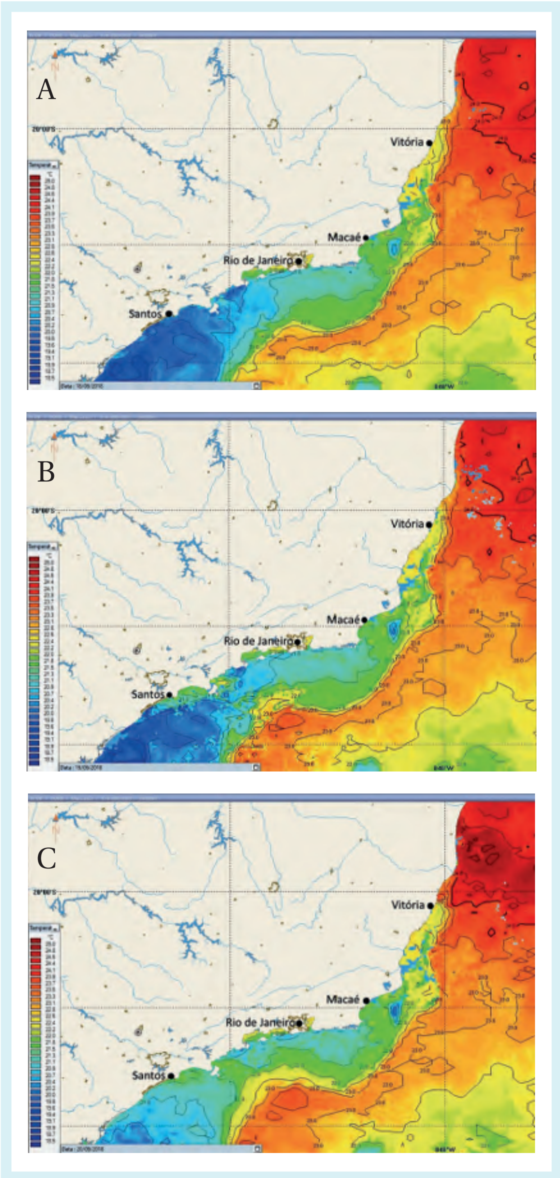


Figure 9. SST of the 18th (A), 19th (B) and 20th (C) of September, showing an advance of warmer waters on the south shelf of Rio de Janeiro.

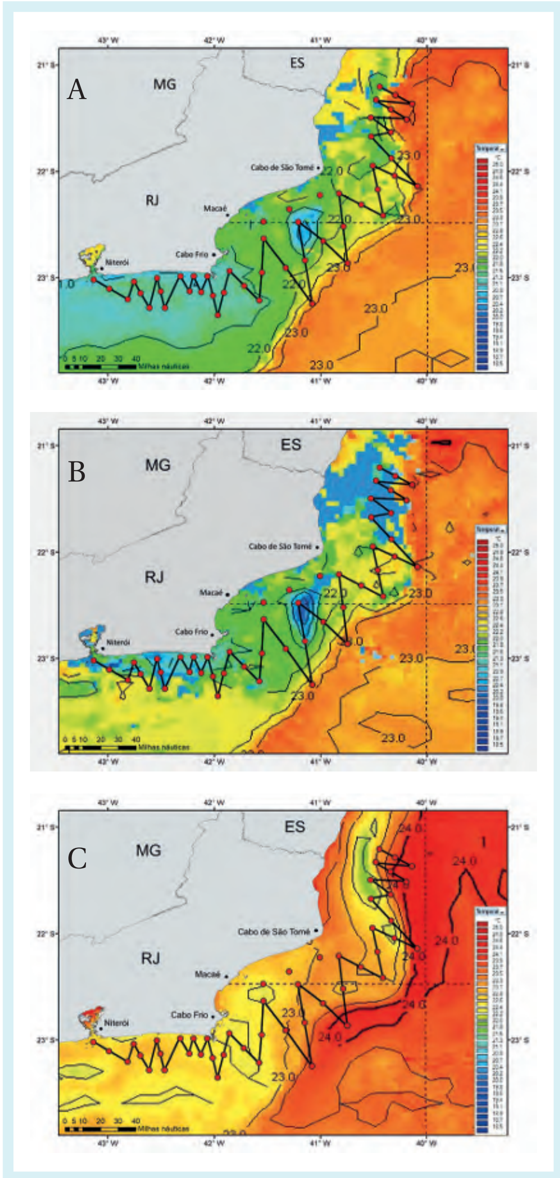


Figure 10. Sample design of Skipjack Tuna cruise 2018 superimposed on the SST images obtained during the development of the work.

As the Skipjack tuna cruise 2018 area is inserted in the northern sector where the skipjack tuna occurs, we sought with these results to draw attention to the variability in the SST, which can occur on the daily scale in that region. These processes are logically inserted in those that occur in the scales of seconds, minutes and hours. The next case studies expand the range of variability of SST in processes that occur over months, years and decades, and investigate their repercussions in the catches of skipjack tuna in the Southwest Atlantic Ocean.

Case Study 2: Skipjack tuna fishing between the years 2012 and 2019

The focus of this case study is directed to the performance of the fleet of six boats from the Leal Santos industry. It is noteworthy here that Rio Grande (RS) is the host port for all six vessels, from where they leave at the beginning of each harvest, prospect areas of interest for fishing, and perform their activities always with the same objective: to reach the best possible yield in catches of skipjack tuna. In addition, prospecting can or not be cooperative between boats. The harvests start in the spring/summer in the vicinity of Paranaguá (PR) and the boats move gradually to the south, where they operate until the end of the summer, near the border with Uruguay. Throughout the autumn, the six boats advance northwards, to Cabo de São Tomé, and the harvest ends, with the proximity of winter, in the vicinity of Cabo Frio (RJ), when everyone returns to Rio Grande (RS).

Fishing boats can be considered as samplers of the marine environment in the areas and in the period in which they exercise fishing activity, since the catch inventories, filled on board and called onboard maps, report what was available in time and space, according to the catch characteristics of each boat, its efficiency and its limitations (COTTER *et al.*, 2007). It is assumed here that the boats that compose this fleet are efficient samplers of skipjack tuna for fishing this species for 25 years in all its distribution area, which is comprised to the north by Cabo de São Tomé (RJ) and to the south near the Brazil-Uruguay border. The geographic distribution of the catches of skipjack tuna by this fleet, between the years 2013 and 2018, is shown in figure 11. Such distribution also shows the great spatial autonomy achieved by the company's fleet.

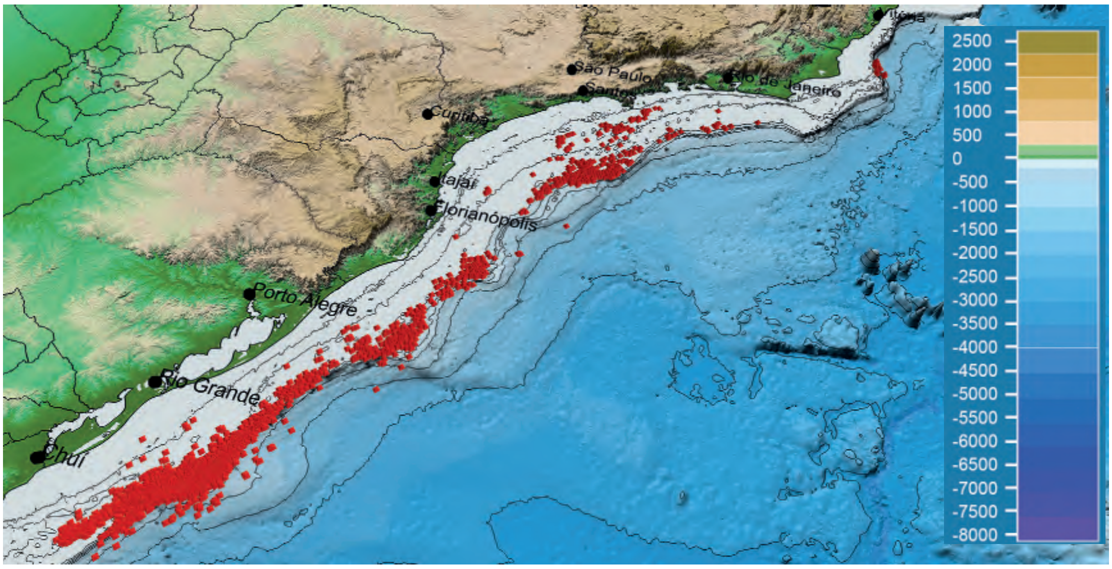


Figure 11. Geographical distribution of catches of skipjack tuna by the Leal Santos fleet between 2013 and 2018. Each red dot represents a fishing position.

At the beginning of the work associated with this Case Study, the research team knew beforehand, based on the specialized bibliography and the experience of the group members, that the seasonal movement of this fleet was closely related to the seasonal movement of the Brazilian current. This current impacts the pelagic environment of the study region and has been the subject of previous studies.

These past studies had as reference the OnBoard Maps that the authors used to interpret the catches and the movements of the boats. In the present study, however, the innovation took place through the interactive work between the University and the Company, which allowed the gradual obtaining of increasingly detailed fishing data, until the desired resolution was finally reached, which resided in the information of the exact geographical point where each school was caught and still duly reported with date, time, latitude/longitude and captured tonnage. Access to the Fishing Vessel Tracking Program (PREPS) made it possible to check these positions, track the trajectory of the boats and validate the data, as well as eliminate those with errors.

At the same time, the continuous access to Operational Oceanography, via CATSAT, also allowed to link the data from the capture of the shoals, for each position, to the variables: (i) Sea Surface Temperature (SST); (ii) concentration of chlorophyll-a; (iii) depth of the thermocline; and (iv) subsurface temperature in the 20 and 30 m strata of the water column. The data were then treated in such a way that each variable was compared with the catches, and then maps were generated that allowed researchers to visualize the intervals within which the largest catches of Skipjack tuna were obtained, following the methodology of Coletto *et al.* (2019). In this work, the authors evaluated the movement of the Leal Santos industry fleet over two years. After these analyzes, the results obtained started to be treated as the best intervals, for the analyzed variables, within which the probability of catching the skipjack tuna would be greater.

The studies with the six boats, the partial results of which were described by Coletto *et al.* (2019), started in 2013 and evolved until 2019. Throughout this period, the boats remained focused on catching the skipjack tuna and it is assumed that their movements consistently mirrored the movement of this species in the South Western Atlantic Ocean.

In the interest of presenting here a summarized result of the performance of the six boats, with the technology of the Embedded Operational Oceanography, a graph was generated that compares the production (catch) of the Leal Santos vessels and their respective diesel consumption between the years of 2012 and 2019. Figure 12 presents these two data and their respective trend lines for the period evaluated, which indicate a reduction over time, both for catches and for fuel consumption. However, the slope in the consumption line is greater than that of the catch.

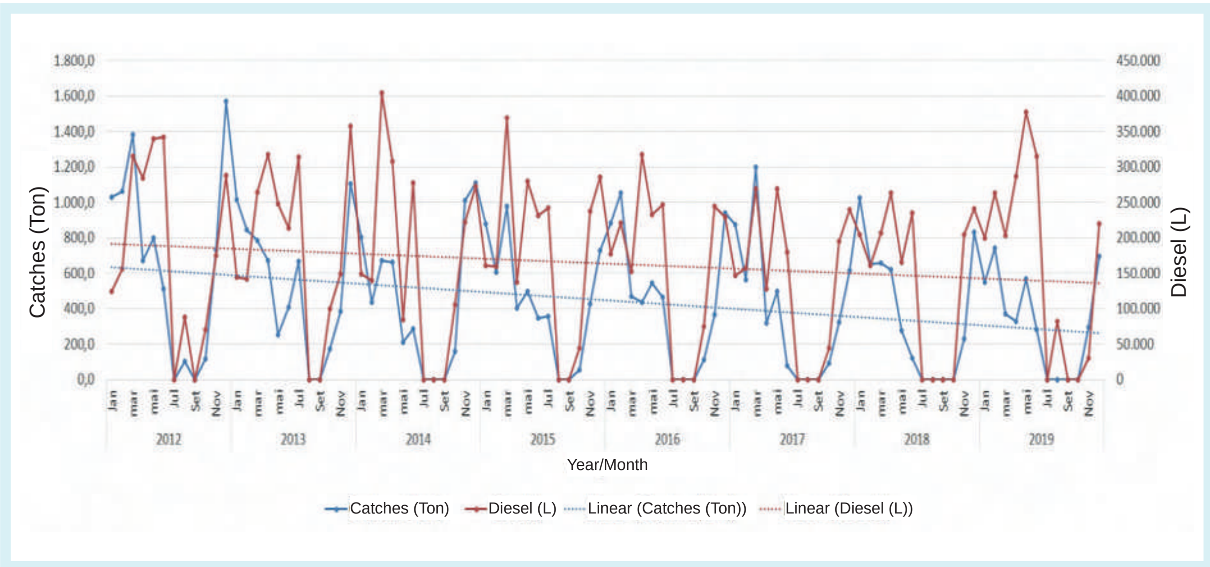


Figure 12. Comparison of the fishing production and diesel consumption of vessels in the fleet of the company Leal Santos between the years 2012 and 2019.

It is worth highlighting the complexity involved with this data due to the movements themselves of each vessel, the type of engine of each one, their cruising speed, etc. In the period analyzed, according to the Leal Santos industry, there were three exchanges of main engines for others, more modern and of lower consumption, one change in 2016, the second in 2017 and the third in 2018. In fact, as shown in figure 12, the two trend lines are further apart at the end of the historical series. However, consumption has decreased since the beginning. For example, we found that in 2013 2.80 ± 0.41 liters of diesel/kg for skipjack tuna were spent, while in 2019 this ratio was only 1.94 ± 0.44 liters of diesel/kg, that is, a reduction in fuel consumption of approximately 30.7% per kilo caught.

Based on these results, the research group was able to conclude that Operational Oceanography had a positive impact on the operation of this fleet, expressed in the lower consumption of diesel in relation to the amount of skipjack tuna caught. This aspect was explored environmentally by Madureira *et al.* (2016), who related the gradual reductions in diesel oil with the proportionally lower emissions of CO_2 and other combustible gases.

However, if on the one hand there has been a reduction in fuel consumption per unit of capture, on the other hand, the same has occurred with catches over the years, which have also been reduced. In this sense, the results presented above were partially positive, from the point of view of fishing.

In order to verify whether the variability in the catches of the Leal Santos fleet had also been observed in the catches of skipjack tuna by the national fleet for the same period, the researchers analyzed separately the catches of skipjack tuna by the industry Leal Santos and the national fleet , and the results are shown in figure 13. In this figure, it can be seen that the national fleet was even more strongly impacted on fishing income, with a sharp reduction from 2014.

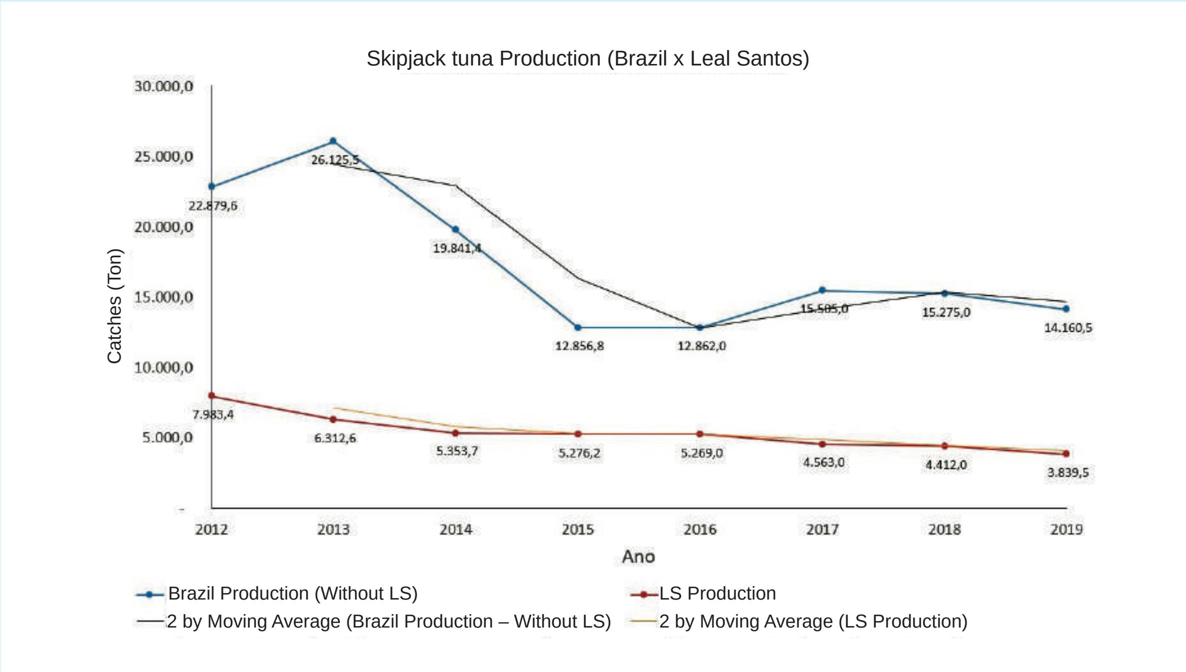


Figure 13. Skipjack tuna catches by the industry Leal Santos (LS) and by the national fleet (Brazil) between 2012 and 2019.

It is important to note that, at the time of writing this chapter, the stock of skipjack tuna in the Western South Atlantic was not at a level considered to be overfishing, nor has it ever been, as will be more detailed in Chapter 10. So, a question remains: why did a gradual reduction in catches of the evaluated fleets occur?

Case Study 3: Temporal variability of SST between 1992 and 2019 and its potential impacts on catches of skipjack tuna and sardines

The South Western Atlantic Ocean (OASO) is a region poor in fishing data and underrepresented in terms of climate change models. However, according to the FAO report (2018), in its chapter 15, global predictive models suggest the possibility of a decrease in fish catches in this region. In addition to this aspect, the publication also states that the oceanic region that includes the south/southeast coast of Brazil, Uruguay and Argentina, centralizes or concentrates (hotspot) a warming in the sea surface temperature in the last 50 years.

The skipjack tuna is an important fishing resource for Brazil, but of low occurrence in the catches of neighboring countries, Uruguay and Argentina (FAO Report, 2018).

Taking as a starting point that the reduction in catches of skipjack tuna observed by the fishing fleet of the Leal Santos industry, between 2012 and 2019, could be related to longer-term variability, the research group decided to evaluate a time series the longest SST in the region of interest, which now includes dozens of years of data, that is, providing an assessment of variability in temporal scales compatible with climatic phenomena that may be associated with daily scales. We call this new research Case Study 3.

So that this evaluation was not restricted to only the skipjack tuna, it was decided to include the sardine in the analyzes. This is due to the fact that, first, this is the most important pelagic species in fishing in Brazil, secondly, because, being pelagic, it could be impacted in a similar way, and thirdly, because this species is preyed upon by skipjack tuna (see Chapter 7). Likewise, so that the assessment was not restricted to the Leal Santos fleet, catches from the national skipjack tuna fleet in the same period were included.

In an attempt to answer the question that closes Case Study 2, the group deepened the studies with greater refinement in the space-time analyzes of the Leal Santos fleet. As mentioned, latitudinal movements of the boats do not happen following a logic in terms of calendar, i.e., on a monthly scale, but that, in the winter, they operated in the northern sector of the fishing region and in the summer, in the south. Coletto *et al.* (2019), in turn, showed that, even within just two years, there was considerable variability in the degree of movement of the boats in relation to the months of the year, which is expressed by the standard deviation bars in figure 14.

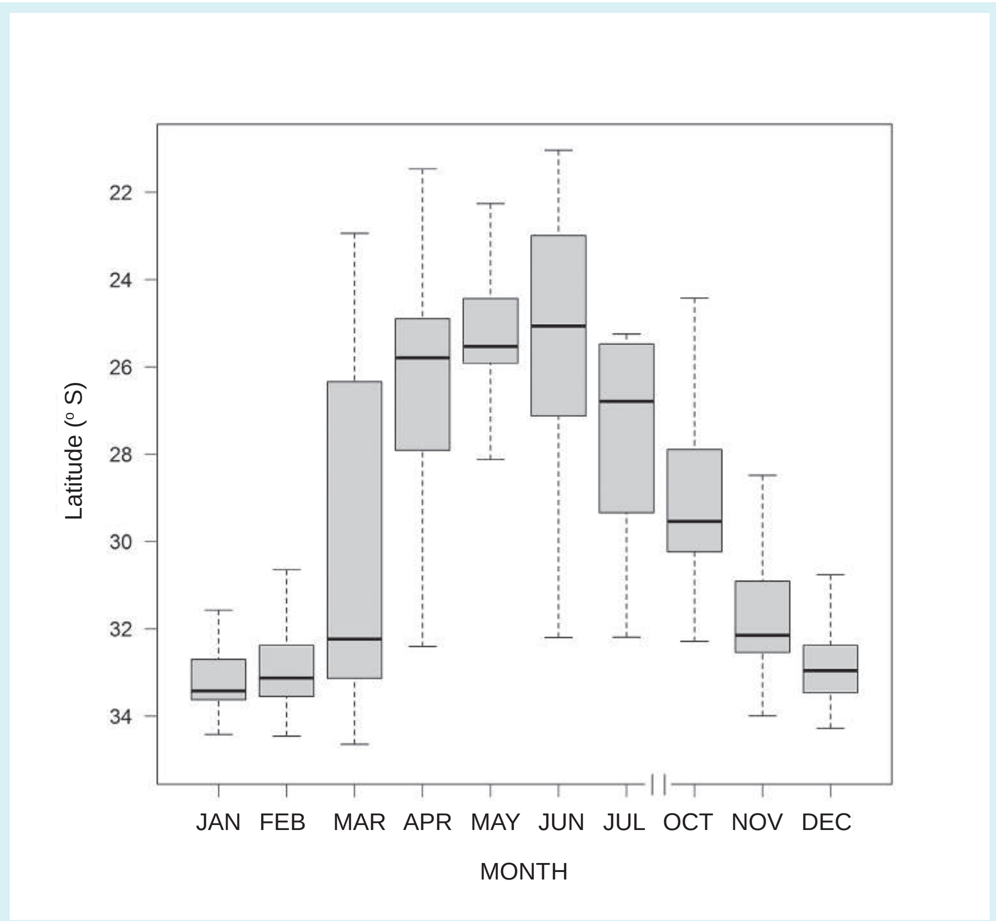


Figure 14. Seasonal distribution of the industry fleet Leal Santos Ltda. (COLETTO *et al.*, 2019).

The environmental variability of the SE/S region between the summer and winter months is very pronounced and so are the areas of concentration of skipjack tuna, as reviewed above. For a start of interpretation on SST's interannual variability and its possible impact on the movements of the skipjack tuna, the research group directed its focus to the study of four winter periods, between the years 2013 and 2016. To this end, satellite images from the same day (06/11) were used over these years (Fig. 15).

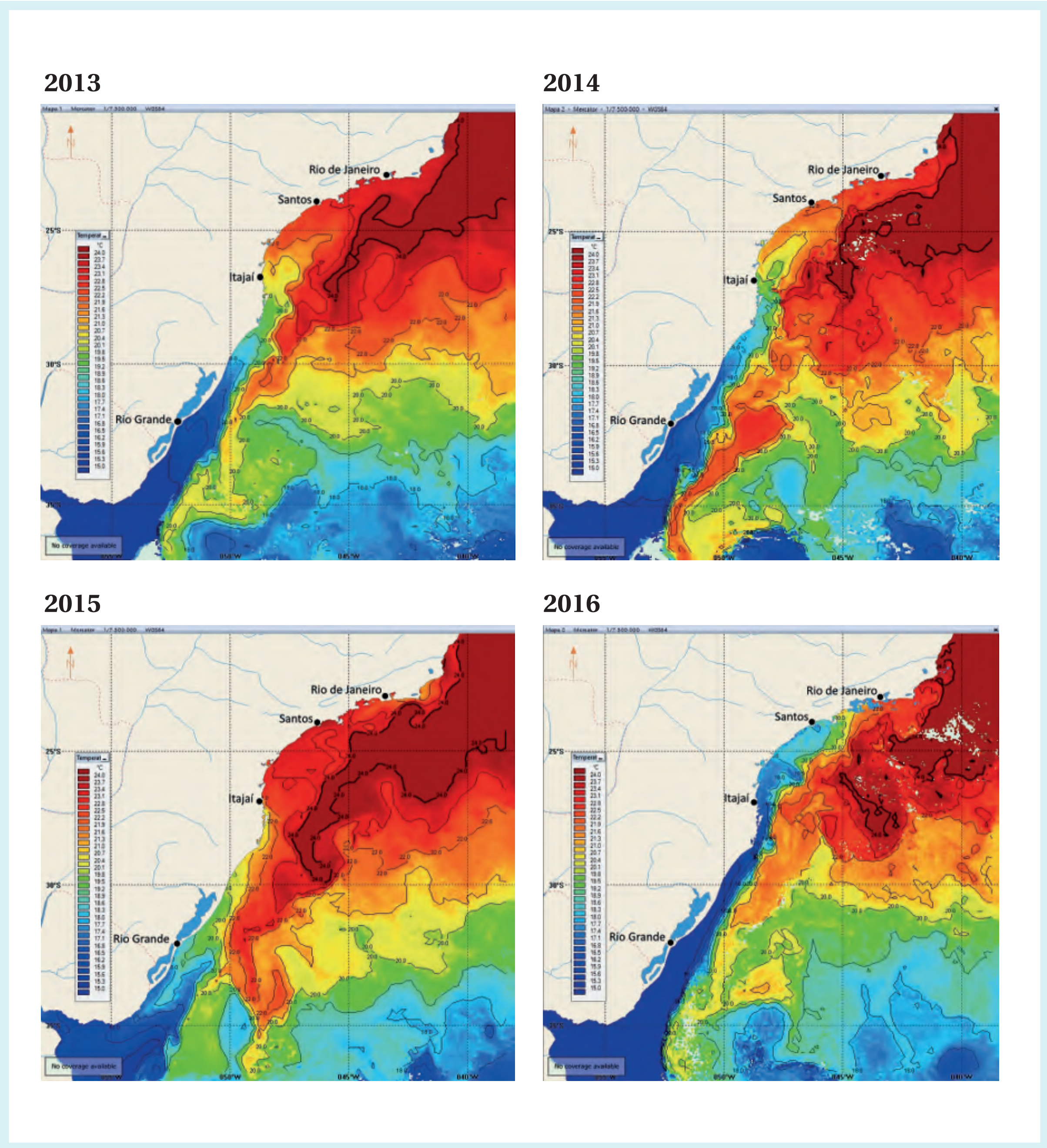


Figure 15. SST interannual variability illustrated by the images of 06/11 between the years 2013 and 2016.

These images show great differences in the latitudinal distribution of SST. The most extreme cases in this series of images refer to the years 2015 and 2016. In 2015, the northernmost point of occupation of the Sub-Antarctic Water Platform, represented by the blue colors in the images, was at 32°23’ S, while in 2016 it was at 24°12’ S, for the same date. These positions, in terms of distance, differ by approximately 1,044 km. Considering this great difference, it is possible to assume that this variability must have an important repercussion in the fishing of skipjack tuna, as well as in other species. So here is one more question: what types of events would be affecting the fishing area studied as significantly as that seen in the images of the four winters?

After a careful evaluation of longer time series for the catching of reall sardines and skipjack tuna in Brazil, which included data from Ibama (Brazilian Institute of the Environment and Renewable Natural Resources), ICCAT (International Commission for the Conservation of Atlantic Tunas) and CONEPE (National Collective of Fisheries and Aquaculture), the members of the research group selected the series of catches between 1992 and 2019 for both species.

The time series that shows the catches of sardines in this period is shown in figure 16, where two sharp drops are observed in the production of this fish. The first of these, in 1997/1998, was treated by a group of experts as a consequence of overfishing of the stock and possibly also associated with climate change. This figure highlights the occurrences of El Niños in 1997 and 1998, and in 2015 and 2016.

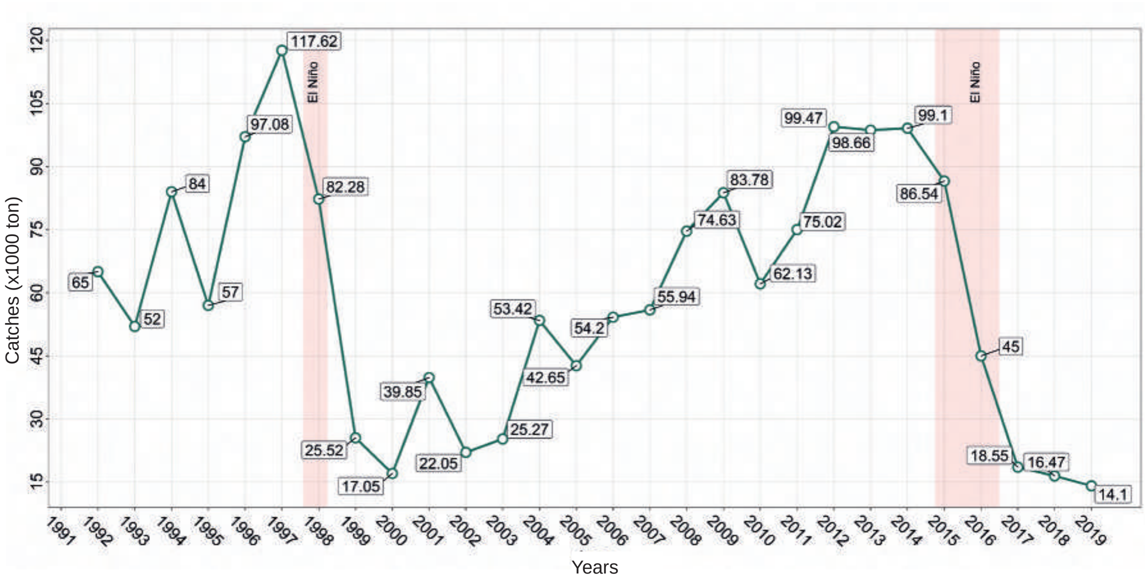


Figure 16. Catch data of sardines in the period from 1992 to 2019, with emphasis on the El Niños from 1997-1998 and 2015-2016.

Figure 16 also shows a trend of growth in the catch from 2000 to 2012, a stabilization of the catch until 2014, and a sharp reduction after this period, the second major drop in catch, in 2015 and 2016, which is apparently related to remote action of climatic modes on the fishing region of interest, as we will see later.

Figure 17, in turn, shows the catches of skipjack tuna for this same period. A behavior similar to that of the catch of the sardine is perceived, with a growth trend from 2002 to 2013, but here accompanied by partial falls greater than those seen for the sardine, and a sharp drop after 2014.

Figure 17. Skipjack tuna catch data for the national fleet from 1992 to 2019, with emphasis on the El Niños from 1997-1998 and 2015-2016. Data until 2018, according to ICCAT, and 2019 according to WS Consultoria.

The intention now is to assess potential impacts on catches that are associated with parameters correlated to climate change, especially in the form of changes in SST, continuing the work of SCHMIT *et al.* (2019). In this sense, the methodology that allowed the generation of a SST time series in the SE/S region was used, corresponding in time and space to the series of catches of true and skipjack tuna sardines covered in figures 16 and 17. To this end, 12 geographic positions were defined, named by the research group of Virtual Foundries (FVs), positioned along the middle shelf and the embankment, between Chuí and Cabo de São Tomé (Fig. 18). Based on data provided by the National Oceanic and Atmospheric Administration (NOAA) the daily SST were stored for the FV positions and their averages and respective anomalies were calculated, based on the historical series.

Figure 19 shows the SST anomalies calculated for the FV Santa Marta Oceânico (SM Oceanic SST anomalies), taken as an example, between 1991 and 2019. The period beginning in 2013 and ending in 2019 stands out, where there is an almost continuous sequence of very strong positive anomalies of SST.

Schmit *et al.* (2019) analyzed the catch data for sardines and skipjack tuna in the period between 1991 and 2017 and evaluated the potential impacts of SST anomaly years for both species. The authors pointed out more significant falls in catches of sardines than in the period. As the skipjack tuna fishing is highly dependent on the sardine, used as live bait (see Chapters and 10), it is possible that the impact of the variable sardine is partly responsible for the variability in catches of the skipjack tuna.

In Figure 13 of Case Study 2, it can be seen that the national fleet of skipjack tuna has suffered a reduction in catches more significant than that of Leal Santos in the period between 2015 and 2017. However, the Leal Santos fleet has a much less important dependence on the sardine, used as live bait in the boats of the national fleet, since this industry started to use the anchovy as a substitute species for the sardine (MADUREIRA *et al.*, 2016). If, on the one hand, this situation establishes an important difference between fleets, on the other, there are also significant differences in their fishing dynamics. The national fleet operates mostly up to Cabo de Santa Marta as a southern boundary and the Leal Santos industry operates from Chuí to Cabo de São Tomé (see Chapter 10).

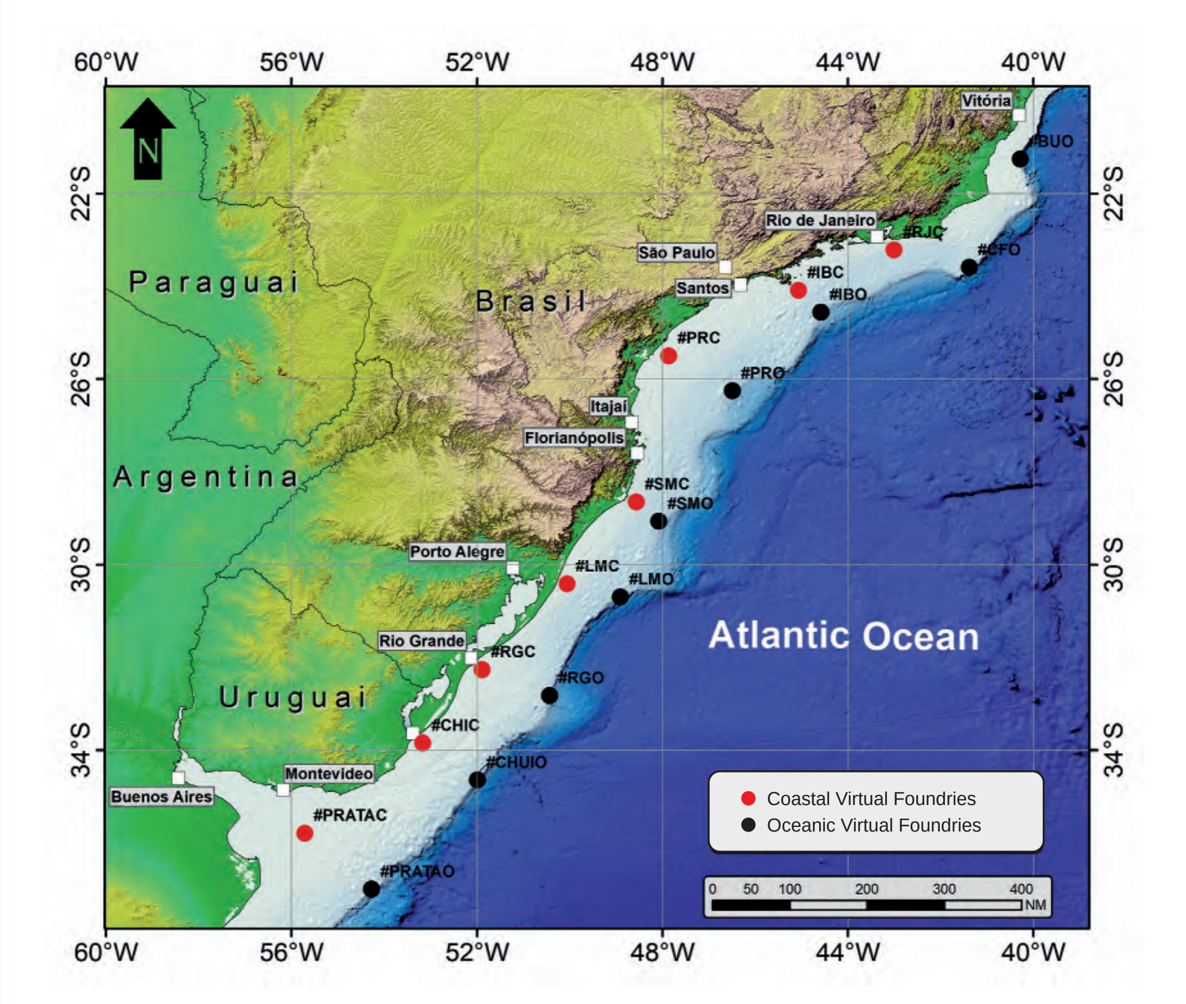


Figure 18. Position of the Virtual Foundries (FVs), Coastal and Oceanic, along the shelf and shelf breaks.

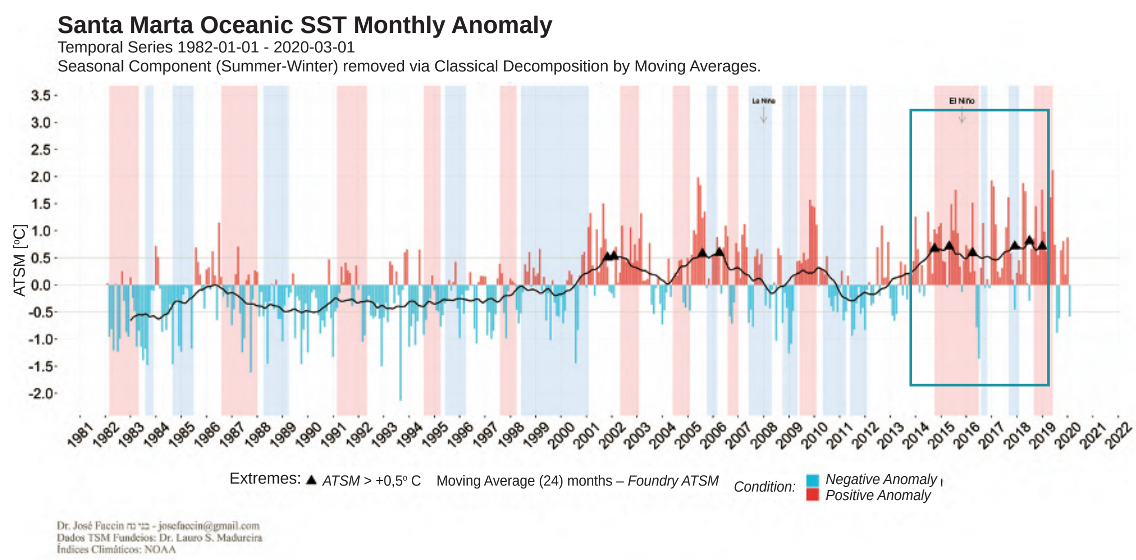


Figure 19. The SST anomalies calculated for the Santa Marta Oceanic FV between 1981 and 2019. The blue rectangle draws attention to the period of positive SST anomalies after 2013.

The bibliography cited in the initial parts of this chapter, especially Andrade (1996) and Matsuura & Andrade (1999), draws attention to the fact that southern fisheries, with high concentrations of skipjack tuna in the summer, are less frequented by the national fleet, but are intensively exploited by the Leal Santos fleet. In a historical perspective, the dynamics of both fleets are practically constant throughout the data series (see Chapter 9), that is, they remained fishing in their traditional fishing grounds, with the national fleet practically restricted to the north of Cabo de Santa Marta. Changes in fishing dynamics were observed in 2018, as seen in Chapter 9, following strong positive anomalies (Fig. 19). While the Leal Santos fleet restricted its operations to the south of Cabo de Santa Marta throughout the year, maintaining good yields of skipjack tuna, the national fleet operated on other resources, due to low yields in traditional areas.

At this point, we return to the question posed above: what types of events would be affecting the studied fishing area as significantly as that observed in the images of the four winters? However, now, we have reformulated it: what types of events would be affecting the studied fishing area in such a significant way as to establish abrupt drops in catches of sardines and the skipjack tuna?

Discussion

The three case studies presented here showed marked variations in SST in intervals of days, a few years and decades, the latter two variations being always accompanied by changes in the catches of skipjack tuna and sardines. The first variation of SST (Case Study 1, in days) should be related to sharp changes of local forces on the days analyzed. That said, there is no way not to seek an explanation for the variability of SST observed in longer periods and, certainly, these variations pass through the action of climatic modes over the South Atlantic Ocean (OAS). A mode of climatic variability is, by definition, a climatic pattern with identifiable characteristics, specific regional effects and oscillatory behavior. Some of these modes have a well-known performance in OAS, such as ENOS (El Niño South Oscillation), DSAS (Subtropical Dipole of the South Atlantic), MAS (Sul Annular Mode) and others. It is worth noting that numerous modes of climatic variability operate simultaneously in the South Atlantic and several others have not yet fully understood their effect. The periodicity of the performance of these modes is different, where we highlight, for example, from that approximately inter-annual of ENOS to the approximately decadal of MAS.

The El Niño (EN) phenomenon is associated with changes in normal SST patterns and trade winds in the Equatorial Pacific region, between the Peruvian coast and the western rim of the Pacific. To monitor the evolution of these SST anomalies, NOAA uses four regions[3] called Niño 1 + 2, 3, 3.4 and 4 (Fig. 20). In addition, in the region of Niño 3.4, a region whose changes have a better correlation with those occurring in the OAS, there is an index for monitoring anomalies of SST called ONI (Oceanic Niño Index).

In addition to indices based on SST values in the Equatorial Pacific, the ENOS phenomenon (where OS now stands for South Oscillation, the atmospheric component of the phenomenon) can also be quantified by the South Oscillation Index (IOS). This index represents the difference in pressure at sea level (PNM) between the Central Pacific (Tahiti) and the Western Pacific (Darwin/Australia). This index is related to the changes in the atmospheric circulation at low levels of the atmosphere, a consequence of the heating/cooling of surface waters in the region. Negative and positive IOS values are indicators of the occurrence of the El Niño and La Niña phenomena, respectively[4].

[3] Available at: https://www.ncdc.noaa.gov/teleconnections/enso/indicators/sst.php. Accessed on: Jul. 08 2020.

[4] Available at: http://enos.cptec.inpe.br/saiba/Oque_el-nino.shtml. Accessed on: Jul. 08 2020.

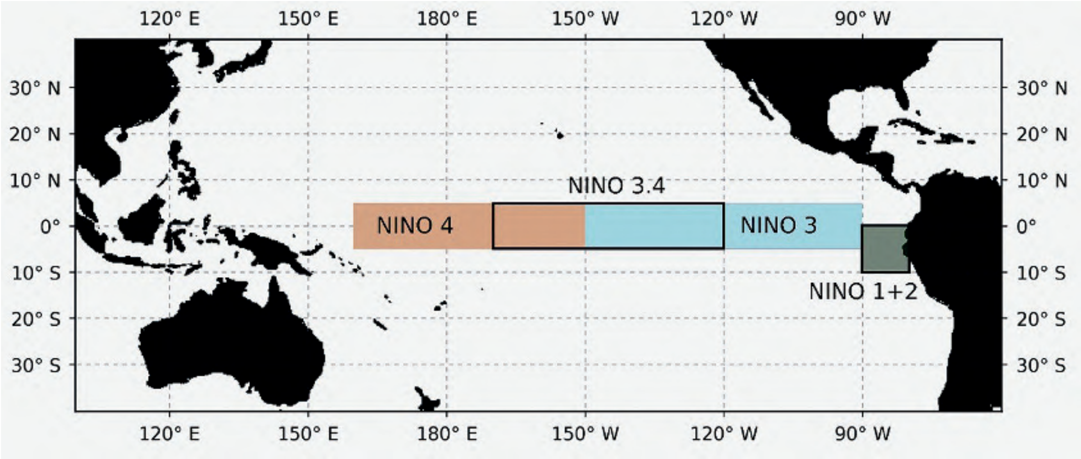


Figure 20. NOAA regions for monitoring SST anomalies, called Niño 1 + 2, 3, 3.4 and 4.

The South Atlantic Subtropical Dipole (DSAS), in turn, is characterized by anomalies in the field of PNM and by a northeast/southwest gradient that involves the spatial distribution of SST anomalies (e.g., PALASTANGA *et al.*, 2002; HAARSMA *et al.*, 2005), which form a dipole pattern, with positive (negative) SST anomalies of to the southwest (northeast) for a positive DSAS and the opposite for a negative DSAS. This climatic mode affects the distribution of SST in the OAS, causes anomalies in the ocean/atmosphere heat flows and changes the thickness of the mixture layer, among other effects. One of the observed effects of DSAS on OAS is the variation in the intensity of resurgence processes at the east and west borders of OAS (e.g., SILVA, 2020). Information regarding MAS can be found in Marshall (2003), Gillet *et al.* (2006), among others.

Table 1 below shows the quarterly ONI, from 1980 to 2020, based on NOAA[5], for the Niño 3.4 region in the Equatorial Pacific. This index is a "measurement" of the intensity of ENOS events. The positive values of this index indicate periods of El Niño, while the negative ones, periods of La Niña[6]. The periods of significant changes in SST in the Equatorial Pacific region are indicated by the color blue, for lower values of SST, and by the color red, for the highest values of SST.

Since in this chapter we have shown that changes in the catch levels of skipjack tuna and sardines undergo changes in the SST of OAS, and these, in turn, suffer the performance of climatic modes in this ocean, discuss certain periods of catches (which stood out) in relation to the occurrence of ENOS events close to these periods, which are, in turn, associated/measured with the ONI indices, which, when ≥ 0.5° C, characterize El Niño phenomena and, when ≤ -0.5° C, characterize La Niña phenomena.

Results of the hydroacoustic evaluation cruise of the sardine biomass called ECOSAR VII, held in 2010 on the platform of the SE/S region, between Cabo de São Tomé and Cabo de Santa Marta, drew attention to the fact that 98.2% of the sardine biomass, estimated at 62,568 tons, was concentrated in waters with temperatures below 22° C, and only 1.8% occurred in areas under hot, oligotrophic Tropical Water (AT) (CERGOLE & NETO, 2011). Whereashere that positive anomalies in the SST are associated with the predominance of AT in the first meters of the water column, a water body characterized by temperatures above 20° C and salinities above 36.20 psu. On the other hand, it is also considered that negative

[5] Available at: https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php. Accessed on: Jul. 08 2020.
[6] Available at: https://www.climate.gov/news-features/understanding-climate/climate-variability-oceanic-ni%C3%B1o--index. Accessed on: Jul. 08 2020.

SST anomalies indicate a predominance of Central Water of the South Atlantic (ACAS), rich in nutrients and high productivity, and characterized by temperatures below 20ºC and salinity values below 36.20 psu.

Table 1. Quarterly ONI, from 1980 to 2020, based on NOAA, for the Niño 3.4 region in the Equatorial Pacific.

Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1950	-1.5	-1.3	-1.2	-1.2	-1.1	-0.9	-0.5	-0.4	-0.4	-0.4	-0.6	-0.8
1951	-0.8	-0.5	-0.2	0.2	0.4	0.6	0.7	0.9	1.0	1.2	1.0	0.8
1952	0.5	0.4	0.3	0.3	0.2	0.0	-0.1	0.0	0.2	0.1	0.0	0.1
1953	0.4	0.6	0.6	0.7	0.8	0.8	0.7	0.7	0.8	0.8	0.8	0.8
1954	0.8	0.5	0.0	-0.4	-0.5	-0.5	-0.6	-0.8	-0.9	-0.8	-0.7	-0.7
1955	-0.7	-0.6	-0.7	-0.8	-0.8	-0.7	-0.7	-0.7	-1.1	-1.4	-1.7	-1.5
1956	-1.1	-0.8	-0.6	-0.5	-0.5	-0.5	-0.6	-0.6	-0.5	-0.4	-0.4	-0.4
1957	-0.2	0.1	0.4	0.7	0.9	1.1	1.3	1.3	1.3	1.4	1.5	1.7
1958	1.8	1.7	1.3	0.9	0.7	0.6	0.6	0.4	0.4	0.4	0.5	0.6
1959	0.6	0.6	0.5	0.3	0.2	-0.1	-0.2	-0.3	-0.1	0.0	0.0	0.0
Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1960	-0.1	-0.1	-0.1	0.0	0.0	0.0	0.1	0.2	0.3	0.2	0.1	0.1
1961	0.0	0.0	0.0	0.1	0.2	0.3	0.1	-0.1	-0.3	-0.3	-0.2	-0.2
1962	-0.2	-0.2	-0.2	-0.3	-0.3	-0.2	0.0	-0.1	-0.1	-0.2	-0.3	-0.4
1963	-0.4	-0.2	0.2	0.3	0.3	0.5	0.9	1.1	1.2	1.3	1.4	1.3
1964	1.1	0.6	0.1	-0.3	-0.6	-0.6	-0.6	-0.7	-0.8	-0.8	-0.8	-0.8
1965	-0.6	-0.3	-0.1	0.2	0.5	0.8	1.2	1.5	1.9	2.0	2.0	1.7
1966	1.4	1.2	1.0	0.7	0.4	0.2	0.2	0.1	-0.1	-0.1	-0.2	-0.3
1967	-0.4	-0.5	-0.5	-0.4	-0.2	0.0	0.0	-0.2	-0.3	-0.4	-0.3	-0.4
1968	-0.6	-0.7	-0.6	-0.4	0.0	0.3	0.6	0.5	0.4	0.5	0.7	1.0
1969	1.1	1.1	0.9	0.8	0.6	0.4	0.4	0.5	0.8	0.9	0.8	0.6
Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1970	0.5	0.3	0.3	0.2	0.0	-0.3	-0.6	-0.8	-0.8	-0.7	-0.9	-1.1
1971	-1.4	-1.4	-1.1	-0.8	-0.7	-0.7	-0.8	-0.8	-0.8	-0.9	-1.0	-0.9
1972	-0.7	-0.4	0.1	0.4	0.7	0.9	1.1	1.4	1.6	1.8	2.1	2.1
1973	1.8	1.2	0.5	-0.1	-0.5	-0.9	-1.1	-1.3	-1.5	-1.7	-1.9	-2.0
1974	-1.8	-1.6	-1.2	-1.0	-0.9	-0.8	-0.5	-0.4	-0.4	-0.6	-0.8	-0.6
1975	-0.5	-0.6	-0.7	-0.7	-0.8	-1.0	-1.1	-1.2	-1.4	-1.4	-1.6	-1.7
1976	-1.6	-1.2	-0.7	-0.5	-0.3	0.0	0.2	0.4	0.6	0.8	0.9	0.8
1977	0.7	0.6	0.3	0.2	0.2	0.3	0.4	0.4	0.6	0.7	0.8	0.8
1978	0.7	0.4	0.1	-0.2	-0.3	-0.3	-0.4	-0.4	-0.4	-0.3	-0.1	0.0
1979	0.0	0.1	0.2	0.3	0.2	0.0	0.0	0.2	0.3	0.5	0.5	0.6
Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1980	0.6	0.5	0.3	0.4	0.5	0.5	0.3	0.0	-0.1	0.0	0.1	0.0
1981	-0.3	-0.5	-0.5	-0.4	-0.3	-0.3	-0.3	-0.2	-0.2	-0.1	-0.2	-0.1
1982	0.0	0.1	0.2	0.5	0.7	0.7	0.8	1.1	1.6	2.0	2.2	2.2
1983	2.2	1.9	1.5	1.3	1.1	0.7	0.3	-0.1	-0.5	-0.8	-1.0	-0.9
1984	-0.6	-0.4	-0.3	-0.4	-0.5	-0.4	-0.3	-0.2	-0.2	-0.6	-0.9	-1.1
1985	-1.0	-0.8	-0.8	-0.8	-0.8	-0.6	-0.5	-0.5	-0.4	-0.3	-0.3	-0.4
1986	-0.5	-0.5	-0.3	-0.2	-0.1	0.0	0.2	0.4	0.7	0.9	1.1	1.2
1987	1.2	1.2	1.1	0.9	1.0	1.2	1.5	1.7	1.6	1.5	1.3	1.1
1988	0.8	0.5	0.1	-0.3	-0.9	-1.3	-1.3	-1.1	-1.2	-1.5	-1.8	-1.8
1989	-1.7	-1.4	-1.1	-0.8	-0.6	-0.4	-0.3	-0.3	-0.2	-0.2	-0.2	-0.1
Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
1990	0.1	0.2	0.3	0.3	0.3	0.3	0.3	0.4	0.4	0.3	0.4	0.4
1991	0.4	0.3	0.2	0.3	0.5	0.6	0.7	0.6	0.6	0.8	1.2	1.5
1992	1.7	1.6	1.5	1.3	1.1	0.7	0.4	0.1	-0.1	-0.2	-0.3	-0.1
1993	0.1	0.3	0.5	0.7	0.7	0.6	0.3	0.3	0.2	0.1	0.0	0.1
1994	0.1	0.1	0.2	0.3	0.4	0.4	0.4	0.4	0.6	0.7	1.0	1.1
1995	1.0	0.7	0.5	0.3	0.1	0.0	-0.2	-0.5	-0.8	-1.0	-1.0	-1.0
1996	-0.9	-0.8	-0.6	-0.4	-0.3	-0.3	-0.3	-0.3	-0.4	-0.4	-0.4	-0.5
1997	-0.5	-0.4	-0.1	0.3	0.8	1.2	1.6	1.9	2.1	2.3	2.4	2.4
1998	2.2	1.9	1.4	1.0	0.5	-0.1	-0.8	-1.1	-1.3	-1.4	-1.5	-1.6
1999	-1.5	-1.3	-1.1	-1.0	-1.0	-1.0	-1.1	-1.1	-1.2	-1.3	-1.5	-1.7
Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
2000	-1.7	-1.4	-1.1	-0.8	-0.7	-0.6	-0.6	-0.5	-0.5	-0.6	-0.7	-0.7
2001	-0.7	-0.5	-0.4	-0.3	-0.3	-0.1	-0.1	-0.1	-0.2	-0.3	-0.3	-0.3
2002	-0.1	0.0	0.1	0.2	0.4	0.7	0.8	0.9	1.0	1.2	1.3	1.1
2003	0.9	0.6	0.4	0.0	-0.3	-0.2	0.1	0.2	0.3	0.3	0.4	0.4
2004	0.4	0.3	0.2	0.2	0.2	0.3	0.5	0.6	0.7	0.7	0.7	0.7
2005	0.6	0.6	0.4	0.4	0.3	0.1	-0.1	-0.1	-0.1	-0.3	-0.6	-0.8
2006	-0.8	-0.7	-0.5	-0.3	0.0	0.0	0.1	0.3	0.5	0.7	0.9	0.9
2007	0.7	0.3	0.0	-0.2	-0.3	-0.4	-0.5	-0.8	-1.1	-1.4	-1.5	-1.6
2008	-1.6	-1.4	-1.2	-0.9	-0.8	-0.5	-0.4	-0.3	-0.3	-0.4	-0.6	-0.7
2009	-0.8	-0.7	-0.5	-0.2	0.1	0.4	0.5	0.5	0.7	1.0	1.3	1.6
Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
2010	1.5	1.3	0.9	0.4	-0.1	-0.6	-1.0	-1.4	-1.6	-1.7	-1.7	-1.6
2011	-1.4	-1.1	-0.8	-0.6	-0.5	-0.4	-0.5	-0.7	-0.9	-1.1	-1.1	-1.0
2012	-0.8	-0.6	-0.5	-0.4	-0.2	0.1	0.3	0.3	0.3	0.2	0.0	-0.2
2013	-0.4	-0.3	-0.2	-0.2	-0.3	-0.3	-0.4	-0.4	-0.3	-0.2	-0.2	-0.3
2014	-0.4	-0.4	-0.2	0.1	0.3	0.2	0.1	0.0	0.2	0.4	0.6	0.7
2015	0.6	0.6	0.6	0.8	1.0	1.2	1.5	1.8	2.1	2.4	2.5	2.6
2016	2.5	2.2	1.7	1.0	0.5	0.0	-0.3	-0.6	-0.7	-0.7	-0.7	-0.6
2017	-0.3	-0.1	0.1	0.3	0.4	0.4	0.2	-0.1	-0.4	-0.7	-0.9	-1.0
2018	-0.9	-0.8	-0.6	-0.4	-0.1	0.1	0.1	0.2	0.4	0.7	0.9	0.8
2019	0.8	0.8	0.8	0.7	0.6	0.5	0.3	0.1	0.1	0.3	0.5	0.5
Year	DJF	JFM	FMA	MAM	AMJ	MJJ	JJA	JAS	ASO	SON	OND	NDJ
2020	0.5	0.6	0.5	0.3								

Source: https://origin.cpc.ncep.noaa.gov/products/analysis_monitoring/ensostuff/ONI_v5.php. Access on: Jun. 30 2020.

Schmit *et al.* (2019) indicated that catches of sardines in the OAS ranged between 15,000 and 117,000 tons between 1992 and 2017, and that the years with the highest and lowest catches of this species occurred in 1997 and 2017, respectively. The high catches of sardines in 1997 were followed by an abrupt drop, reaching the historic low in 1999/2000. The authors also indicated that a sequence of positive SST anomalies reduced catches of sardines and skipjack tuna by 85 and 50%, respectively, between 2014 and 2017. Table 1 shows the occurrence of El Niño events in this period, as well as in 1997/1998. These authors did not evaluate more recent years, but in figure 21 it can be seen that throughout 2019 and 2020 there was a sharp reduction in positive anomalies and the occurrence of negative anomalies, taking as an example the Coastal FV of Santa Marta. Regarding this last fact, we can now see in Table 1 the entry of a neutral period from the middle of 2019.

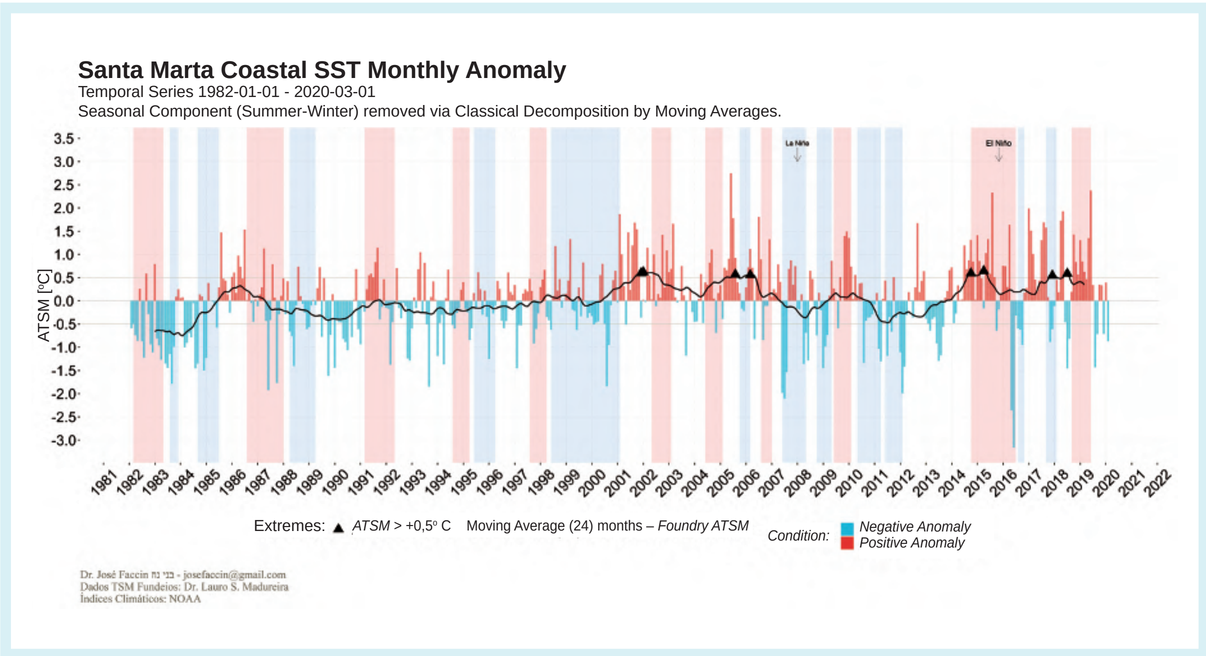


Figure 21. SST anomalies calculated for the Santa Marta Coastal FV between the years 1981 and 2019.

It is still early for more grounded assessments in relation to the current state of OAS in terms of SST, but it is important to note that the catches of sardines obtained from 02/15 to 04/15/2020 have already been equivalent to the catches of the whole year 2019 (Source: SINDIPI). In the same direction, the production of skipjack tuna from January to March 2020 has already reached the equivalent of 60% of the 2019 production of the Leal Santos industry (personal communication: Alexandre Llopart - Company Director). Therefore, within the context of the reduction of positive anomaly years and the occurrence of negative anomalies, as mentioned above, 2020 is the most promising year for the skipjack tuna and sardine fishing sector in the SE/S in Brazil since the very strong catches in 2015/2016. Here the association between great catches and the non-occurrence of El Niño events is clearly perceived.

Fortunately for the fishing sector, NOAA[7] has been pointing to a strong tendency for 2020 to be a neutral year, as shown in figure 22, below, which presents the probabilities, according to the CPC/IRI (Climate Prediction Center and the International

Research Institute for Climate and Society), of the occurrence of the three possible scenarios (La Niña, El Niño and neutral), with updated data until mid 2020. For all quarters, the dominance of the gray bar is noticeable, indicating the probability for neutral scenarios,

[7] Available at: https://www.cpc.ncep.noaa.gov/products/precip/CWlink/MJO/enso.shtml`discussion. Accessed on: July 3 2020.

which is quite strong (over 50%) in the first five quarters evaluated. As the year progresses, despite this dominance still lingering, there is an increase in the probability of the occurrence of La Niña events (blue bar). The probability of El Niño events (red bar) remains practically constant at around 20% from the June/July/August (JJA) quarter.

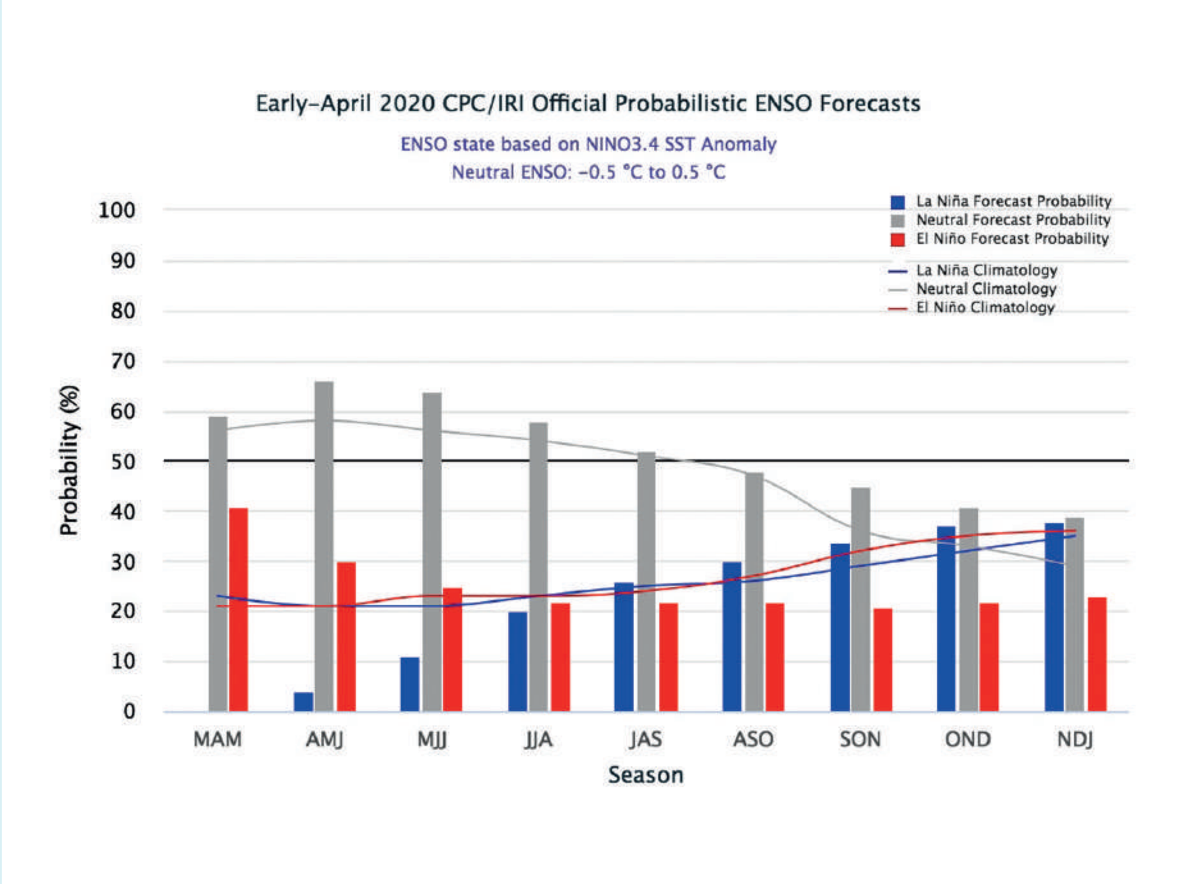


Figure 22. Probabilities, according to NOAA and IRI, of the occurrence of the three possible scenarios (La Niña, El Niño and neutral), with updated data until mid 2020. Sources: https://www.cpc.ncep.noaa.gov/products/analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf and https://iri.columbia.edu/our-expertise/cli-mate/ forecast/enso/current /. Accessed on: Jul. 08 2020.

Likewise, figure 23 indicates the trend in SST anomalies shown by numerical models, considering the Niño 3.4 of the Equatorial Pacific, which also point to a neutral year in the northern hemisphere in the summer and autumn seasons, as shown NOAA and CPC/IRI. It is noticed that the vast majority of models place the predictions (forecast) of SST anomalies within the range of ± 0.5º C, which characterizes a neutral scenario. A few models have estimated anomalies close to -1.5º C.

In general terms, between 2012 and 2014 there was neutrality in SST anomalies in the south/southeast region of the Brazilian coast (anomalies considered neutral are those with variations between + 0.5 ° C and -0.5 ° C, similarly to the neutral phases of ENSO), calculated as the averages obtained in the FVs, in the distribution area of skipjack tuna, for the referred period. It is also important to note that between 2012 and 2014 there was an increase in catches of skipjack tuna for the national fleet as a whole (see Chapter 9), which would be related to negative SST anomalies. In the following years, from 2014 to 2016, as previously mentioned, with the presence of a more pronounced El Niño event, positive anomalies of SST settled in this same region. With this scenario, there was a decrease in catches.

At the end of 2018, NOAA already pointed out in its technical reports a strong tendency to change in the trade winds, which, in turn, seemed to be associated with ENSO, and perhaps even with the South Atlantic Subtropical Dipole (DSAS). From mid-2019, and with a neutral tendency of El Nino already manifesting, negative SST anomalies appear to be a new trend, and then there are higher rates of primary production and higher plankton levels, if compared with those of the 2016/17/18 triennium. The spatial density of cyclonic turns, which bring nutrients to shallower waters, increased and the occurrence of ACAS was closer to the surface. These outcrops of ACAS generate differentiated primary production. In 2020, the catch levels are very high, coming close to the levels of previous whole years.

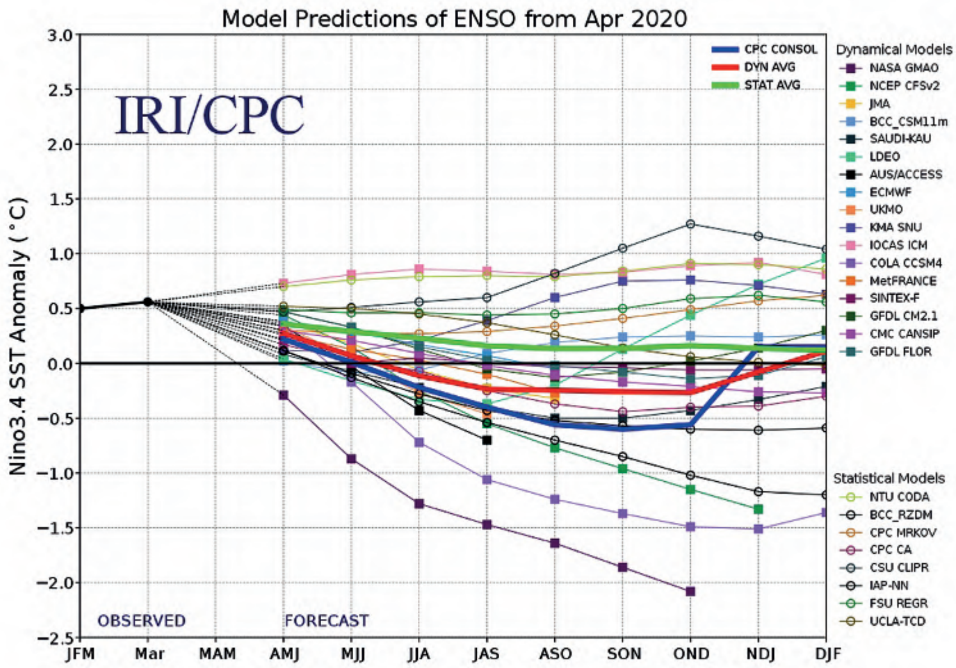


Figure 23. Trend in SST anomalies shown by numerical models, considering the Niño 3.4 of the Equatorial Pacific, according to NOAA and IRI, which also point to a neutral year in the Northern hemisphere in the summer and autumn seasons (and seasons winter and spring in the southern hemisphere). Sources: https://www.cpc.ncep.noaa.gov/products/ analysis_monitoring/lanina/enso_evolution-status-fcsts-web.pdf and https://iri.columbia.edu/our-expertise/cli-mate/ forecast/enso/current /. Accessed on: Jul. 08 2020.

As we have seen so far, the ONI (*Oceanic Niño Index*) is related to SST anomalies in the Equatorial Pacific. The question that could be asked here is: what is the relationship between the changes that occurred in the SST in the Equatorial Pacific and those of the South Atlantic SST? This question is not easy to answer. The South Atlantic SST is influenced by numerous climatic modes, ENOS being one of them. Numerous others can be listed (MAS and others). Despite being related to regional effects, these modes end up affecting spatially non-contiguous regions, which is known as teleconnection. It is not difficult to imagine how complex the teleconnections that affect the SST of the global ocean are. Many studies and research will still be needed to have a reliable answer to the question posed above. The causes that act as a “trigger” for an El Niño or La Niña event to be “triggered” in the Equatorial Pacific are still unknown, the main cause being atmospheric. Always remembering that the SST in the south/southeast region of the Brazilian coast does not respond only to variations in the ONI.

A line of research that assesses the impacts of the events mentioned in the oceanographic structure to the north of Santa Marta, which is effectively the fishing area of the national fleet, and also to the south of this cape, presents itself as an important development perspective, in order to expose a scenario for the skipjack tuna fishing area as a whole, with regard to SST anomalies and their impacts on catches.

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Use of electronic tags for identification of skipjack tuna movement patterns

3

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Introduction

Tuna and related are pelagic fish, and top predators of the migratory food chain that move at high speeds, crossing large distances in the oceans. Their life habit is facilitated by anatomical, biological and physiological specializations, which allow them to swim constantly at high speeds and to enter cooler waters, maintaining a thermal gradient between body temperature and the appropriate room temperature (GUNN & BLOCK , 2001).

The size, power and speed of movement of tunas and the like represent a challenge to the study of their biology. Considering their rapid movement across wide geographical areas, it is difficult to obtain data on population dispersion patterns, due to the limited resolution of analytical tools available for the study of these pelagic fish (BLOCK *et al.*, 1998).

A strategy that has been used for a long time to overcome these limitations has been the tagging and re-catching of individuals in a population. Caught fish receive tag implants of different shapes and sizes, according to their morphological characteristics (Fig. 1). At the same time, information about weight and size is obtained and associated with the tag registration number. After implantation, the tagged fish are returned to the natural environment, mixing again with the school and, consequently, with their original population. Eventually, these individuals are recaptured by fishing and the data of the registration number of the tag, the weight and size of the individual, as well as the place of capture, are recovered (MURPHY & WILLIAMS, 1996), providing important information for analysis aimed at recognizing movement patterns in space and time.

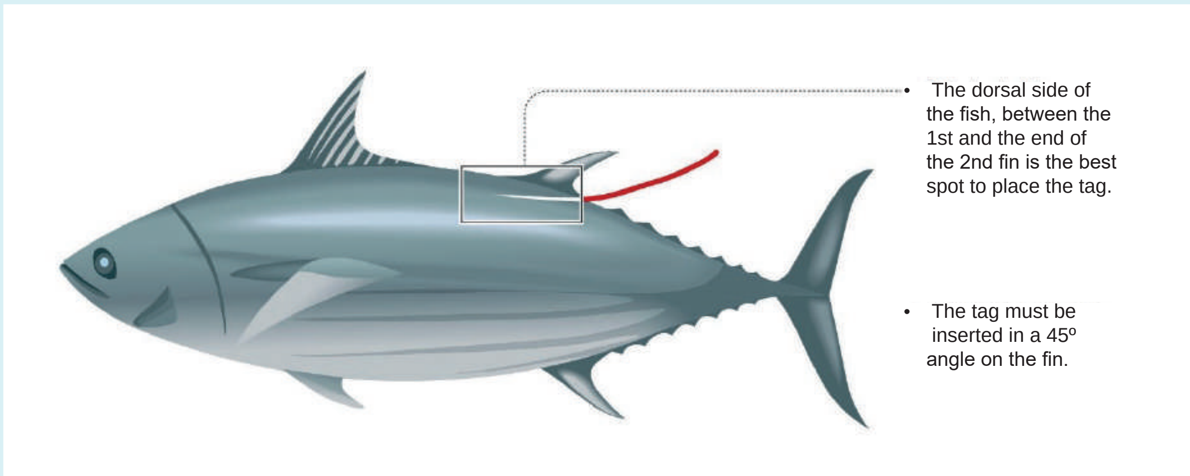

Figure 1. Example of a tag used in skipjack tuna, with indication of its positioning.

The information obtained in this procedure allows to estimate migratory movements, population structure and size, in addition to growth and mortality parameters (BLOCK *et al.*, 1998). Although these experiments provide roughly rough estimates of population movements, little is known about what happens in the interstices between the tagging and recapture sites, that is, the migratory routes and the daily variations in the movement behavior in the water column . At the same time, as the recapture depends intrinsically on commercial fishing (artisanal or industrial), the recovery of these individuals may be reflecting the activity of the fishing fleets, instead of the true amplitude of movement of the study population (BOLLE *et al.*, 2005), such as, for example, being recaptured in any intermediate phase of the migration that it would effectively perform.

More recently, research on the movement and migration of large pelagic fish has benefited from the development of new technologies, including electronic tags, satellite communication, remote sensing and the ability to process information by high-performance computers (GUNN & BLOCK, 2001). In this sense, electronic tags that archive or transmit stored data to satellites have helped to map habitats used by highly migratory fish in pelagic ecosystems (METCALFE & ARNOLD, 1997; BLOCK *et al.*, 2005).

Electronic tags of the Pop-up Satellite Archival Transmitting Tag (PSAT) type are devices that, implanted in the fish, record and archive data for a certain time, after which they detach themselves from the individual and start transmitting this information via satellite. Once transmitted, geolocation data, sea water temperature, depth of diving, as well as other information of interest, can be retrieved on scientific platforms for analysis (BLOCK *et al.*, 2005). Many studies have been carried out using these electronic tags on several species of tuna, such as, for example, Block (2019), which presented a synthesis of migratory patterns of bluefin tuna (*Thunnus thynnus*) in the Atlantic Ocean, while Nimit *et al.* (2020) studied the oceanographic preferences of the yellowfin tuna (*T. albacares*) in stratified tropical oceans.

The movement patterns of the skipjack tuna (*Katsuwonus pelamis*) in the Atlantic Ocean have been extensively studied by the International Atlantic Tuna Commission (ICCAT). Using traditional "spaghetti" tags, it was observed that, for the Atlantic as a whole, there are only two records of transatlantic migrations in the east-west direction. In the eastern Atlantic, migrations generally follow the contour of the African coast between latitudes 15º S and 30º N (ICCAT, 2006). This same report also points out that, for the western Atlantic, there is little information, restricted to the only records of south-north migratory movements along the south-southeastern Brazilian coast and sparse information in the Caribbean. Records of the occurrence of *K. pelamis* eggs and larvae in the Exclusive Economic Zone of Northeast Brazil (PINTO *et al.*, 2002) and the discharges from associated school fisheries carried out in the same area point to the presence of the species in the region (SILVA *et al.*, 2019).

Until now, electronic tags have never been used to study the movement patterns of the skipjack tuna. In this chapter, the experience and results obtained with the use of electronic tags of the PSAT type will be reported in order to characterize the patterns of habitat use and the detachment behavior in the water column (vertical and horizontal) of the skipjack tuna in the Southwest Atlantic, in addition to exploring records of hydroacoustic prospecting cruises that mapped one of the main prey of the skipjack tuna in the study region.

Materials and Methods

To identify the movement patterns of the skipjack tuna, electronic devices like MiniPAT®, manufactured by the company Wildlife Computers Inc., Redmond, WA, USA, were used. Each device has an anchor that is implanted in the specimen and a cable (*tether*) connecting the device to the anchor. The equipment is approximately 10 cm long and has an antenna for connection to the ARGOS satellite (*Advanced Research and Global Observation Satellite*), in addition to temperature, light and pressure sensors (ie, depth), communication port for programming, system for connect the equipment automatically in contact with sea water (ie, wet/dry sensor), and a device release pin at the end of the predetermined period (Fig. 2).

A total of 12 tags were purchased for use in tagging the skipjack tuna. In the laboratory, each tag was programmed to record information and release in accordance with the procedures specified in the instruction manual provided by the manufacturer, Wildlife Computers. In the laboratory, the team was trained to tag the specimens in the field. To this end, 15 specimens of skipjack tuna were purchased for laboratory tests. The recommended point for the insertion of the anchor, aiming at better support, was below the 2nd dorsal fin, crossing the pterygiophors.

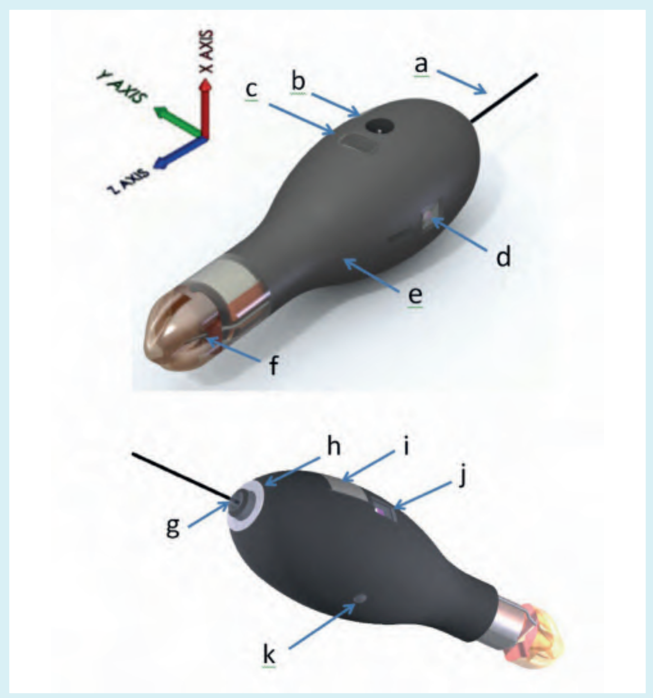

Figure 2. Representative illustration of the MiniPAT® electronic tag showing: (a) ARGOS antenna, (b) temperature sensor, (c) communication port, (d) light sensor (1 of 2), (e) float, (f) release pin, (g) LED light, (h) humidity sensor, (i) grounding plate, (j) light sensor (2 of 2), (k) pressure sensor (Image courtesy of ©Wildlife Computers, Redmond, WA, USA, for use in this publication).

The tags were programmed by establishing the intervals for recording the information and the total time in days for its release. Then, the tags were sealed and kept in the drive mode in contact with water. All tags were packed in closed plastic bags, avoiding accidental contact with water or moisture, which could trigger the mechanism before the desired time.

The capture of individuals was carried out on board the vessel "Katsushio Maru 6", which belongs to the fishing fleet of pole and live bait of the company Industrias Alimentícias Leal Santos Ltda. Following the ICCAT recommendations for tagging tunas[1], larger specimens were caught by fishermen, carefully removed from the hook and placed on a padded table with blindfolds, for immobilization and stress reduction. After measuring the furcal length, the MiniPAT® tags were implanted and the specimens were returned to the sea immediately (Fig. 3).

After the release of the tagged specimens, 7 of the 12 tags began transmitting data to the ARGOS satellite system, being accessed and decoded on the online portal made available by Wildlife Computers, submitted to treatment and generation of the results. The vertical movement of the individuals were analyzed using the Time Series data sheet, which, in summary, records information about the date, time, depth and temperature of where the fish has been. The residence time in different depth strata (TAD) and temperature ranges (TAT) were calculated in function of the percentage of time that the fish remained in each depth/temperature interval and classified by period of the day (i.e., day/night) (Fig. 4, 5a and 7).

[1] Available at: https://www.iccat.int/aottp/AOTTP-Document-Library/Manuals/AOTTP-Tagging-Handbook-EN.pdf. Accessed on: Jul. 08

Figure 3. Skipjack tuna specimen with implanted MiniPAT® tag, ready to be released to the sea. Detail of the tagging bed adapted with measuring tapes to measure the furcal length. Foto: Lauro A. Saint Pastous Madureira.

The dive profile as a function of the monitoring time was calculated using all depth records by date and time, and in relation to the periods of the day and twilight (i.e., dawn and dusk) (Fig. 5b). The depth-by-temperature profile (PDT) was analyzed from the maximum, minimum and six daily percentiles of depth and temperature (Fig. 8).

The geolocation of the skipjack tuna was calculated using the GPE3® software from Wildlife Computers, a discrete Hidden Markov space-state model (i.e., step-by-step progress), which uses observations of brightness, sea surface temperature, maximum depth, and known locations (e.g., marking/recapture location or acoustic detections). The final model incorporates a movement model based on the speed parameter (defined by the researcher) and an observational model, based on the variables described above, resulting in a grid of associated locations (0.25° x 0.25°) to probability of the fish being in a certain position at each step. These data were plotted in ArcView to superimpose on sea surface temperature (SST) and Ocean Surface Color (CSO – a proxy for plankton concentration) images, obtained by CATSAT software, through a license to use Leal Santos Ltda.

Results

Between 14 and 15 days in June 2019, 12 specimens of skipjack tuna, with a furcal length varying between 64 and 86 cm, were tagged on board the vessel "Katsushio Maru" approximately 50 miles from the coast in front of Cabo Frio. Table 1 presents the main data of the implanted tags, such as, for example, details about the tagged specimens, the serial number of each tag and the respective schedule for release.

Of the total number of tags implanted, seven transmitted signals in time intervals ranging from one to eight days, which was considered premature since, although all the care had been taken in the operation, these tags were released before the original schedule.

The causes of premature releases may be related to the death of individuals (17P0338, 17P0556, 17P0585 and 17P0593) or the improper anchoring of the tag, a fact that occurred effectively with the tags 17P0122, 17P0128 and 17P0129. Jepsen *et al.* (2015), after a careful review of the literature, observed that there are specific problems with respect to PSAT tags, with a high proportion of premature losses and death of marked individuals, in addition to other factors, especially in smaller species. On the other hand, Hammerschlag *et al.* (2011), point out a 10% failure rate of the tags used in studies with sharks and which, according to Hays *et al.* (2007), may be the result of mortality, failures in the wet/dry sensor, damage to the antenna or premature detachment.

Table 1. Serial number of tags, PTT ARGOS identifier, geographic tagging position, furcal length (cm) of specimens, programmed and effective registration time (days).

Serial Number	PTT ARGOS	Geographic Position	Size (cm, CF)	Record Time (days)	
				Programmed	Effective
17P0441	49517	23º49' S/ 41º46' W	82	35	No signal
17P0556	49518	23º49' S/ 41º 46' W	74	35	14/06 - 16/06 (3)
17P0573	49530	23º49' S/ 41º46' W	86	35	No signal
17P0604	49535	23º45' S/41º45' W	79	35	No signal
17P0122	49511	23º45' S/41º45' W	64	90	13/06 (1)
17P0128	49513	23º45' S/41º45' W	75	90	15/06 - 23/06 (8)
17P0338	49516	23º45' S/41º45' W	77	90	15/06 (1)
17P0572	49529	23º45' S/41º45' W	75	90	No signal
17P0129	49515	23º45' S/41º45' W	82	145	15/06 - 16/06 (2)
17P0593	49534	23º45' S/41º45' W	75	145	15/06 - 17/06 (3)
17P0581	49531	23º45' S/41º45' W	75	180	No signal
17P0585	49533	23º45' S/41º45' W	79	180	15/06 - 16/06 (2)

It is important to note, that this is the first time that PSAT electronic tags have been used in skipjack tuna throughout the world. Despite this, even if considered to be premature release, it was possible to extract important information from these tags.

Figure 4 shows the percentage of time spent in different depth strata (TAD) by the tagged individuals. The distribution shows that the skipjack tuna reached maximum depths close to 250 meters. However, two patterns were observed, one in the 40-49 m class and the other in 100-149 m depth.

Considering the distribution of data in the day and night periods, there is a tendency for individuals to remain at lower depths, above 50 m, at night. During the day, a more homogeneous distribution is observed in several depth strata, but with a recurring pattern in the 150 m class (Fig. 5a). These migrations can be better observed in the pattern presented by the individual 17P0556 (Fig. 5b). The data recorded for three days showed that, at night, the individual remained at depths below 50 m, while during the day, the depths varied between 100 and 200 m.

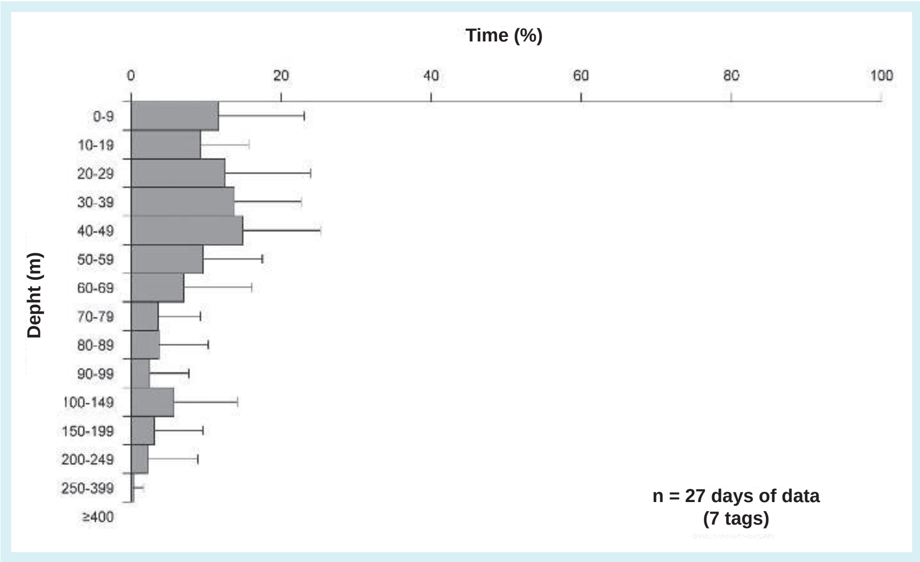

Figure 4. Percentage and standard error of time spent by tagged individuals of *Katsuwonus pelamis* in different depth strata (TAD).

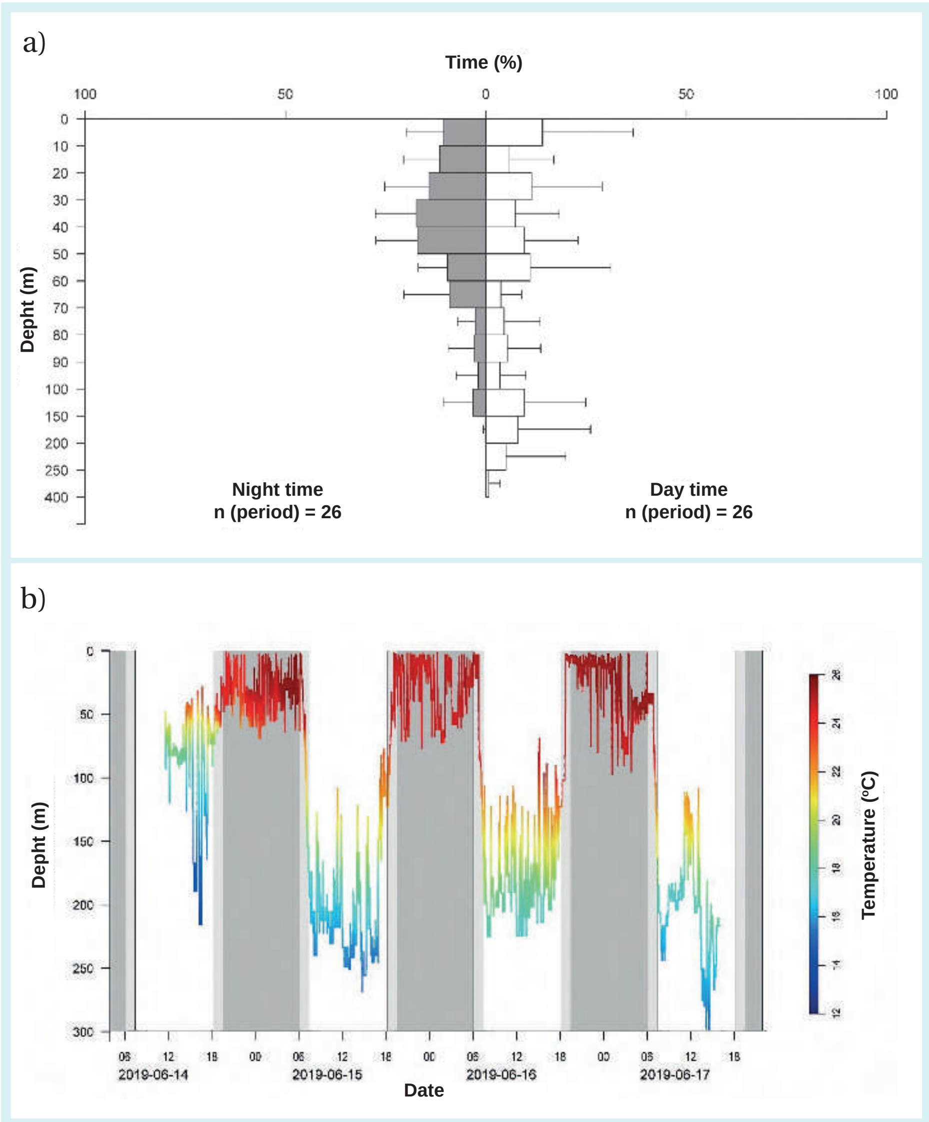

Figure 5. a) Percentage and standard error of time spent by individuals tagged by *Katsuwonus pelamis* in different depth strata during the day and night. b) Daily vertical movement of individual 17P0556, between June 14th and 17th, 2019.

Regarding the water temperature, most of the time was spent in water between 22ºC and 25ºC. However, it can be observed that the monitored individuals occupied temperature ranges around 14ºC to 15ºC for short periods of time (Fig. 6). These forays into colder waters can be better understood by looking at the thermal profile of the daily movement of the individual 17P0556 in relation to the depth. The lowest temperatures occurred at greater depths, between 200 and 250 m, coinciding with exploratory dives in deeper strata during the day (Fig. 7).

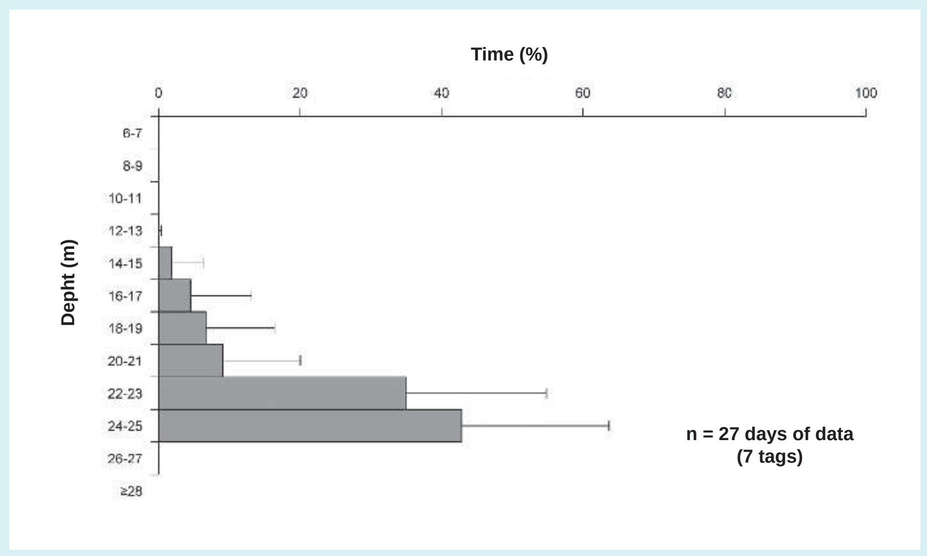

Figure 6. Percentage and standard error of residence time of individuals tagged by *Katsuwonus pelamis* in different temperature strata (TAT).

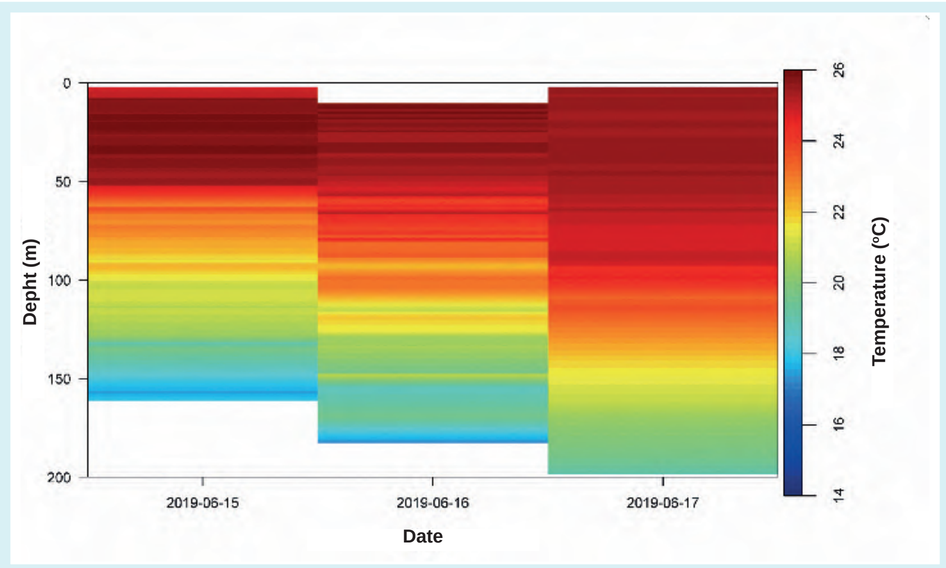

Figure 7. Thermal profile of the daily movement of individual 17P0556 in relation to depth (PDT), between 14 and 16 June 2019.

Figures 8, 9 e 10 shows the movement routes of the seven tagged skipjack tuna individuals, superimposed on the image of the high oceanic bottom, Sea Surface Temperature (SST) and Color of the Ocean Surface (CSO). It is observed that the majority of movements occurred in ocean waters outside the continental shelf (Fig. 8). However, at least two individuals moved on the shelf, one in the NE direction and the other in the W direction, practically skirting the 200 m isobath in the S/SW course.

The superposition of the movement routes with the SST image of the tagging time obtained in the CATSAT program indicates that the movements of the individuals follow the thermal fronts around a cyclonic vortex of the Brazilian current, with a core of colder waters (Fig. 9).

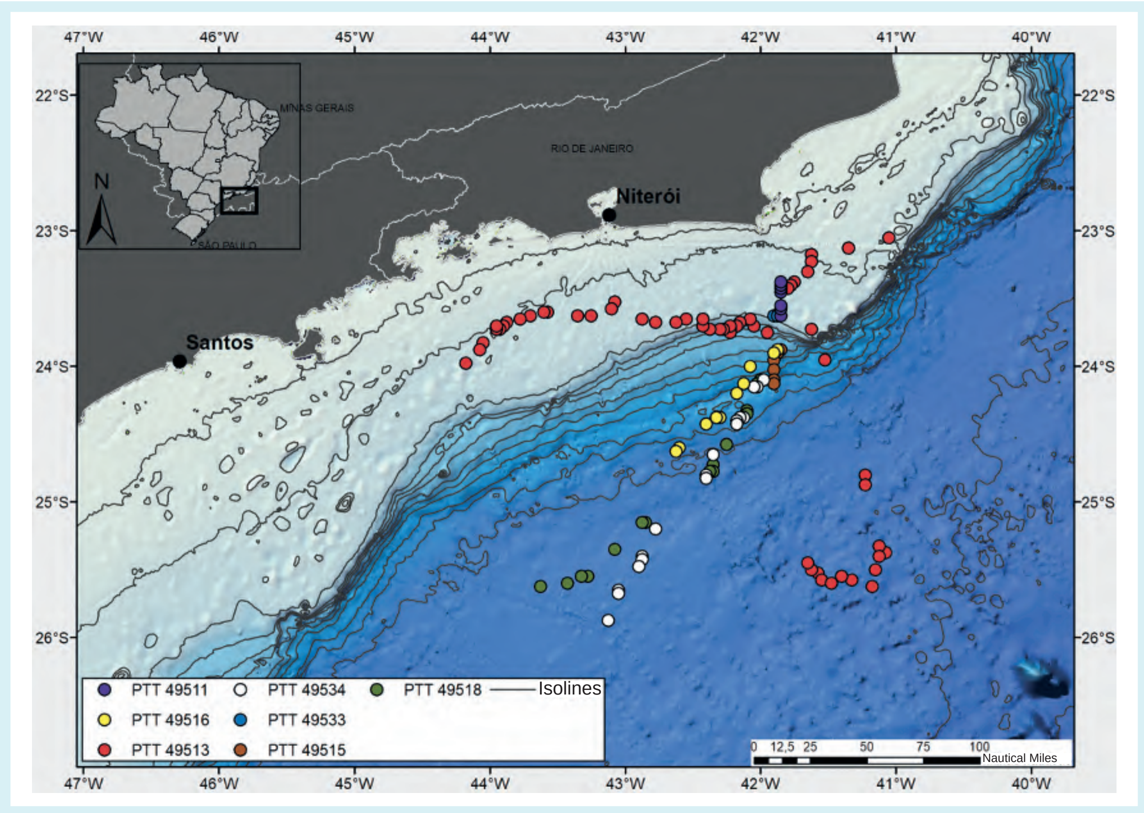

Figure 8. Movement routes of the tagged skipjack tuna in relation to the bathymetry. Image of the 14th and 17th of June 2019.

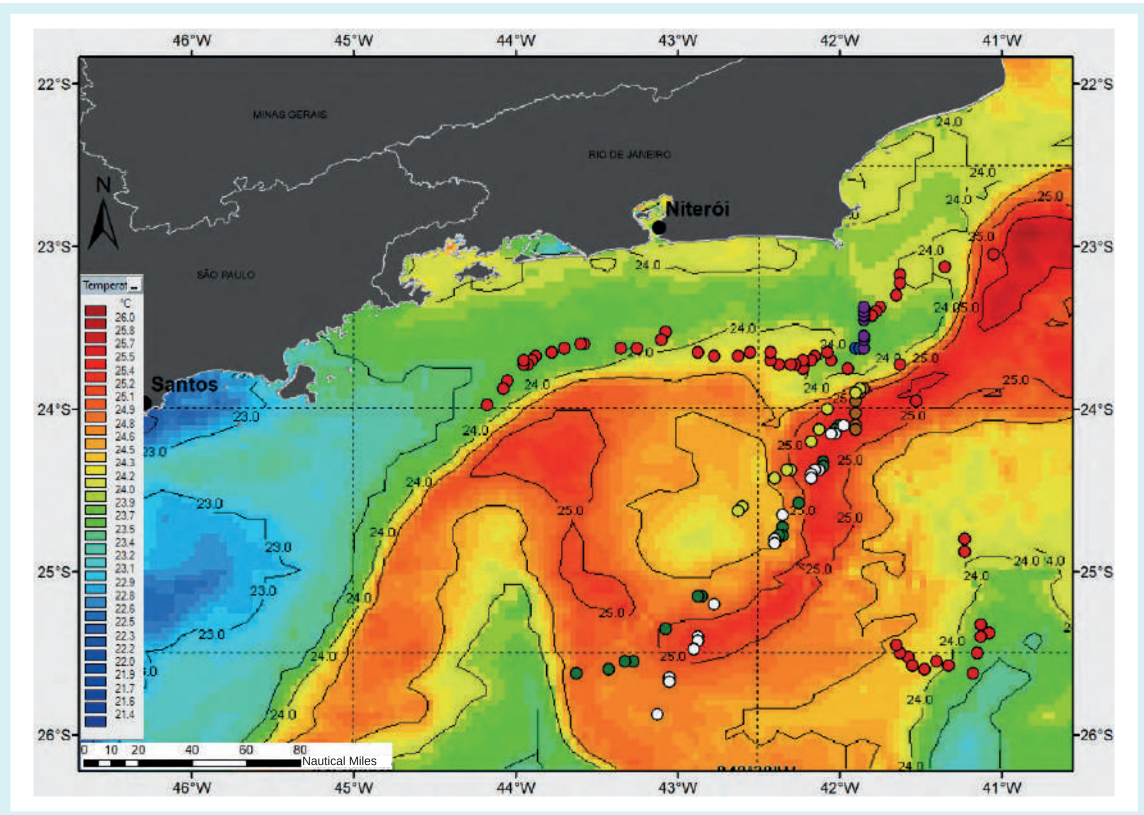

Figure 9. Surface Sea Temperature (SST). Image of the 14th and 17th of June 2019.

Planktonic productivity associated with the vortex (Fig. 10), as well as the fishing evidence obtained in the literature, demonstrate the importance of these oceanographic formations for local productivity, and, consequently, for the aggregation of schools of the skipjack tuna.

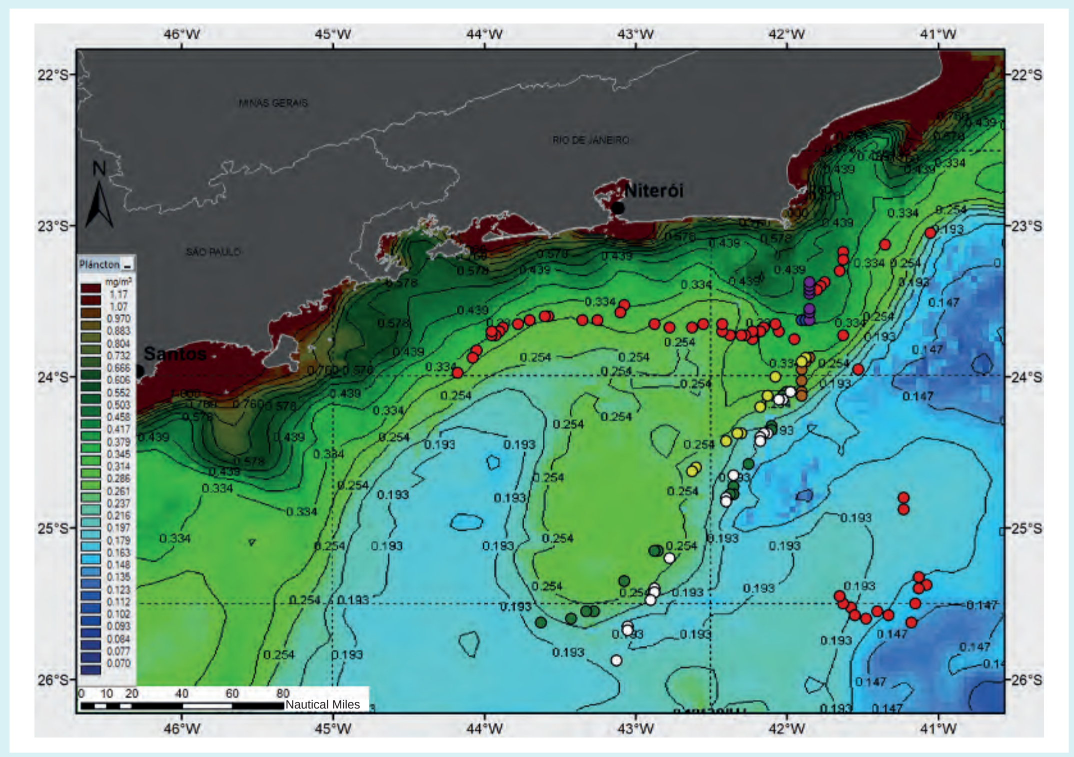

Figure 10. Ocean Surface Color (CSO). Image of the 14th and 17th of June 2019.

The routes are divided into two axes bordering this vortex. One facing the shelf and one facing the embankment in the W/SW direction. Both going south, from the tagging point off Cabo Frio. The overlapping of the data with the CSO image indicates movement routes over areas with a higher probability of plankton concentration, and, consequently, a greater probability of available food for the skipjack tuna. Data from the activities of the fishing fleet of pole and live bait (Fig. 11) show that catches are associated with oceanographic fronts, with individuals moving along more suitable isotherms and feeding in cooler and enriched waters.

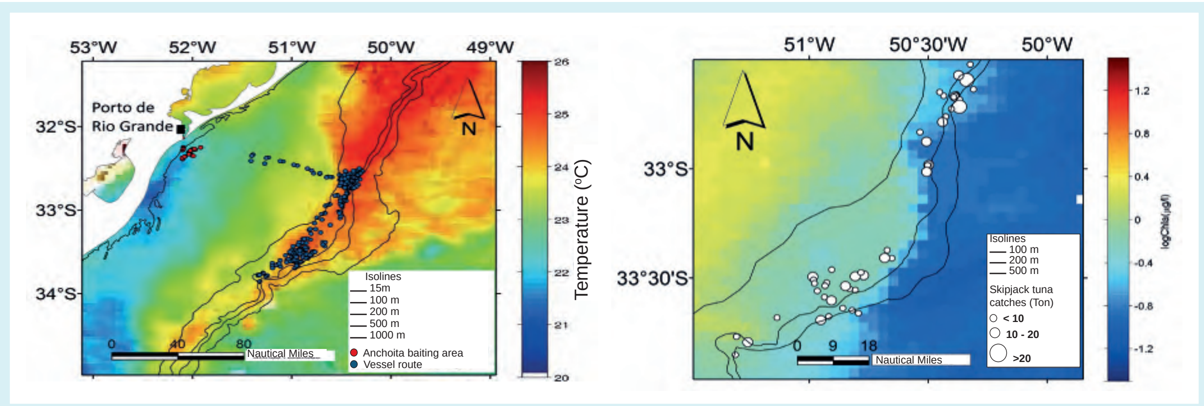

Figure 11. Catches of skipjack tuna by the pole and live bait fleet occurring on the thermal front (a), and on the surface color front (b).

Discussion

The skipjack tuna is a top predator. Chapter 7 presents the advances related to the trophic ecology of the species obtained in research associated with Skipjack Tuna FUNBIO project and data from the bibliography. The lantern fish , *Maurolicus stehmanni,* is considered the second most important prey of the skipjack tuna, preceded by eufausiáceos, gathered under the name krill.

Krill mappings are quite complex due to the small size of these organisms, but it has been the subject of studies around the world (SIEGEL, 2016; LEONORI *et al.*, 2017; KRAFFT *et al.*, 2018). On the other hand, the lantern fish is more conspicuous in acoustic records and has already been mapped along prospecting cruises on the SE/S coast of Brazil.

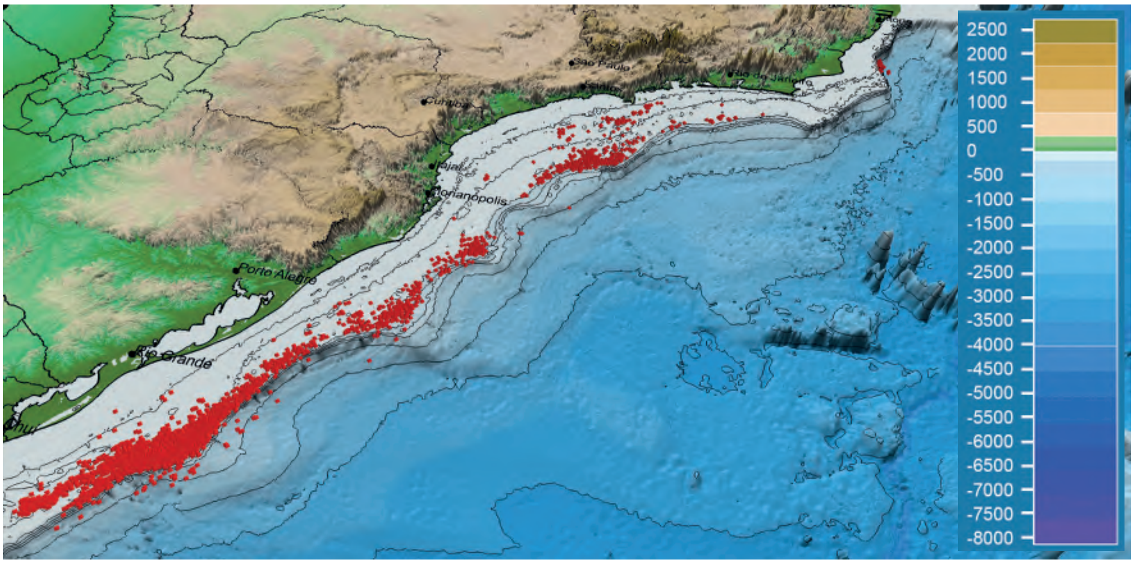

Figure 12. Map with the skipjack tuna catch points by the Leal Santos fleet between 2013 and 2018.

Figure 12 presents a map of the distribution of skipjack tuna caught by vessels of the company Leal Santos Ltda. between the 2013 and 2018 harvests, and figure 13 a map of the distribution and density of the lantern fish, obtained from the oceanographic liner REVIZEE I, performed in the winter of 1996 (MADUREIRA *et al.*, 2005). The skipjack tuna and lantern fish records show a notable spatial overlap in areas between the north and south limits, in addition to a strong association with the continental embankment.

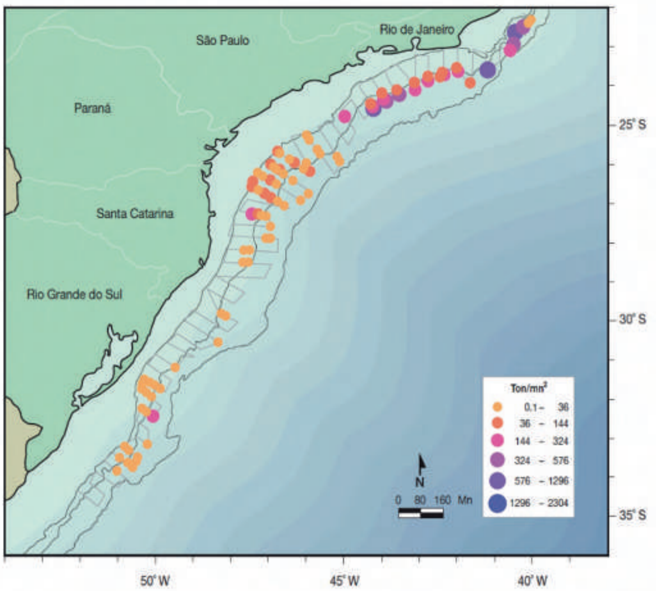

Figure 13 Distribution map and density of the lantern fish obtained with scientific sounding during ocean liner REVIZEE I in the winter of 1996.

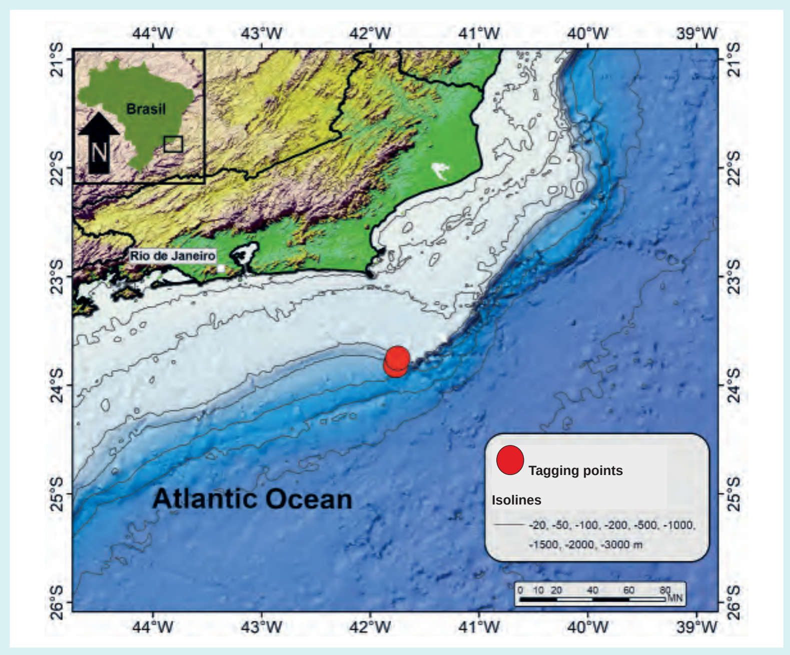

Figure 14. Geographical position of the tagging points for the skipjack tuna specimens in June 2019.

Figure 14 shows the points where the skipjack tuna taggings were performed during the winter of 2019, which are discussed in this chapter. In figure 15, details of the densities of the lantern fish in the winter of 1996, where it is possible to verify an abundance peak south of Cabo Frio. Historical data suggest that there is a strong trophic association between the skipjack tuna (predator) and the lantern fish (prey) in the study region.

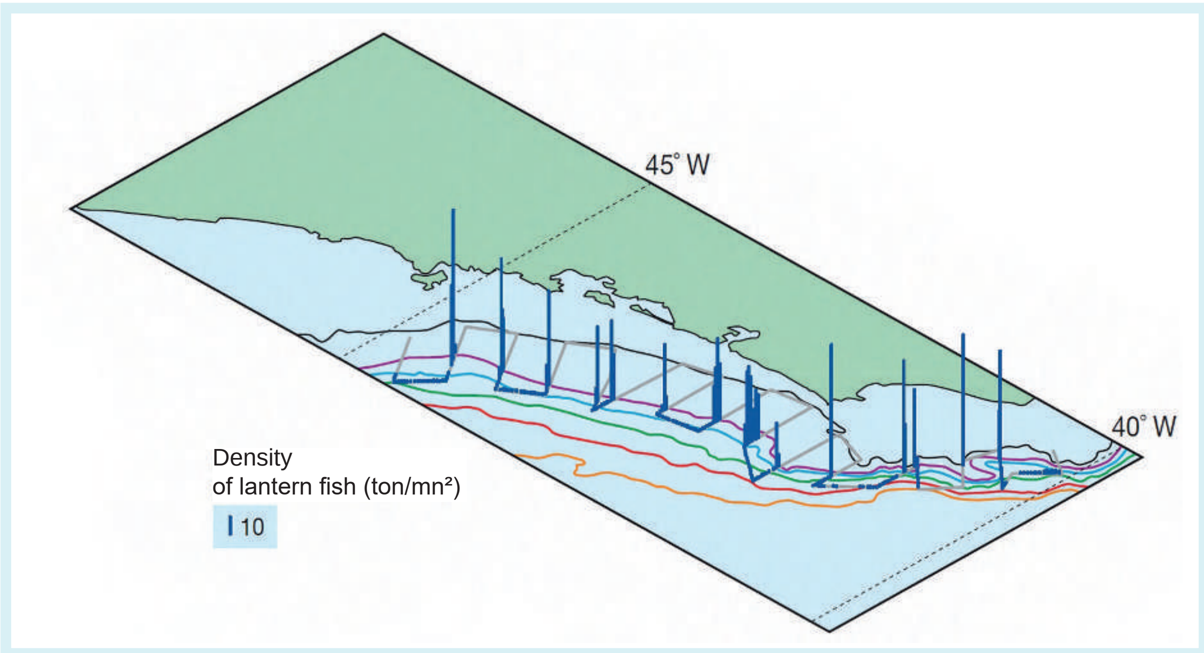

Figure 15. Density data of *Maurolicus stehmanni* on REVIZEE I winter cruise of 1996.

In addition to these aspects, there is an important correlation between the behavior of the skipjack tuna, evaluated from the vertical movements in the water column (dives) and the nictemeral behavior of the lantern fish. Figure 16 presents in an integrated way the data of depths, times, frequency of dives from the Skipjack tuna with the tag 17P0556, and acoustic records of *Maurolicus stehmanni*, obtained with a SIMRAD scientific echo sounder model EK-500 (38 kHz). This same figure also presents the diving trends of the skipjack tuna (bottom panel), predominantly shallower at night and deeper during the day.

The day-to-day movement of the lantern fish is a typical example of movement associated with anti-predation, approaching the surface to feed at dusk, decreasing its vulnerability to predators such as the skipjack tuna.

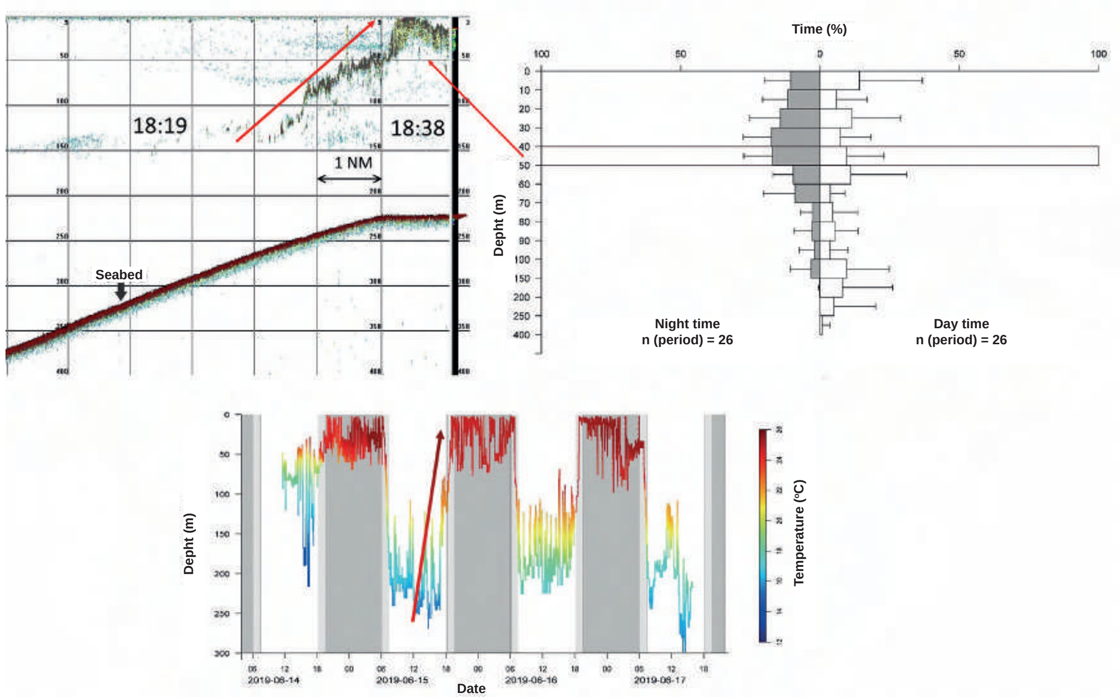

Figure 16. Integration of information between the depths, times and frequency of the dives of the tagged skipjack tuna specimens (top panel on the right), *Maurolicus stehmanni* records obtained with scientific echo sounder (38 kHz) (top panel on the left). Movement data of the individual with the tag 17P0556 during day (light) and night (dark gray) (bottom panel). The arrow on the right panel shows the depth (between 40 and 50 m) from which there is a greater frequency of nocturnal dives of the skipjack tuna and points to the depth of 50 m in the acoustic record (on the left). The arrow on the left panel indicates the depth where the upward movement of M.stehmanni starts, from 150 m, to the surface, at approximately 18:19 hrs. The arrow on the bottom panel shows a quick change in the depth of the skipjack tuna dives in the day/night interface (lighter gray).

The vertical movement of the lantern fish, to move away from the area with the highest brightness, occurs in the early hours of the day, as can be seen in figure 17, which shows an acoustic record of the species and moves it to greater depths at dawn. At the same time, the tagging data show that the skipjack tuna dives also follow the same trend.

Figure 18 shows different patterns with higher frequencies of dives at depths below 50 m at night, compatible with what is shown in figure 17. However, during the day, the movement of the skipjack tuna is more complex, however, in general, it shows an exploratory behavior of deeper strata, with patterns between 30 and 60 m and between 100 and 250 m. In figure 18, records of lantern fish are observed in dense concentrations between 50 and 100 m, with peaks reaching 40 m, and less dense between 100 and 250 m, in a period that precedes vertical migration (left panel). The lower panel shows the behavior of the predator with deep dives during the day and shallow dives at night, in addition to intermediate dives, compatible with the records of its prey.

Madureira *et al.* (2005) estimated a *Maurolicus stehmanni* biomass of more than 666 thousand tons in the study area, indicating that there is a large availability of prey. In addition, Gasalla *et al.* (2007) found that *M. stehmanni*, together with other species of planktophagous mesopelagic fish and the anchovy (*Engraulis anchoita*) represent the main base links of the pelagic nectonic trophic chain, the first being mainly associated with the platform breaking areas and the last, to the continental and coastal continental shelf.

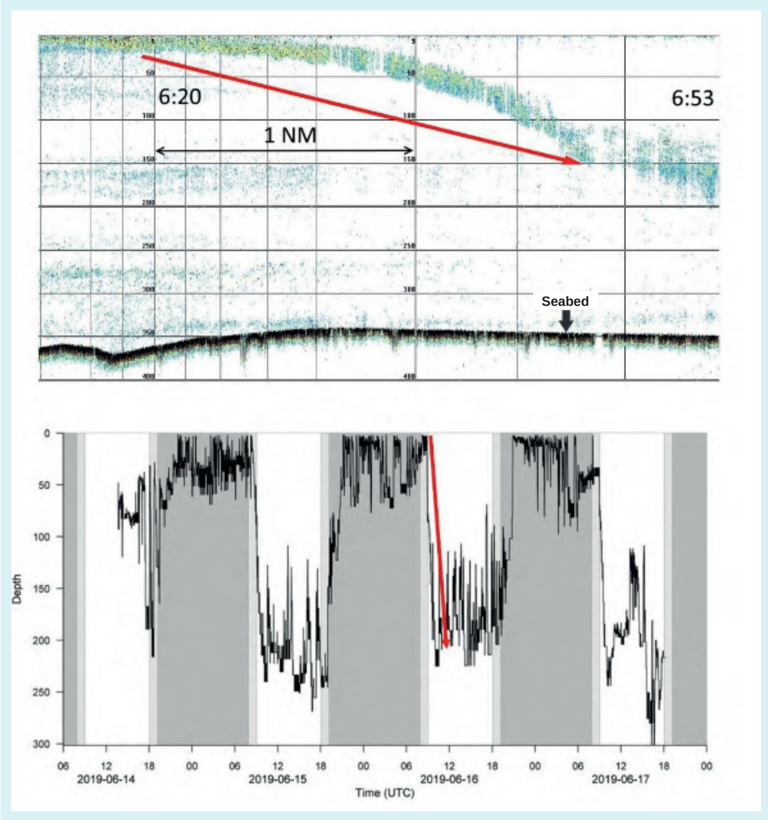

Figure 17. *Maurolicus stehmanni* records obtained with scientific echo sounder (38 kHz) (top panel). The arrow indicates the downward movement of *M. stehmanni* from the surface (6:20 h.), Towards depths greater than 150 m in the acoustic record. The arrow on the bottom panel shows the quick change in depth of the skipjack tuna dives in the night/day interface (lighter gray).

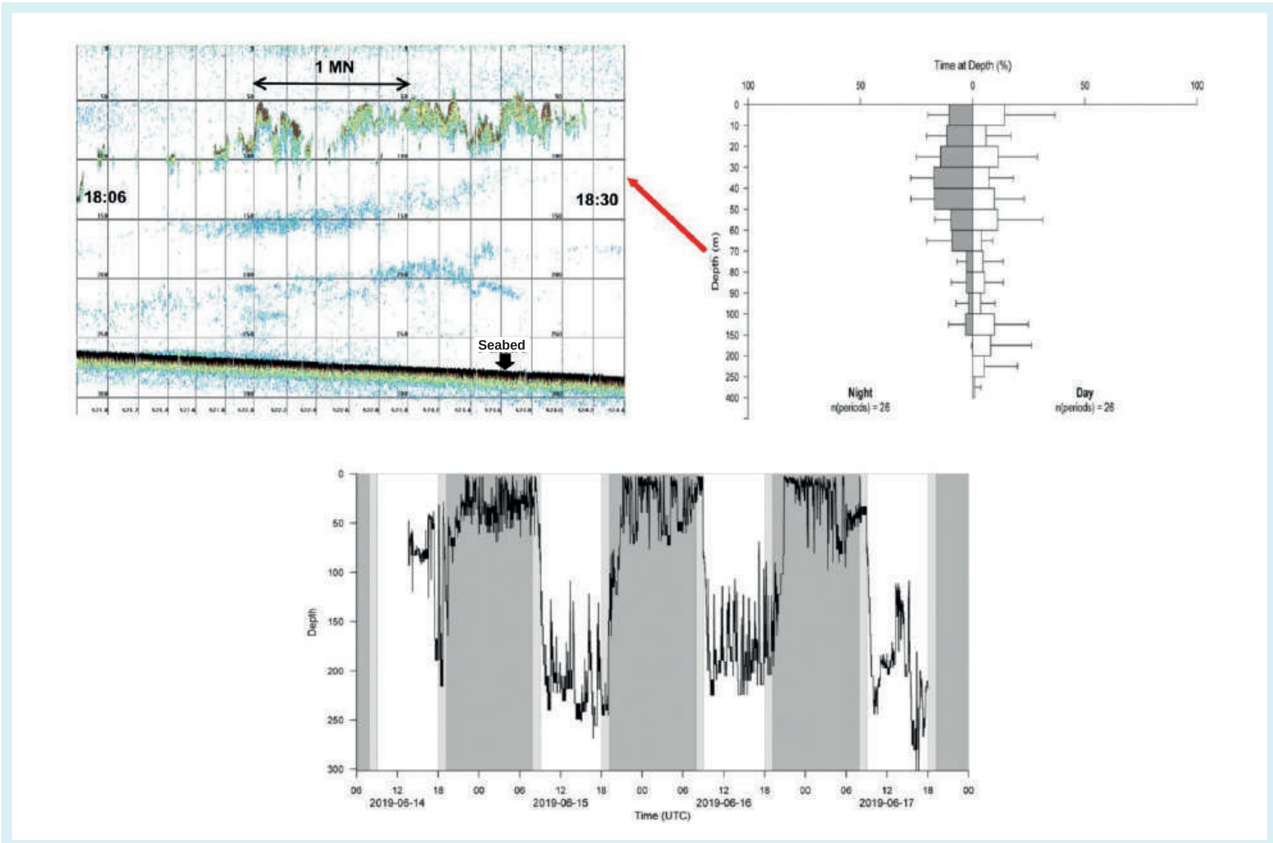

Figure 18. Integration of information between the depths, times, frequency of the dives of the tagged skipjack tuna (top panel on the right), records of the lantern fish obtained with scientific echo sounder (38 kHz) (top panel on the left), movement data of the individual marked 17P0556 during day (light) and night (dark gray) (bottom panel). The panel on the right shows a trend in the frequency of diving between 30 and 60 m and another between 100 and 250 m. The left panel shows a dense concentration of lantern fish between 50 and 100 m, with peaks reaching 40 m, and less dense between 100 and 250 m, in the period before vertical migration. The bottom panel shows the depth variability of the dives, deep in the day and shallower at night, but also intermediate dives.

Although these records are not concurrent, they serve to exemplify the relationship between the vertical distribution of prey and the vertical movements of the predator. A similar fact was observed by Williams *et al.* (2015) for Albacore (*Thunnus alalunga*) in the South Pacific Ocean. In tropical latitudes, albacore showed a characteristic pattern in the vertical use of the habitat, occupying shallower and warmer waters above the mixing layer at night, and deeper and colder waters below this layer during the day.

Final Considerations

The tagging of skipjack tuna with electronic PSAT marks provided the generation of important information that independently complements previous analyzes from fishing activity and oceanographic research liners. The association of this technology allows to increase the knowledge of the species' habits, which can be used to optimize the catches in the fishing area.

The skipjack tuna species proved to be a very sensitive species to manipulation and tagging with electronic PSAT tags. Despite the efforts of the team and the crew, the dynamics of operating a fishing boat under normal fishing conditions was a major challenge. One aspect to be considered in future appointments is to catch the specimens with a line and reel in order to tire them out and, thus, facilitate the handling and placement of the tag itself. However, this task may perhaps only be performed on a scientific liner dedicated to this activity.

Some adjustments can be implemented if new experiments are carried out with PSAT tags in skipjack tuna. Considering the size of the tagged animals, we believe that the *tether* (cable) was too long, which may have resulted in greater drag for smaller specimens, thus hindering their swimming. In some cases, the anchoring of the tag may not have been as deep, which would facilitate the early detachment of the anchor and loss of the tag. In addition to the reduction in the size of the *tether*, it is recommended to try anchoring at the base of the 1st dorsal fin and not at the base of the 2nd, as has been done and has been recommended for other species of tuna and the like.

The technology made it possible to recognize aspects of the species' behavior in relation to thermal fronts and color fronts (plankton concentration), as well as its vertical dynamics in the water column. This indicates that with the use of additional technology on board, fishing could benefit from information of this nature, being more effective in looking for schools and, consequently, increasing its success, optimizing operating costs (expenses with ice and food for the crew) and even more sustainable, with less consumption of diesel oil, and therefore CO_2 emissions into the atmosphere. The technologies with potential direct benefit to skipjack tuna fishing boats would be: 1) installation of double-frequency, i.e., high and low (e.g. 50 and 200 kHz) echo sounders, for detecting prey between the vicinity of the surface and the 300/400 m, and 2) the system for receiving images of the most significant oceanographic variables, such as SST, sub-temperature, chlorophyll (see Chapter 2). In addition, the generatio, expansion and deepening of knowledge about the movement patterns of pelagic fish of commercial importance such as skipjack tuna, also allow the construction of theoretical references necessary for the preparation and application of any management measures that consider the exploitation sustainable use of the resource.

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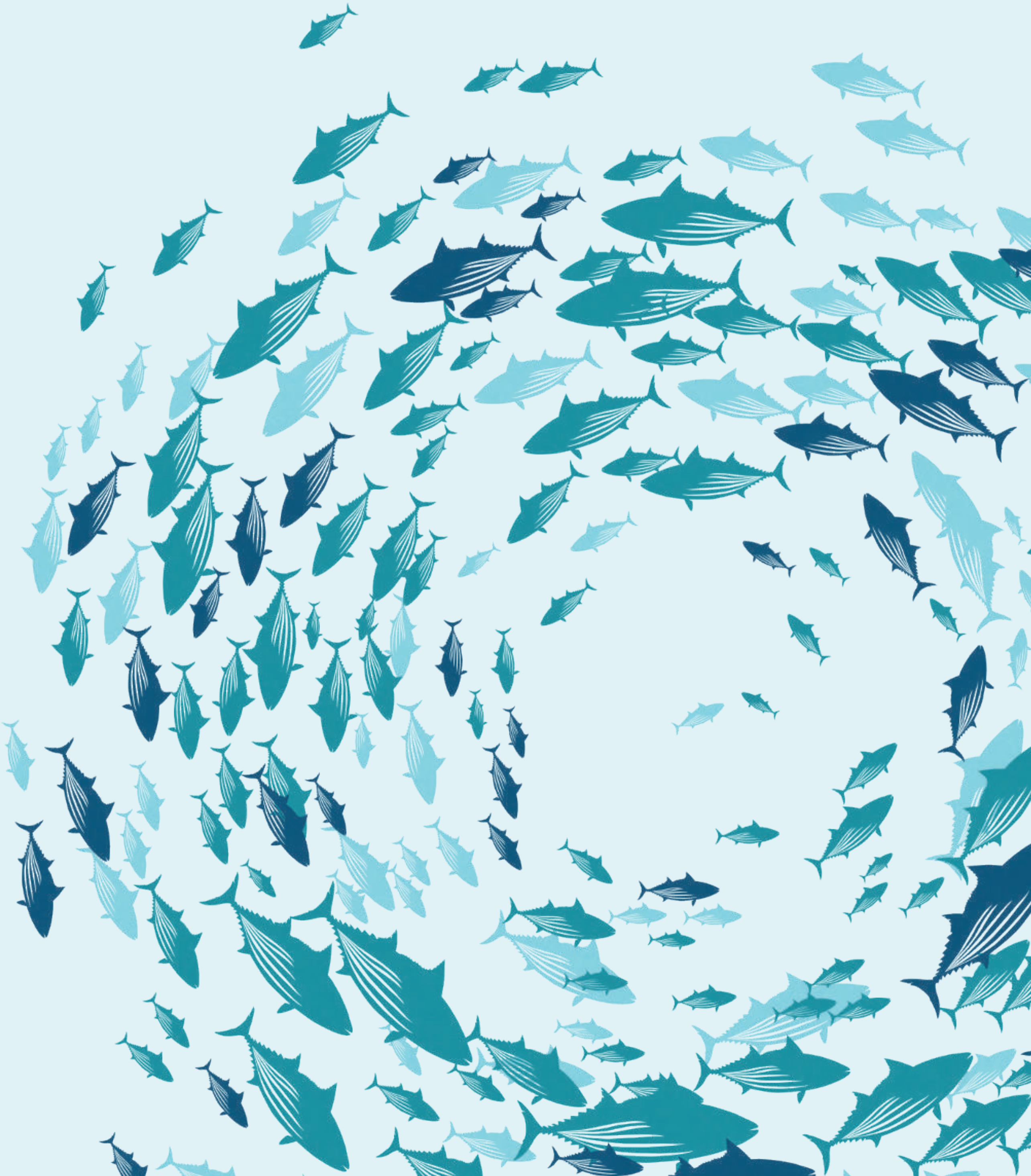
Unit II

LIFE STORY



Life cycle phases of the skipjack tuna on the Brazilian coast

4

Mario Katsuragawa,
Érico Silva Lima Gomes dos Santos,
Claudia Akemi Pereira Namiki,
Maria de Lourdes Zani-Teixeira,
Yasunobu Matsuura (in memoriam)

Ontogeny

The skipjack tuna (*Katsuwonus pelamis*), like the other fish of the Scombridae family, is oviparous with planktonic larvae and eggs. Typically, the larvae are tall, with large heads, mouths and eyes, and the preopheresis spines are well developed even before the start of flexion of the notochord (Fig. 1). The pre-anal distance (between the tip of the snout and the anus) varies with development, going from short to relatively long, when the anus is located after the middle of the body, at the beginning of the post-flexion stage.

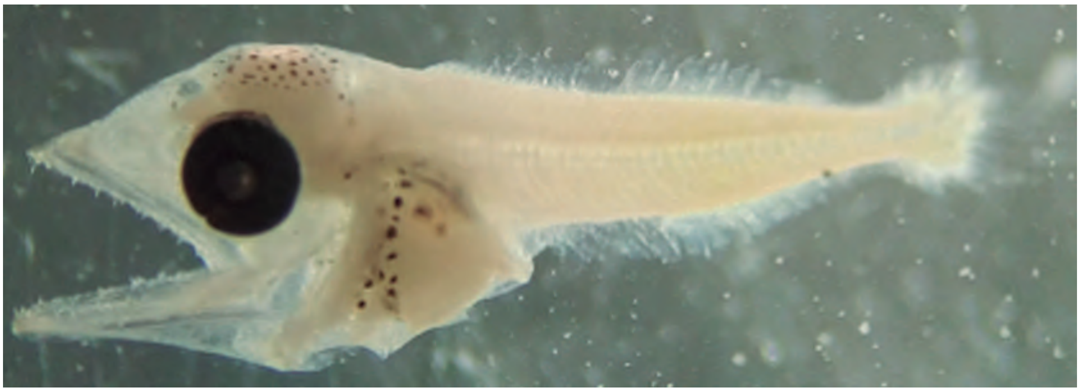


Figure 1. larva in flexion stage, approximately 6.5 mm long, collected off the southeast coast of Brazil. Photo: Érico S.L.G. Santos.

The development during the early stages of the life cycle of this species has been studied and described by several authors, such as Matsumoto (1958; 1961), Mayo (1973), Collette *et al.* (1983; 1984), Ambrose (1996), among others.

The skipjack tuna egg (Fig. 2) it has a spherical shape, with a diameter varying between 0.84 and 0.94 mm, the chorion is smooth, has a drop of oil of about 0.24 mm in diameter and the yolk is homogeneous. Hatching occurs at about 2.60 mm in length, presumably after a 24-hour incubation period (MAYO, 1973).

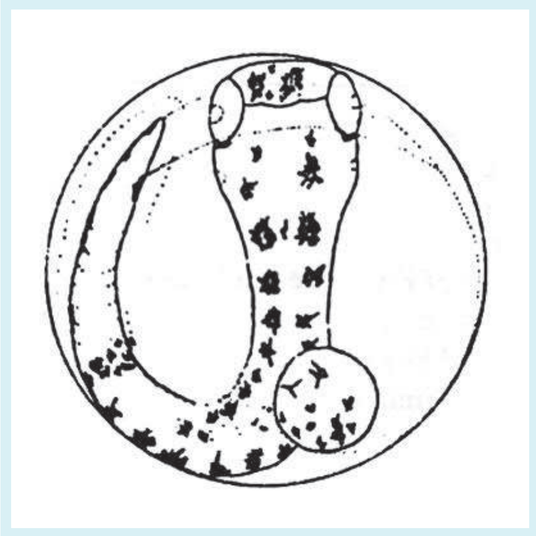


Figure 2. Skipjack tuna egg showing the developing embryo, yolk and drop of oil (MAYO, 1973; RICHARDS, 2006).

Matsumoto (1958) pioneered the stages of larval development of this species, based on 476 specimens, between 2.3 and 20.1 mm in length, collected with a plankton net in Central Pacific waters. According to the author's description, a 3.7 mm larva between the yolk sac and pre-flexion stages (Fig. 3), it has a long body and its ventral and dorsal parts bordered by a continuous and transparent membrane, called the vitelline membrane. The digestive tract is approximately triangular in shape, ending at the anal opening located slightly anterior to the midpoint of the larva's total length. It has a large mouth and the upper and lower jaws contain 4 and 6 teeth respectively. They have 3 spines along the margin of the pre-operculum, with the median region being the longest. The beginnings of the pectoral fins are visible, but the pelvic fins are still absent. The caudal fin is still at a primordial stage of formation. Pigmentation in this phase consists of a group of chromatophores scattered in the midbrain region, the tip of the mandible, at the dorsal edge of the digestive tract, below the tip of the notochord, and on the ventral line, close to the 34th myomer. This last pigment appears to be a consistent character that prevails in the other stages of larval development. The beginning of flexion of the tip of the notochord occurs around 6.0 mm in length.

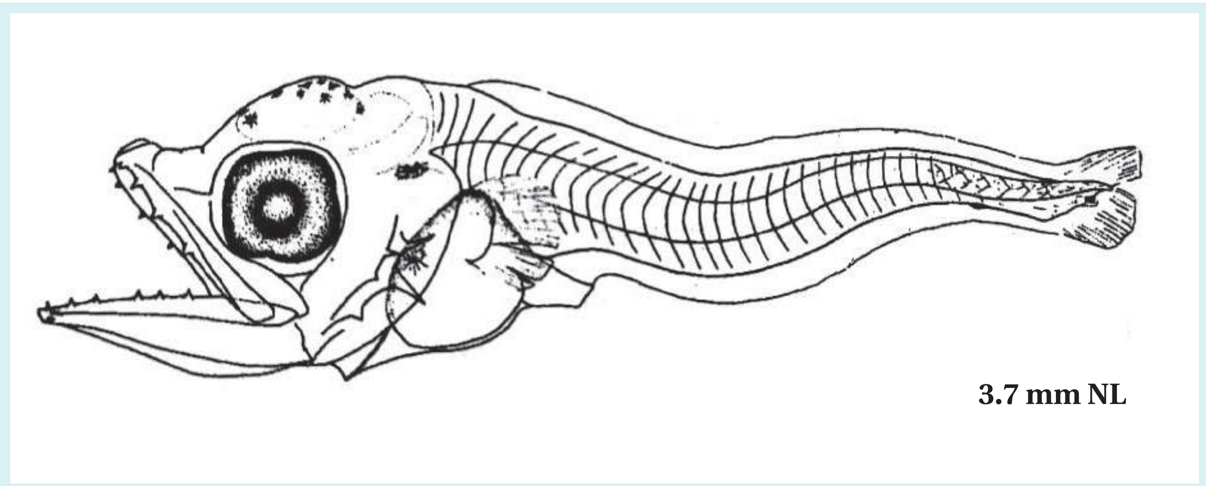


Figure 3. Larval stage in pre-flexion measuring about 3.7 mm in length (MATSUMOTO, 1958; RICHARDS, 2006).

Following the description of Matsumoto (1958), in the larva of about 5.4 mm (between the pre-flexion and flexion stages), the head represents 38.7% of the total length, very large in relation to the rest of the body, the snout being strongly pointed and slightly longer than the diameter of the eye orbit (Fig. 4). The size of the mouth is equivalent to 71.6% of the length of the head. Teeth are more developed and more numerous than in the previous stage. There is also an increase to 6 in the number of spines in the preoperculum. Pigmentation is then more extensive, covering more than half the area of the mesencephalon. The pelvic fin is still only a primordial. The vertebrae are not yet formed and the myomers (between 41 and 42) are slightly visible. In the region of the caudal flare, the tip of the notocorda is at the beginning of the flexion, and it is possible to observe the principle of formation of the hippuric elements.

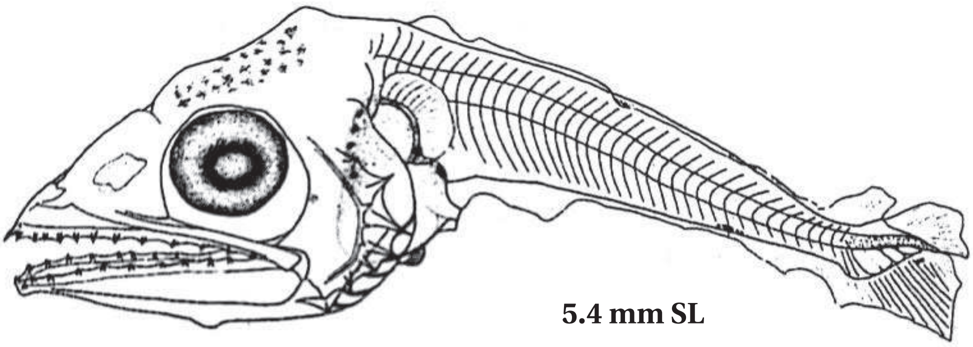


Figure 4. Larval stage at the beginning of flexion, measuring about 5.4 mm (MATSUMOTO, 1958; RICHARDS, 2006).

In a more advanced stage, at 6.7 mm (Fig. 5), characterizing the end of the flexion phase, great and important advances in larval development are observed, especially in the sense of providing greater mobility. The first spines of the first dorsal fin and, at the same time, the differentiations of the second dorsal fin and anal fin are visible. An important development is taking place in the region of the tailwader, with the end of the notochord bending and the differentiation of the hipural elements, not yet ossified, already supporting 18 rays. There is an increase in the number of chromatophores in the mesencephalon region and two strong concentrations of chromatophores are seen on the prosencephalon. One or two large chromatophores appear on the side of the head, close to the dorsal end of the pre-operculum. The chromatophore near the ventral margin of the caudal region still persists.

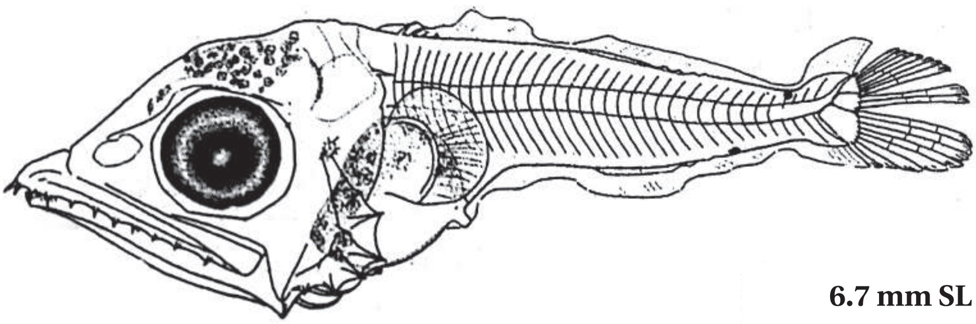


Figure 5. Larval stage at the end of flexion, measuring about 6.7 mm (MATSUMOTO, 1958; RICHARDS, 2006).

At 8.8 mm in length (Fig. 6), the larva already has a robust appearance, suggesting a high mobility capacity, however, with a still large head, representing 41.3% of the body length, and the mouth representing 66.0% of the head length. 8 to 9 spines are seen in the first dorsal fin and about 10 rays and 6 to 7 pinules, both in the second dorsal fin and in the anal fin. The pelvic fins are well developed with 1 spine and 5 rays, while the pectoral fins are only at the beginning of development, it is not possible to count their elements. Changes in pigmentation consist of an increase in the number of chromatophores spread over various parts of the body. A group of chromatophores spreads at the tip of the snout and the single chromatophore of the mandible is now in a more central position. Also on the head, groups of chromatophores are observed around the orbit and on the pre-opercular surface posterior to the eye. Some chromatophores are observed in the post-temporal bone region, along the base of the first dorsal fin and close to the insertion of the second dorsal fin. The outer margin of the first dorsal fin is pigmented by about 6 large chromatophores, from the third to the sixth inter-radial membrane. Chromatophores are also present along the caudal fin.

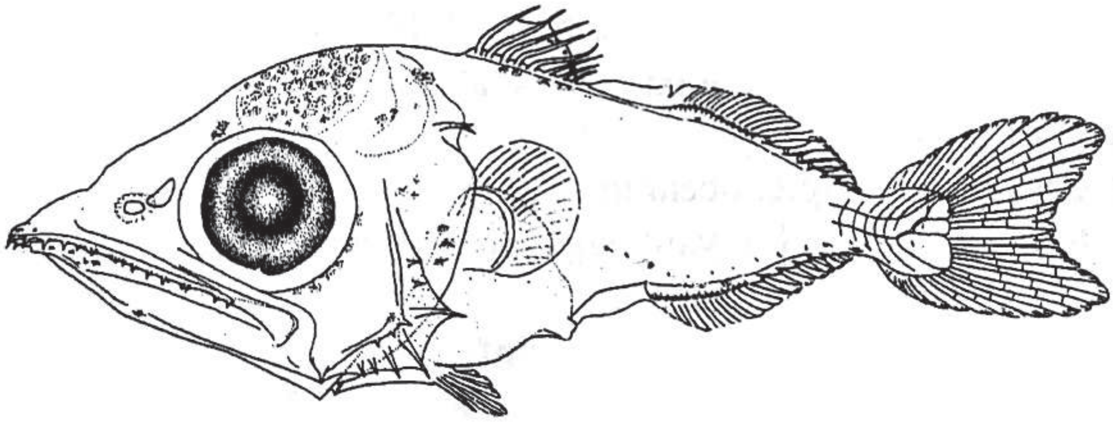


Figure 6. Larval stage in post-flexion, measuring about 8.8 mm (MATSUMOTO, 1958; RICHARDS, 2006).

At 14.5 mm in length (Fig. 7) we can already see an individual whose body starts to acquire a hydrodynamic shape, typically more related to that of a juvenile than that of a larva. The body is no longer as tall as in the previous stages and the head is small in relation to the body (37.2%). The digestive tract lengthens and the anal opening is located next to the insertion of the anal fin. You can see the nostrils well differentiated. The mouth is relatively small when compared to the previous stages, corresponding to about 57.9% of the head length, with about 15 teeth in the upper jaw and about 17 teeth in the mandible. 6 teeth are still evident in the palatal bone. The first dorsal fin takes on the concave characteristic of the adult fish and the pelvic fins are well developed. The pectoral fins have 20 rays each and the tail fin, initiating an evolution to the furcated form, has 22 rays in the upper part and 22 rays in the lower part. Pigmentation covers the body more extensively in relation to the previous phases.

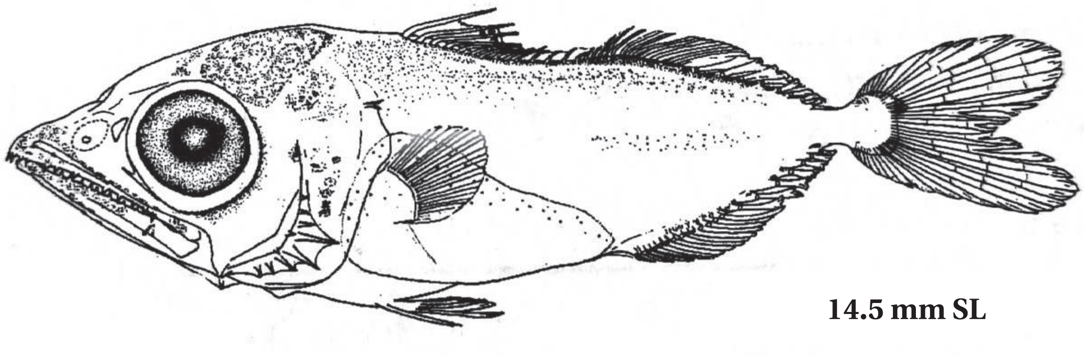


Figure 7. Larval stage near the end of post-flexion, measuring about 14.5 mm (MATSUMOTO, 1958; RICHARDS, 2006).

In terms of meristic characteristics, the following values are reported, according to Richards (2006):

Vertebrae: pre-tail = 20; tail rate = 21; total = 41.
Spines and rays of the fins: first dorsal = 14-16; second back = 14-16;
dorsal pinules = 7-8; anal = 14-16; anal papules = 6-8; pectoral = 26-28;
pelvic = I, 5; total flow = 47-51 (secondary dorsal = 15-17, main = 9 + 8,
secondary ventral = 15-17).
Total gill trails in the first arc = 51-63.

The great similarity of the skipjack tuna larvae with those of other species of the family makes the task of identification quite difficult. Richards (2006) indicates that the pigmentation pattern is used to separate the skipjack tuna larvae from *Thunnus*, Auxis and Euthynnus. To distinguish the skipjack tuna from other species of Scombridae, the diagnostic characters are the pigmentation pattern and the number of myomers.

Growth

Regarding the development time and growth of the skipjack tuna, during the initial phases, Matsumoto (1984), based on cultivation experiments, reported an incubation period varying between 23 and 35 hours, in water with temperature between 24.5 and 29°C. The size of the larva at the time of hatching was between 2.6 and 2.7 mm, with total absorption of the yolk occurring about two days after hatching. Growth was not observed during the other stages of development of the species, as the larvae only survived for five days. However, growth is supposed to be very fast, especially in the first 10 days. In the case of another mackarel (*Thunnus albacares*), Matsumoto (1984) reports that a 10-day larva grew from 5.8 mm to 51 mm in 28 days, indicating a linear growth rate of 1.6 mm/day, at a temperature between 25.6 and 28.6ºC. In juveniles, the maximum growth rate was 3 mm / day, in individuals up to 20 days after hatching (TANABE *et al.*, 2003). The rapid growth of skipjack tuna larvae, as well as other mackarel, is favored by the relatively large size of its mouth and the early development of the digestive tract, which allows it to capture and digest large foods, including other fish larvae (TANAKA *et al.*, 1996).

Spawning area on the Brazilian coast

According to Matsuura (1986) and Andrade & Santos (2004), the spawning area of the skipjack tuna is concentrated in the oceanic area of the north, northeast and east coasts of Brazil (Fig. 8). The spawning seems to occur throughout the year, however, a seasonal variation in the larval index, as well as a variation in the gonadsomatic index, indicate that the spawning would be concentrated between January and March (MATSUURA, 1986; GOLDBERG & AU, 1986; MATSUURA & ANDRADE, 2000). The recruitment of the species on the coast seems to occur throughout the year, with a peak in the summer decreasing over the spring (ANDRADE & SANTOS, 2004). Other studies indicate that spawning occurs throughout the year in equatorial and tropical waters, and seasonally in subtropical regions, where the water surface temperature is above 24 °C (NISHIKAWA *et al.*, 1985; MUHLING *et al.*, 2017; SCHAEFER, 2001).

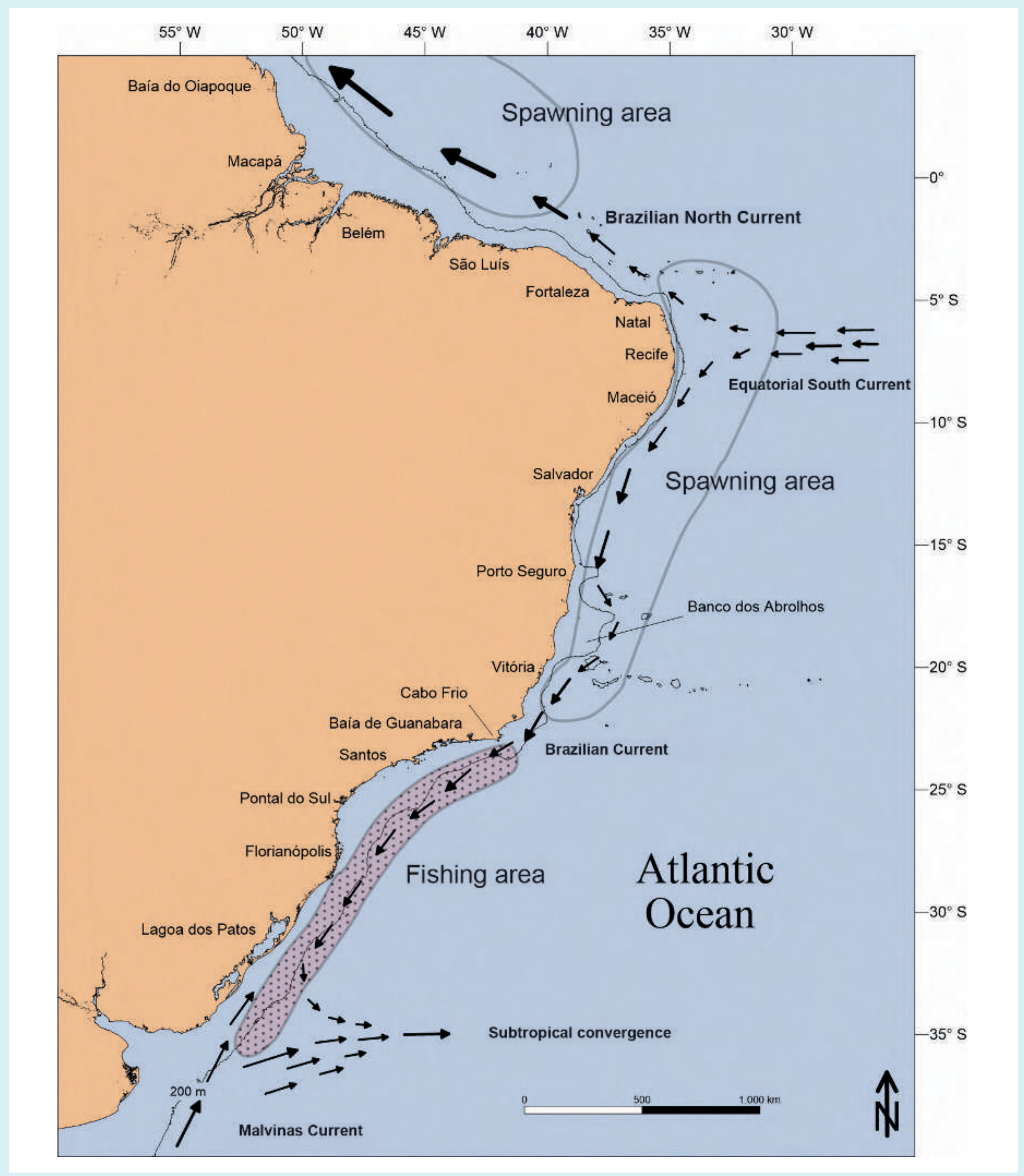


Figure 8. Map of the Brazilian coast showing the boundary of the possible spawning areas of the skipjack tuna and the main fishing area (ANDRADE & SANTOS, 2004).

Distribution and abundance

The skipjack tuna larvae are distributed from Amapá to Santa Catarina (Fig. 9), but occur almost exclusively in ocean waters, near the edge of the continental shelf (MATSUURA, 1986; MATSUURA & SATO, 1981). The largest concentrations were recorded on the north coast, in the region of Banco de Abrolhos and on the seamounts of the Vitória-Trindade chain (MATSUURA, 1986). The occurrence and distribution on the northeastern coast is further confirmed by the studies by Nascimento *et al.* (2000) and Pinto *et al.* (2002), who analyzed ichthyoplankton data collected during the REVIZEE Nordeste program, between 1995 and 1998.

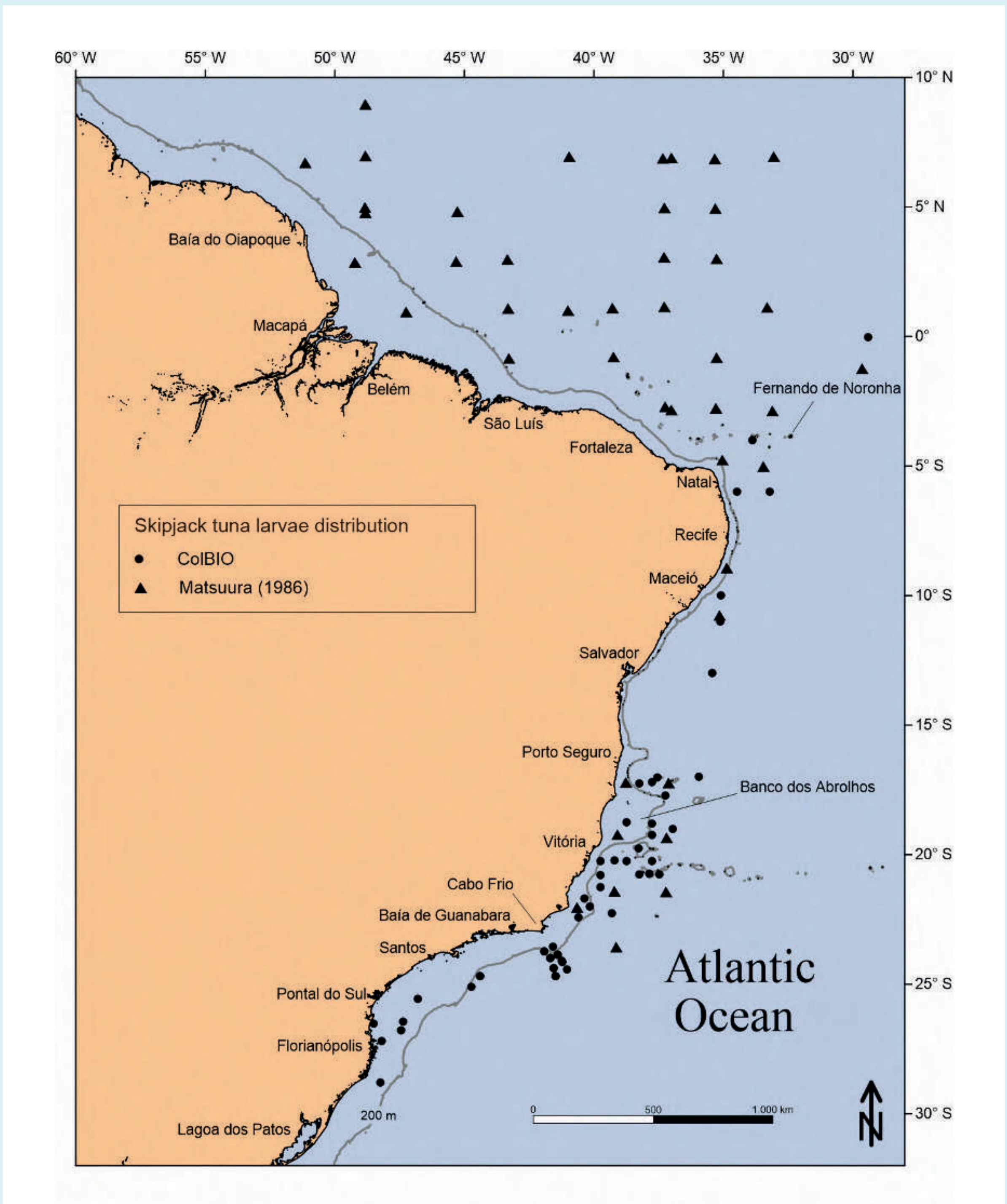


Figure 9. Distribution of skipjack tuna larvae on the Brazilian coast according to data from ColBIO (Prof. Edmundo Nonato from the Instituto Oceanográfico da Universidade de São Paulo) and Matsuura (1986).

In the records of the Biological Collection Prof. Edmundo Nonato of the Instituto Oceanográfico da Universidade de São Paulo (ColBIO), which includes thousands of samples collected between the 1960s and 2010, there are only 20 records of skipjack tuna larvae on the continental shelf, with minimal catch depth in 23 m, off Santa Catarina (Fig. 9). The few records of skipjack tuna larvae in the Santos Basin, between Cabo Frio (RJ) and Cabo de Santa Marta Grande (SC), should reflect the low number of samples collected in the ocean area of this region. Matsuura & Sato (1981), analyzing the results of four liners carried out in November-December 1975, January, May and September - October 1976, on the continental shelf of the Santos Basin, found only two skipjack tuna larvae, one being off Cabo Frio and another off São Francisco do Sul (SC).

In Matsuura (1986), the water temperature on the surface in the positive seasons for skipjack tuna ranged from 24.9 to 28.7°C, with an average of 26.8°C, and the salinity between 35.4 and 37.4, with an average of 36.4.

The distribution of the skipjack tuna larvae on the Brazilian coast follows the same pattern observed in other regions of the world, such as in the Pacific Ocean, where the larvae are found during spring and summer in waters with temperatures above 24°C (MUHLING *et al.*, 2017; NISHIKAWA *et al.*, 1985).

According to the records of ColBIO and the publications on ichthyoplankton, it is evident that the studies carried out on the southeast coast, in their majority, were carried out on the continental shelf, not privileging the area where the larvae are expected to occur the most skipjack tuna. Due to this fact and the difficulty in identifying these larvae, there is a lack of information about the biology and ecology of the skipjack tuna larvae in the region.

As the skipjack tuna species is a highly valued species commercially, it would be interesting that projects focused on the study of the initial stages of its development were developed, increasing the understanding of the factors that affect the distribution and survival of the species in this phase, and, in a way, contributing to fisheries management.

Acknowledgments

We thank ColBIO (Prof. Edmundo Nonato from the Instituto Oceanográfico da Universidade de São Paulo) for providing information on data on the occurrence and distribution of the skipjack tuna larvae on the Brazilian coast.

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Life cycle knowledge of the skipjack tuna in the Southwest Atlantic

5

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Introduction

The skipjack tuna, *Katsuwonus pelamis* (skipjack tuna – SKJ, acronym from ICCAT[1]), belongs to the Scombridae family, composed of tunas and related species. It is the only species of the genus *Katsuwonus* and has an elongated, fusiform and rounded body (COLLETTE & NAUEN, 1983). It presents a dark coloration with purple and blue tones in the dorsal region and four to six continuous dark lines in the lateral-ventral region, configuring a typical characteristic of the species (Fig. 1). There is no apparent sexual dimorphism (COLLETTE & NAUEN, 1983).

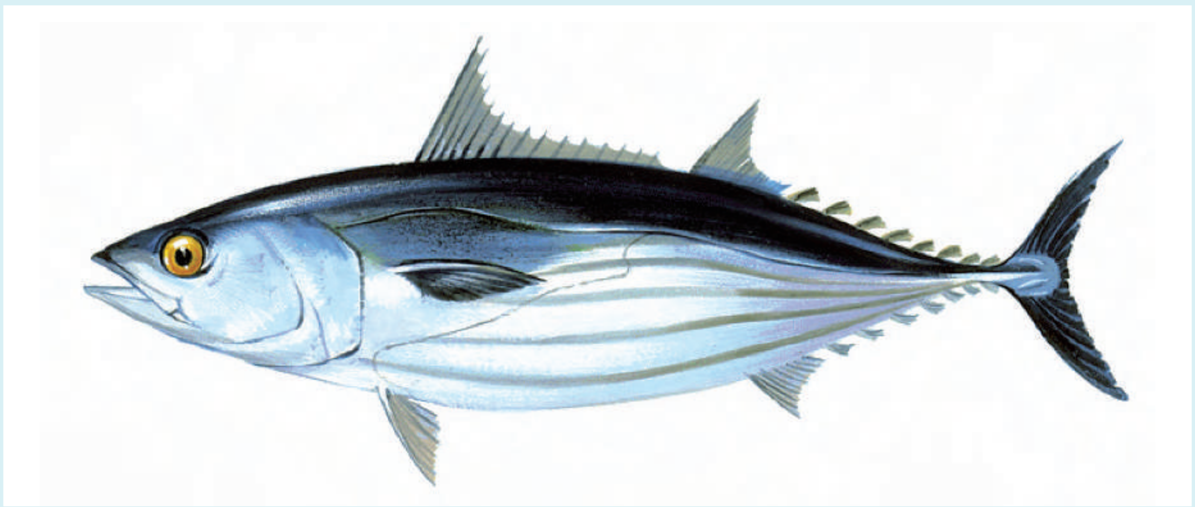

Figure 1. Side view of the skipjack tuna (*Katsuwonus pelamis*). Source: ICCAT (2006).

It is a migratory pelagic species with wide geographical distribution (cosmopolitan) that occurs in tropical and subtropical waters. It has a carnivorous feeding habit and forage behavior, preying on zooplankton, pelagic fish and cephalopods (CASTELLO, 2000). It is an opportunistic spawning species with synchronized spawning (ANDRADE, 2006; CASTELLO, 2000) and reproductive period between the spring and summer season, with a peak in January in southeastern Brazil (SOARES *et al.*, 2019).

The skipjack tuna is among the top five marine resources captured in the world and is the most abundant in Brazil, occurring more frequently on the intermediary shelf and upper embankment. Off the Brazilian coast (Atlantic Southwest), its distribution it seems to be conditioned by the temperature distribution in the surface layer of the sea.

[1] *International Commission for the Conservation of Atlantic Tuna.* Commission responsible for the conservation of tuna and related species in the Atlantic Ocean and adjacent seas. It coordinates investigations and evaluates stocks, as well as making agreements on relevant resource management measures.

The average temperature with the highest occurrence is around 23.3°C and an amplitude from 17.8° to 26.2°C. Schooling concentrations seem to be more frequent in the presence of well-developed termocline (particularly in the summer), with an average depth of 38 m and a gradient of 2°C / 10 m. During winter and part of spring (May-October / November), the colder waters of sub-Antarctic origin and related to the coastal branch of the Malvinas Current advance over the shelf and upper embankment causing the movement of the schools to the north (northeast coast of Brazil). From the second half of spring, the waters of the Brazilian Current flow southwards, until the beginning of autumn, allowing the return of schools to the southern region of the Brazilian coast, where they find ideal trophic conditions, ie, high secondary productivity. These ridges occur at depths between 60 and 410 m. The occurrence in these depths is explained by the presence of its main prey associated with the tropical water of the intermediate platform (CASTELLO & HABIAGA, 1989; CASTELLO, 2000).

Catch Areas

The catches of the skipjack tuna occur throughout its entire area of distribution in the Southwest Atlantic, especially on the coast of the south and southeast regions of Brazil, also called the Southwest Atlantic. Two of the industrial fleets operating on this resource are based in the fishing ports of Rio Grande (RS) and Niterói (RJ). Both fleets realize the pole and bait fisheries over the edges of the continental shelves in the southern region (PCS) and southeastern region (PCSE) of Brazil.

Study Methodology

Between January 2017 and August 2018, 66 ports from catches made by the pole and bait fleets dedicated to fishing for Skipjack tuna in the Southwest Atlantic were monitored simultaneously in Rio Grande[2] and Niterói[3], with a bi-weekly and/or monthly frequency for biological data collection. In each occasion, 100 to 300 individuals were randomly separated biometrically. Each individual was measured for their furcal length (CF) in centimeters (from the upper mandible tip to the tail fin fork) following the ICCAT standards (2016).

Between 15 and 30 individuals were taken from each sample, also randomly, generating a subsample to obtain biological information, such as: total weight (g), gutted weight (g), innard weight (g), weight of gonads (g), weight of liver (g), sex (male, female and undetermined), identification of the stage of maturity of the gonads, removal of the first spine of the 1st dorsal fin and the sagittae otoliths (pair).

For the analysis of spacial-temporal variations, the size data (CF) were separated by region (south and southeast) and by seasons, considering the following division: summer (January-March), autumn (April-June), winter (July-September) and spring (October-December). The size data were grouped into classes with intervals of one centimeter and their frequencies were tabulated in order to observe the patterns of modal shift.

The establishment of size relations is one of the initial steps in the study of fishery biology, since it allows the conversion of different measures of length or weight. The weight-length ratio was estimated separately for each region and for the grouped data (Southwest Atlantic), regardless of gender[4].

[2] By the FURG Institute of Oceanography.

[3] By the ECOPESCA Laboratory of the Biology Institute of UFF and FIPERJ.

[4] This relationship was expressed by the relation $PT = a^*CF^b$, where: PT represents the total body weight, CF the furcal length, a and b are parameters related to the type of fish growth. The difference between the b values for the different regions was verified using the Student's t test. This test was also used to determine the type of allometry ($b = 3$, identifies isometry).

The study on age and growth is one of the fundamental steps for knowing the dynamics of a population, since it allows the conversion of data from length to age, in addition to generating longevity estimates and serving as a basis for construction predictive models on the status of a population and / or fishing resource. The growth curves from the furcal length were estimated for the grouped data (both sexes) for each region, using monthly size frequency distributions grouped into two-cm classes[5].

Cuts of the hard spines of the 1st dorsal fin were also interpreted, which alternately present opaque (active growth) and translucent (slow growth or arrest) bands in 497 individuals from the southern region. The values of asymptotic length (CF_∞) and instantaneous growth rate(k_{vB}) were estimated using three approaches:

A) Minimum residual variance method according to Gonçalves & Fontoura (1999), using the MINIVAR routine (BERVIAN & FONTOURA, 2007). Longevity ($A_{0.95}$), as defined by Taylor (1958), is the time to reach 95% of the maximum average length (CF_∞) and was estimated as: $A_{0.95} = 0.996 / k$;

B) Using the CF patterns identified in the composition by sizes and applying the routines available in the FISAT program (Gulland & Holt, Faben's Plot, Appeldorn and the automatic routines that minimize variances); and

C) Using the ages determined in the spine readings to adjust the parameters of the growth model in such a way as to minimize the squares of the differences between the observed and estimated values (SOLVER routine of the Excel program).

Mortality rates indicate the losses that the population suffers from natural causes (M) and from fishing (F). The total mortality rate (Z) represents the sum of these two components, while the catch rate (E) is the ratio between fishing mortality and total mortality (E=F/Z). The estimate of the natural mortality rate (M) was generated from several empirical models that use information about the species' life cycle, such as: Linf, k and $A_{0.95}$.[6] The method used to determine total mortality was the linearized catch curve, which uses the length structure observed on ports, transformed into an age structure. The survival rate (S) was calculated using the equation: $S = e^{-z}$ or $S = 100 * e^{-z}$. In this way, the rates derived from total mortality and its variations indicate the degree of impact of fishing on the analyzed population structure.

Studies on the reproductive cycle are commonly applied to guide measures for the management of fisheries aimed at protecting stocks in spawning areas or times, as well as protecting part of the population that has not yet reached sexual maturity, in order to restore new individuals to adult populations. The reproductive cycle of the skipjack tuna was described through gonadal indices and maturation curves. All of these indices were calculated for each individual and then grouped into averages and confidence intervals, to be presented by month and region. The gonadosomatic index (IGS) expresses the percentage that the gonads represent of the individuals' weight and thus indicate the time when the gonads are more turgid and mature[7].

The average length of first sexual maturation indicates the length at which 50% of individuals begin the process of sexual maturation. This length was estimated directly by adjusting the parameters of the logistic curve to the data on the percentage of mature individuals by length class using the interative method.

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[5] By monitoring the movements of the average lengths of each age group (BHATTACHARYA modal decomposition method - GAYANILOET *et al.*, 2005), the von Bertalanffy (1938) growth curve was adjusted: $CF_t = CF_\infty * (1^{-e-k_{vB}*(t-t_0)})$; where CF_t is equivalent to the average length of individuals of age t; CF_∞, represents the maximum average length; and, corresponds to the basis of the natural logarithms; k_{vB}, is the constant of growth and t_0, time at age zero and/or birth or recruitment.

[6] These rates were calculated using the application (*Tools for fisheries scientists and Field practitioners - app "Natural Mortality"; http://barefootecologist.com.au/apps*) to obtain an average value of M.

[7] It is estimated from the equation: IGS = PTg / PT * 100, where PTg is the total weight of the gonads and PT is the total weight of the fish. The hepatosomatic index (IHS) was calculated according to the equation: IHS = Pf/PT*100, where, Pf = weight of liver; PT = total weight of fish. The allometric condition factor was derived from the weight-length relationship and calculated as: $K = PT / CF^b$.

Morphometric characteristics of otoliths are complex and highly species-specific and, like other morphological characters, are influenced by clinical variations related to distance, geographic location and / or environmental variables (WILSON, 1985; DEVRIES *et al.*, 2002). Bearing in mind that the interactions between genetic and environmental factors produce differences within species (CADRIN, 2000), morphological analyzes are efficient tools for the identification and discrimination of stocks and / or populations. Sagittae otoliths have been widely used in fisheries biology studies because they allow such differentiation in a fast, low cost and robust manner (TRACEY *et al.*, 2006). To perform the morphometric and shape analysis of the otoliths (Fourier Elliptical analysis-AFE), 103 individuals (54 from the south and 49 from the southeastern region) with CF between 40 and 70 cm (all adults) were used, thus avoiding effects of variations ontogenetic in the otoliths form[8]. To identify the shape patterns from the morphometric analysis and the Fourier coefficients, two multivariate techniques were used. The first, a cluster analysis based on the Ward method (REIS, 1997), was used to identify the number of otolith morphotypes. The second, an analysis of main components (ACP), whose objective is to reduce the size of the data, was applied to the conjugated Fourier data and morphometric variables, allowing the characterization of the variability between groups (regions vs. observed morphotypes).

Results

Growth

In the period between January 2017 and August 2018, 20 discharges were carried out in Rio de Janeiro (SE) and 46 in the port of Rio Grande (S), with samples of furcal length and weight of a total of 1,031 specimens. (RJ = 566 and RS = 465). In the southern region, the distribution of the furcal length frequencies for the entire period was practically unimodal, with an amplitude of 37 to 70 cm and pattern in the 49 cm class (Fig. 2a). The highest frequencies occurred in the summer in the classes between 46 and 52 cm, the largest individuals in the fall and the smallest in the spring and summer, suggesting modal progression from the summer (Fig. 2b).

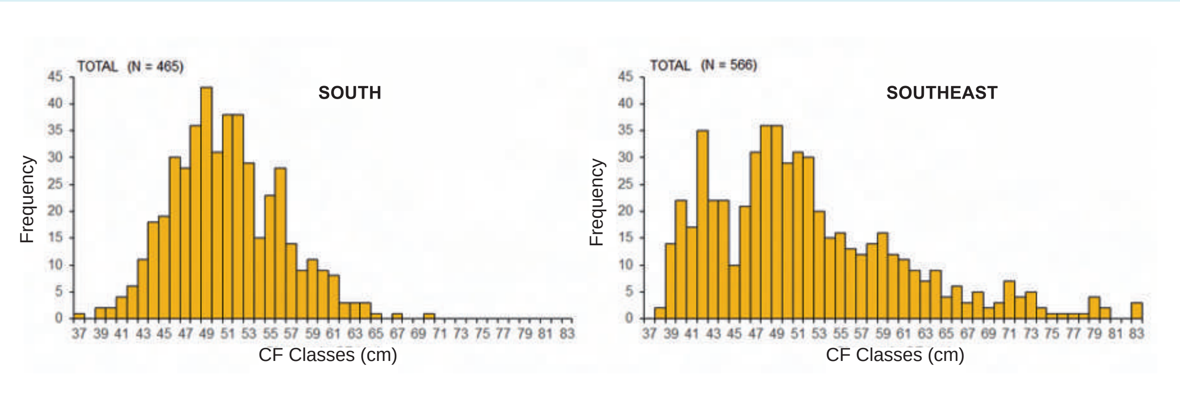

Figure 2a. Seasonal frequency distributions of furcal length (cm) of *K. pelamis* in the period between January 2017 and August 2018, by region.

[8] The descriptors used were: area (A) and perimeter (P) of the otoliths, obtained using the Image J software, while the roundness, Rectangularity and eccentricity were calculated according to the methodology proposed by Tuset *et al.* (2003). The fractal size was calculated using the FracLac plugin, from the Image J software, using the box counting method. The Fourier coefficients (FC) were generated by the SHAPE software (IWATA & UKAI, 2002), based on the axes of the main components and Fourier series called harmonics. Finally, a principal component analysis (PCA) was applied in order to reduce the size of the data, allowing the characterization of the variability between groups (regions and morphotypes observed). Collinear measurements were removed from the analysis in order not to cause noise (area and fractal dimension).

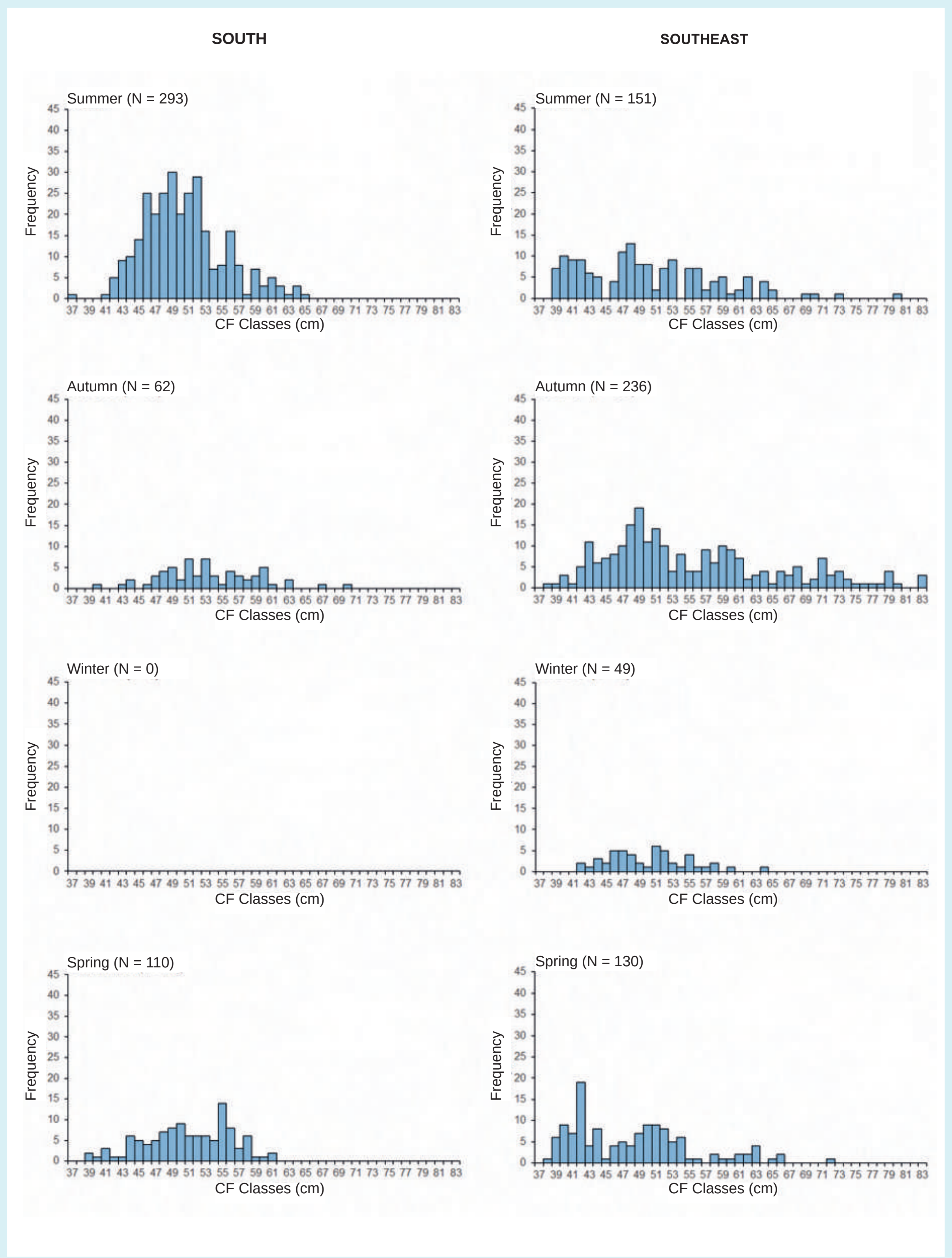

Figure 2b. Seasonal frequency distributions of furcal length (cm) of *K. pelamis* in the period between January 2017 and August 2018, by region.

Winter discharges were not monitored in the southern region, when the Rio Grande-based fleet remains inactive. In the southeast, there were specimens between 38 and 83 cm of CF, with a polymodal frequency distribution for the entire period, with at least two well-defined patterns (42 cm and 48-49 cm). Seasonally, individuals of the smallest size classes did not occur in winter. The largest size classes were well represented in the fall, where the largest specimens occurred.

The weight-length ratio determined for the skipjack tuna in the southern region was: PT = $0.0128CF^{3.1363}$, showing $R^2 = 0.9039$. For the southeast region the equation obtained was: PT = $0.0028CF^{3.5075}$, with $R^2 = 0.9642$, while for both regions the equation was: PT = $0.004CF^{3.4217}$ and an $R^2 = 0.9461$ (Fig. 3).

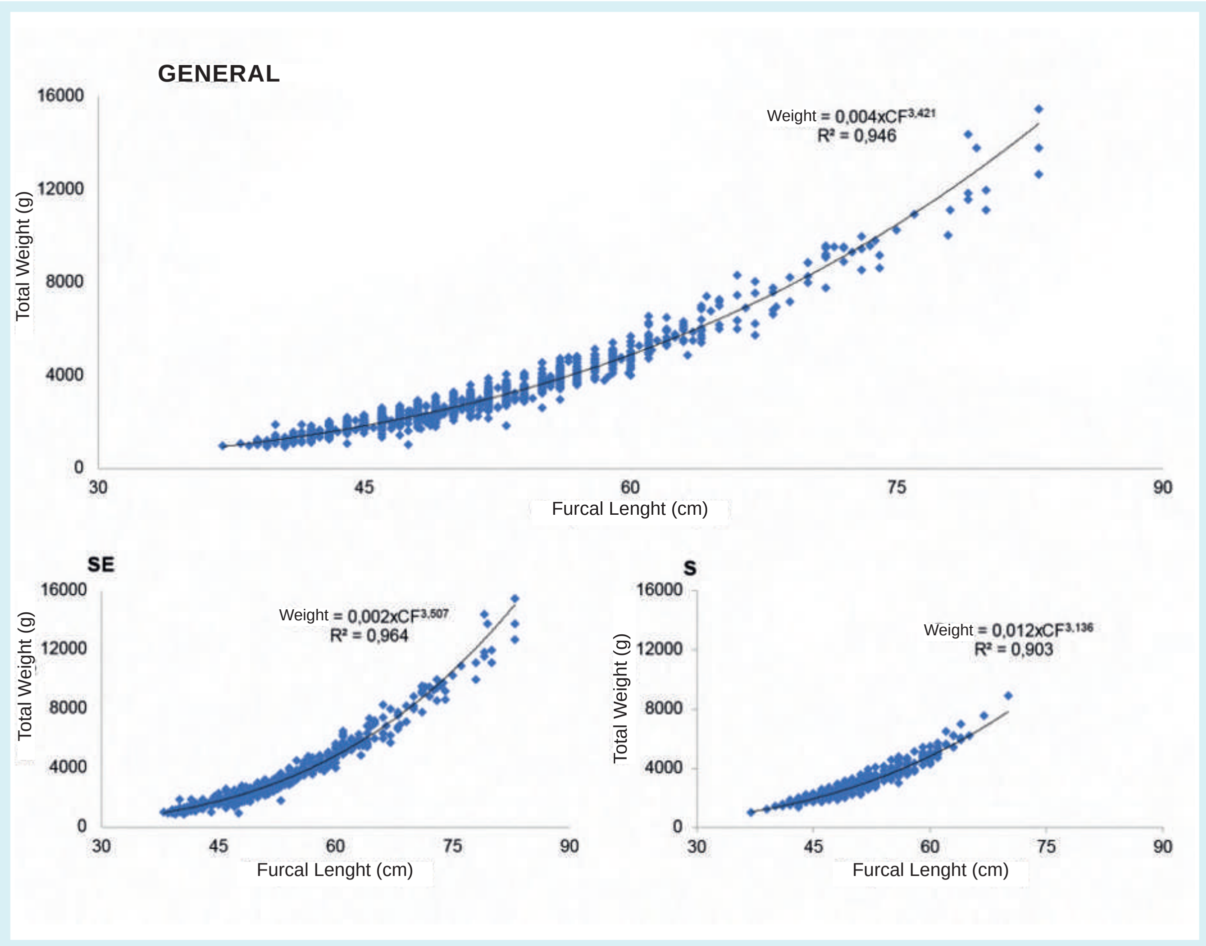

Figure 3. Furcal weight-length ratio of *K. pelamis* individuals caught for the Southwest Atlantic (general) between January 2017 and August 2018, and in the southeast (SE) and south (S) regions.

The modal decomposition of the frequency distributions of furcal length pointed to the presence of four to five cohorts over the sampled period (Tab. 1). From the data of average length and the different age groups / cohorts, the growth parameters were estimated.

Table 1. Parameters of modal decomposition obtained by the Battacharya method: age groups, average furcal lengths, standard deviation, separation index of the frequency distributions of multi-two lengths and estimated ages (via MINIVAR).

	South Region				Southeast Region				Southwest Atlantic			
Age Groups	Estimated Age	Average CF	Standard Variance	Index of Separation	Estimated Age	Average CF	Variance pattern	Index of Separation	Estimated Age	Average CF	Variance pattern	Index of Separation
1	–	–	–	–	2.34	42.05	1.77	0.00	2.42	42.23	1.95	0.00
2	2.79	49.11	3.82	0.00	2.83	49.61	3.04	3.14	3.32	49.60	3.20	2.86
3	3.24	53.43	3.09	0.96	3.32	54.60	3.87	2.68	4.22	57.32	3.32	2.36
4	3.69	57.20	1.00	2.36	3.81	58.70	1.86	2.59	5.12	63.92	3.72	1.88
5	4.14	60.00	1.30	2.74	4.30	62.40	1.92	2.90	6.02	69.40	1.70	2.99
6	4.59	62.10	2.88	1.34	4.79	65.20	2.26	3.87	6.92	74.30	2.31	3.88

The best statistical results (less residual variation) were obtained from the "seed" values of age of the individuals in the first sample / cohort, i.e., based on the average furcation lengths of individuals caught in the summer (south and southeast: 2.34 years and Southwest Atlantic: 2.42 years) (Tab. 2). This parameter works as a "biological anchor", whose starting case is the time interval between the known reproductive peak (summer / autumn, SOARES *et al.*, 2019) and the first sample. Thus, the parameters of the growth curve were estimated from the modal progression of the first age group identified in the summer samples and followed for an entire year.

Table 2. Growth parameters estimated by different methods.

CF_∞ = asymptotic furcal length; CV = coefficient of variation; K_{vB} = instantaneous growth rate; R^2 = coefficient of determination; Rn = adjustment index; MQ = least squares method and Vm = minimum residual variance.

Routines	Method	CF_∞	CV-CF_∞	K_{vB}	CV-K_{vB}	t_0	R^2/Rn/MQ/Vm	Phi
FISAT (CF pattern analysis)	Gulland & Holt	90.00		0.32				3.42
	Faben's Plot	47.46						
	Appeldorn	106.72	0.32	0.19	0.64		0.86	3.34
	Munro	80.00						
	Automatic Search 1	86.35		0.30			0.18	3.35
	Automatic Search 2*	87.15		0.20			0.10	3.18
SOLVER (Espines)	N: 486	55.52		0.88		0	12912	3.43
	N: 497	106.49		0.09		-5.10	24062	3.01
	N: 9**	234.20		0.04		-4.75	51.10	3.34
MINIVAR	South Region	75.60		0.37		-0.34	0.09	3.33
	Southeast Region	87.50		0.28		-0.46	0.67	3.33
	Southwest Atlantic	91.80		0.24		-0.54	0.67	3.31

* In this automatic calculation routine, CF_∞ was initially estimated as a "seed" based on the Taylor relationship, where $CF_\infty = CF_{max}/0.95$.

** In this case, each age was given the same weight.

Figure 4 shows the estimates of growth rates (k) for the southern, southeastern and southwestern Atlantic regions, and longevities ($A_{0.95}$)as a function of different simulated values of asymptotic length (CF_∞). The best adjustments (minimum residual variation) for the von Bertalanffy model were obtained when the asymptotic lengths (CF) were 75.6; 87.5 and 91.8 cm, respectively (South: k = 0.37; $A_{0.95}$ = 7.9 years; Southeast: k = 0.29; $A_{0.95}$ = 10.3 years and Southwest Atlantic: k = 0.24; $A_{0.95}$ = 12.6 years). The growth curves with minimal residual variation are shown in figure 5. Thus, the mathematical expressions of the growth curves in length are: South: $CF = 75.6*(1-e^{-0.37(t)})$; Southeast: $CF = 87.5*(1-e^{-0.29(t)})$ and Southwest Atlantic: $CF = 91.8*(1-e^{-0.24(t)})$.

The catch curves for each region and for the Southwest Atlantic were represented based on the age compositions in the corresponding catches (Fig. 6). Mortality rates (Z, M and F), catch and estimated survival were:

South: Z = 1.62; M = 0.58, F = 1.04, E = 0.64 and S = 19.8%;
Southeast: Z = 0.96; M = 0.45, F = 0.51, E = 0.53 and S = 38.3%; and
Southwest Atlantic: Z = 1.17; M = 0.37, F = 0.80, E = 0.68 and S = 31.0%.

Comparing the estimated values for M and F of both regions, it is possible to conclude that fishing was the most important mortality factor (F > M) for the Southwest Atlantic stock. All estimated catch rates (E) were compared with the reference value equal to 0.5, which according to Gulland (1983) can be considered an indicative value of overexploitation. However, we can observe that for the southeast region, the E value is close to the sustainable limit, showing different capture strategies between the regions that make up the Southwest Atlantic.

Another way to analyze the effect of mortality is to assess its opposite, survival. In this sense, the southeastern region has a higher survival rate (38.3%) compared to the south (19.8%). If only natural mortality were at work in these regions, the survival rate in the south would be 56.0% and in the southeast, 63.8%. Even so, we observe a reduction in the survival rate due to fishing in the southern region when compared to the southeast region. Nevertheless, the assessment for the Southwest Atlantic also corroborates this pattern with opposite capture and survival rates.

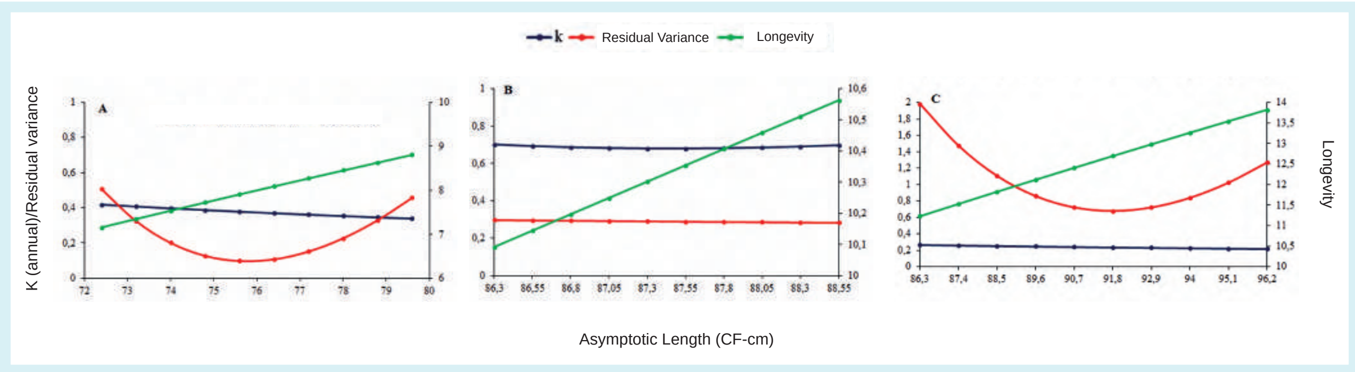

Figure 4. Estimated values of the growth constant (k), longevity ($A_{0.95}$) and residual variance in relation to the simulated values of the asymptotic lengths (CF_{∞}) of *K. pelamis*. A – south region, B – southeast region and C – Southwest Atlantic. Adjusted parameters MINIVAR routine (Microsoft Excel; LEWIS & FONTOURA, 2005, unpublished data).

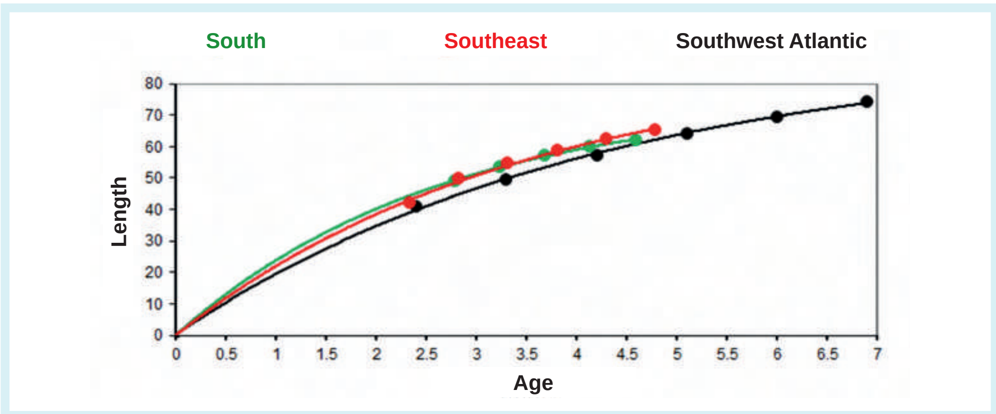

Figure 5. Growth curves in furcal length of *K. pelamis* captured off the Southwest Atlantic, between January 2017 and August 2018.

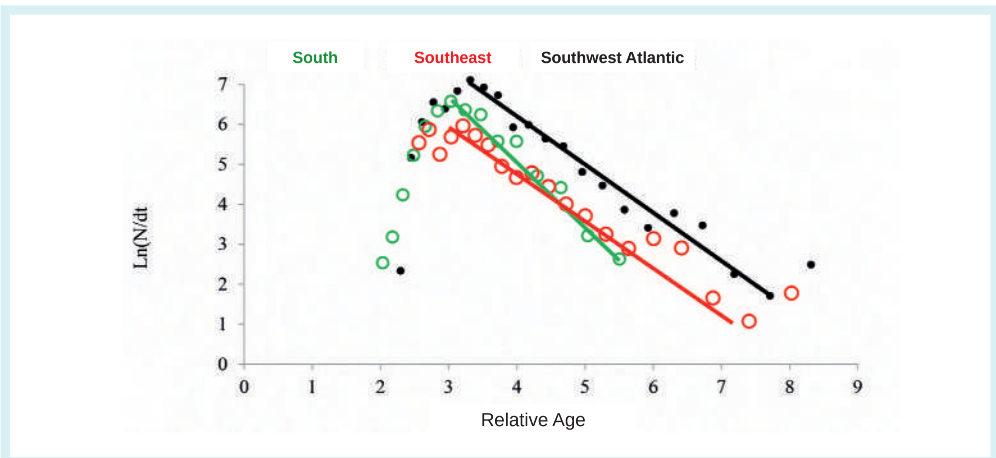

Figure 6. *K. pelamis* linearized catch curves for the South, Southeast and Southwest Atlantic regions.

Principal component analysis (ACP) applied to the integrated data of morphometric measurements and otolith morphotypes generated from the analysis of Fourier coefficients explained 53.4% of the variation in the first axis (PC1), while the second axis (PC2) explained 25.2%. The first two axes together explained 78.6% of the total variance. The perimeter and circularity showed a positive correlation with the first component (r = 0.66 and 0.65, respectively), while the rectangularity showed a positive correlation with the second axis (r = 0.92). Eccentricity showed a negative correlation with both axes (r = 0.34). The first two axes of the ACP were plotted by region and by morphotypes, with no separation pattern for both factors, indicating a single stock unit for the region (Fig. 7).

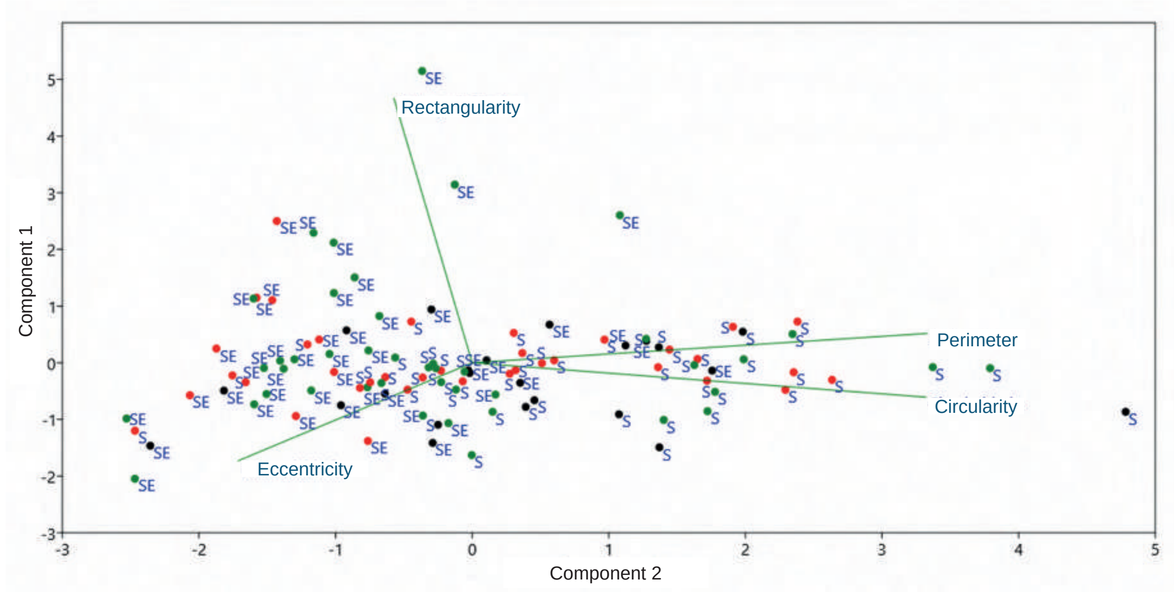

Figure 7. Ordering of samples based on the analysis of main components of Fourier variables combined with morphometric variables. Samples coded by region (S and SE) and morphotypes (colors).

The integration of morphometric and morphological data allowed the identification of 3 otolith morphotypes. Morphotype 1 shows a deep crack in the back and a higher elevation in the back when compared to morphotypes 2 and 3. Morphotype 2 has a deep crack close to the anterior dorsal region when compared to morphotype 1 and 3. Morphotype 3 shows a crack in the anterior dorsal part that is deep and a higher elevation in the posterior dorsal part. Co-occurrence of all types is an indication of the presence of a single stock in the area due to the lack of spatial separation between them.

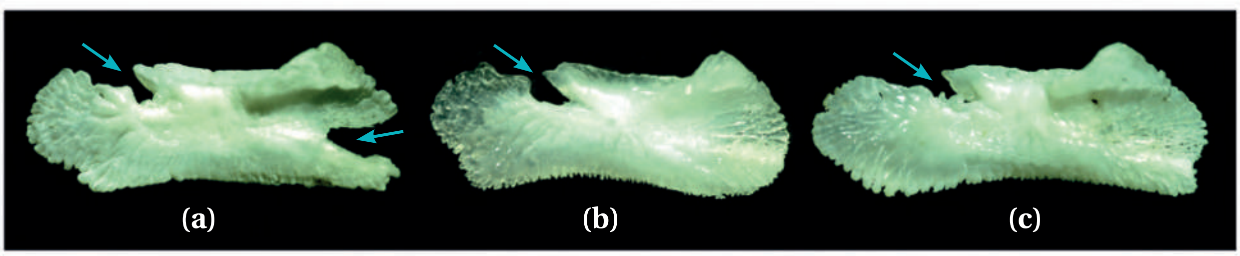

Figure 8. Otolith morphotypes: morphotype 1 (a); morphotype 2 (b); morphotype 3 (c). The blue arrows show the excesses. Photos: Marcus Rodrigues da Costa.

Reproduction

The skipjack tuna is a species known as opportunistic spawning, which presents a synchronized spawning when in schools. The small variation of IGS observed in the southern region throughout the year (N = 394; med = 0.6 ± 0.5) contrasts with the large variations recorded in the southeast (N = 424; med = 1.0 ± 1.1 ; between 0.95 and 0.04), suggesting the formation of reproductive aggregates off of this region during the summer, as observed by SOARES *et al.* (2019). Previous studies, produced on the south-southwest coast of Brazil (CAYRÉ & FARRUGIO, 1986; GOLDBERG & AU, 1986), also indicate a reproductive period between December and March, with a spawning peak between January and February.

The highest condition factor (k) values in the southern region (Fig. 8) in practically all seasons of the year they suggest that this is an area of food and growth, where individuals who are in the process of maturing gain body mass to move to spawning areas further north.

The marked regional differences revealed in the monthly values of the Hepatosomatic Index (IHS), almost three times higher on average in the southeast, reinforce the idea of a temporal pattern marked with an area of food in the south and a more expressive reproductive area in the southeast (Fig. 9).

The records of the presence of *K. pelamis* eggs and larvae in greater densities close to the Abrolhos archipelago (BA) by Matsuura (1986) and the scarce presence of skipjack tuna larvae and juveniles in the southeast-south regions support the case that there is a reproductive migration in the south-north direction (JABLONSKI *et al.*, 1984).

The average furcal length of first maturation (CF_{50}) for males and females (group sexes) was estimated at 45.5 cm (confidence interval of 44.8 and 45.9 cm) (Fig. 10). There were no significant differences between genders (45.4 for males and 45.5 for females) and between the south and southeast regions. These values are below the values estimated in the 1980s by Vilela & Castello (1993), and close to those estimated by Soares *et al.* (2019) to the southeast in the previous three years (2014 to 2016).

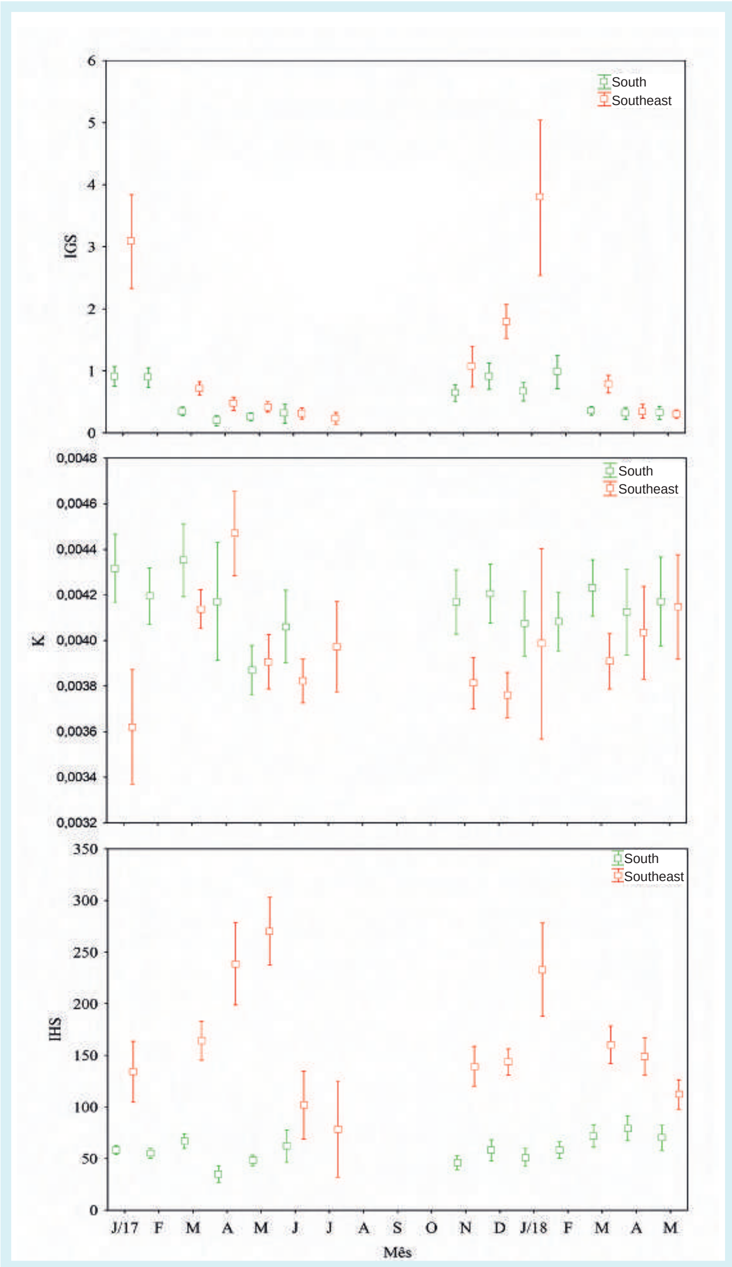

Figure 9. Monthly variation (average and confidence interval) of the Gonadosomatic Index (IGS), Condition Factor (k) and Hepatosomatic Index (IHS) by catch area (south and southeast) of the southwest coast.

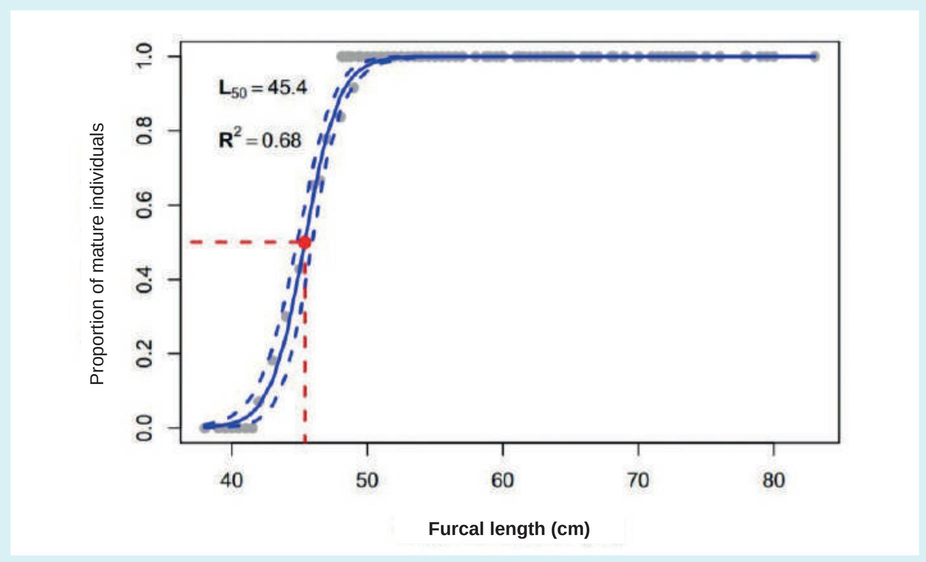

Figure 9. Relationship curve between the proportion of mature individuals and the furcal length of *K. pelamis* on the southwest coast of Brazil.

Final Considerations

The implementation of systematic and continuous monitoring programs for natural resources allows the scientific community to understand the standards and processes that govern the life history of fishing resources. Among the main attributes that are used in the evaluation of tuna and the like we can mention the size, weight and reproductive dynamics.

A unimodal pattern of recurrent size since the 1980s still persists along the Southwest Atlantic, with individuals between 50 and 56 cm in furcal length. Between the south and southeast regions the sizes of the highest frequencies were similar, with a slight tendency to decrease this amplitude and the presence of individuals between 47 and 53 cm. A smaller, well-marked pattern, observed only in the southeastern region, shows the appearance of a population stratum that corresponds to a new recruitment to the fishing stock, whose lengths are below 45.4 cm, a size in which 50% of the population is considered able to reproduce (CF_{50}). Although there are records of individuals with sizes smaller than CF_{50} in the southern region, metabolic (IHS) and physiological (condition factor) evidence suggest that the region is used as a breeding area, ie, food, growth and sexual development.

The monitoring of length frequency patterns, associated with studies of otolith morphometry and morphology, in addition to assisting in the identification of stocks, also supports other information on the skipjack tuna life history, such as growth and reproductive period.

The weight-length relationship allowed us to infer that the skipjack tuna gains more weight in relation to its growth in length. Such a pattern has been observed over the past three decades in this area of the Southwest Atlantic.

As for the growth parameters influenced by the different environmental characteristics, the skipjack tuna from the south region gain more body weight and, as they move to the southeast region, they continue to increase their weight, culminating in the reproductive period in summer, with peak in January. As for the parameters of population growth, arising from the integrated analysis of each captured individual, different behaviors were observed between the regions, which is naturally expected due to the environmental peculiarities of each region. It should also be noted that the development of accentuated thermal fronts in the Brazilian Current in the south of the country acts as a trigger for migratory movements that trigger vital stimuli for maintaining a stock susceptible to commercial exploitation.

From the reproductive indices and other characteristics derived from the size and weight of the individuals, it was also possible to infer about the reproductive patterns and probable formations of reproductive aggregates. In the southeast region, there were catches of individuals with the best reproductive conditions, followed by the transition between these regions. Such evidence points out that the reproductive process occurs in the lower latitudes of the Southwest Atlantic, where there are records of the highest densities of eggs and larvae of the species. The relationship between the seasonality of the movements of the Brazilian Current and the movement patterns of the species shows the use of the area to maintain the stock over time. Another aspect that corroborates this hypothesis is the integration of the condition and hepatosomatic indexes that indicated high levels of individual well-being, as well as the transfer of reserve energy (liver) shortly before and / or concurrently with reproductive activities, the in order to guarantee this vital process, ie, perpetuation of the species and transmission of information from generation to generation to maintain the characteristics of the species.

The population growth parameters obtained (k_{vB}, L_∞ and longevity) from the captured individuals follow a pattern of values similar to those of the last decades for the Southwest Atlantic, with latitudinal distinctions determined by natural conditions (temperate, intertropical and tropical zones), as well as through fishing. Estimates on the population status of the stock available for fishing generated from these parameters (mortality, survival and capture rates) are primary information for taking stock management and ordering measures. The results obtained indicate that fishing is more intense in the south, compared to the southeast. However, the stock still seems to be in an exploration phase below the limit of 50% of maximum sustainable catches. These same estimates also alert the scientific community to the effective establishment of continuous and systematic programs for monitoring fish landings/fishings, in order to develop a fully sustainable production chain on this fishing resource.

Also based on an anatomical structure of the skipjack tuna, the otolith, a circular limestone located inside your inner ear and responsible for balance, was used as a natural marker capable of differentiating or not population stocks within the range of the species. For the Southwest Atlantic, no intra-population differentiation was observed (also confirmed by genetic studies – Chapter 6), which allows us to say that in the region there is only a single stock unit that uses three geographic regions of the Brazilian coast (S, SE and NE). In this area of the Southwest Atlantic, patterns of use of habitats (regions) associated with environmental conditions can be observed, such as the Brazilian Current and the primary productivity vortices that are formed in different seasons of the year, at specific latitudes of the coast. In this way, we can conclude that off the Southwest Atlantic this unique unit of skipjack tuna stock presents bioecological peculiarities that corroborate behavioral patterns described in the literature for the region, besides presenting similarities with other studies of other oceanic areas, influenced by different environmental conditions and fishing effort. Such results allow integrated analyzes in different current and historical perspectives, supporting management measures aimed at the sustainability of the skipjack tuna stocks.

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Genetics of the skipjack tuna on the Brazilian coast: connectivity and demographic aspects

6

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Introduction

In the 21st century, problems related to global changes (conservation of the environment, water and food safety, etc.) have posed important challenges for the economic and social order of countries, as well as for the relations between them. In a context of population expansion, one of the fundamental issues is that of exploiting natural resources, and the related problem that arises from it, its conservation. In this sense, building strategies for the rational exploitation of natural resources has become a necessity for nations in the medium and long term. It is at this point that the objectives of the sciences of Fishery Biology and Conservation Biology intersect to produce data that are fundamental to a country's economy.

Until recently, fishing resources were considered inexhaustible, a concept based on the view that the ocean was practically infinite and that the mortality rate caused by fishing was negligible in relation to that caused by natural causes, such as predation, for example (HUXLEY, 1883). However, with fishing stocks in the North Atlantic having been reduced by 90% by technological advances in fishing in the 20th century, the misunderstanding was evident (CHRISTENSEN *et al.*, 2003). Similar patterns of the impact of fishing on stocks have been observed around the world (PAULY *et al.*, 2005), and the collapse of extractive fishing for the middle of this century has been postulated (WORM *et al.*, 2006).

Faced with the threat of the last natural resource exploited on a large scale for human consumption, issues such as the regulation of fishing activity and the sustainability of fishing entered the political agenda of countries. In this context, Fisheries Biology has established itself as the science capable of providing the necessary subsidies for the ordering and conservation of fishing, aiming, basically, to allow maximum productivity that does not affect the recovery of resources, the so-called Maximum Sustainable Income. To achieve this goal, knowledge of the natural history of species is integrated into mathematical modeling that also includes social, economic and political aspects of fishing activity (CARVALHO & HAUSER, 1995) which can often be conflicting.

For the sustainable management of fishing resources, it is essential to know its Smallest Operating Unit, that is, the stock. A stock can have different definitions depending on the specific interest involved (biological, political, social, practical) (GULLAND, 1969; JAMIESON, 1973; BOOKE, 1981; OVENDEN, 1990; SMITH, 1990; CARVALHO & HAUSER, 1995; BOOKE, 1999), however, it can be considered that the most accepted and used concept is that which defines a stock as an intraspecific group of individuals intermingling randomly, presenting a temporal and spatial integrity (IHSSEN *et al.*, 1981). This concept considers the biological, geographical and temporal dimensions, and is therefore sufficiently generalist and inclusive.

Morphological, morphometric, meristic, chemical elements, traces and even parasite distribution patterns are used for the characterization of fishing stocks. However, with the development of genetic markers, especially since the 1960s, a concept of stock that has become more and more important for management strategies is the genetic concept of stock. This importance is due to the fact that this concept objectively defines the group of individuals within the species that maintains its genetic integrity as an intercrossing group, that is, those individuals within the species that are more similar from the genetic point of view and, therefore, has maintained its integrity as a reproductive unit. The biggest advantage of genetic markers is that, unlike morphology, for example, they are less influenced by the environment. In addition, some markers present a pattern of Mendelian inheritance that is easily interpreted and understood, in contrast, for example, with morphometric characteristics, whose inheritance is complex, multi-factorial and not fully understood.

The use of genetic markers to identify stocks includes, in general, steps such as the sampling of organisms in the areas of interest, definition of the markers to be used and analysis of the distribution pattern of the different forms of this marker between the sampled areas. With this, the main objective is to try to make the units (stocks) defined to be maximally faithful to the functional biological unit (taking into account multiple biological parameters such as recruitment rates, mortality, migration, reproduction, among others), bringing together the stock and population concepts, which would be ideal for a manager. Thus, the results produced allow feeding increasingly complex models regarding the behavior of fish stocks, increasing the chance that they better reflect the real world.

In this work, the tools of genetics and genomics were used to produce data regarding the genetic composition and geographical limits of the possible stocks of the skipjack tuna (*Katsuwonus pelamis*) in the Southwest Atlantic off the Brazilian coast. Thus, both analyzes from population genetics were used, which allow inferring patterns of connectivity between stocks or populations, and phylogeographic analyzes, which explore the relationships between biogeographic patterns and the genealogy of specific genes, thus allowing to infer processes such as migration, vicariance[1] and population reduction-expansion. All of this information is essential to assist in the conservation and management of skipjack tuna fishing.

Genetics Report Management

To produce information about the genetics of an organism, it is necessary to obtain tissue samples from individuals in the different locations where the species occurs. In the case of fish species, this tissue is usually a small piece (weight of a bean) of muscle or fin. It is from this piece of tissue that, by different protocols, it is possible to extract the DNA from the cells. This DNA is composed of many different regions, so that, depending on the region, it is possible to identify differences in the level of species (when the region of the DNA varies little), populations (when the region varies moderately) and even individuals (when the region is hypervariable). These differences are called genetic variations, which originate both in the recombination that occurs in sexual reproduction, and in low frequency events called mutations, which are random errors that occur in DNA replication. Although mutations are low-frequency events, they have been occurring over the millions of years of the organism's life history. Thus, it is possible to state that even the recombinational differences between individuals had their primary origin in past mutations. The set of these differences between individuals in a population constitutes what is called "polymorphism", that is, the different forms of DNA of different individuals.

[1] Vicariance is the evolutionary mechanism in which a biotic area is fragmented, separating populations of certain species. The lack of gene flow between the two formed sub-populations will cause them to become increasingly different and, if the barrier is maintained long enough, will lead to speciation.

The most important thing to understand the use of genetics in the study of fish stocks is the fact that individuals who cross paths will share the same polymorphisms. Therefore, a population in which there are no restrictions for cross-breeding among its individuals must share the same polymorphisms. Conversely, populations that are isolated or rarely meet should not share polymorphisms or share very few polymorphisms. This is how genetics can be used to identify different stocks (or populations). Those individuals who share the same polymorphisms must belong to the same stock. Otherwise, individuals who do not share polymorphisms must, most likely, belong to different stocks. Whenever individuals from different regions have polymorphisms in common, it is said that these regions are in genetic connectivity. The absence of shared polymorphisms indicates an absence of connectivity between regions. Figure 1 graphically exemplifies what has been said so far.

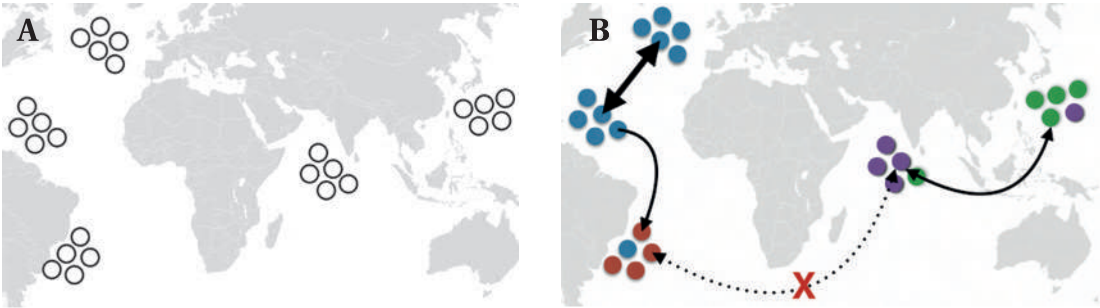

Figure 1. Hypothetical diagram of an analysis of polymorphisms to identify whether fish individuals from different locations are cross breeding, that is, whether they are in genetic connectivity. In figure A we see individuals (represented by circles) from five regions (three of them in the Atlantic Ocean, one in the Indian and one in the Pacific). The absence of color for the circles indicates that the polymorphisms of these individuals are not known. In figure B we see the circles marked by different colors. Each color is equivalent to a different polymorphism, so that circles with similar colors indicate those that fish have the same genetic polymorphism. Regions with fish sharing the same polymorphisms are considered in connectivity, that is, there are reproductive encounters between fish in these regions. In conclusion, the degree of genetic connectivity between regions is indicated by arrows. The direction and thickness of the arrows indicate the intensity of connectivity between the regions.

Another important information that genetic data brings to managers is how much the species keep from polymorphism, that is, from genetic variability[2]. It is precisely this variability that gives a population (or stock) its capacity for resilience and survival in the face of environmental variations. Climatic changes, greater fishing pressure, the occurrence of a new parasite or the decrease in the usual supply of food are some examples of environmental changes that can be better addressed by a stock if it has genetic variability. In other words, the greater the genetic variability of an organism, the greater its chance of adapting to environmental changes. Similarly, but inversely, based on the genetic variability of a stock it is possible to infer, from some mathematical models, whether it has suffered, over time, impacts of environmental changes, such as a strong decrease in population size or an expansion of that size. This information (resilience of a stock or impacted stock) are relevant from the point of view of handling and managing a natural resource under commercial exploitation.

[2] Polymorphisms can also be called gene variation, genetic variation or gene diversity, genetic diversity.

Still using information on genetic diversity, it is possible, from mathematical models of population genetics, to infer the order of magnitude of the size of a stock. Thus, genetic diversity can be used as an indirect measure to assess whether a stock has a size of the order of tens, hundreds or millions of individuals. Such information (order of magnitude of the number of individuals) can be used by managers to infer the total biomass of a given stock and its comparison with fishing records (biomass fished annually, for example), and deduce what impact of fishing activity on stocks.

Methodology

Sampling and Sequencing

As previously presented, the first stage of genetic work consists of obtaining samples from individuals of the species of interest (in this case, the skipjack tuna) in different areas of its occurrence. This was done in areas in the South, Southeast and Northeast regions of Brazil. The sampled tissues were kept in ultra-pure alcohol in a concentration close to 100%, when, then, using specific protocols, DNA extraction was performed (ALJANABI & MARTINEZ, 1997). Once the DNA was extracted, it was subjected to a process known as sequencing, which is nothing more than identifying the units that make up some of the regions of this molecule in each of the individuals sampled or, alternatively, the entire molecule. Equal units between individuals indicate absence of genetic variation, while different units between individuals, stocks or populations represent polymorphisms. The presence of polymorphisms represents the genetic variation (or diversity) between individuals and stocks. The data thus obtained were also compared with those from other locations in the world. Obtaining these global data is simple, since genetic data produced in scientific works are usually deposited in an international and public database on the World Wide Web, called *Genbank*[3] (Genetic Database).

In this work, two different sequencing techniques were used. The first was the technique called Sanger[4]. This method is relatively simple and inexpensive, and has the advantage of being comparable with much of the data already available on Genbank. On the other hand, it offers limitations in inferring the degree of connectivity between populations and, therefore, is less efficient to define fish stocks in very close regions. In this sense, the results obtained by this technique were used in the comparisons made between the three regions sampled on the Brazilian coast and the data available on GenBank. With this technique, specific regions (fragments of specific genes) were sequenced for two different forms of DNA: mitochondrial DNA and nuclear DNA. From the mitochondrial DNA, the regions of the gene encoding the cytochrome B protein (CytB) and the I subunit of the cytochrome c oxidase (COI) protein were sequenced. These two regions of mitochondrial DNA are widely used in population studies of fish. From the nuclear DNA was sequenced the gene that encodes the protein rhodopsin (Rho), present in the rods cells of the eyes of fish and also widely used in fish population studies.

[3] *GenBank* is an NLM / NCBI Nucleotide database, located at the *National Institute of Health* (NIH), storing information on nucleotide sequences of approximately 260,000 species (Benson *et al.*, 2013; PMID: 23193287). GenBank is part of a collaborative network together with the *European Molecular Biology Laboratory* (EMBL) and the *DNA Data Bank of Japan* (DDBJ). Together, these three banks form the *International Nucleotide Sequence Database Collaboration* (INSDC), storing and exchanging information to gather the nucleotide sequences deposited at these banks and ensure that these sequences are accessed worldwide. The three nucleotide databases are exchanging information daily, so sequences found in one bank will also be found in other banks.

[4] In reference to Frederick Sanger, English researcher who won the Nobel Prize for the development of this technique.

Some technical information is important for this part of the job. The obtaining of these specific regions of DNA (mitochondrial and nuclear) are obtained by the *Polymerase Chain Reaction* (PCR) method which, basically, from the total DNA, produces a very large number only of the region that you want to study. To obtain this region of interest, it is necessary to use in the PCR some molecular identifiers of these regions, called primers. In this work the *primers* used were:

a) For cytochrome b (CytB) - FishcytB-F / TruccytB-R (SEVILLA *et al.*, 2007);
b) For cytochrome c oxidase I (COI) - FishF1 / FishR1 (WARD *et al.*, 2005); and
c) For rhodopsin (Rho) - Rod-F2w / Rod-4R (SEVILLA *et al.*, 2007).

The PCR reactions were performed under the conditions proposed by the literature, the results were verified by electrophoresis in 1% agarose gel and the sequencing was done by the commercial company Macrogen Inc. All sequences received from the company were examined, edited and aligned using the computer program DAMBE 5.0.8, built for these functions (XIA & XIE, 2001).

The second sequencing technique used was the next generation sequencing (*Next Generation Sequencing* - NGS), more expensive and laborious, however, offering a total sequencing of the DNA molecule, which allows for more refined analytical inferences. In this case, small differences in polymorphisms between proximal geographic regions (such as those studied in this work) can be better identified. As thousands of DNA units are compared, it is possible to identify the so-called single-site polymorphisms (*single nucleotide polymorphisms* – SNPs). Thus, this method was used to infer the geographical limits of the individuals sampled in the three regions of the Brazilian coast.

For the NGS sequencing, the Illumina platform was used. The steps were performed by the company EcoMol[5]. DNA extraction was performed with the *DNeasy Blood & Tissue Kit* (Qiagen). The result was initially quantified and had its Absorbance ratio 260/280 nm defined in a *NanoDrop 2000* spectrophotometer (Thermo Scientific). DNA quality was assessed by three methods: absorbance ratio in a spectrophotometer to 260/280 nm (values between 1.7 and 1.9 are ideal), visualization by 1.5% aga-rose gel electrophoresis and quantification in *Qubit* (Invitrogen), followed by normalization to 10 ng / µL for sequencing. A GBS library (*Genotyping by Sequencing*) was built according to Elshire *et al.* (2011). To reduce the genome complexity of each sample (digestion), the restriction enzyme PstI was used. The quality of the GBS library was evaluated on the *BioAnalyzer Agilent* 2100 equipment, using the *High Sensitivity DNA* kit. Before sequencing, the GBS library was quantified using real-time PCR with the *KAPA Biosystems Quantification* Kit (Illumina[6]). The library was then diluted to 2 pM and sent to the genetics center at ESALQ / USP to be sequenced on the *HiSeq* 2500 Illumina platform, high throughput mode, single-end (*HiSeq* v4 kit, 100 cycles). The sequencing result was analyzed using appropriate bioinformatics tools, on the NUPEM-UFRJ server. The STACKS *pipeline* (CATCHEN *et al.*, 2011; 2013) and the TRIMMOMATIC program (BOLGER *et al.*, 2014) were used specifically for the trimming stage (cutting the adapters placed in the laboratory in the original DNA). The steps of demultiplex, alignment without reference genome (referred to as "*new*" alignment) and population genomics were performed by STACKS using the commands *process_radtags*, *denovo_map.pl*, and populations. The command *denovo_map.pl* was executed with the standard parameters (-m 3 -M 4 -n 4) for screening the quality of the sequences.

[5] http://ecomolconsultoria.com.br
[6] Illumina, Inc., San Diego, CA.

Data Analysis

The data obtained were submitted to several analyzes which are briefly described below:

1) Haplotype networks. A haplotype is a form of genetic polymorphism identified between the sequences of specific regions of the DNA of different individuals. The network analysis constitutes the construction of a diagram of connections between the different haplotypes identified. Each haplotype in the haplotype network is represented by a circle. The size of these circles is variable, and is proportional to the number of individuals who presented that haplotype. Thus, the larger the size of the circle, the greater the number of individuals sampled who had that genetic variety. The different colors contained in the circles represent, as in a pie chart, the proportion of each geographical origin of the individuals who presented that haplotype. The connections between the circles indicate the number of differences between the haplotypes or mutational steps (marked as dashes). These analyzes were performed exclusively for the Sanger sequencing data.

2) Diversity indices and other indicators. There are several indices that indicate genetic diversity. In this work, we used: (a) haplotypic diversity, indicating the number of haplotypes identified in the total of sampled individuals; (b) nucleotide diversity, indicating the number of differences (mutations) between the DNA units (called nucleotides) of the sequences; and (c) neutrality tests, to determine if the differences observed between the sequences are due to chance or the action of evolutionary forces (natural selection, genetic drift, mutation and migration). These analyzes were performed exclusively for the Sanger sequencing data. The molecular diversity indices (haplotypic and nucleotide), as well as the Tajima D neutrality tests (TAJIMA, 1989), Fu Fs (FU, 1997) and Theta S index, were performed using the DnaSP 5.1 software (LIBRADO & ROZAS, 2009).

3) Molecular analysis of variance (AMOVA). This method assesses how genetic diversity is distributed among different regions and was used to test the levels of geographic differentiation (also called structuring) between the different sampled locations. The tests were performed using the Arlequin 3.5.1.2 software (EXCOFFIER & LISCHER, 2010). These analyzes were also carried out exclusively for the Sanger sequencing data and the comparative tests performed depending on the availability of sequences in the sampled regions. Thus, the CytB sequences were divided into three groups (Rio de Janeiro, Northeast Atlantic and Pacific Islands), the second group being divided into three populations (Canary Islands and Azores, Madeira Archipelago and Spain). For COI, the samples were divided into four groups (Pacific, East Atlantic, Indian and West Atlantic), with the Atlantic groups being subdivided into South Africa and the Mediterranean (East Atlantic), Rio de Janeiro, Caribbean and North Atlantic (West Atlantic). The Rho sequences were organized into only two groups (Rio de Janeiro and East Atlantic), the second of which is subdivided into three populations (Canary Islands, Madeira Archipelago and Spain).

4) Effective population size. The size of a stock or population (represented by “N”) indicates the absolute number of individuals. However, the “N” of a population or stock is generally misleading, since not all individuals in a population contribute effectively (read reproductively) to the next generation. The number of adult individuals who are effectively involved in reproductive activities and, therefore, in connectivity between populations is called Effective Population Size (represented by “Ne”). In this work, the Effective Population Size (Ne) was estimated based on both data from mitochondrial DNA sequences and those from nuclear DNA sequences. In the case of mitochondrial DNA, the formula “Theta = 2Nef. mi” (based on CHARLESWORTH, 2009) was used, where “Nef” is the effective population size for females in a population (since mitochondrial DNA has exclusively maternal inheritance) and “mi” is the mutation rate.

In the case of mutation rates, approximate estimates were used based on data from the literature, since there are no estimates of the mutation rate of the regions studied in the species *K. pelamis*. For CytB and COI there is a reasonable consensus that mutation rates vary between 1% and 2% (eg, DELRIEU-TROTTIN *et al.*, 2017) in fish. The results showed a haplotypic diversity of CytB higher than that of COI, therefore, mutation rate values of 2% and 1%, respectively, were used. With respect to the Rho region, it is known that nuclear DNA has lower evolutionary rates due to positive selection pressure (LIN *et al.*, 2017; CHEN *et al.*, 2018; HILL *et al.*, 2019). In this case, a rate of 0.5% was used. The final result for Rho was divided by four, considering that Ne for mitochondrial DNA is four times smaller than for nuclear DNA (STORZ *et al.*, 2001). All of these estimates were made using the DnaSP 5.1 program.

5) Estimated number of populations. This analysis was performed exclusively for the data generated by NGS. Basically, the three regions of the Brazilian coast were considered and it was recommended that three scenarios be evaluated: (a) existence of a single population covering the three regions; (b) the occurrence of two genetically distinct populations; and (c) the existence of three genetically distinct populations. The data obtained from the NGS were transferred to the STRUCTURE program using the *populations* command, which generated an input file and determined which loci (SNPs) were in Hardy-Weinberg equilibrium. The commands used were: - *structure* (generates an *input* file for the STRUCTURE program) and --*hwe* (calculates the divergence of the Hardy-Weinberg equilibrium for each locus). The *output* file generated for the STRUCTURE program (FALUSH *et al.*, 2003; HUBISZ *et al.*, 2009) was modified in Excel (OFFICE package for Windows) to remove header lines generated automatically by STACKS, which prevent correct reading of the file by STRUCTURE, as suggested by STACKS[7]. Due to the limited number of columns in the Excel program, the population analysis used the first 1021 SNPs found during the genomic stages. Genetic structuring was also studied with a Bayesian analysis implemented in the STRUCTURE program (PRITCHARD *et al.*, 2000). This analysis seeks to estimate the number of K populations that best explains the data obtained. The algorithm uses a Hardy-Weinberg imbalance minimization process to try to assign individuals to populations. In our analysis, 5 independent runs were made for each of the K values (representing the number of potential populations, ranging from K = 1 to K = 3). In each of the runs, 100,000 replicates of burn-in were used followed by 1,000,000 replicates by Monte Carlo via Markov Chains (MCMC), being considered a model of mixed ancestry (admixture). After the runs, the averages of the likelihood values between all runs were calculated and the most likely K value was inferred as the one with the highest average value of LnP (D) (PRITCHARD *et al.*, 2000). The data obtained by the independent runs were compiled by the CLUMPP program (JAKOBSSON & ROSENBERG, 2007) and the structure obtained was visualized in the DISTRUCT program (ROSENBERG, 2004).

Results

Sanger sequencing (Different regions of mitochondrial and nuclear DNA)

78 sequences of 1097 nucleotides for the CytB gene were obtained (88 sequences if data available from Genbank were included) for which 84 haplotypes were identified. The haplotypic diversity index was 0.999 and the nucleotide diversity index was 0.010 (Tab. 1). The neutrality tests D of Tajima and Fs of Fu resulted in negative values (D = -1.93; Fs = -34.44). The haplotypic network (Fig. 2) shows the distribution and frequency of haplotypes on the Brazilian coast (original data from this work) and for the North Atlantic islands, Spain and the Pacific Ocean (sequences obtained from Genbank). It is possible to perceive a balanced frequency distribution between haplotypes and regions.

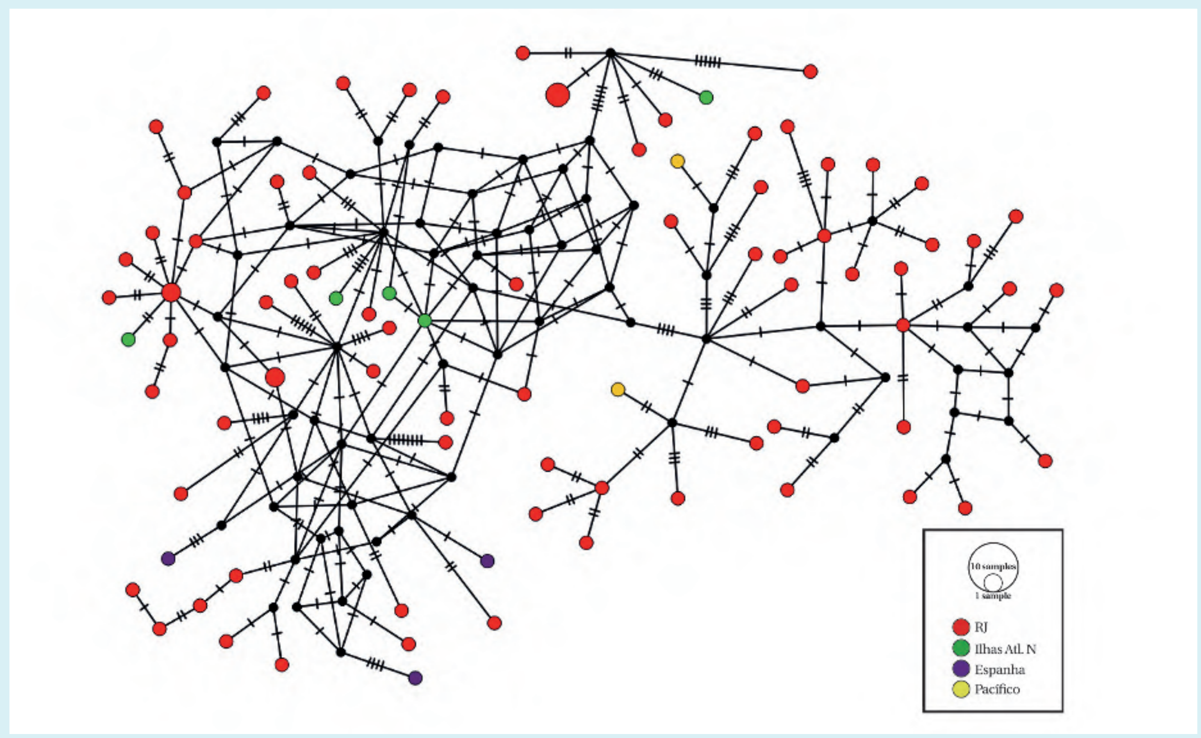

Figure 2. Haplotypic network for the CytB gene.

For the COI gene, 33 sequences of 410 nucleotides were obtained. Including data available from Genbank, 103 sequences were analyzed, with a total of 27 haplotypes. For this total, the haplotypic diversity index is 0.704 and the nucleotide diversity index is 0.003. The neutrality tests D of Tajima and Fs of Fu resulted in negative values (D = -1.93; Fs = -34.44). The haplotype network is shown in figure 3, which includes, in addition to the Brazilian coast, sequences from Mexico, the Caribbean, the Mediterranean Sea, South Africa and the Indian and Pacific oceans, as well as regions of the Western Atlantic.

For the Rho gene, 70 sequences of 479 nucleotides were obtained. Including data available from Genbank, 77 sequences were analyzed, with a total of 21 haplotypes. The haplotypic diversity index is 0.872, and the nucleotide diversity index is 0.006. The neutrality tests D of Tajima and Fs of Fu resulted in negative values (D = -2.41; Fs = -9.58). The haplotype network is shown in figure 4 and includes, in addition to the Brazilian coast, the North Atlantic and Spanish islands.

Table 1 summarizes the results related to haplotypic diversity, nucleotide diversity, neutrality tests and estimate of effective population size for the three studied DNA regions (mitochondrial DNA: CytB and COI; nuclear DNA: Rho). Since the results of AMOVA (Tab. 2) did not indicate significant results for geographic differentiation between the localities analyzed, regardless of the region of DNA used, it is possible to consider only one population for the studied skipjack tuna samples. Thus, for the CytB, COI and Rho genes, the estimated effective population sizes are approximately 1.28 billion, 520 million and 1.87 billion individuals, respectively.

Table 1. Genetic diversity data, neutrality tests and effective population size.

Gene	N	N. hapl.	h	ϖ	D of Tajima	Fs of Fu	Theta S	Ne
CytB	88	84	0.999	0.010	-1.93	-34.44	0.02329	1.28E+09
COI	103	27	0.704	0.003	-2.25	-29.63	0.01265	5.19E+08
Rho	70	17	0.872	0.006	-2.41	-9.58	0.01954	4.68E+08

N: number of samples, N. hapl.: number of haplotypes, h: haplotypic diversity, ϖ: nucleotide diversity, Ne: Effective Population Size.

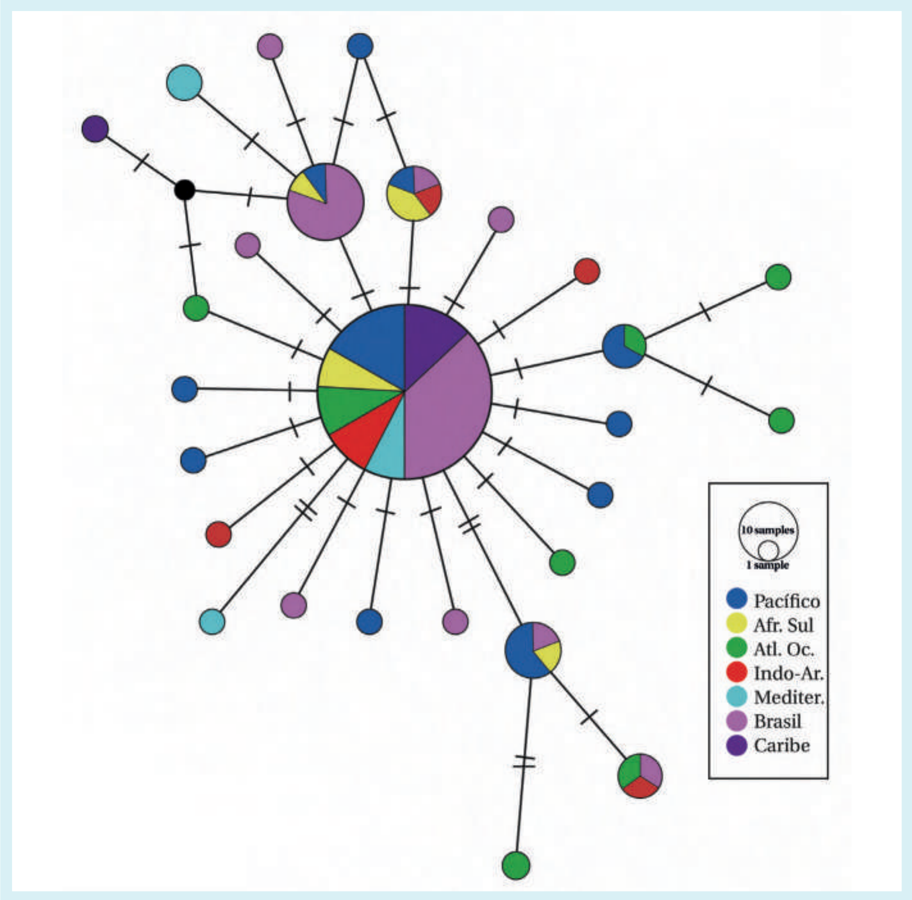

Figure 3. Haplotypic network for the COI gene.

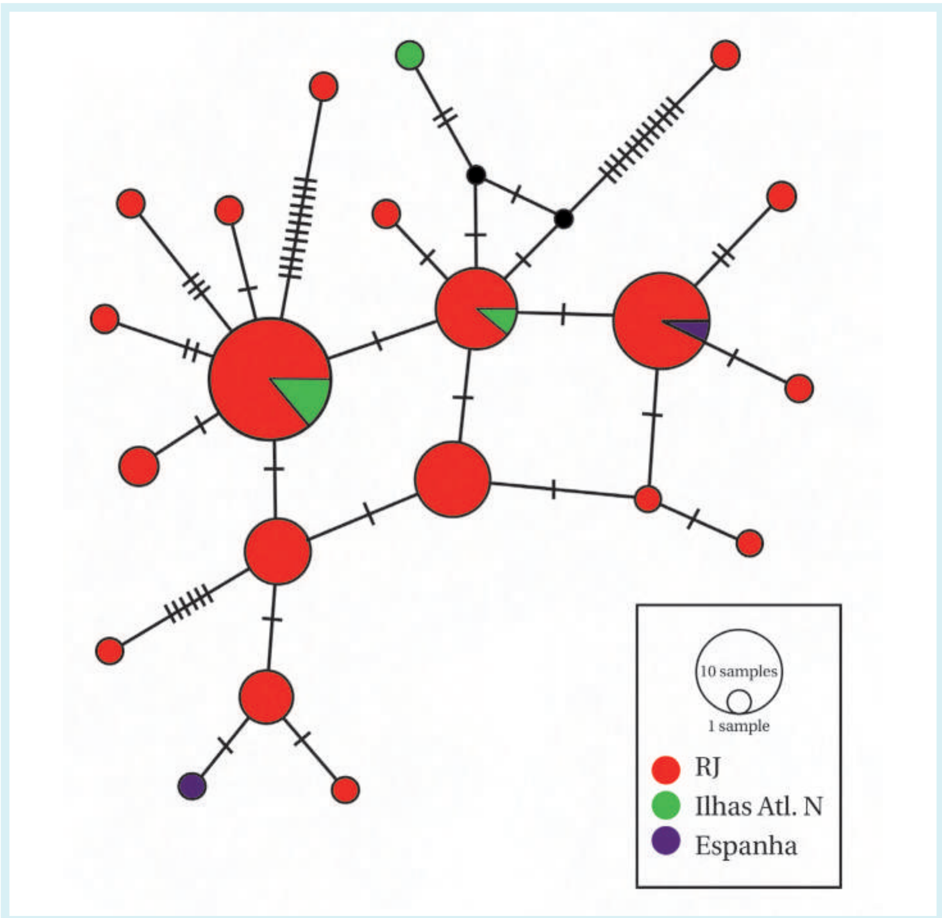

Figure 4. Haplotypic network for the Rho gene.

Table 2. AMOVA results for the three genes used in this work.

Gene	Source of variation	Variation %	Fixation Index	F-Statistica	P
CytB	Between groups	6.79	FCT	0.06793	0.19648
	Between populations / Within groups	0.72	FSC	0.00771	0.05670
	Within populations	92.49	FST	0.07511	0.06256
COI	Between groups	-3.48	FCT	-0.03478	0.89345
	Between populations / Within groups	4.60	FSC	0.04442	0.04497
	Within populations	98.88	FST	0.01118	0.13587
Rho	Between groups	4.59	FCT	0.04590	0.49756
	Between populations / Within groups	-11.56	FSC	-0.12115	0.83675
	Within populations	106.97	FST	-0.06969	0.62854

In summary, the results of the Sanger sequencing and its comparison with the sequences obtained from Genbank showed a homogeneity in the distribution of genetic variability between the regions of the Atlantic Ocean and between the oceans. In other words, based on the DNA regions studied in this work, it is not possible to say that there is spatial segregation of the species of skipjack tuna(*Katsuwonus pelamis*) between the locations analyzed. As for the genetic diversity indices, these indicated a historical stability of the effective population sizes. In other words, there are no marked traces of loss of diversity throughout the species' life history for the genes studied in the regions covered by this work. With the exception of the COI gene, which showed particularly different results, all other analyzes point to old and stable populations from the point of view of genetic diversity.

NGS sequencing

NGS sequencing data were obtained for 34 individuals, 12 of them from the south, 12 from the southeast and 10 from the northeast. Results based on 1021 SNPs (STRUCTURE) indicated that the three regions form a single population. That is, there is high genetic connectivity between the three regions studied.

Discussion

Connectivity

Genetic analyzes indicated little or no geographic differentiation of the skipjack tuna on the Brazilian coast, either based on data produced by Sanger sequencing (more traditional and less sensitive), or based on data produced by NGS (data from SNPs that present great sensitivity to estimate genetic connectivity in a short evolutionary time scale). These results are consistent with data on genetic connectivity between relatively short distances for tuna and yellowfin species. Little or no structure was found, for example, between different locations in the Atlantic Ocean for these migratory fish. Exceptionally, for *Thunnus alalunga*, the Mediterranean Sea has a distinct population in relation to the rest of the Atlantic, while *T. thynnus* presents a structure between western and eastern ends of the Atlantic (ALBAINA *et al.*, 2013). For species such as *T. albacares* (PECORARO, 2018), *T. obesus* (CHOW *et al.*, 2000) and *K. pelamis* (ELY *et al.*, 2005), no structure was found in the Atlantic.

Regarding the connectivity of the Brazilian coast with other regions and oceans in the world, the results of haplotype networks and AMOVAs also suggested high connectivity. The little evidence of intrapopulation variation was most likely due to the small sample sizes analyzed. For example, for CytB and Rho genes the number of sequences used in the analyzes was extremely low. The results for the three genes studied (mitochondrial DNA: CytB, COI and nuclear DNA: Rho) were complementary and, therefore, were interpreted together. With the exception of CytB, which presented a very high haplotypic diversity, the other genes showed haplotypes sharing between different locations, being, once again, an indication of connectivity within a time window related to the rate of evolution of these genes. These results are all consistent with the standards known for other species of tuna and the like. For example, medium to large scombroids with migratory habits are cosmopolitan and have little genetic structure. In the North Pacific, including samples from Japan, Mexico and Panama, *Thunnus orientalis* and *T. albacares* have low genetic variability and no population structure (NOMURA *et al.*, 2014). Allozyme-based data revealed little variation for *T. thynnus* between the western and eastern Atlantic, and no genetic structure between Mediterranean Sea locations and the Azores archipelago (PUJOLAR *et al.*, 2003).

SNP studies, however, have been more successful in finding evidence of geographic differentiation. For example, studies with populations of *T. alalunga* from the Atlantic, Pacific and Indian oceans have been able to identify evidence of geographic differentiation between these regions, in addition to an expressive differentiation between populations from the Mediterranean and the Atlantic, the same can be said for populations of *T. alalunga* between the western and eastern North Atlantic for *T. thynnus* (ALBAINA *et al.*, 2013). Still for *T. alalunga*, similar results regarding the structuring between the three oceans and the Mediterranean were found, thus supporting the current definition for their stocks (LACONCHA *et al.*, 2015). For T. albacores, SNPs showed differentiation of stocks for the Atlantic, Pacific and Indian oceans (BARTH *et al.*, 2017; PECORARO, 2018). What these studies with scombrids have shown is a pattern in which population structure, when it exists, is related to the limits of the Atlantic, Pacific and Indian oceans. However, even the use of SNPs obtained by NGS sequencing was not able, in this study, to demonstrate any evidence of geographic differentiation in the analyzed samples.

Demographic Aspects

The values of genetic diversity proved to be relatively high, suggesting the absence of signs of historical events or demographic variation that could have dilapidated the genetic variability of the stocks studied. The results are suggestive of old and well-established populations. The highest values of diversity were found for the cytochrome B gene, of mitochondrial origin, which is an expected result, since mitochondrial DNA accumulates mutations faster than most nuclear genes. However, the values of genetic diversity for the COI gene (also mitochondrial) were lower than the values for rhodopsin (a nuclear gene). This result suggests the existence of evolutionary forces acting specifically on the COI gene. In fact, the neutrality tests (D and Fs) for COI suggest that there was some evolutionary process that shaped the current genetic diversity of the species.

One of the cases suggested by the negative results of D is that of a process of population expansion, which would coincide with the pattern of distribution of allelic frequencies of its haplotype network. The expansion means that the number of individuals in a population has increased substantially. However, population expansion is not the only possible case due to the results of the neutrality tests. There are specific forms of natural selection that can shape today's diversity in a similar way. A selective sweep selection process is recognized as possibly responsible for the establishment of this standard (JENSEN *et al.*, 2005; KORNELIUSSEN *et al.*, 2013). This process happens when haplotypes of a certain gene are lost as a result of the selection acting in favor of another gene that is close to it. In this case, the expected result would be a reduction in the genetic diversity indexes, as was observed for COI in relation to the other two genes in this work. Likewise, the negative value of Fs of Fu can be indicative of population expansion or of a hitchhiking effect (*genetic hitchhiking*) (FU, 1997). Considering that the results of the diversity indexes for CytB and Rho pointed to a stable population, it is likely that the COI gene is in fact under the effect of selection forces.

In summary, the most likely scenario is that, in fact, the skipjack tuna population has remained stable for a long time and that some natural selection process has taken place in the COI gene. This gene is part of a key mitochondrial protein complex for cellular respiration in almost all living beings. In fish, a process known as "purifying selection" is described as the reason for this gene to be conserved (WARD & HOLMES, 2007). This process eliminates haplotypes that are harmful due to mutations unfavorable to their function, thus maintaining a prevalent version of the functional gene. Thus, the discrepancy found between the evolutionary and demographic scenario of each gene in the results of this work can be explained by the action of natural selection.

Finally, the results for the effective population size (Ne) presented are a rough estimate. The robustness of the results is dependent on the precision of the evolutionary rate used in the calculations. This rate is specific to each gene of each species and, for the skipjack tuna, the values of these rates are still unknown. In these calculations, approximations were made based on the known mutation rates of other bone fish species. The result must therefore be interpreted according to its order of magnitude. Among the extreme values, it is possible to estimate something from 500 million to 1.3 billion fish directly involved in the reproduction and constitution of a new generation each year. The value is considerable when compared to other medium to large pelagic fish. The mahi-mahi (*Coryphaena hippurus*) has an estimated effective population size of 470 thousand individuals, in the Mediterranean Sea population, to 1.2 million, in the Pacific Ocean population. Among the scombrids, the albacore (*Thunnus albacares*) has an estimated 10 million. Skipjack tuna itself has estimates of around 98 million (ELY *et al.*, 2005). A summary of these data can be seen in table 3.

Table 3. Comparison of effective population size (Ne) for different species of pelagic migrating fish, including results of this work.

Name	Species	Ne	Population	Reference
Mahi Mahi	*Coryphaena hippurus*	470 mil a 1.2 million	Mediterranean and Pacific	Díaz-Jaimes *et al.*, 2010
Marlim	*Tetrapturus georgii*	1.4 a 10.5 million	Western Atlantic	Bernard *et al.*, 2014
White marlim	*Kajikia albida*	10 a 11.5 million	Western Atlantic	Bernard *et al.*, 2014
Albacore	*Thunnus albacares*	10 million	Global	Ely *et al.*, 2005
Skipjack tuna	*Katsuwonus pelamis*	98 million	Global	Ely *et al.*, 2005
Skipjack tuna	*Katsuwonus pelamis*	500 million a 2 billion	Global	This work

Final considerations

According to Ely *et al.* (2005), catches of *K. pelamis* in the world were around 670 million individuals, with an average weight of 3 kg. In 2008, 149,000 tons of *K. pelamis* were captured in the Atlantic Ocean, a value close to the average of the previous five years (STECF, 2009), which allows an estimate of between 50 million (average weight 3 kg) and 15 million (average weight 10 kg) of individuals. The genetic estimate of the effective population size presented in this work varies within the same order of magnitude as the registered catch and one order above (ie, billions of individuals). Although data on genetic diversity do not indicate a population decline, the catch numbers raise concerns about approaching the actual population size. Is it important that population size estimates, based on fishing, ecological or genetic data, are refined and interpreted together. According to IUCN (COLLETTE *et al.*, 2020), among the knowledge gaps for *K. pelamis* are precisely population size and trend. An effort to meet this demand for information is fundamental today.

In general, the results of this work show that *K. pelamis* belongs to a single genetic stock for the western south Atlantic. Sequencing data also suggest that fish that occur across the Atlantic Ocean are also from a single genetic stock. However, this conclusion must be observed carefully. The data used to assess Atlantic regions are not sensitive to recent changes in stock structure or recent changes in historical patterns of genetic connectivity. Therefore, such data are not sufficient to counter the parameters currently accepted as stock limits proposed by ICCAT. According to ICCAT[8], the ocean can be divided into two large fishing areas for the skipjack tuna, corresponding to the East Atlantic and West Atlantic. Supplementary data are needed to assess this possible lack of population structure, especially for the regions of the Western North Atlantic and the Indo-Pacific, where genetic variability is still poorly understood. Still, for this work, no signs of decline or demographic increase were detected and, possibly, the population has been stable for a long time. Although they are not of concern from a genetic point of view, the estimates of effective population size raise attention to the number of specimens caught annually. The establishment of more precise mutation rates for calculating the effective population size (Ne) and the inclusion of genomic data are necessary directions for advancing the theme of defining these fish stocks.

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Trophic ecology of the skipjack tuna in the southeastern and southern regions of Brazil

7

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Introduction

Studies describing the organisms' diet and eating habits make it possible to understand energy transfer and trophic relationships in communities and ecosystems (MUTO *et al.*, 2005). They allow the identification of the ecological role of each species and are essential for the development of trophic models, for the evaluation of the structure, processes and dynamics of ecosystems (GASALLA & SOARES, 2001; GASALLA *et al.*, 2007). Studies that quantify trophic relationships are especially important in ecosystems exploited by fishing, supporting management measures that seek the preservation of marine ecosystems and the sustainability of fisheries (CURY *et al.*, 2008; JENNINGS *et al.*, 2011).

Despite the high economic importance in Brazil, until now, information about the trophic ecology of the skipjack tuna (*Katsuwonus pelamis*) was limited to studies of Stomach Content Analysis (ACE) carried out in the 1990s. These studies have indicated that small pelagic organisms, such as krill (*Euphausia similis*), anchovy (*Engraulis anchoita*) and sardines (*Sardinella brasiliensis*), and mesopelagics, such as lanternfish (*Maurolicus stehmanni*), are the main prey in the skipjack tuna diet in the southeast-south region (ANKEBRANDT, 1985; VILELLA, 1990).

ACE is traditionally used to study the fish diet (PINKAS *et al.*, 1971; HYSLOP, 1980; CORTÉS, 1997), and has the advantage of allowing the quantitative and qualitative identification of prey ingested prior to capture. In the case of skipjack tuna, the high frequency of empty stomachs and/or still, those filled with the species used as live bait (i.e., juvenile sardine and anchovy, MADUREIRA *et al.*, 2016), may represent limitations of the ACE. In this sense, an adequate sample number and the use of complementary techniques can be used to determine the composition of the assimilated diet and to study the trophic ecology of the skipjack tuna.

Chemical tracers, such as the analysis of stable isotopes (IEA) of carbon ($\delta^{13}C$) and nitrogen ($\delta^{15}N$), can be used as indicators of a predator's eating habits, allowing the study of the diet on a broader time scale than ACE (MADIGAN *et al.*, 2012). This technique is based on the premise that the values of ^{13}C and $\delta^{15}N$ in a consumer's tissues reflect those of his prey, with a small enrichment in the heavier isotopes associated with tissue assimilation and synthesis (i.e., increased δ value), called trophic discrimination (FRY, 2006). Tissues that have a fast rate of renewal (i.e., blood and liver) reflect information on the diet eaten between days and weeks, while others (i.e., muscle) reflect the diet on a monthly scale (MARTINEZ DEL RIO & CARLETON, 2012). The enrichment at each trophic level is higher in the case of $\delta^{15}N$ (2–4 ‰), and lower for $\delta^{13}C$(0–2 ‰) (DENIRO & EPSTEIN, 1978; 1981). Thus, in addition to tracking the diet, $\delta^{15}N$ is used to estimate the trophic position (POST, 2002), while $\delta^{13}C$ is used to identify sources at the base of the trophic chains (PETERSON & FRY, 1987).

IEA can be used as a complement to ACE in mixing models, which use the isotopic composition of the consumer, the prey and the predatory trophic predator-prey discrimination factor, estimating the proportion of prey in the consumer's diet (PHILLIPS *et al.*, 2014).

The accuracy of the models depends on the isotopic difference between the prey, and decreases the greater the number of sources. Thus, isotopically similar prey can be grouped a *priori*, and their contributions estimated through functional groups (NEWSOME *et al.*, 2004; PHILLIPS *et al.*, 2005; MADIGAN *et al.*, 2012; PHILLIPS *et al.*, 2014).

The objective of this study was to describe the seasonal and spatial ontogenetic variations (related to growth) in the skipjack tuna diet in the southeast-south regions, through analysis of stomach contents and to determine the composition of the assimilated diet using stable isotope analysis.

Materials and methods

Stomach Content Analysis

Skipjack tuna samples from commercial fishing of the pole and live bait fleet landed in Niterói (RJ) and Rio Grande (RS) were collected between January 2017 and December 2018. The systematic monitoring of landings was performed by the teams of the Laboratory of Biology of Necton and Fishing Ecology (ECOPESCA - UFF), the Fisheries Institute Foundation of the State of Rio de Janeiro (FIPERJ) and NUPEM/UFRJ, in Niterói, and by the teams of the Laboratory of Pelagic Fishing Resources and Fishing Technology and Hydroacoustics of FURG, in the facilities of the company Leal Santos, in Rio Grande. For the same vessel, individuals were collected from different "urns", aiming at the search for a better representation of different areas, schools and lengths (ANDRADE, 1998).

In biological sampling, furcal length (CF), total and gutted weight (PT and PEv), gonad, liver and stomach weight (PG, PF and PE, respectively) were recorded, and repletion index (IR), in addition to gender identification and maturation stage, according to a scale proposed by Brown-Peterson *et al.* (2011). Food items were identified down to the smallest possible taxon. For each food item (taxon) the number, total weight and degree of digestion were recorded.

The importance of the prey was assessed through the percentages of the frequency of occurrence (%FO), number (%N), weight (%P) and the Relative Importance Index (%IRI) (PINKAS *et al.*, 1971; HYSLOP, 1980; CORTÉS, 1997). The IRI was calculated as IRI =% FO x (% N +% P), and% IRI as % IRI = 100 x IRI / ∑IRI.

The alimentary intensity of the skipjack tuna was evaluated by the Stomach fullness index (RI), calculated as: RI = 100 x BW / (PT-PC), where BW = weight of stomach contents (g) and PT = total fish weight (g). The prey of each food item was classified on a 5-point degree of digestion (GD) scale similar to that of Vaske-Jr *et al.* (2004).

The specimens were classified according to the areas of capture in the southeast (20° -28° S) and south (28° -34° S), taking the Cabo de Santa Marta (SC) as separation between these areas with a distinct oceanographic system (GARCIA, 1997; Chapter 2 of this volume).

To assess ontogenetic changes in the diet, fish were grouped into three size classes according to the furcal length (CF) in which 50% and 100% of individuals reach sexual maturity (SOARES *et al.*, 2019) as follows : juveniles (<47 cm), young adults (47-63 cm) and adults (> 63 cm). The composition of lengths of skipjack tuna (n = 886 specimens) analyzed for diet study can be seen in figure 1. It can be seen that for both periods (harvests) and regions the three size categories are represented.

Examples of sardines (*Sardinella brasiliensis*), a species used as live bait by fishing vessels, were frequent in the diet, some still in the mouth (or freshly ingested), suggesting that probably many were baits. However, we consider that a part of the skipjack tuna can consume the bait without being caught, and, as a consequence, they end up being part of the diet of these specimens.

In this sense, freshly ingested sardines (GD≤2) were excluded from the analyzes, and those already digested (GD≥3) were analyzed as an integral part of the diet, and also inserted together with other pelagics in the isotopic mixture models. Stomachs containing only true sardines with GD≤2 were considered empty.

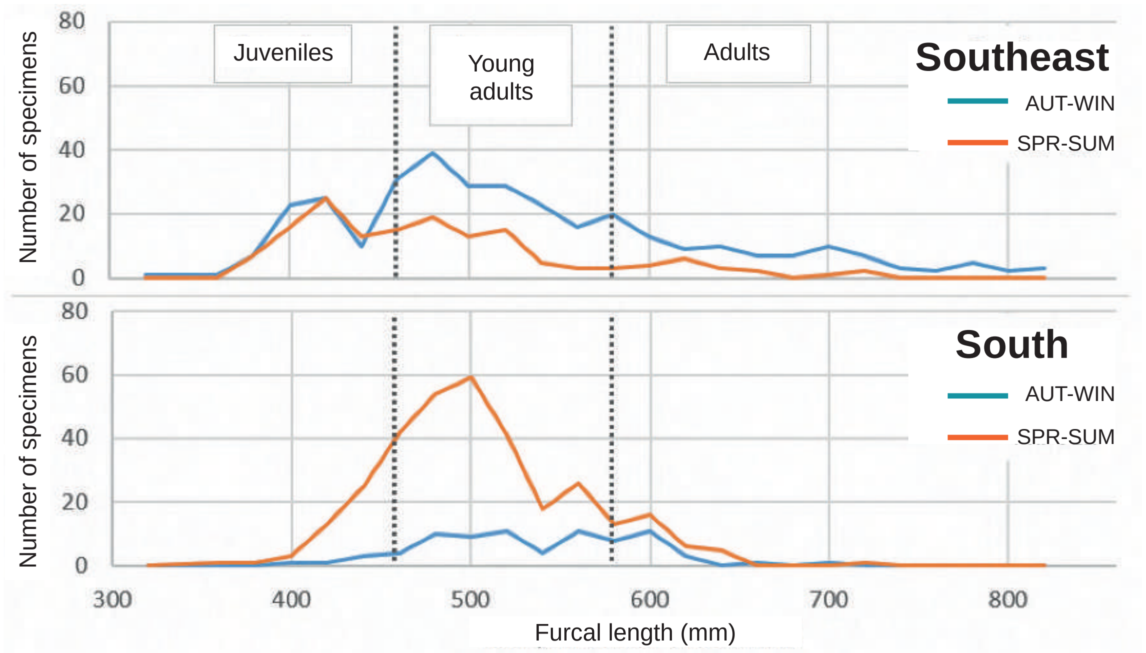


Figure 1. Length composition of 886 specimens of skipjack tuna analyzed for description of the diet.

Stable Isotope Analysis

For AIE, skipjack tuna muscle samples were removed near the first spine of the dorsal fin using a scalpel, washed with distilled water, and kept in a freezer (-20°C) until processing. The tissues were subsequently lyophilized or oven dried (60°C) for 48 hours, and ~ 0.5 mg Rates were weighed in tin capsules and sent to the Center for Stable Isotopes (University of New Mexico) or to Stable Isotope Facility (University of California) for the analysis of stable isotopes of carbon and nitrogen in continuous mass spectrometers. The isotopic ratio is reported in delta (δ) notation using the equation:

$$\delta X = [(R_{Sample} / R_{Standard}) - 1] \times 1000$$

where: X is ^{13}C or ^{15}N, and R is the ratio of the light to the heavy isotope($^{13}C/^{12}C$ or $^{15}N/^{14}N$) (PETERSON & FRY, 1987). The international standards were Vienna Pee Dee Belemnite (V-PDB) and atmospheric N_2, for $\delta^{13}C$ and $\delta^{15}N$, respectively. The analytical precision between measurements (± SD) was estimated by analyzing the internal protein standards of each laboratory, and estimated at ± 0.1 ‰ for the values of $\delta^{13}C$ and $\delta^{15}N$. Due to the low C: N ratio (3.2 ± 0.1) in the skipjack tuna samples, no chemical treatment was performed to remove lipids (POST *et al.*, 2007).

The contribution of food sources to the skipjack tuna diet was determined for each region and for the size classes through mix models in the SIMMR package (PARNELL, 2019) of the R software (R Development Core Team, 2019). Bayesian models estimate a distribution of possible values for the proportion of prey, and were reported using the median and 95% credibility intervals. For mixing models, skipjack tuna prey obtained in the analysis of stomach contents and collected on research cruises on the South Atlantic Ship, between 2009-2015, in the Talude / IO-FURG Project were analyzed. In each region, the prey were grouped by family, and the averages of $\delta^{13}C$ and $\delta^{15}N$ were compared using the Tukey HSD test. Prey with a similar isotopic composition (p-value> 0.05 for $\delta^{13}C$ and $\delta^{15}N$) was grouped *a priori* (PHILLIPS *et al.*, 2005; PHILLIPS *et al.*, 2014).

The trophic discrimination values used in the mixture models for skipjack tuna were those reported for Pacific tuna (*Thunnus orientalis*) obtained in a controlled diet experiment ($\Delta^{13}C$= 1.8 ± 0.3 ‰; $\Delta^{15}N$ = 1.9 ± 0.4 ‰ ; MADIGAN *et al.*, 2012b). The average values (and deviations) of each group of the mixing models of the Southeast and South regions are shown in figure 5. For the southeastern region, the groups used as sources of the mixing models were: (1) krill (Euphausiidae); (2) fish and cephalopods (Carangidae, Exocoetidae, Ommastrephidae); (3) lantern fish (Sternoptychidae); and (4) small pelagic fish (Clupeidae, Engraulidae). For the southern region, the groups of the mixed models were: (1) krill (Euphausiidae); (2) cephalopods (Ommastrephidae); (3) lantern fish (Sternoptychidae) and; (4) small pelagic fish (Clupeidae, Engraulidae). Finally, the relative biomass of prey in each region, calculated by ACE, was used as *a priori* information in the mixing models (SWAN *et al.*, 2019).

Results

Stomach Content Analysis

Altogether, 63.5% of the 740 stomachs analyzed for skipjack tuna contained prey (Fig. 2a). Fish with food in the stomach were more frequent in the south (73.4%) than in the southeast (55.4%) (Fig. 2A). Juveniles in the southern region showed higher values of food frequency (83.4% of stomachs contained food) than those in the southeast region (49.1%). In general, the average values of the repletion index showed a small reduction with the increase in the length of the skipjack tuna: Juvenile = 4.0, Young Adults = 3.7, Adults = 3.1 (Fig. 2B).

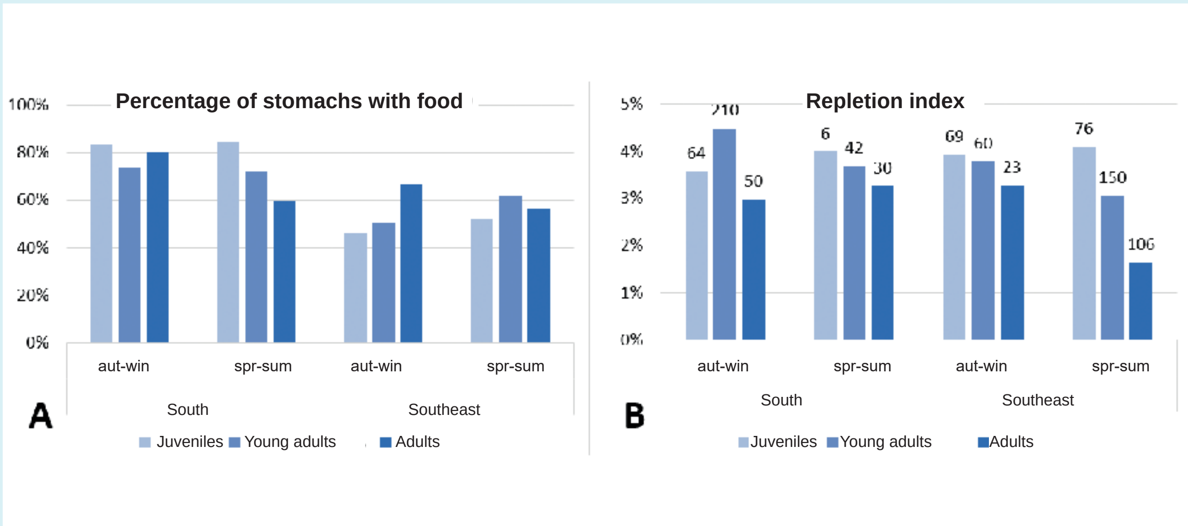


Figure 2. Percentage of stomachs with food and average repletion index (IR%) by region, period and size classes. Number of specimens analyzed at the top.

In total, more than 642 thousand food items from 30 different taxa were identified, 16 of which were identified at the species level, others at the family or order level. Five species of pteropod molluscs and three cephalopods, one species of euphusiac crustacean and seven species of teleosteal fish were identified at the species level. Skipjack tuna presented a wide diet, consuming everything from zooplankton (krill, pteropods, decapod larvae), to nectonic organisms (small pelagic fish, juvenile demersal fish, plus demersal squid and pelagic octopus).

In general, the main item found in the skipjack tuna diet was the small krill planktonic crustacean (*Euphausia similis*). Krill represented 41.0% by weight and 99.1% of the total number of prey in the diet (636.5 thousand specimens). In the specimens of skipjack tuna that consumed krill, an average of 3,600 specimens and 72g per content were observed, with a maximum of 39,300 specimens in a stomach.

Other important items were fish from different families (Clupeidae, Sternoptychidae, Engraulidae, Carangidae and Dactylopteridae, in order of numerical importance). Minor items were pteropod and cephalopod molluscs (demersal squid and pelagic octopus), as well as larvae of decapod crustaceans. Figure 3 presents a summary of the skipjack tuna diet. It is possible to verify a great difference in the diet of skipjack tuna between the two regions. While the diet of the southern skipjack tuna was basically composed of krill (% P = 69.3,% IRI = 97.3), those found in the southeast consumed mainly fish (% P = 90.3,% IRI = 66, 9), but also krill (% P = 8.2,% IRI = 32.9).

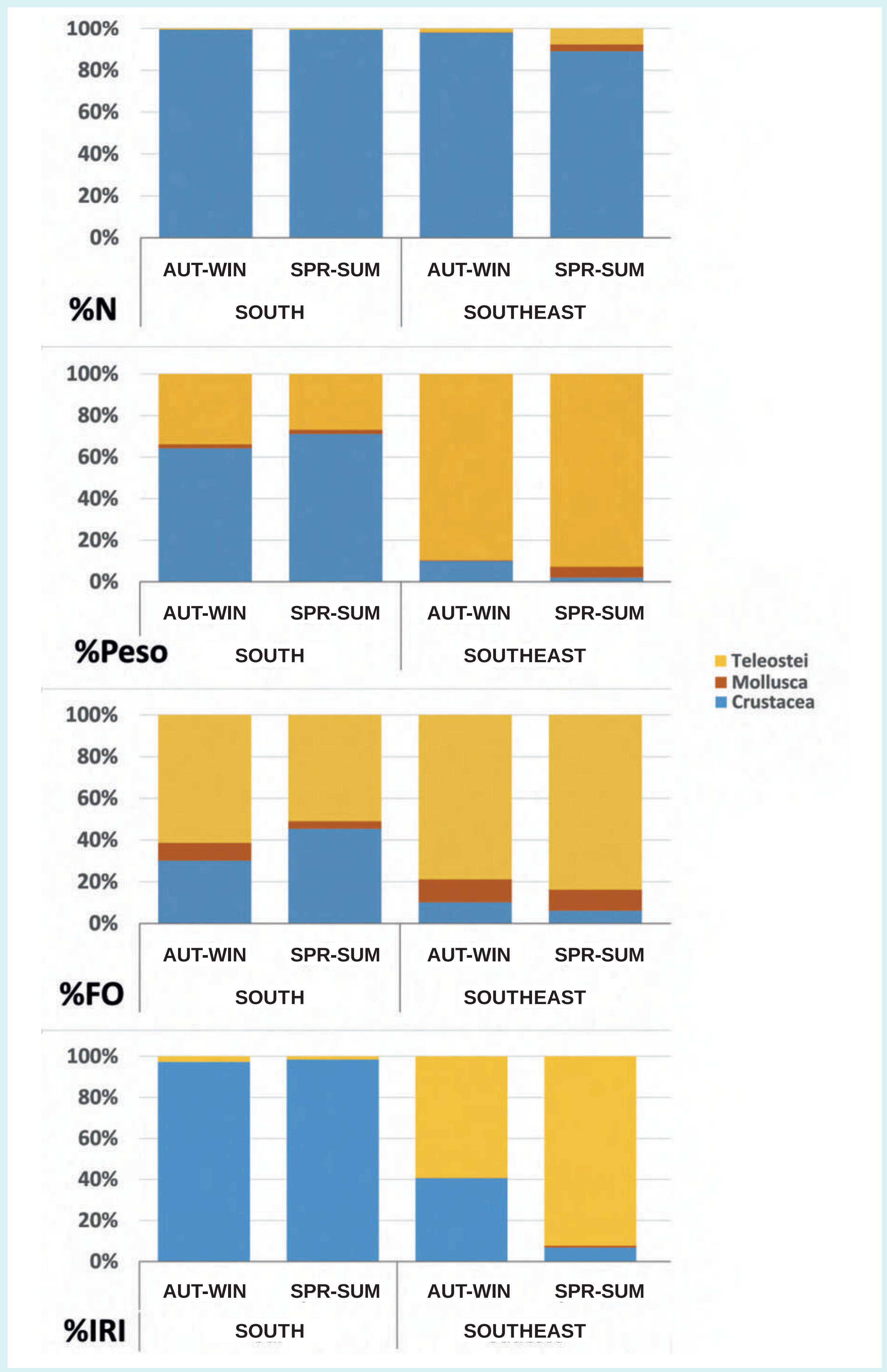
Figure 3. Importance in number (% N), weight (% P), frequency of occurrence (% FO) and Relative Importance

Index (% IRI) of the main groups of prey in the skipjack tuna diet, by size and region. Juvenile (360-460mm CF), Young Adults (470-560mm CF) and Adults (570-830mm CF).

Considering only the fish, the sardine (*Sardinella brasiliensis*), the flying gurnard (*Dactylopterus volitans*) and the anchovy (*Engraulis anchoita*) were more abundant in the diet of the skipjack tuna in the southeast, representing respectively 30.8%, 14.3% and 4.6%, in number, of the fish identified. In the south, the main fish consumed were the lantern fish(*Maurolicus stehmannni*) and anchovy representing respectively 60.0% and 19.4%, in number, of the identified fish.

Marked seasonal differences were observed in the skipjack tuna diet in the southeast. During spring-summer there was a 95% reduction in krill consumption in% N and% P (Fig. 4). In the south, the diet was mainly composed of krill, with little seasonal variation.

Figure 4. Comparison of skipjack tuna diet between periods of the year and regions. Percentage in number (% N),



weight (% P), frequency of occurrence (% FO) and Relative Importance Index (% IRI).

Stable Isotope Analysis

The average values (and deviations) of δ¹³C and δ¹⁵N of the skipjack tuna, corrected with the discrimination factors, are within the mixture polygon formed by the average values of δ¹³C and δ¹⁵N of the sources in both regions (Fig. 5), indicating consistency of the models proposed for determining the diet of the skipjack tuna. Figure 6 shows the results of the mixing models, indicating the estimated proportions of prey in the skipjack tuna diet, comparing the three size classes and the south and southeast regions.

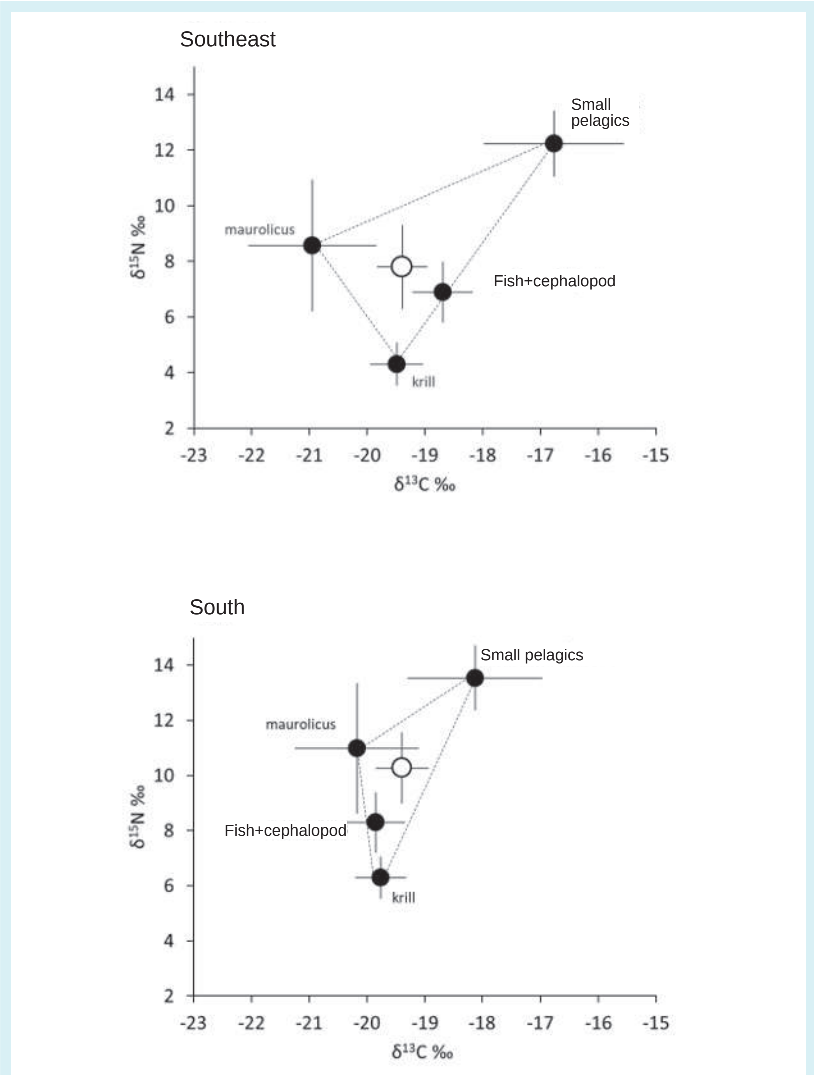


Figure 5. Bi-plot of δ¹³C and δ¹⁵N with mixing polygons of skipjack tuna (white circles) and their prey (black circles) in the southeastern and southern regions.

In the southeast region, the skipjack tuna diet consists of krill, lantern fish and small pelagics, with a smaller proportion of the group of fish and cephalopods. The juvenile size class had a higher proportion of krill and lantern fish in the diet. The proportion of small pelagics increased in the young adult and adult classes, compared to the juvenile.

In the southern region, the proportions of krill, lantern fish and small pelagics in the diet are similar, while that of cephalopods is very low. The proportions of krill and lantern fish decreased with the increase in the size of the skipjack tuna, while the contribution of small pelagics increased in the larger size classes. The small number of adult individuals (FC> 63 cm) who had their isotopic composition determined in the southern region (n = 7) made it impossible to determine the diet through mixing models.

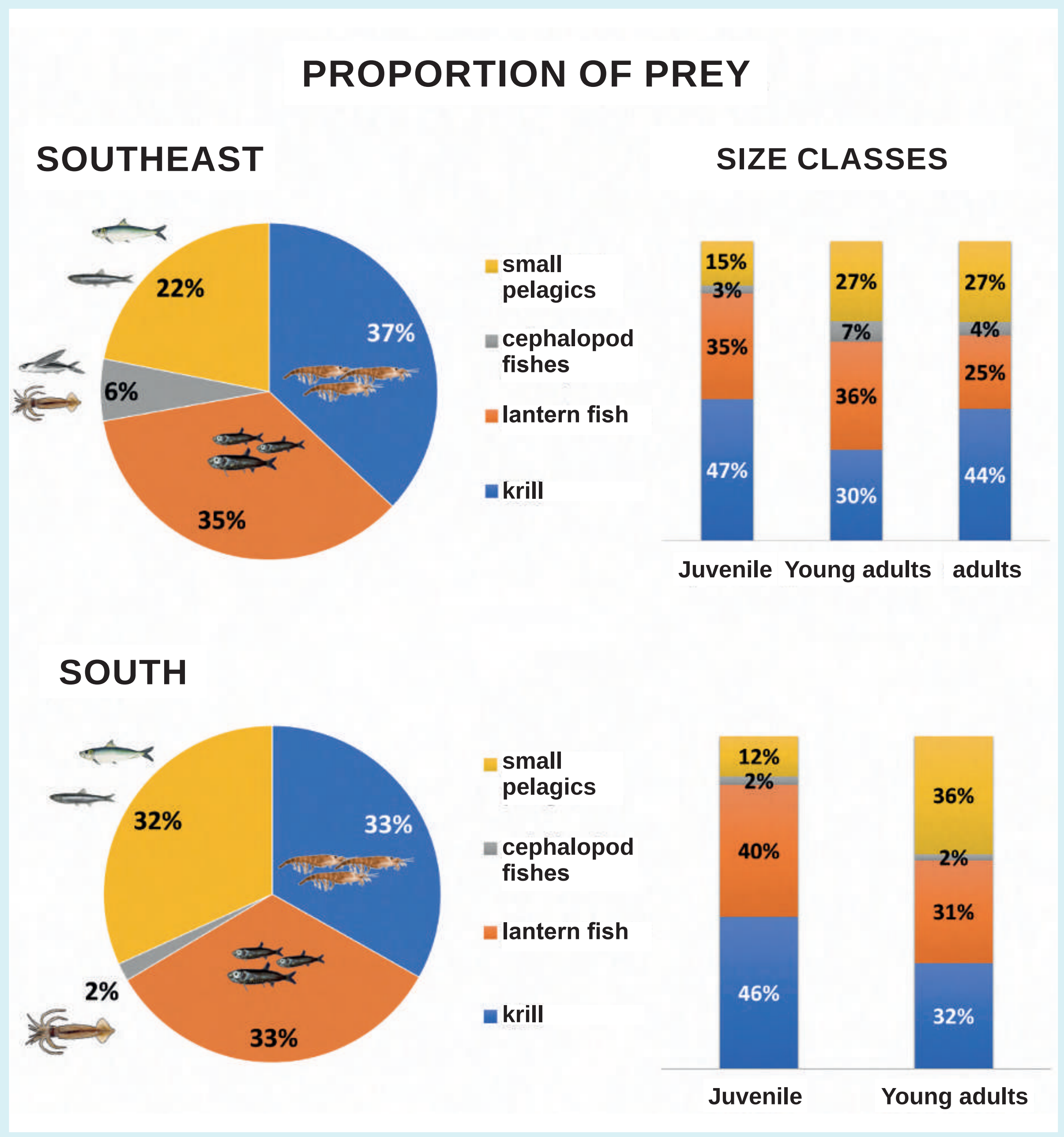


Figure 6. Proportion of prey estimated through mixing models in the skipjack tuna diet in the southeastern and southern regions, and in size classes.

Discussion

The higher food frequency observed in the southern region suggests that this is a more intense eating area, for all groups, but especially for juveniles. Considering the fish from the south and southeast regions, only 36.5% of the stomachs analyzed were empty. These results contrast with studies carried out in the 1980s, which found empty stomachs in 41.9% of the skipjack tuna in the southeast (ANKENBRANDT, 1985), but up to 73% considering the two areas (VILELLA, 1990).

The results found in this study, from ACE, showed few ontogenetic changes in the skipjack tuna diet in the south, but greater variations in the southeast, caused by differences in krill consumption between size classes. A low ontogenetic change indicates a high intraspecific food overlap, and, consequently, can increase competition between groups of different size classes migrating in the same period.

Spatial variation was observed in the skipjack tuna diet when comparing the results obtained in the south and southeast regions. Seasonal variation in diet was observed only in the southeastern region, caused by a higher consumption of krill in the winter-spring period, while in the southern region, krill consumption was high throughout the year. Comparing the two areas, in the southeast region there was less consumption of krill, with a greater relative contribution of fish. These seasonal and spatial variations alter the patterns of intraspecific food overlap, and, consequently, the distribution by resources between size classes.

In general, the ACE results show that the skipjack tuna has a wide diet, consuming everything from zooplankton (krill, pteropods, decapod larvae) to nectonic organisms (such as small pelagic fish, juvenile demersal fish, in addition to demersal squid and pelagic octopuses).

The mixing models indicated that three energy sources support the population of the skipjack tuna in the southeast and south: krill, lantern fish and small pelagics. The skipjack tuna diet in the Atlantic has been reported to be mainly composed of crustaceans and fish (OLSON *et al.*, 2016). On the southeastern Brazilian coast, Ankenbrandt (1985) highlighted the lantern fish as the main prey consumed between 1981-82 (26.7% of the volume in stomach contents, V), followed by krill, *Euphausia similis* (22.2% V). These estimates are similar to the proportions estimated by the mixing model for the southeast region (Fig. 6).

The group composed of small pelagic fish, represented by fish from the families Clupeidae and Engraulidae in this study, plays a key role in pelagic food chains, as they feed on phytoplankton and zooplankton (SCHWINGEL & CASTELLO, 1994; CASTELLO, 2006), transfer energy to higher levels in the trophic chains, which adds to its high biomass in this region (MADUREIRA *et al.*, 2005; COSTA *et al.*, 2016). Anchovy, for example, is an important food resource for pelagic fish, demersals, sea birds and mammals in the Southwest Atlantic (CASTELLO, 1997; COSTA *et al.*, 2016). The sardine is identified as the trophic correspondent of anchovy in the southeast region, although the species coexist in both regions (MADUREIRA *et al.*, 2005; CASTELLO, 2006).

The sardine showed a high biomass in the stomach content of specimens from the southeast region (74.6%), while the mixing models estimated proportions between 22% of small pelagics in that region. In the southern region, krill was the dominant prey in ACE, with 82.5% of the biomass, but the mixing models estimated a proportion of 33% of this item in the assimilated diet. In the case of sardines, it is possible that its use as live bait introduces a bias in estimating the importance of the species in the diet of the skipjack tuna, from the ACE. In the case of krill, it was observed that full stomachs of this item are associated with high yield in the fishery, while empty stomachs are related to smaller schools with low yield, probably overestimating the importance of krill. Roger (1994) observed a similar relationship in the Indian Ocean, between the size of the tuna schools and the amount of prey in the stomach contents. This information shows the importance of using complementary techniques to determine the trophic relationships of skipjack tuna with samples from commercial fishing.

Studies on the importance of cephalopods in the energy transfer of the trophic chains of the southwestern Atlantic classify the skipjack tuna as a less frequent predator (<10%) of this group (SANTOS & HAIMOVICI, 2002). The small proportion of cephalopods estimated by mixing models was consistent with the stomach content in this and in the past studies of the skipjack tuna diet in the region (ANKENBRANDT, 1985; VILELLA, 1990).

Unlike anchovies and sardines, which occur mainly on the continental shelf, the lantern fish (*Maurolicus stehmanni*) is abundant in waters of an external shelf and upper embankment (MADUREIRA *et al.*, 2005), and performs daily vertical migration, remaining in the mesopelagial (> 150m) during the day, and ascending to the zone epipelagic during the night (GREIG, 2000; MADUREIRA *et al.*, 2005; Chapter 3 of this volume). Like anchovies and sardines, the lantern fish plays the ecological role of forage species, feeding on zooplankton and being preyed on by squids and large pelagic fish such as skipjack tuna, establishing the intermediate link between basal and superior components of the trophic network (ALMEIDA, 2001).

Several studies suggest ontogenetic changes in the diet of tuna (OLSON *et al.*, 2016). Graham *et al.* (2007) observed that juvenile yellowfin tuna (*Thunnus albacares*) feed mainly on crustacean larvae, while adults consume shrimps and teleosts. Young *et al.* (2010) found an increase in the prey-predator length ratio with an increase in the average length of pelagic predators. Ankenbrandt (1985) observed a decrease in the importance of krill and an increase in the importance of fish, mainly lantern fish, with the growth of skipjack tuna. In the present study, the mixed models indicate that skipjack tuna juveniles had a diet composed predominantly of krill, while the contribution of small pelagics was greater in young adults and adults (Fig. 6).

The present study showed that krill (*Euphausia similis*) was the main source of energy used by skipjack tuna, particularly in the southern region and for the juvenile class. Despite its small size, *E. similis* can occur in dense aggregations (GORRI, 1995; HIROTA *et al.*, 1990; MONTÚ *et al.*, 1998), providing food in large quantities to migratory schools. The importance of krill as an energy source for the skipjack tuna was also reported in the Pacific Ocean, where it contributed 60% of the biomass in the stomach content (OLSON *et al.*, 2016). Dense patches of this crustacean occur close to the fronts formed between hot oligotrophic and cold productive waters (FIEDLER & BERNARD, 1987), a relevant oceanographic process for the foraging of the skipjack tuna in the southwest Atlantic (COLETTO *et al.*, 2019).

More than 90% of krill specimens were found in the skipjack tuna diet caught between 32.5° S and 34° S latitudes, and the rest at 26° S latitudes. In surveys with plankton nets, Gorri (1995) observed high concentrations of *E. similis* in autumn, in southern Brazil, close to the latitude of 33° S. Fischer (2012) observed a high abundance of *E. similis* in the macrourid diet on the southern embankment of 32° S, in late summer and early spring, and between 27° S and 28° S in the fall.

Euphausia similis is a species of hot and cold temperate waters, typical of the transition region between subtropical and sub-Antarctic waters (ANTEZANA & BRINTON, 1981; GIBBONS *et al.*, 1999) and its occurrence indicates the Brazilian current in the Brazil / Malvinas convergence. *E. similis* presents high biomass peaks on the embankment (MONTÚ *et al.*, 1998), representing 40-60% of the zooplankton captured between spring and summer (GORRI, 1995), a time when the associated resurgence (fertilization) processes the currents of the Brazilian Current reach their maximum in the region (GARCIA, 1998; ODEBRECHT & CASTELLO, 2001). Krill is a filtering organism that can reduce phytoplankton biomass (GRANELI *et al.*, 1993; ATKINSON *et al.*, 1999), rapidly increasing its population biomass. They can feed on large phytoplankton (eg, large diatoms and chain-forming), typical of resurgence events (HERRARA & ESCRIBANO, 2006; HUTCHINGS *et al.*, 1995; SHIN *et al.*, 2017), reducing the length of the food chains, increasing the energy transfer efficiency (POST *et al.*, 2000; CLOERN & DUFFORD, 2005) and allowing greater productivity of fish of a higher trophic level, as is the case of the skipjack tuna fish.

On the other hand, krill biomass is highly variable and dependent on certain oceanographic processes, which makes feeding, growth, reproduction and the skipjack tuna population bio-mass also associated with these processes. Oceanographic processes also influence the migratory routes used by the skipjack tuna (HUMSTON *et al.*, 2000; LEHODEY, *et al.*, 2004), which, like other tunas, migrates looking for frontal zones and vortexes (UDA *et al.*, 1973; RAMOS *et al.*, 1996; ANDRADE, 2003; SYAMSUDDIN *et al.*, 2016; ZAINUDDIN *et al.*, 2017; COLETTO *et al.*, 2019), where in general there is greater local productivity (BRANDINI, 1988; CAMPOS *et al.*, 1999; 2000; BRANDINI *et al.*, 2000; SILVEIRA *et al.*, 2004; GAETA & BRANDINI, 2006) and aggregation of biomass (LIMA & CASTELLO, 1994; FRANCO *et al.*, 2005; 2006; LOPES *et al.*, 2006a; CASTELLO, 2007).

Conclusions

Tuna predation strategies have evolved to satisfy their high bioenergetic demand by maximizing food intake, being considered opportunistic predators (OLSON *et al.*, 2016). The opportunism in the feeding strategy of skipjack tuna is evident by: 1) consuming several types of abundant pelagic and mesopelagic prey and of aggregated distribution, 2) consuming larger prey as they grow, 3) taking advantage of seasonal peaks in the abundance of prey, enabling the storage of energy and growth of younger individuals to complete the biological cycle of the species.

Analysis of stomach content of skipjack tuna in the southeast-south region, between 2017-2018, indicated that the main food item was krill (*Euphausia similis*), followed, in order of numerical importance, by small fish, including sardines, the lantern fish, the anchovy, in addition to species of Carangidae and the coió-voador, *Dactylopterus volitans*.

The spatial and seasonal variations observed in the diet were associated with differences in krill consumption, which govern intraspecific food overlap patterns, and, consequently, the distribution by resources. The models of isotopic mixture corroborate that krill is the main energy source, but show that lantern fish and small pelagics (sardines and anchovy) are also important sources in the diet of the species.

The main prey of the skipjack tuna (krill, sardine, lantern fish, anchovy) present great seasonal variations in the biomass related to the oceanographic conditions, indicating that the energetic flow of the trophic chain of the skipjack tuna is connected to the oceanographic processes, that they cause variations in the productivity and distribution of prey, and demonstrate that the biology of the skipjack tuna is subject to the effects of global climate change.

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Contribution to the study of parasitism by helminths in skipjack tuna

8

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Introduction

Helminth parasitism is one of the biggest causes of economic losses, both in terms of human health and in livestock, aquaculture and agronomy. These parasites also cause losses in the biodiversity stocks of wild animals in a free-living environment, especially species at risk of extinction, as well as in settlements, as noted by Brandão (2009).

Another important aspect, which has been evidencing the importance of helminth parasitism, is the possibility that these parasites interfere with the immune system of the hosts (WEISS, 2002). However, little has been researched about the benefits and losses of this relationship, not only with the human host, but also with other animals, so that it is possible to understand the degree of parasitic action of the helminth throughout its evolutionary cycle.

Helminths are metazoans, many of which parasitize man and other animals (RUPPERT & BARNES, 2005). Among the groups of helminths we can highlight the phyla: Platyhelminthes, Acanthocephala, Nematoda (BRUSCA *et al.*, 2018).

The presence of helminths has been reported in tuna obtained in different locations, with Platyhelminthes species being observed in the stomach and gills by Bussieras & Aldrin (1968), Adams *et al.* (2017) and Palacios-Abella *et al.* (2017), and Nematoda in the stomach, intestine, abdominal cavity and gonads by Moravec *et al.* (2007), Cardenas *et al.* (2009) and Knoff *et al.* (2017) and Acanthocephala in the gut by Amin *et al.* (2009).

The Phylums of the Helminths

Phylum Platyhelminthes

They are organisms that can be found in different environments, being aquatic (fresh or salt water) or terrestrial, and can be free-living or parasitic (RUPPERT & BARNES, 2005). Most species are hermaphroditic, have an incomplete digestive system, have no anus, and no respiratory system. Fixation-related structures are, in most species, located at the anterior extremity, which may be folding or suction folds, depending on the group (BRUSCA *et al.*, 2018). This phylum is composed of the classes Trematoda and Cestoda, which have parasitic species of fish.

Trematoda Class

The Trematoda class gathers helminths that present a flat dorsoventral body, however, it does not present evident segmentation. Most species have thorns, and these structures help their fixation in the host's organism, and the presence of suction cups can also be observed.

According to Fonseca & Pereira (2002), some species may have male and female individuals, which is considered an exception within this group of helminths.

One of the biological characteristics that allows dissemination in the aquatic environment is the possible involvement with marine mammals, birds, fish and crustaceans, as well as the need for part of the helminth species in this group to require more than one host species to complete their cycle of life, being characterized as hetero-xenes (GONZALEZ, 2017). This cycle involves the participation of fish from the top of the food chain, birds, marine mammals and, eventually, the human as the definitive host, and the others as intermediate hosts. It should be noted that, as well as crustaceans and smaller fish, all the others could also act as an intermediate host (MARCHIORI, 2008).

Eiras *et al.* (2017), making a compilation on the main aspects related to ichthyosparasites, observed the presence of helminths in fish as of wide distribution, regardless of issues related to the climate. Species include *Clonorchis sinensis, Opistorchis felineus, Opistorchis viverrini, Heterophyes* spp., *Metagonimus* spp., *Diplostomum spathaveum, Pygidiopsis summa, Stellantchas musfalcatus, Procerovum varium, Haplorchis* spp., *Nanophyetus schickhobalowi, Cryptocotyle lingua, Gonadosdasmius* sp., *Metorchiscon junctus, Echinoschasmus perfoliatus, Echinostoma hortense, Clinostomum complanatum, Pseudamphistomum truncatum*, and *Isoparorchis hypselobagri*.

Cestoda Class

Within this class we find organisms widely known as tapeworms, helminths that present the body divided into three parts. An anterior region called scolex or scolice, which may present suction cups or folds of the integument, in addition to other fixation structures, such as hooks (RUPPERT & BARNES, 2005). Right after this region there is a constriction, called the neck, which is responsible for the production of the third part of the body, called strobilus (BRUSCA *et al.*, 2018). This strobile is segmented and each segment is called a proglotid or proglot (MARKELL, 2003).

The size of the body varies according to the species. They are organisms with an absent or incomplete digestive system (BRUSCA & BRUSCA, 2007). From a biological point of view, the cycle has the complexity of requiring more than one species to be a host, and in the marine environment, in addition to fish, it will involve the participation of crustaceans (FORTES, 2004). Adult cestodes are found in the intestinal lumen of the definitive hosts (REY, 2014), and the larvae are found in the musculature, viscera and abdominal cavity (EIRAS, 1994).

There are several studies in the literature on parasitism in fish by helminths in this group, including: *Tentacularia coryphaenae, Nyblelina* sp. and *Mixonybelinia* sp. (SÃO CLEMENTE *et al.*, 2007), *Pterobothrium crassicolle* (PORT *et al.*, 2014), and species of the genus *Diphyllobothrium* (CHAI *et al.*, 2005).

Phylum Acanthocephala

They are organisms that have retractable proboscis with hooks, followed by the neck and trunk (RUPPERT & BARNES, 2005), with the proboscis being the structure that has the greatest relevance for species identification (EIRAS, 1994).

According to Eiras (1994), there are about 400 species of Acanthocephala for fish parasites. Santos *et al.* (2008), through bibliographic reviews, registered 23 genera and 13 species of acanthocephalous parasites of 119 fish collected from freshwater, brackish and marine from Brazilian fauna.

Phylum Nematoda

This phylum comprises helminths recognized by the shape of the elongated, non-segmented, cylindrical body with tapered ends (REY, 2014). According to records, there are approximately 700 species of fish parasitic nematodes (EIRAS, 1994).

In this group, due to the extensive zoonotic potential, the Anisakidae family is the most prominent (ACOSTA & SILVA, 2015), being the main genera: *Anisakis*, *Phocanema*, *New land*, *Contracecum*, *Pseudoanisakis*, *Hysterothylacium* (OKUMURA *et al*., 1999), *Eustrongylides* (NEVES, 2009), *Capillaria*, *Angiostrongylus* and *Gnathostoma* (MASSON & PINTO, 1998).

The predicted cycle for fish parasitic nematodes involves distinct host species, being definitive hosts marine mammals or fish at the top of the food chain, and crustaceans as intermediate hosts (PEREIRA, 2000). In this cycle, the presence of paratenic or transport hosts has also been observed (GÓMEZ SÁENZ *et al*., 1999).

Due to the relevant role of helminth parasitism in fish and the need for a better understanding of the action of these parasites in humans, it is evident the need for more studies that can identify the largest number of ichthyosparasites and thus, subsidize actions aimed at human health and strategies to avoid loss of fishing resources.

Methodology

For this study, 45 specimens were analyzed, 15 of which were collected within the scope of the Skipjack tuna Project by the Laboratory of Biology of Nectar and Fishing Ecology - ECPESCA / UFF and 30 obtained in the fishing landing of Niterói by the Integrated Laboratory of Zoology - UFRJ. In both cases, collections took place on the coast of the state of Rio de Janeiro.

Helminth Collection

The collection of helminths by both ECOPESCA and the Laboratory of Immunoparasitology – UFRJ, *Campus* Macaé, followed the same protocol.

During the necropsy of the fish, an opening was made of the cavity and exposure of the organs. These were separated individually in Petri dishes, containing 0.9% sodium chloride solution. The organs were inspected and the helminths collected were washed in 0.9% NaCl solution, separated according to the inspected organ and the phylum, and packed in flasks containing AFA (Glacial Acetic Acid, 37% Formaldehyde and Ethyl Alcohol 70%).

Light Microscopy

To obtain morphological and morphometric data, the helminths were clarified in 90% phenol, mounted between slide and coverslip and observed with the aid of an Olympus CX31 microscope coupled with a clear chamber, as proposed by Mafra & Lanfredi (1998). The micrographs were performed in an Olympus BX51 optical microscope coupled to the Olympus DP-71 image capture system, at the Integrated Morphology Laboratory (NUPEM – UFRJ).

Quantitative descriptors of parasite populations

Parasitological indices, such as prevalence and average intensity, were raised according to Margolis *et al*. (1982) and Bush *et al*. (1997), being calculated:

– Prevalence = number of fish infected by a given species divided by the number of hosts examined x 100;

– Average intensity = total number of parasites of a species divided by the number of hosts infected by that species.

Results and Discussion

For the analysis, 45 specimens of Skipjack tuna were collected with average total length and standard deviation of 49, 5 ± 3.4 cm for females and 48.5 ± 5.1 cm for males, and average weight and its standard deviation of 5.3 Kg ± 98.45 g for females and 4.9 Kg ± 115 g for males.

Quantitative descriptors of parasite populations

Of the 45 specimens, 100% were parasitized by 794 helminthic specimens collected and identified according to the literature. Of the 45 Skipjack tuna, 30 were infected with nematodes, 8 with acanthocephalus and 1 with baskets. The infection sites were muscle, intestine, stomach and liver. The distribution is shown in table 1.

During the analysis of the first sample batch, when the fish was thawed, there was a change in the texture of the tissues and signs of decomposition, which may have influenced the failure to observe encapsulated helminths in the musculature, cavity and organs. To avoid discrepancy in the prevalence index, it was decided to calculate these descriptors separately, for each batch.

The parasitic prevalence of Acanthocephala was 53.3%, considering the first sample batch. While the second sample batch, which consisted of fresh fish, obtained the following prevalence data: 100% infected by Nematoda and 3.3% by Cestoda. Regarding the incidence (in number), it was observed: 14; 22.7; 1 for Acanthocephala, Nematoda and Cestoda, respectively.

Table 1. Total prevalence and body distribution of helminths

Group	Nº of fishes examined	Nº of fishes infected	Prevalence Total (%)	Number of Parasites				
				Stomach	Liver	Muscle	Peritoneum	Intestine
Frozen	15	8	53.3	–	–	–	–	8
Fresh	30	30	100	30	46	242	24	444

Morphological Aspects of Helminths Found

In this study it was found that nematodes were the most prevalent parasites. By the characteristics observed, they belong to the family Anisakidae (Fig. 1) and the data corroborate the results obtained by Cavaleiro *et al.* (2017) analyzing *K. pelamis* collected in the Madeira Archipelago. In addition, anisakids were reported by Cardoso *et al.* (2006) in fish sold in Rio de Janeiro and identified through mole-cellular biology by Kuhn *et al.* (2013) and Anshary *et al.* (2014). Freire *et al.* (2016), analyzing *K. pelamis* obtained at the Municipal Fishing Terminal of Aracaju, observed the presence of *Anisakis* sp with a prevalence of 38.4% of the specimens analyzed.

Anisakids arouse interest not only because of their role as ichthyosites with high prevalence, but also because of their role in human public health, being pointed out as the main zoonosis transmitted by fish infected by larvae of *Anisakis*, *Pseudoterranova*, *Contracaecum* (BROGLIA & KAPEL, 2011). Little is known about the consequences of this infection on fish in the out-of-confinement environment, while on humans, according to studies by Martínez *et al.* (2009) and Magalhães *et al.* (2012), cause symptoms ranging from episodes of gastrointestinal changes to allergies.

Studies carried out by Alves & Luque (2006) have shown that nematodes of the Anisakidae family, to complete the life cycle, need to infect other species, which are classified as intermediate host and paratenic of different trophic levels, until finally they infect marine mammals, which would act as the definitive host.

Reviewing ichthyomatic parasites that have zoonotic paper, Eiras *et al.* (2016) reports the existence of five human cases of fish-borne nematodes in Brazil: two confirmed reports and one probable with species of *Gnathostoma* (imported case), a case with *Anisakis* sp and a case with *Dioctophyma renale*.

According to Magalhães *et al.* (2012), the larvae ingested with the fish caught by humans may not cause symptoms or generate symptoms that resemble other pathological pictures, eventually causing allergic conditions (PURELLO–D'SAMBROSIO *et al.*, 2000), with Japan being the country that commonly presents the highest prevalence of human anischostasis (CHAI *et al.*, 2005).

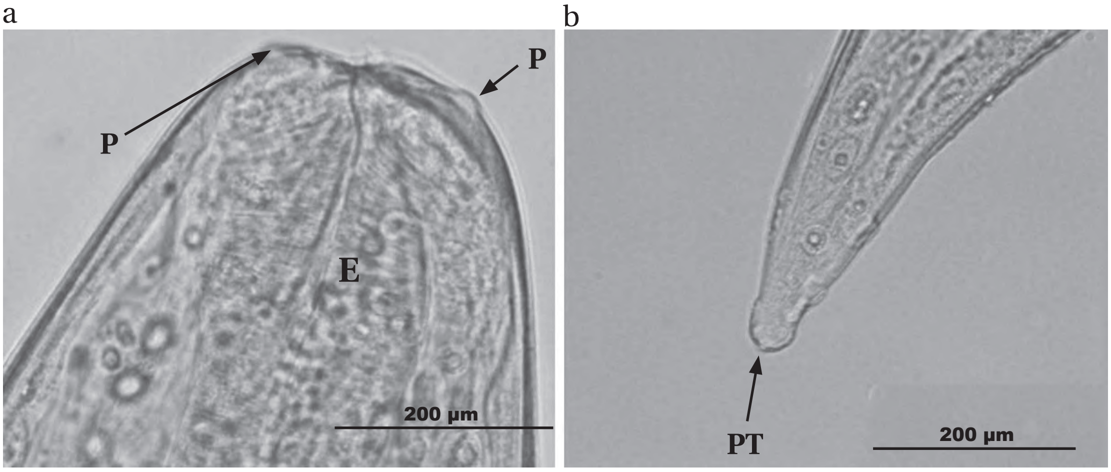


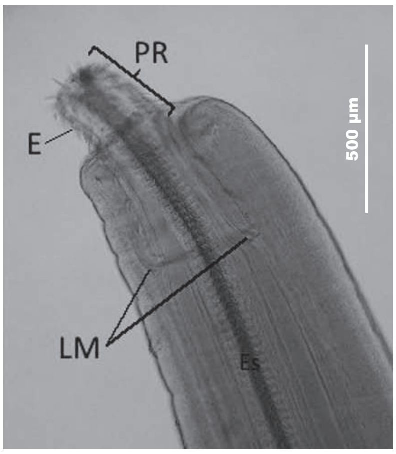
Figure 1. Light microscopy of Anisakidae found parasitizing *Katsuwonus pelamis*. (a) Anterior extremity showing the papillae (P) and the esophagus (E). (b) Detail of the posterior end showing the terminal papilla (PT). Source: Personal Collection

During the analysis, the presence of Acanthocephala (Fig. 2). Infection with Acanthocephala is quite recurrent in fish (SANTOS *et al.*, 2008), however, there are few reports in *K. pelamis*. Amin *et al.* (2009), analyzing *K. pelamis* collected on the Pacific coast, make a morphological redescription of the species *Rhadinorhynchus ornatus*, using scanning electron microscopy, and report that the length and thickness of the hooks are important criteria for defining the species. Parasitism by *R. ornatus* was also observed by Freire *et al.* (2009) in skipjack tuna specimens collected in Aracaju, with a prevalence of 92.3%.

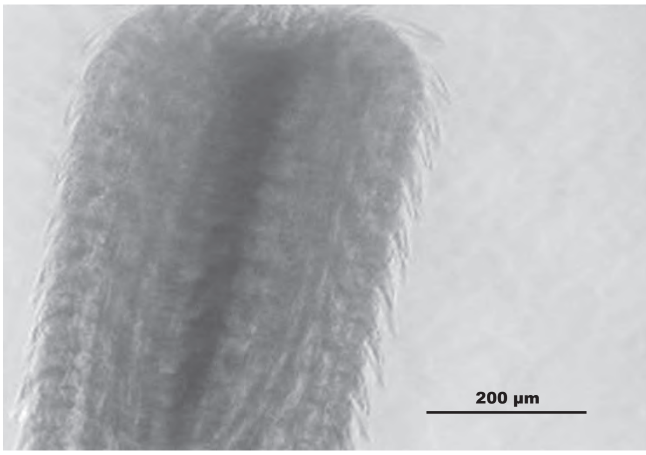
Although there are no studies associating the infection of *K. pelamis* with acanthocephalic fish health indicators, possibly due to the parasite`s adhesion profile causing injuries by penetrating the organs, it is possible that it causes damage, as observed in other species (FISCHER, 1998).

Malta *et al.* (2001) observed a 100% prevalence of acanthocephali studying parasitism in Tambaqui, causing an intense mortality rate. These losses in captivity due to parasitism were reported by Santos & Malta (2010) and Mariano & Tavares-Dias (2015), as well as the hygienic-sanitary importance, due to the disgusting aspect it causes in the fish tissue (SÃO CLEMENTE, 1995; MATOS *et al.*, 2003), which makes its commercialization impossible.

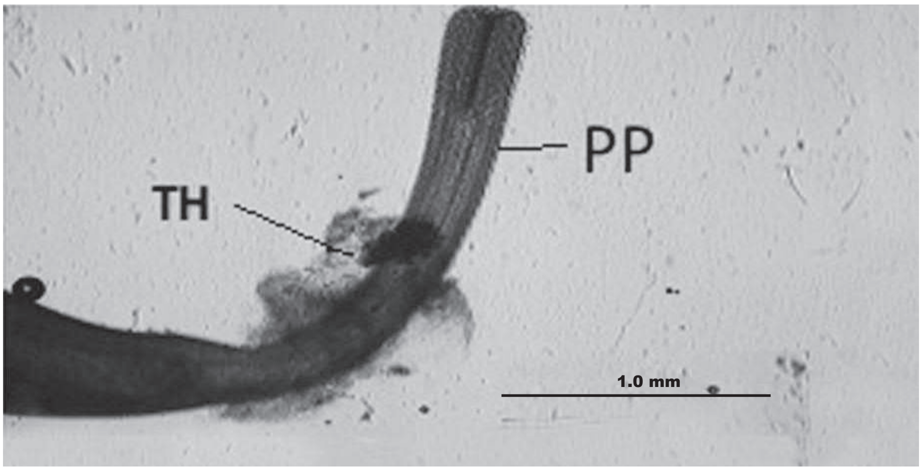
Despite the low prevalence of Cestoda (3.3%), it is important to note that similarly, there was a low prevalence of this group in the study by Freire *et al.* (2009), however, studies by Hermida *et al.* (2018) report a high prevalence of Cestoda in the larval stage, both analyzing parasitism in *K. pelamis*.



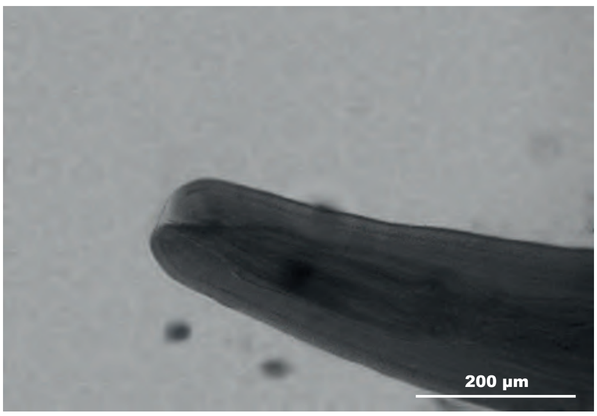
(a) Anterior end showing retracted proboscis cylindrical trunk (PR) with spine, pair of leminiscus (SCI) and esophagus (Es).



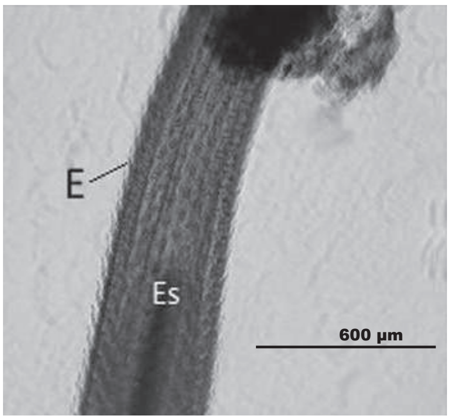
(b) Detail of the anterior end showing the proboscis spines.



(c) Projected proboscis (PP) with fragments of host tissue (TH).



(d) Detail of the cylindrical rear end.



(e) Anterior extremity showing proboscid projected with spines (E) and esophagus.

Figure 2. Light microscopy of Acanthocephala found parasitizing *Katsuwonus pelamis*. Source: Personal Collection

Although only one Cestoda was found in our analysis (Fig. 3), there are many studies addressing parasitism with baskets in fish, with a relevant number on the order Trypanorhyncha (DIAS *et al.*, 2010). São Clemente *et al.* (1995), studying pigfish, report a prevalence of about 80% of parasitism by this group. In *K. pelamis* presence of Cestoda was reported by Freire *et al.*, 2018. It should be noted that as described by Oliveira *et al.* (2009), even though they are not transmissible to man, some species of helminths end up making commercialization unfeasible due to the appearance that the muscles parasitized by helminths present.

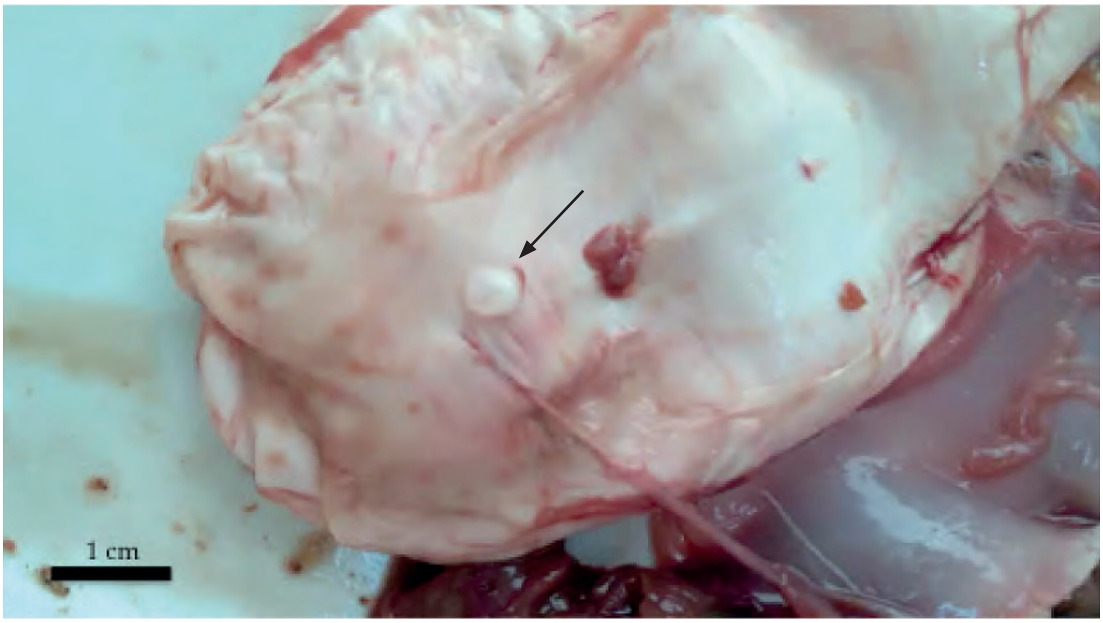


Figure 3. Cestoda perforating the stomach of *Katsuwonus pelamis*. Source: Personal Collection

Despite being prevalent in fish, the presence of *Diphyllobothrium* spp in the samples analyzed in this study. Infections by *Diphyllobothrium* spp present great relevance, being necessary great attention in the inspection of the viscera and mus-culatura of the fish, for being one of the biggest cause of zoonoses by Cestoda (JIMENEZ *et al.*, 2012). Data compiled by Oliveira *et al.* (2017) demonstrate that there were through epidemiological surveillance, 92 cases in Brazil between 2004–2008. However, it is likely that there will be a lot of underreporting in cases due to symptoms that are nonspecific.

Hermida *et al.* (2019) demonstrate that, in general, there is a seasonal difference between helminth parasitism in *K. pelamis* collected in the archipelago region of Madeira Island. The fact that there were no collections in different seasons of the year, may justify the results of the present study, since despite *K. pelamis* present high parasitic relevance, there was low diversity among the parasites found.

From the legal point of view and due to the intense parasitism, it is recommended that the inspection of the fish to be marketed takes place. According to the regulatory laws in health surveillance, it is important to observe what is covered by national legislation, namely:

a) CODEX STAN 190-1995 STANDARD FOR FROZEN FISH FILLET Fillets QUICKLY. Adopted in 1995. Revised in 2011, 2013, 2014. A sample that reveals the presence of two or more parasites per kilogram of encapsulated sample with more than 3 mm in diameter or the presence of a non-encapsulated parasite with more than 10 mm is considered defective (BRASIL, 2014).

b) DECREE No. 9.013, OF MARCH 29, 2017 - Industrial and Sanitary Inspection Regulations for Products of Animal Origin (RIISPOA):

> ***Art. 209.*** *The official controls of fish and their products, where applicable, cover, in addition to the provisions of art. 10, the following: control of parasites.*
>
> ***Art. 499.*** *In addition to the cases provided for in art. 497, fish or fish products must be considered unfit for human consumption in the form in which they are present where:*
>
> *I - are in poor condition and look repugnant; (...)*
>
> *IV - have massive muscle infection by parasites; [...]*
> (Brasil, 2017)

It's compliance with current regulatory standards is extremely necessary, since little is known about methods that can make fish infected with larvae or adult helminths without risk to the consumer, even after cooking.

Final Considerations

Due to the relevance of Skipjack tuna in the national fishing scenario and the scarce results regarding the impact of parasitism, both for animal health and for human health, it is increasingly necessary to carry out studies on the biology of parasitism as a strategy to prevent outbreaks, which, by not identifying the parasitic agent, could cause the worsening of the pathology in humans and the economic loss in the fishing market.

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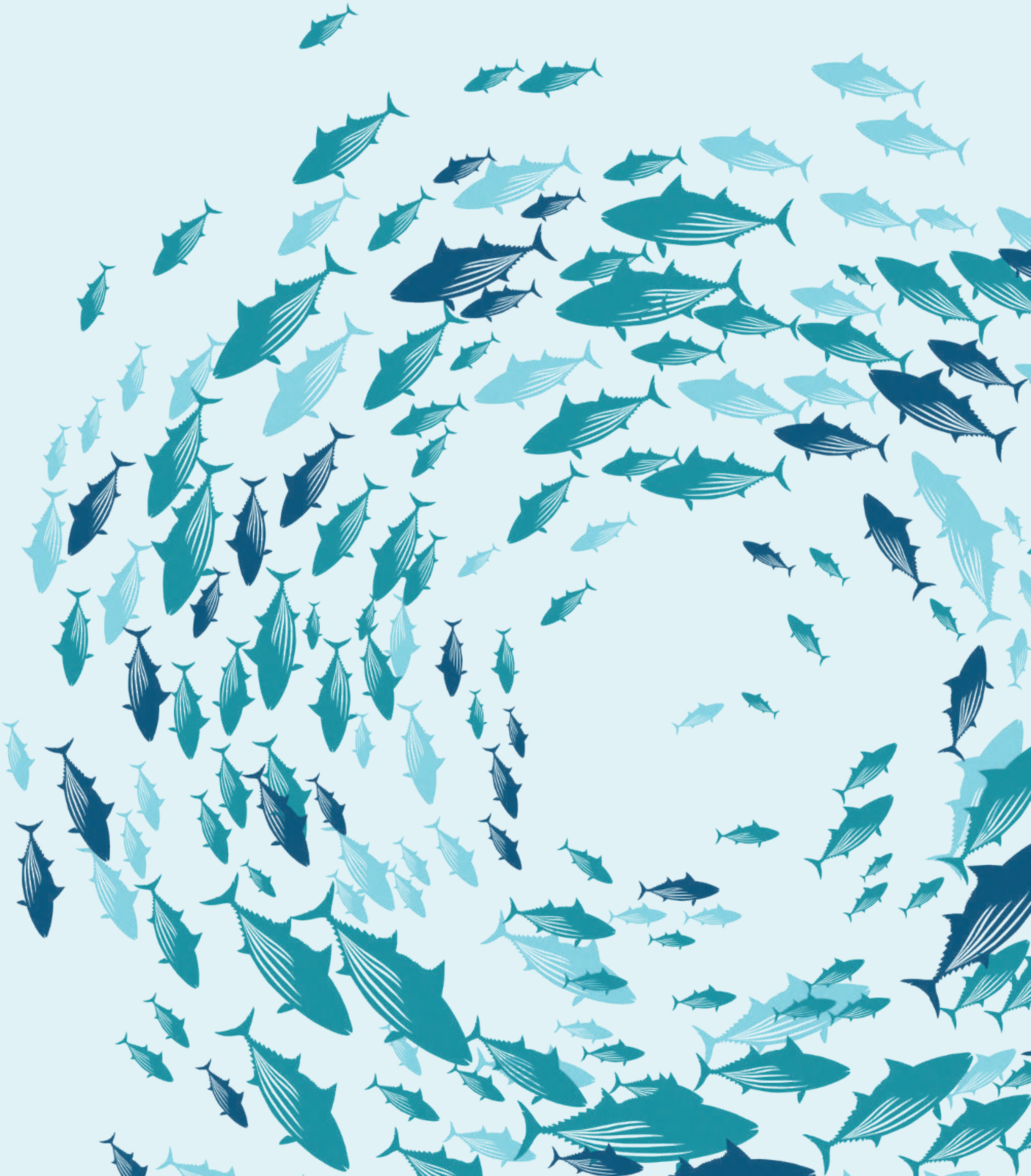
Unit III

FISHERIES AND SUSTAINABILITY



Dynamics of the pole and live bait fleet in the Southwest Atlantic

9

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Introduction

Tuna and related species are important fishing resources caught by different modalities, in particular, siege, pole and live bait and longline fisheries. The skipjack tuna (*Katsuwonus pelamis*), the yellowfin-tuna (*Thunnus albacares*), yellowfin-mandolin (*T. obesus*), and mackerel species (*Scomberomorus* spp.) are responsible for 75% of the group's worldwide catches (FAO, 2018). These species are captured by artisanal and industrial fleets from different countries, and are widely consumed and valued in the global market (ARRIZABALAGA *et al.*, 2012; GRANDE, 2014).

Due to its production volume, the skipjack tuna is the most important species of tuna in the world (FAO, 2018). Brazil stands out as the fourth largest world producer of tuna and the like, using the pole and live bait method, and the skipack tuna method (*Katsuwonus pelamis*) is the main target species (MADUREIRA *et al.*, 2016). The fishing trip of the fleet can be divided into two stages: one dedicated to the capture of live bait, and the other directed to capture the target species.

The Brazilian pole and live bait fleet is based in the states of Rio de Janeiro, Santa Catarina and Rio Grande do Sul, where the largest tuna canning factories and exporting companies in the country are installed, despite the idle capacity of Rio de Janeiro (MADUREIRA *et al.*, 2016; FIPERJ, 2019; UNIVALI / EMCT / LEMA, 2020). The strategic proximity to the migratory routes of the main stocks of tuna and the like in the South Atlantic reinforces the importance of this resource for the fishing sector in Brazil (HAZIN & TRAVASSOS, 2007).

Analysis of the dynamics of the fishing fleets are useful tools to identify the fishing strategies adopted by the vessels, allows to evaluate the use of the habitat, as well as the abundance of fishing resources (ANDRADE *et al.*, 2003; COLETTO *et al.*, 2019), in addition to providing biological and socioeconomic indicators of relevance to personal management. In this context, this chapter aims to describe the physical structure of the pole and live bait fleet and the patterns of fishing dynamics in southeastern and southern Brazil, with an emphasis on catches of skipack tuna, identifying the operating strategies of the fleet.

Methodology

The fishing data analyzed in this chapter came from the pole and live bait fleet that unloaded at the ports located in Niterói, in the state of Rio de Janeiro (Fig. 1), and in Rio Grande, Rio Grande do Sul, in two distinct periods: the first in 2012-2013, and the second in 2018-2019.

The Rio de Janeiro data set comes from the Fishing Activity Monitoring Program, conducted by the Rio de Janeiro State Fisheries Institute Foundation (FIPERJ), and the methodologies are described in Lima-Green & Moreira (2012) and FIPERJ (2013; 2018). The data set for Rio Grande do Sul comes from the onboard maps pre-filled by the masters of the vessels of Indústrias Alimentícias Leal Santos Ltda. (Grupo ACTEMSA), located in Rio Grande. These vessels were responsible for 87% and 95% of the total production unloaded in Rio Grande in 2018 and 2019, respectively. For 2012, with the exception of the total and monthly catch data by category of fish, information from Rio Grande do Sul was not available for all fishing trips in the analyzed fleet. In all, 584 fishing operations were analyzed, 365 of which were discharged in Niterói and São Gonçalo, and 219 in Rio Grande. The number of days at sea, number of days of bait, volume discharged by category of fish, and fishing areas, were obtained per trip and considered as parameters of analysis.

Figure 1. Landing of skipjack tuna in the port in Niterói (RJ). Photo: Rosane Boechat.

The current physical structure of the pole and live bait fleets in operation was assessed through the number of active vessels and their physical attributes: total length, gross tonnage, hull material, type of conservation on board, engine power (HP) and year of construction. For this assessment, only the vessels active in 2019 based in each state were considered.

Subsequent analyzes were conducted considering the port of unloading of vessels, with an emphasis on catches of skipack tuna. The evaluation of the activity of the pole and live bait fleet over time was carried out through the annual consolidation of the number of vessels that unloaded in these states and the number of registered discharges. The annual catch composition was analyzed using the representativeness of each category of fish in the total volume discharged in the year (% and ton). The contribution of the skipjack tuna to the catch was assessed quarterly in order to verify if there are variations in the pattern of the catch composition.

The number of fishing days per trip was chosen as a unit of effort for the analyzes carried out. This indicator corresponds to the number of days at sea minus the number of days spent to bait (ANDRADE *et al.*, 2007). Median, quantile and minimum and maximum values of the number of fishing days per trip employed by the vessels was evaluated annually and quarterly. For all analyzes, the quarters were considered depending on the seasons:

summer - January, February and March; autumn - April, May and June; winter - July, August and September; and spring - October, November and December.

The yield, in tons, of skipack tuna per fishing day (t/fishing days) was used as a parameter to infer about the availability of this resource for the pole and live bait fleet in time and space. Catch seasonality was assessed based on the quarterly income distribution, represented by median, quantile and minimum and maximum values. In order to describe the seasonal movement of the pole and live bait fleet in the fishing areas and the distribution of skipack tuna in the studied area, the spatial-seasonal distribution of yields was evaluated using the mapping of median yields in grid 1st latitude by 1st longitude. For trips with more than one informed capture position, the effort and total production were divided by the number of positions.

In order to verify significant differences between effort and performance throughout the seasons and between the periods analyzed, the Kruskal-Walis test was applied (level of significance $p = 0.05$).

Results

Capacity of the pole and live bait fleet

The current capacity of the pole and live bait fleet is presented in the form of an analysis of the physical structure of vessels based in the states of Rio de Janeiro and Rio Grande do Sul (Fig. 2).

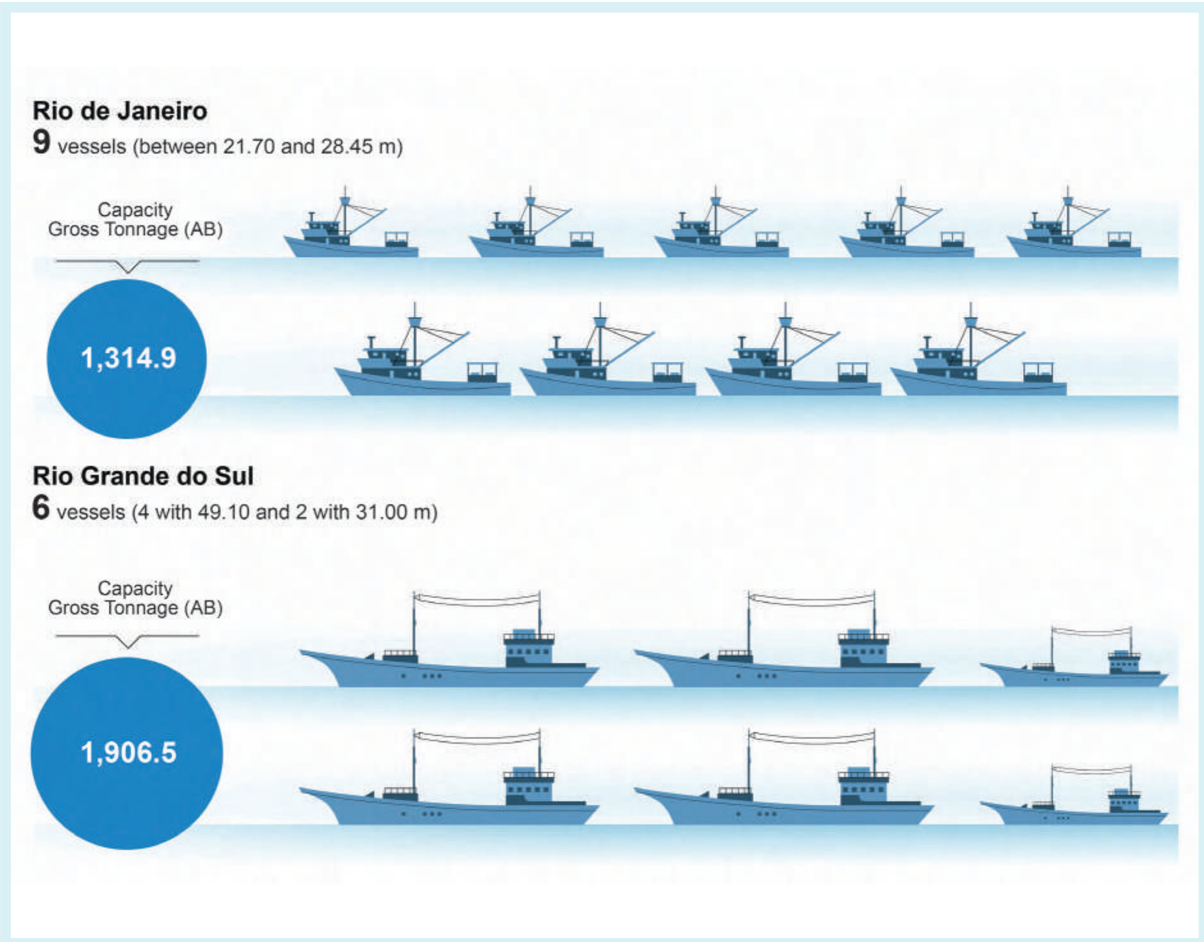

Figure 2. Comparative illustration of the physical structure (number and gross tonnage) of the vessels that make up the pole and live bait fleet in the states of Rio de Janeiro and Rio Grande do Sul.

In 2019, Rio de Janeiro's fleet (Fig. 3) was composed by nine vessels that Presented a length average of 26.3 m (DP = 2.29), with values between 21.7 and 28.5 m. Gross tonnage (AB) varied between 98 and 187 AB, with a mean of 146.1 (DP = 29.93). The engine power was reported between 350 and 580 HP, with an average of 429 HP (DP = 88.79). About 66% of vessels had steel hull and the rest of Wood All vessels tions used ice as Conservation method fished on board. The oldest vessel was built in 1969 and since 2005 there are no records of new vessels incorporated into the fleet.

Figure 3. Vessel of the Rio de Janeiro fleet. Photo: Joabe Rezende.

The Rio Grande do Sul fleet (Fig. 4) it consisted of six vessels with steel hulls, of which four had a length of 49.1 m and 381 AB, and two 31 m in length and 191.5 AB. The power of the engines was reported between 540 and 1600 HP, where two presented engines of 540 HP, two of 1300 HP and two of 1600 HP. All vessels use chilled brine as a method of preserving fish on board and were built in 1973. Although the Rio de Janeiro fleet has a larger number of active vessels, the Rio Grande do Sul fleet has a 31% higher fishing capacity, with a total of 1,314.9 AB for Rio de Janeiro and 1,906.5 for Rio Grande do Sul.

Figure 4. Vessel of the fleet of the company Leal Santos, Rio Grande do Sul. Photo: Lauro A. Saint Pastous Madureira.

Fleet activity and catch composition

The activity of the pole and live bait fleet that used the ports of Rio de Janeiro and Rio Grande do Sul is shown in table 1, based on the number of vessels and the number of unloadings recorded.

In Rio de Janeiro, 18 vessels were registered in all periods analyzed, 16 of which originated in Rio de Janeiro (n = 16) and 2 in Santa Catarina (n = 2). The fleet based in Rio de Janeiro was composed of 15 vessels in 2012.However, in 2013, 13 vessels were registered. The drop compared to 2012 was the result of a shipwreck and one that left the fishery. In 2018, 10 vessels from Rio de Janeiro were registered. The difference in relation to 2013 was due to two vessels that paralyzed the activities, one that sank, and a new one that entered. In 2019, with the shutdown of a vessel, the Rio de Janeiro fleet totaled 9 vessels. Santa Catarina vessels operated in Rio de Janeiro in 2013 (n = 2) and 2018 (n = 1).

The number of discharges at the ports of Rio de Janeiro accompanied the drop in the number of vessels between the periods analyzed. The highest amount of discharges was recorded in 2012 (n = 155) and the lowest in 2018 (n = 42) (Tab. 1). The average annual number of discharges per vessel based in Rio de Janeiro fell from 10.3 in 2012 to 4.2 in 2018, with 5 discharges per year / vessel registered in 2019. Santa Catarina vessels made 4 discharges in Rio de Janeiro in 2013 and 1 in 2018.

Table 1. Number of vessels and discharges of pole and live bait by state of origin, total production (tons) and relative participation (%) by category of fish caught by the pole and live bait fleet that discharged in the states of Rio de Janeiro * and Rio Grande do Sul in the years 2012 and 2013, 2018 and 2019.

Rio de Janeiro		**2012**		**2013**		**2018**		**2019**	
Catch composition	**Scientific name**	**Ton.**	**%**	**Ton.**	**%**	**Ton.**	**%**	**Ton.**	**%**
Skipack tuna	*Katsuwonus pelamis*	5,778.1	83.9	4,805.5	87.9	587.5	49.9	1,535.5	79.1
Albacore	*Thunnus alalunga*	450.9	6.5	438.5	8.0				
Big eye tuna	*Thunnus obesus*	265.0	3.8	106.1	1.9	73.0	6.2		
Tuna	*Thunnus* spp.	153.6	2.2	86.6	1.6	392.8	33.4	393.5	20.3
Skipack tuna	*Scombridae*	70.7	1.0	0.7	<0.01	19.0	1.6		
Yellowfin	*Thunnus albacares*	46.8	0.7	8.0	0.2	18.0	1.5		
Mackeral	*Thunnus* spp.	42.2	0.6	6.0	0.1				
Mahi Mahi	*Coryphaena hippurus*	36.9	0.5	7.7	0.1	13.5	1.1	10.0	0.5
Serra	*Sarda sarda*	28.2	0.4						
Frigate tuna	*Auxis thazard thazard*	11.4	0.2	9.2	0.2	36.1	3.1		
Jacks	*Caranx* spp.	1.2	<0.01	0.2	<0.01	27.6	2.3	1.2	0.1
King Mackerel	*Scomberomorus cavalla*	0.8	<0.01						
Little Tunny	*Euthynnus alletteratus*					9.0	0.8		
Amberjack	*Seriola* spp.					<0.01	<0.01		
Total production		6,885.8	100.0	5,468.6	100.0	1,176.5	100.0	1,940.2	100.0
Number of vessels	RJ Vessel	15		13		10		9	
	SC Vessel			2		1			
Number of discharges	RJ Vessel	155		118		42		45	
	SC Vessel			4		1			
Rio Grande do Sul		**2012**		**2013**		**2018**		**2019**	
Catch composition	**Nome científico**	**Ton.**	**%**	**Ton.**	**%**	**Ton.**	**%**	**Ton.**	**%**
Skipack tuna	*Katsuwonus pelamis*	7,983.4	94.3	6,056.6	88.4	4,510.0	95.0	3,988.5	96.7
Yellowfin slab	*Thunnus albacares*	87.9	1.0	95.9	1.4	239.0	5.0	64.0	1.6
Yellowfincha	*Thunnus alalunga*	362.5	4.3	697.6	10.2			73.0	1.8
Skipack	*Auxis thazard thazard*	30.3	0.4						
Produção total		8,464.1	100.0	6,850.1	100.0	4,749.0	100.0	4,125.0	100.0
Total production	RS Vessel	6		6		6		6	
Number of discharges	RS Vessel	33		58		68		60	

*For Rio de Janeiro, the production presented consists of monitored production.

The Rio Grande do Sul fleet was made up of 6 vessels during all periods. In 2013, 58 discharges were recorded. The peak number of discharges in Rio Grande do Sul was 68 in 2018, dropping to 60 in 2019. The average annual number of discharges per vessel, fluctuated between 9.6 in 2013, 11.3 in 2018 and 10 discharges per year/vessel in 2019, and did not vary significantly.

The composition of catches from the fleets that landed in Rio de Janeiro and Rio Grande do Sul, shown in table 1, also highlights the production values by category of fish recorded annually in both states. In the period from 2012 to 2013, for Rio de Janeiro, skipack tuna was responsible for more than 80% of the annual total of fish caught, reaching almost 90% in 2013. The yellowfin and the yellowfin-ban-dolim followed, contributing about 10% of the catches (Tab. 1). It is also noted the presence of other resources in catches, although with low representativeness, reaching, together, about 10% of the total captured in 2012. For Rio Grande do Sul, the importance of the skipjack tuna in the composition of the catches was even greater, with a share of more than 88% in the period. In 2013, the yellowfin tuna represented 10% of the catch, being the only resource with significant participation in this period.

When bringing this analysis to a more current perspective (2018 and 2019), it is possible to notice the modification of the catch composition of the Rio de Janeiro fleet, mainly motivated by the drop in the participation of skipack tuna in 2018 to 50% (Tab. 1). Tuna species, such as yellowfin tuna, yellowfin tuna and yellowfin mandolin, totaled about 40%. In 2019 skipack tuna showed a recovery, however, without reaching the levels of the previous period, above 83%. The Mahi Mahi and the jacks category were present in all the years evaluated. The composition of the catches remained practically constant for the Rio Grande do Sul fleet, with less participation of other species in the catches (Tab. 1).

The representativeness of the skipjack tuna in the total catches of the vessels is illustrated in figures 5A (Rio de Janeiro) and 5B (Rio Grande do Sul).

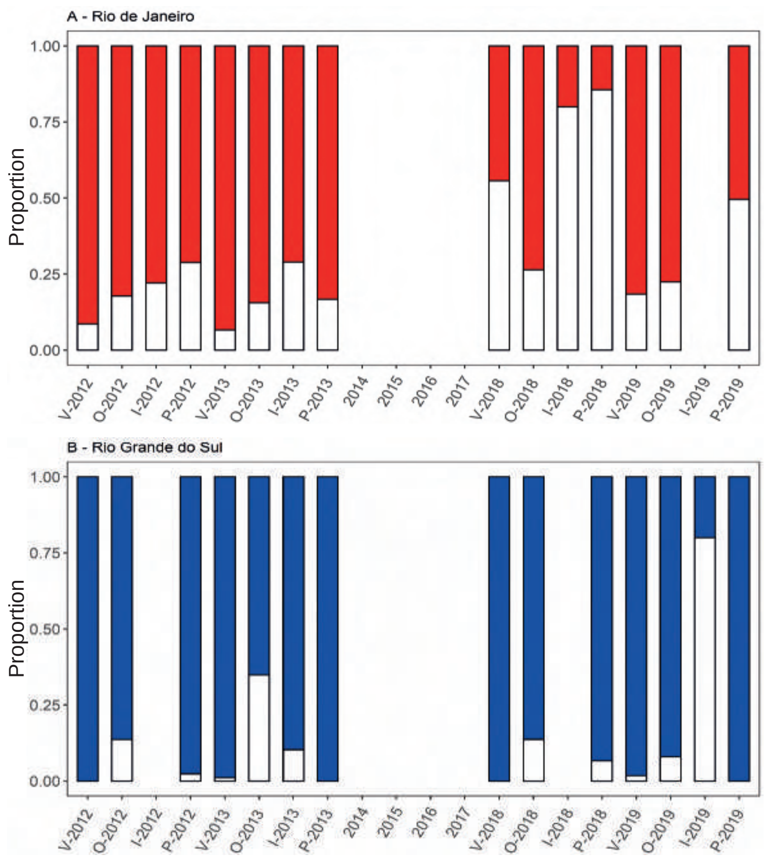

Figure 5. Quarterly proportion of skipack tuna (A - Rio de Janeiro, red bars; B - Rio Grande do Sul, blue bars) and other categories (white bars) in the total catches of the pole and live bait fleet in the years 2012, 2013, 2018 and 2019. Where V - Summer; O - Autmn; I - Winter; and P - Spring.

Discharges in Rio de Janeiro showed variations between the two periods analyzed, and, in general, their proportion decreases from summer to spring. In the summer and autumn of 2012 and 2013, the skipjack tuna contributed more than 89% of the total registered (Fig. 5A). In 2018, it had a lower participation of the entire study period, especially in winter and spring. In 2019 there was an increase in the contribution of skipack tuna in catches, demonstrating the same pattern of the 2012 and 2013 period.

The participation of the skipjack tuna in the catches of Rio Grande do Sul was regular, with proportions above 98% in the summer and spring of the four years analyzed (Fig. 5B). In the fall, the proportions of other resources increased, and in the period 2012 and 2013 were more important, reaching about 30% in 2013. In the winter of 2019, the proportion of skipjack tuna was the least expressive, and it differed from the other years analyzed.

Annual and quarterly change in fishing effort

When analyzing the annual distribution of effort (fishing days) employed by the fleet that landed in Rio de Janeiro, it is possible to identify an increase from the first period (2012 and 2013) to the second (2018 and 2019) ($\chi^2(3) = 65, 78$, $p < 0.001$). The analysis of the seasonal factor revealed lower values associated with summer and higher values with winter ($\chi^2(14) = 99.08$, $p < 0.001$) (Fig. 6A). In the first period, the highest medians for effort occurred in the winter (12 fishing days, DP = 3.60 and DP = 5.20, in 2012 and 2013, respectively), while the lowest in the summer of 2013 (7 days of fishing, DP = 3.01). In the period between 2018 and 2019, the highest median occurred in the winter of 2018 (16 fishing days, DP = 5.67), and the lowest in the summer of 2018 (9 fishing days, DP = 3.22) (Fig. 6A).

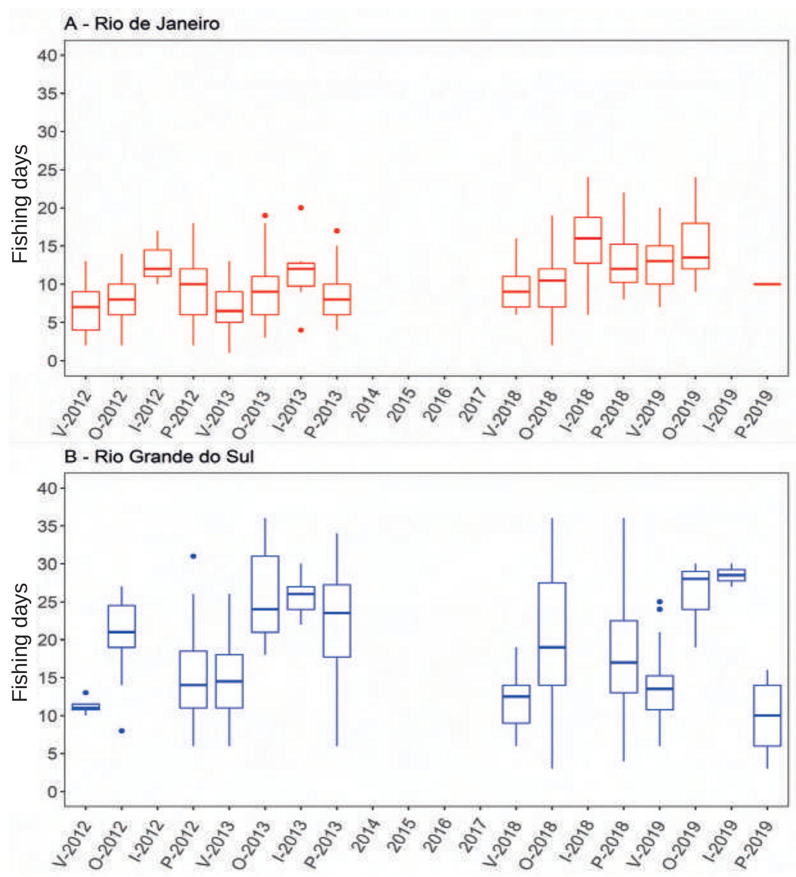

Figure 6. Quarterly effort variation (fishing days) of the pole and live bait fleet in the years 2012, 2013, 2018 and 2019, for A - Rio de Janeiro and B - Rio Grande do Sul. The horizontal line represents the median and the vertical line represents the amplitude; the points, the outliers and the boxes contain the 2nd and 3rd quantiles of the distribution. V - Summer; O - Autmn; I - Winter; and P - Spring.

The effort (fishing days) of vessels in Rio Grande do Sul showed a trend of stability between all periods analyzed, but in 2018 it was significantly lower than 2013 (χ^2 (3) = 14.41, p = 0.002). The greatest effort was employed in the autumn and winter months, as the vessels were further away from their port of origin, while the lowest values were identified in the summer and spring, for both periods analyzed (χ^2 (13) = 101, 41, p <0.001) (Fig. 6B). In the period from 2012 to 2013, the highest median occurred in the fall of 2013 (24 fishing days; DP = 5.77), while the lowest in the summer of 2012 (11 fishing days; DP = 1.25). In the most recent period (2018 and 2019), the highest median was observed in the winter of 2019, reaching 28.5 fishing days per trip (DP = 2.1). The lowest was registered in the spring of 2019, having been the lowest value of the entire period (10 fishing days; DP = 4.8) (Fig. 6B).

Spatial-seasonal distribution of the skipjack tuna yield

The highest yields for the fleet that unloaded in Rio de Janeiro were obtained in the years 2012 and 2013 (χ^2 (3) = 63.648, p <0.001). There was a trend of higher values in the summer months and lower values in the spring, during the entire period studied (χ^2 (11) = 57.174, p <0.001) (Fig. 7A). In 2012 and 2013, the highest average in 2013 (6.43 t / day of fishing, DP = 4.31), while the lowest occurred in the spring of 2013 (2.77 t/fishing day, DP = 2.62). In the period 2018-2019, the highest average yield was 3.33 t/fishing day (DP = 1.92), during the summer of 2019, and the lowest, recorded in the spring of 2018 (0.15 t/fishing day, DP = 0.06) (Fig. 7A).

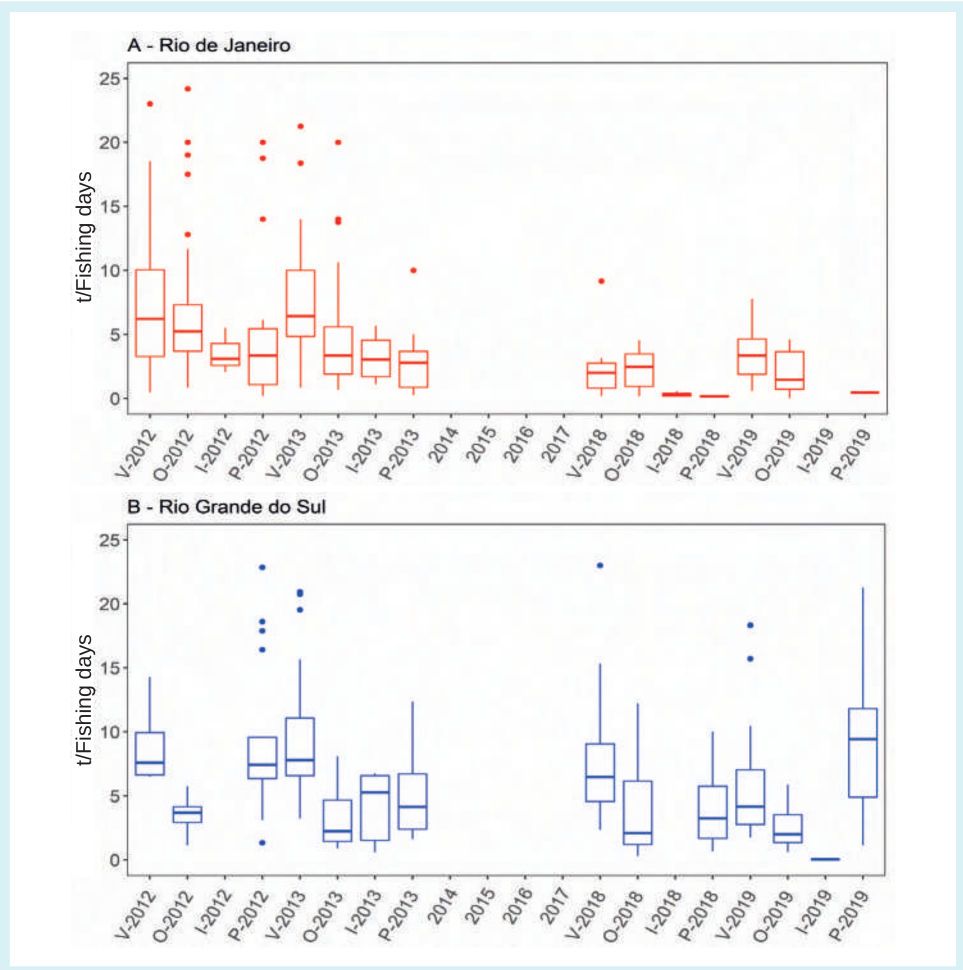

Figure 7. Quarterly variation in the income of skipjack tuna in the years 2012, 2013, 2018 and 2019, for A - Rio de Janeiro and B - Rio Grande do Sul. The horizontal line represents the median and the vertical line represents the amplitude; the points, the outliers, and the boxes contain the 2nd and 3rd quantiles of the distribution. V - Summer; O - Autmn; I - Winter; and P - Spring.

The Rio Grande do Sul fleet showed a similar pattern in all years, with no statistically significant differences (χ^2 (3) = 7.1118, p = 0.068). Seasonal analysis suggests higher values of yields in spring and summer, and lower values in autumn and winter (χ^2 (12) = 72.901, p <0.001) (Fig. 7B).

In 2012 and 2013, the median ranged from 7.78 t / day of fishing (DP = 5.26), obtained in the summer of 2013, to 2.24 t/day of fishing (DP = 2.23), in the autumn the same year. In the period from 2018 to 2019, spring 2019 drew attention, with a peak of 10.38 t/day of fishing per trip (DP = 8.43), while the lowest value was recorded in autumn 2019 (2 t/day of fishing, DP = 1.45) (Fig. 7B).

The catches of skipjack tuna made by the fleet of pole and live bait that discharged in Rio de Janeiro were distributed between the south of Espírito Santo (20º S) and the coast of Santa Catarina, in Itajaí (27º S) (Fig. 8).

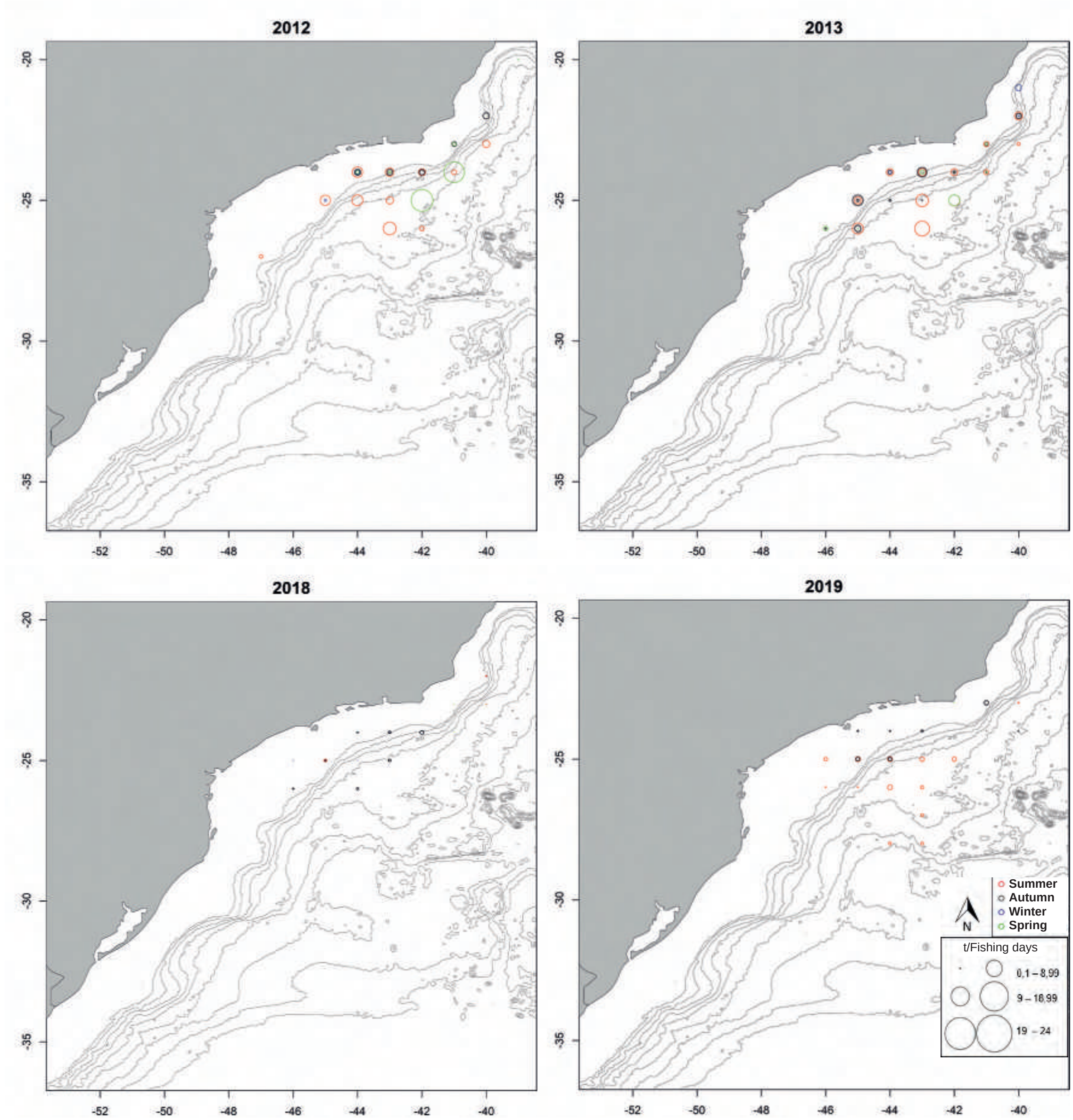

Figure 8. Spatial-seasonal distribution of yield (t / fishing days) of skipjack tuna obtained by the pole and live bait fleet that it unloaded in Rio de Janeiro in the years 2012, 2013, 2018 and 2019.

Despite this, operations were concentrated between Ilha Bela (SP) and Paranaguá (PR) (23º and 25º S) in all periods analyzed, almost always following the continental shelf break line. During the summer and fall of 2012 and 2013, moderate yields were observed south of latitude 23º S. In the summer of 2012 and 2013, the catches with the highest yields extended to areas further from the coast (close to the pre-salt platforms, 2000 m isobath). In the winter and spring of 2013, operations were distributed close to Cabo de São Tomé (21º S), but with values below 2 t/day of fishing. In 2018 there was less dispersion of operations, concentrating between 23º S and 25º S. In the summer of 2019 the vessels moved to latitude 27º S, with yields below 3 t/day of fishing, confirming a pattern observed in every year, acting further south this season.

The spatial-temporal distribution of the skipack tuna fishery carried out by the Rio Grande (RS) fleet is shown in figure 9.

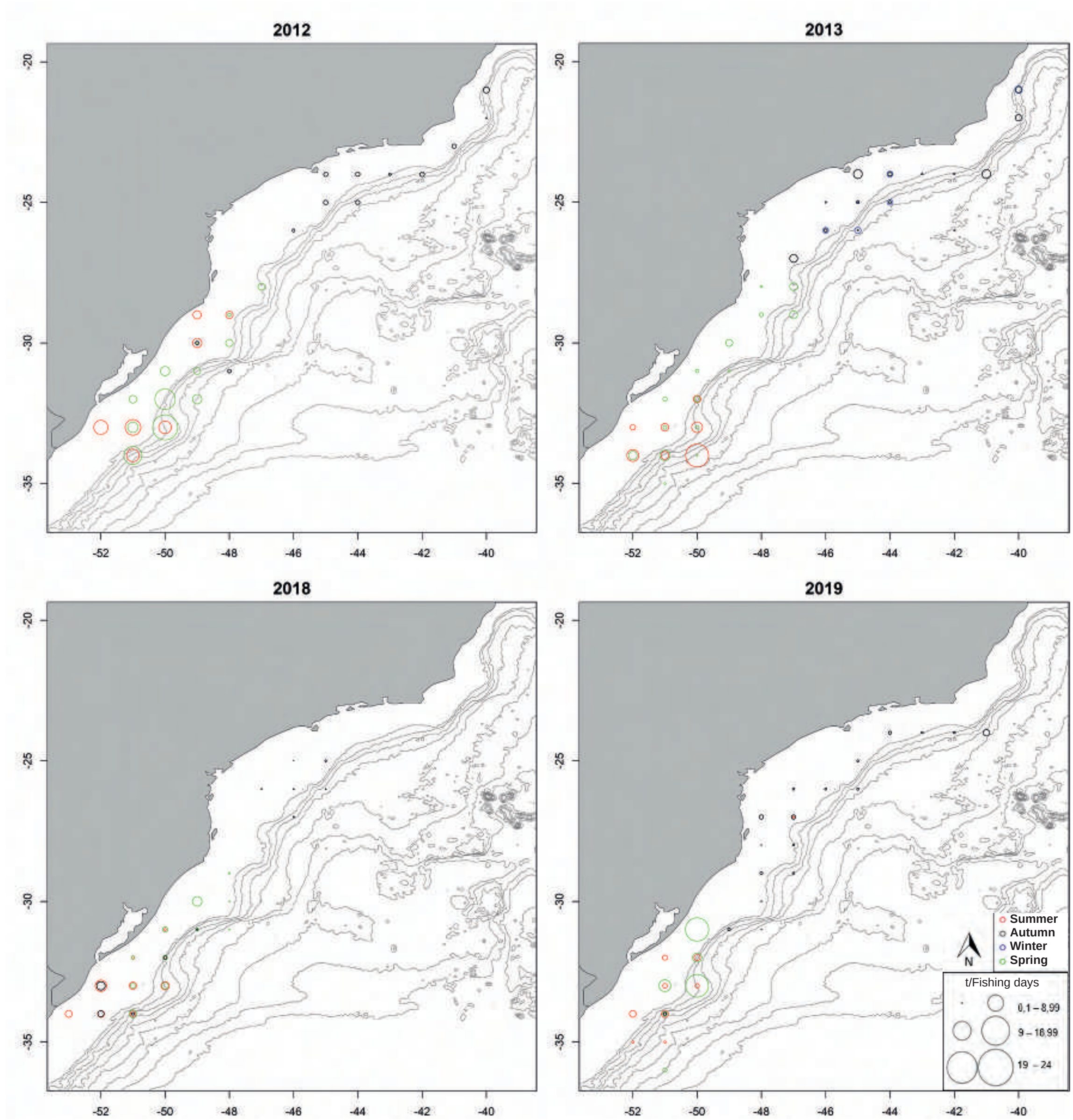

Figure 9. Spatial-temporal distribution of the yield (t/fishing days) of obtained by the skipjack tuna and live bait fleet that it unloaded in Rio Grande do Sul in the years 2012, 2013, 2018 and 2019.

In general, the vessels operated along the entire south and southeast coast, from the border with Uruguay to the north of Rio de Janeiro, with notable inter-annual and seasonal variations. With the beginning of the skipack tuna crop in southern Brazil in the spring, the vessels gradually moved south and concentrated in these areas until the summer. The highest yields (> 9 t/day of fishing) were recorded in these quarters and areas (35º S - 30º S). In the fall and winter of 2012 and 2013, operations were distributed to the north and reached Cabo de São Tomé (21º S), where they presented lower yields per day of fishing. The association of operations with the continental shelf breaking regions, especially close to the coast of Rio de Janeiro and the extreme south of Brazil, was observed. On the coast of São Paulo, in Ilha Bela, fishing seems to be associated with the internal and intermediate platform during the autumn.

In 2018, the operating area of this fleet was restricted to the south of Cabo de Santa Marta Grande (> 28º S), with the highest yields maintained in the spring and summer. Unlike other years, there were catches during autumn in the extreme south. In the fall of 2019, the vessels operated until the east of Cabo Frio (RJ), but without confirming the same pattern of performance in the vicinity of Cabo de São Tomé (21º S), as observed in 2012 and 2013 (Fig. 9).

Discussion

The fishing strategies are influenced by the availability of resources and climatic and meteorological conditions in the fishing areas, by market opportunities and by regulations in its most diverse instances, such as, for example, fisheries management, market and labor (SMITH, 2012). The pole and live bait fleet in Brazilian Currently consists of approximately 40 vessels, located in the states of Rio de Janeiro, Santa Catarina and Rio Grande do Sul, which operate in the ports of Niterói, Itajaí / Navegantes and Rio Grande, respectively (MADUREIRA *et al.*, 2016). The average length and gross tonnage of vessels in the Rio de Janeiro fleet has increased since the 2000s, when they had an average length of 24.6 m, and just over 100 GRT (MENEZES *et al.*, 2010). The Rio Grande do Sul fleet, on the other hand, had a capacity much higher than that of Rio de Janeiro, with vessels about 17 m bigger, almost twice as much gross tonnage and engine power reaching 1600 HP. In this way, the Rio Grande do Sul fleet demonstrates greater fishing power to operate along the area of the skipack tuna

Both states evaluated showed a decrease in fisheries production in the period of 2018 and 2019 in relation to 2012 and 2013, but the magnitude was more important for Rio de Janeiro. The fall in fishing production was accompanied by a decrease in the activity of the tuna fleet in Rio de Janeiro, especially in the 40% reduction in the number of active vessels (from 15 to 9), and in the average number of discharges per vessel (from 11 for 5 discharges/ vessel/year).

Official data available for the years studied corroborate the decline in activity observed for 2018. According to ICCAT (2019), the year of greatest productivity for the Brazilian pole and live bait fleet was 2013, followed by 2012. 2018 was the year with the worst result, with only 14,886 t registered of the resource. Rio de Janeiro and Rio Grande do Sul together represented 32.5% of the Brazilian production of skipack tuna in 2012, 34% in 2013 and 36.4% in 2018. Available data indicate that the fleet that unloaded in Santa Catarina made 256 trips in 2012 and was responsible for 60% of the capture of skipack tuna recorded for Brazil in 2012, while in 2018 it dropped to 95 discharges, totaling 37% of skipack tuna national (UNIVALI / EMCT/LEMA, 2020).

Differences in the composition of the catches are expected due to the area of operation of the fleet and the strategies adopted by the vessels in Rio de Janeiro and Rio Grande do Sul. The interannual variability of fishing strategies was verified for Rio de Janeiro through the proportion of skipack tuna in total catches in 2018, which reached 50%, the lowest value ever recorded in the literature. Species of the genus *Thunnus* spp. sustained the income of the fleet in this period, and the skipjack tuna, sardines and the Mahi Mahi occurred frequently over the years analyzed, maintaining the pattern reported for the 2000s (MENEZES *et al.*, 2010).

For the Rio Grande do Sul fleet, catches of skipack tuna represented 100% of the total annual catch, especially in the spring and summer months in all the studied years, when the fleet operated in southern Brazil, and only the species of the genus *Thunnus* were recorded in discharges in Rio Grande. The proportion of skipack tuna in the total catches of the fleet that operated in Rio de Janeiro is below the national average, estimated at 90%, while that of Rio Grande do Sul was above (ICCAT, 2019). Andrade *et al.* (2005) reported a greater proportion of skipack tuna in the southern fishing areas, and in the northern areas, the schools are composed of different species, and corroborates the pattern found in the present study.

The analysis of fishing effort parameters and skipack tuna performance highlighted the different fishing strategies adopted by each fleet analyzed, and also demonstrated changes in catch patterns in the period from 2018 to 2019, compared to 2012 and 2013, and previous years (MENESES DE LIMA *et al.*, 2000, ANDRADE, 2008; COLETTO *et al.*, 2019). For Rio de Janeiro, the annual factor was significant in explaining the increase in of the number of fishing days and decrease in skipack tuna yields between 2012–2013, and 2018–2019. These yields were also influenced by the seasonal factor, with the highest values concentrated in the summer and autumn months in both periods, corroborating the results of Meneses de Lima *et al.* (2010) for the year 2007. The spatial aspect of the yield did not show great variations and indicates the concentration of the Rio de Janeiro fleet predominantly in the area between 25º S and 23º S throughout the year. The movement above Cabo Frio (> 23º S) was observed in autumn in 2012 and throughout 2013, however, less frequently. In 2018 and 2019, the vessels restricted the area of operation and concentrated in latitudes above 23º S.

In turn, the Rio Grande do Sul fleet demonstrated a strong spatial-temporal pattern in effort per trip and in the income of skipack tuna in the years studied. In the spring, the harvest begins in the south of Brazil, with the concentration of operations in the areas further south until the summer (> 28º S). In this period, shorter trips and consequently less effort, contributed to the increase in income, justified by the time of greater abundance of the skipjack tuna in these areas (ANDRADE, 2008, COLETTO *et al.*, 2019). During the autumn, the vessels operated at latitudes below 28º S. In this context, the lower yields are also associated with the gradual removal of the vessels from their port of discharge, following the migration of the skipjack tuna (CASTELLO & HABIAGA, 1989). In 2018, the Rio Grande do Sul fleet changed its operating pattern with the decrease in the latitudinal range of operation, but maintained its operating levels. Apparently, it proved to be a successful strategic change, unlike what appened for Rio de Janeiro, which remained in lower latitudes and presented low yields.

The aggregating structures of shoals along the coast of Rio de Janeiro can also explain the results found on the dynamic patterns of performance of the pole and live bait fleet and the availability of skipack tuna during the operations of vessels in latitudes below 25º S and also external to the slope. There are several theories about the aggregating effect of buoys, floating objects and oil platforms on tuna, such as the skipjack tuna (FAO, 2017). One theory concerns the dynamics of the food chain that forms around these devices, another proposes that they attract schools that seek areas with a higher concentration of nutrients, however, the areas are oligotrophic. In addition, it is assumed that these devices attract fish by the contrast of light or shadow generated in these structures, causing the fish to remain under them for a longer time. Although no theory is conclusive, it is believed that tuna are attracted for different reasons to areas close to the devices (FAO, 2017). The presence of a large number of oil platforms on the coast of Rio de Janeiro therefore encourages the maintenance of the fishing strategy directed at these aggregation areas throughout the year by the Rio de Janeiro fleet (MENESES DE LIMA *et al.*, 2000; JABLONSKI, 2008). Standard is traditional and was accompanied by Jablonski (2008), who recorded an intense activity of the pole and live bait fleet on schools of great density close to platforms in the Campos Basin and the Santos Basin.

The composition of the catches, the type of processing and the place where the products are unloaded are defined by the fishing strategies of the vessels and determinants for the viability of coastal communities and fisheries, by influencing the revenues from operations (ASHE *et al.*, 2015). In this sense, we can relate the conservation methods on board the vessels and the regional market demand as factors that may also have influenced the differences in the use of fauna accompanying the skipjack tuna among the fleets. The strategy of restricted use of skipack tuna was adopted by the Rio Grande do Sul fleet that uses brine as a method of conservation on board, and is owned by a canning industry. For this reason, it is assumed that there would be no advantage in using the fish without entering the company`s production line, since the production is directed exclusively to the industry.

As for the vessels in Rio de Janeiro, the strategy of using the accompanying fauna can be defined as mixed, since it supplies the canning industries and also the fresh fish market (FIPERJ, unpublished data). This strategy can only be adopted once they use ice as a method of conservation on board, and if on the one hand it represents a disadvantage in terms of autonomy or quality of the fish, the advantage is flow to the fresh fish market in the metropolitan region of Rio de Janeiro, one of the main regions in terms of consumption in Brazil (INFOPESCA, 2010). Thus, it is suggested that the local market demand for fresh fish for fish susceptible to capture by the pole and live bait fleet and the availability of these resources in the fishing areas of this fleet, guarantees extra revenue for vessels, and represents an advantage for the adoption of a strategy of full use of other species of fauna accompanying the skipjack tuna.

The operating standards of the Rio de Janeiro and Rio Grande do Sul fleets went from their traditionality to an atypical standard in 2018, and to a lesser extent in 2019. Unfortunately, the data presented does not allow to clarify the determining factors for this change. Changes in eating behavior can help explain the lower yields of skipack tuna in this period (Andrade, 1999). On the other hand, it cannot be ruled out that the tuna fleet`s operations were affected by the low availability of live bait. This statement makes sense by taking into account the high level of dependence on the pole and live bait fleet by the sardine (SCHWINGEL *et al.*, 1999), and the influence of El Niño, which causes heating in the water in the south and southeast, causing dispersion of this species (SCHMIDT *et al.*, 2019), with catches declining until 2018 (FIPERJ, 2018, 2019; UNIVALI / EMCT / LEMA, 2020).

However, considering especially the composition of the catches of the Rio de Janeiro fleet and the continued good yields of the RS fleet in restricted areas in southern Brazil in 2018, it is suggested that the live bait factor was not the only one for the change fleet dynamics. The oceanographic dynamics in the skipjack tuna distribution area explored in more detail in Chapter 2 helps to connect the results presented here with the oceanographic standards for the period 2018-2019.

Final considerations

The permissioned fleet for pole and bait fishing in the southeast and south is composed of vessels that operate on the skipjack tuna stock using different strategies, related to the port of origin and discharge of production, physical characteristics of the vessels, composition catches discharged, effort distribution on fishing days for trips and movement between fishing areas.

The fleet based in Rio Grande do Sul consists of six large vessels, one of the largest in Brazil operating in the pole and live bait modality. The self-nomination revealed in fish storage and conservation capacity allowed the fleet to explore the entire southeastern and southern coast in search of the best skipack tuna yields. The climatological and oceanographic characteristics of the coast adjacent to Rio Grande do Sul influence the trigger for the migration of the target resource of this study, which becomes unavailable in these areas in well-marked seasonal patterns under normal conditions, determining the movement of vessels between areas fishing. In atypical situations, as observed in 2018, the fleet demonstrates versatility to operate in the areas of concentration of the skipjack tuna, revealing a specialist profile in the resource. As demonstrated in Chapter 2, the use of cutting-edge technology (called Operational Oceanography) to read the marine environment in search of areas more conducive to catches, through partnerships with universities, has allowed the improvement of fishing strategies with increased capture efficiency, reduced operating costs and greater preparedness to deal with the need to change traditional fishing dynamics.

The fishing pole and live bait appeared in Rio de Janeiro and in 2019 the state had nine vessels prepared to act, according to its installed technology, in search of the skipjack tuna available in fishing areas privileged in nutrients due to the resurgence of Cabo Frio, in artificial aggregators, such as oil platforms, and close to the port of origin. Under normal conditions, with flow for the industry and with oceanographic characteristics, these factors allow shorter trips and less operational cost, guaranteeing the maintenance of the fish flow to meet the demand of the consumer market. Under atypical conditions, as verified in 2018, especially the larger vessels managed to remain in activity, see the departure of four vessels in relation to the year 2012. The versatility of the Rio de Janeiro fleet is in the privilege of being able to act on resources other than the skipjack one to maintain the generation of alternative revenues in the face of the unavailability of technological resources and other risk management tools. On the other hand, the main disadvantage is the distance between the port of origin and the canning park, creating instability for the productive sector.

The present work evaluated the capture segment of the skipack tuna production chain and concluded that each of the fleets analyzed responded to the drop in the availability of skipack tuna in latitudes above 28º S in its way in 2018. Probably the reflexes of the strong El Niño event that occurred in the 2015-2016 period influenced the observed patterns and the result should be interpreted as an alert for all players in the fishing sector. In view of the uncertainties and difficulties in forecasting catches and the consequent supply of raw materials to the market, an understanding of the factors that interfere in the dynamics of the catching sector should be sought using long-term monitoring of economic, social, biological and environmental factors, to manage in advance. The integration of the results presented in this book illustrates the future that must be pursued, by correlating the different aspects that involve the skipjack tuna productive chain. It is believed that only in this way it is possible to evaluate the population status in the southwest Atlantic and the prospects for the development of the productive chain in Brazil.

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Stock assessment of skipack Tuna in the Southwest Atlantic

10

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Introduction

For the vast majority of world fisheries stocks, there are no time-series series of capture, effort, lengths and ages that, combined with data independent of fishing, allow the adjustment of population dynamics models (COSTELLO *et al.*, 2012). Adjusting these types of models makes it possible to assess the state of exploitation of stocks, which, in turn, is a fundamental step to guide fisheries management. However, data limitation should not be used as an excuse, as there are currently several valuation models for stocks with limited data availability (DOWLING *et al.*, 2014).

For skipack tuna *Katsuwonus pelamis* (Linnaeus, 1758) of the West Atlantic Ocean there is a certain limitation in the data available and possible to be used in inventory assessment models. For example, the use of time series of capture per unit of effort (CPUE) as representative of changes in abundance may be questionable due to the phenomenon known as hyperstability (HARLEY *et al.*, 2001). This phenomenon occurs mainly when fishing is carried out on concentrations of individuals, which keeps the CPUE values high, even when the general stock abundance is decreasing. Almost all catches of skipack tuna in the western Atlantic Ocean are made over large concentrations of individuals (shoals), using fishing gear such as pole and live bait, hand line and enclosure (GARBIN & CASTELLO, 2014; SOARES *et al.*, 2019). As a result, the monitoring of CPUE series may not represent the real trend of abundance.

The International Commission for the Conservation of Tunas and the Like (ICCAT, 2020), for management purposes, uses the premise that the skipjack tuna caught throughout the West Atlantic comprises a single stock, which extends from the waters of the east coast of the USA (North Atlantic) to the south of Brazil (South Atlantic). However, marking and recapture studies demonstrate that the movement of individuals between the Northern and Southern hemispheres is limited, with an average distance of less than 500 miles between the marking and recapture positions, and the recovery of individuals over distances greater than 1500 miles (1% of recaptures) is very rare (GAERTNER, 2014). Due to these limited movements, the authors concluded that there is a very low probability of mixing between the skipjack tuna distributed in the North Atlantic with that of the South Atlantic, and doubts still persist regarding the population structure of the species across the Western Atlantic. Considering that the majority of catches of skipjack tuna in the Western Atlantic[1] occurs in the southern region of this ocean, carried out mainly by pole and live bait fleets based in the states of Rio de Janeiro, Santa Catarina and Rio Grande do Sul (GARBIN & CASTELLO, 2014; SOARES *et al.*, 2019), in this chapter two stock structuring scenarios were designed for evaluate its state of exploitation: 1) a single stock throughout the Western Atlantic, and 2) a stock in the Southwest Atlantic.

[1] Approximately 90% (ICCAT, 2020).

The time series of total catches landed (ICCAT, 2018) can be considered as the most accurate information on the quantities of skipack tuna removed from the Southwest Atlantic stock over time, since: 1) the production of the western stock it is predominantly Brazilian; 2) historical landings were recorded and the current ones are mostly concentrated in three states in Brazil (RJ, SC and RS); and 3) all captured individuals are landed, that is, there is no rejection on board. Landings of skipack tuna landings from catches in the West Atlantic are available for the period from 1952 to 2018, and for the Southwest Atlantic for the period between 1979 and 2018 (ICCAT, 2020).

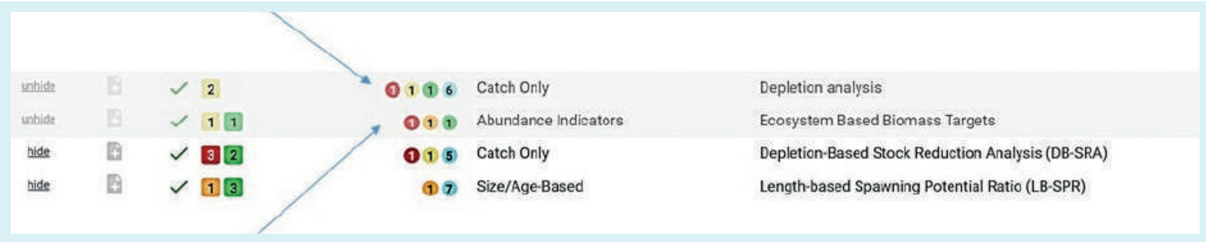
The state of exploitation of the stock (current level of depletion) is an important entry for several evaluation models, as it informs the relative change of a parameter that expresses the current quantity of the stock in relation to a virginal situation, or without fishing. Stock depletion can be estimated, for example, by comparing the current spawning biomass or spawning potential in relation to a biomass or virginal spawning potential, without fishing (THORSON *et al.*, 2012). Recent methods, based on length compositions, allow estimating the current spawning potential from compositions representative of the length structure of the individuals in the stock and life history parameters (HORDYK *et al.*, 2015).

In this sense, the skipjack tuna life story presents a considerable variability between studies and areas of distribution (JUAN-JORDÃ *et al.*, 2013). For the West Atlantic Ocean, there are several technical-scientific studies on the parameters of the population dynamics of skipack tuna. These studies estimated growth-cement parameters (VILELLA & CASTELLO, 1991; GARBIN & CASTELLO, 2014; SOARES *et al.*, 2019; ANDRADE *et al.*, 2004), length of first maturation (CAYRÉ & FARRUGIO, 1986; VILELLA & CASTELLO, 1991) and natural mortality (GARBIN & CASTELLO, 2014). In order to estimate a sustainable catch level for the skipack tuna stock in the West and Southwest Atlantic, we applied a decision support system in fisheries management (FishPath – DOWLING *et al.*, 2016) to choose the most suitable models to be applied to the stock, considering the availability of the data. At first, the current level of stock depletion was estimated with a spawning potential model (*Spawning Potential Ratio* – SPR), based on the length composition and life history information (HORDYK *et al.*, 2015). This estimate was combined with a series of capture data to reconstruct the stock's biomass history and estimate a total allowed capture value through a stock reduction analysis based on the current level of depletion (DICK & MACCALL, 2011).

Materials and methods

The models used to assess the Atlantic Southwestern skipjack tuna stock were selected with a decision support system, FishPath (DOWLING *et al.*, 2016), which considers 60 options of assessment models and uses criteria, via the decision tree, to select the methods that can be applied in view of the availability of data on the stock.

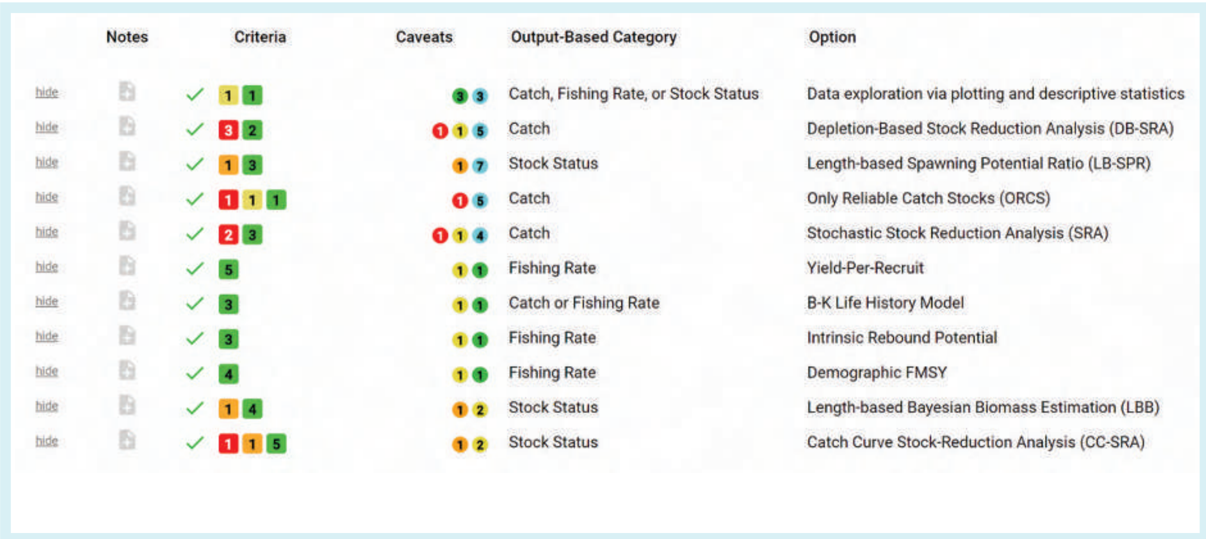
The selection of the models was carried out by excluding those that could not be applied, by several criteria, as in the example below (Fig. 1), where the exclusion of two models is demonstrated, *Depletion analysis and Ecosystem Based Biomass Targets*, because they are applied to fishing resources with specific characteristics, not found in the case of skipjack tuna.



	Notes	Criteria	Caveats	Output-Based Category	Option
unhide		✓ 2	1 1 1 6	Catch Only	Depletion analysis
unhide		✓ 1 1	1 1 1	Abundance Indicators	Ecosystem Based Biomass Targets
hide		✓ 3 2	1 1 5	Catch Only	Depletion-Based Stock Reduction Analysis (DB-SRA)
hide		✓ 1 3	1 7	Size/Age-Based	Length-based Spawning Potential Ratio (LB-SPR)

Figure 1. Example of the model selection step, showing two of the models excluded from the list of options. The first was disregarded because it is a model used for species with population dynamics like "boom and boost", for example, small pelagics. The second was disregarded because it is a model used for coral reef species, with information on relative abundances in trophic plots.

After excluding the models due to the lack of necessary data or that could not be applied due to their nature, the system selected 11 types of models from a total of 60 options (Fig. 2).



	Notes	Criteria	Caveats	Output-Based Category	Option
hide		✓ 1 1	3 3	Catch, Fishing Rate, or Stock Status	Data exploration via plotting and descriptive statistics
hide		✓ 3 2	1 1 5	Catch	Depletion-Based Stock Reduction Analysis (DB-SRA)
hide		✓ 1 3	1 7	Stock Status	Length-based Spawning Potential Ratio (LB-SPR)
hide		✓ 1 1 1	1 5	Catch	Only Reliable Catch Stocks (ORCS)
hide		✓ 2 3	1 1 4	Catch	Stochastic Stock Reduction Analysis (SRA)
hide		✓ 5	1 1	Fishing Rate	Yield-Per-Recruit
hide		✓ 3	1 1	Catch or Fishing Rate	B-K Life History Model
hide		✓ 3	1 1	Fishing Rate	Intrinsic Rebound Potential
hide		✓ 4	1 1	Fishing Rate	Demographic FMSY
hide		✓ 1 4	1 2	Stock Status	Length-based Bayesian Biomass Estimation (LBB)
hide		✓ 1 1 5	1 2	Stock Status	Catch Curve Stock-Reduction Analysis (CC-SRA)

Figure 2. List with the 11 options of inventory evaluation categories available to be applied to skipjack tuna stock.

In view of the objective of this work of estimating an acceptable total capture value for the two stock scenarios and the list of options available according to the decision support system, two models were selected to be used in a complementary way, they are: 1) *Length-based Spawning Potential Ratio* (LBSPR) (HORDYK *et al.*, 2015) and 2) *Depletion-based Stock Reduction Analysis* (DBSRA) (DICK & MACCALL, 2011).

The model Length-based Spawning Potential Ratio (LBSPR) was used to estimate the current fraction of the spawning potential, which, in turn, was considered as a proxy current stock depletion level (THORSON *et al.*, 2012). The current level of stock depletion was used as input for the model *Depletion-based Stock Reduction Analysis* (DBSRA), which made it possible to reconstruct the biomass history and estimate a value of total allowed catch (TAC) for the two inventory scenarios.

The LBSPR method compares a modeled length composition of a stock without fishing mortality (virginal condition) with the current length composition observed in the catches. This method assumes a condition of stock balance (all biomass lost by stock due to natural and fishing mortality is recovered by recruitment in the following year) and the following premises: (i) the von Bertalanffy equation adequately describes growth; (ii) a single growth curve can be used for both sexes with the same probability of capture; (iii) growth rates remain constant between cohorts within a stock;

(iv) selectivity is asymptotic; (v) the length at each age is normally distributed; (vi) recruitment remains constant over time; and (vii) natural mortality remains constant in adult age groups (HORDYK *et al.*, 2015).

The spawning potential fraction (SPR) for the exploited population is a function of the ratio between fishing mortality and natural mortality (F/M), selectivity and the two life history invariant M / k and L_{50} / L_{∞}, where: k is the growth coefficient of von Bertalanffy, L_{50} is the size of maturity and L_{∞} is the asymptotic size. The composition of the virginal length can be obtained through the growth parameters of von Bertalanffy (L_{∞} e k), natural mortality (M) and the furcal length of 50% and 95% of maturity (CF_{50} and CF_{95}).

There are several estimates of life history parameters for the species in the West Atlantic (Tab. 1). To calculate the SPR we consider several combinations between different life history estimates to include uncertainties. The LBSPR method is very sensitive to the natural mortality rate (M), the individual growth rate of von Bertalanffy (k), and the invariant life history M/k (HORDYK *et al.*, 2014). M/k values above 4.5 were excluded from the analysis due to the lack of observation of close values in a meta-analysis work with 123 species (PRINCE *et al.*, 2014).

Table 1. Life history parameters considered for the estimation of the fraction of the reproductive potential of *Katsuwonus pelamis* in the Southwest Atlantic Ocean.

CF_{∞}	*k*	*M*	*M/k*	CF_{50}	CF_{95}	*Growth source*	*M source*
92.50	0.16	0.98	6.10	46.50	52	Garbin & Castello (2014)	ICCAT (2013)
92.50	0.16	0.8	5.00	46.50	52	Garbin & Castello (2014)	ICCAT (2014)
92.50	0.16	0.72	4.50	46.50	52	Garbin & Castello (2014)	ICCAT (2014)
92.50	0.16	0.63	3.90	46.50	52	Garbin & Castello (2014)	Garbin & Castello (2014)
87.12	0.22	0.98	4.50	46.50	52	Vilella & Castello (1991)	ICCAT (2013)
87.12	0.22	0.80	3.60	46.50	52	Vilella & Castello (1991)	ICCAT (2014)
87.12	0.22	0.72	3.30	46.50	52	Vilella & Castello (1991)	ICCAT (2014)
87.12	0.22	0.63	2.90	46.50	52	Vilella & Castello (1991)	Garbin & Castello (2014)
90.10	0.24	0.98	4.10	46.50	52	Soares *et al.* (2019)	ICCAT (2013)
90.10	0.24	0.80	3.30	46.50	52	Soares *et al.* (2019)	ICCAT (2014)
90.10	0.24	0.72	30.00	46.50	52	Soares *et al.* (2019)	ICCAT (2014)
90.10	0.24	0.63	2.60	46.50	52	Soares *et al.* (2019)	Garbin & Castello (2014)

The furcal length of 50% and 95% of maturity was considered CF_{50} = 46.5 cm and CF 95 = 52.0 cm, which is the average value for females between the estimate made by Cayré & Farrugio (1986) (CF_{50} = 42.0 cm and CF 95 = 49.0 cm) with individuals from the east and west of the Atlantic Ocean, and the estimate made by Vilella & Castello (1993) (CF_{95} = 51.0 cm and CF_{95} = 55.0 cm) with individuals from the southwest Atlantic. The value used for the CF parameter 50 is in accordance with the value estimated in the meta-analysis carried out by Juan-Jordá *et al.* (2013).

To validate the use of the length-based SPR as a depletion estimator, we applied the model for stock length composition in two periods. The first, representative of the beginning of fishing with pole and live bait in the south and southeast of Brazil (early 1980s), sampled by Vilella & Castello (1993). The second period is representative of the current state of the stock sampled on landings from the pole and live bait fleet during the 2017–2018 and 2018–2019 fishing seasons (Fig. 3). These samplings took place in unloadings of the industrial fleet of pole and live bait in the cities of Rio Grande (RS) and Niterói (RJ).

The samples from the two fishing seasons were weighted by the total catches of each state and combined to reflect a current "photograph" of the composition of stock sizes. More than 80% of species landings in the West Atlantic come from pole and live bait fishing (ICCAT, 2014), therefore, the length composition of this fishery can be considered as representative of the length structure of the adult fraction of the stock.

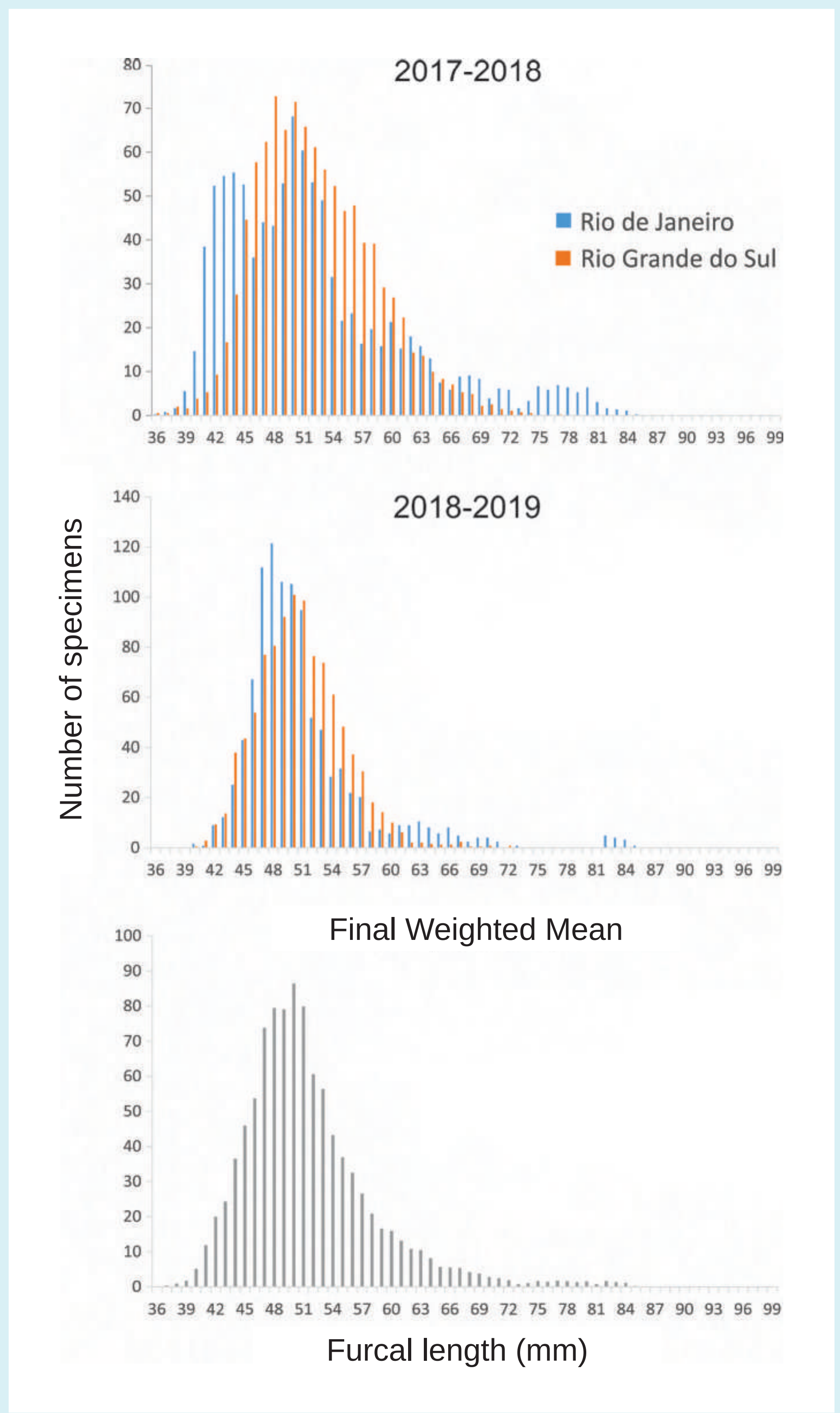


Figure 3. Composition of lengths of skipjack tuna sampled in landings of the pole and live bait fleet during the 2017-2018 and 2018-2019 fishing seasons by the skipjack tuna FUNBIO project team.

The series of catches (1952-2018 for the Western Atlantic, and 1979-2018 for the Southwest Atlantic) used in this work were extracted from the catch statistics in the Western Atlantic provided by ICCAT (2018) (Fig. 4). For the stock scenario in the West Atlantic, catches were low from 1952 to 1979 (on average 2,700 tonnes). During this period, catches were made almost entirely in the North Atlantic, in the early 1980s they increased sharply, from 6,000 tons in 1979 to 32,000 tons in 1982, due to the beginning of pole and live bait fishing in the south and southeast of Brazil (MATSUURA, 1983). From the beginning of the 1980s to 2018, catches showed a cyclical behavior with a period of five to six years and a general tendency slightly decreasing (Fig. 4). For the scenario of a stock in the Southwest Atlantic, catches show an abrupt increase soon after the start of catches in 1979 and until 1982, and subsequently an increasing trend, reaching its peak in 2013, with 32,400 tons (Fig. 4).

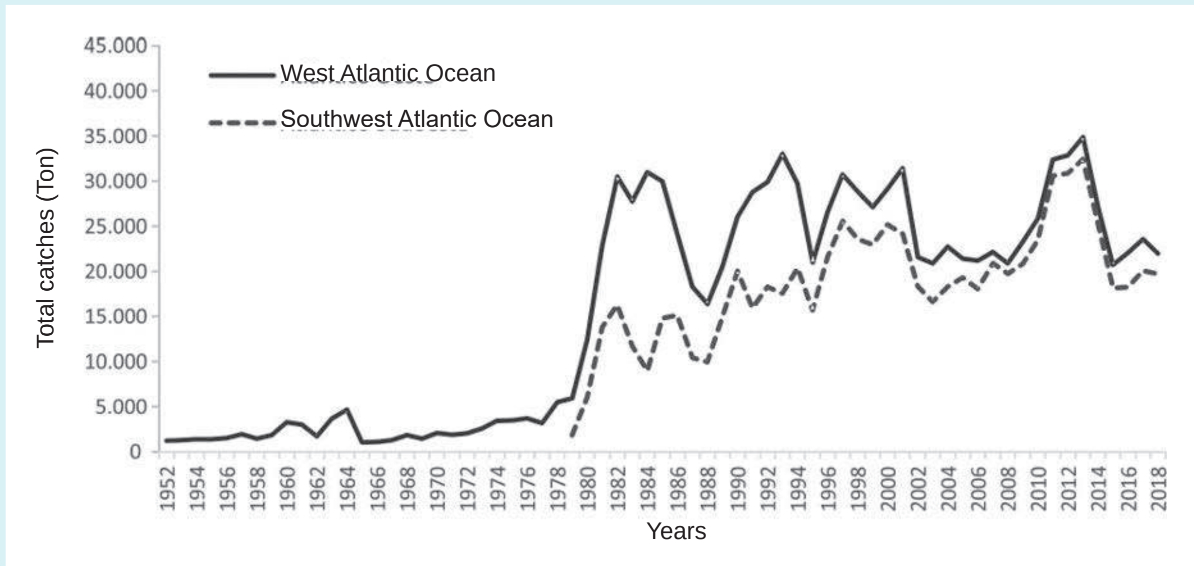


Figure 4. Total catch series of *Katsuwonus pelamis*, as reported by ICCAT for the West Atlantic Ocean between 1952 and 2018, and for the Southwest Atlantic Ocean between 1979 and 2018.

Depletion-based stock reduction analysis (DBSRA) (DICK & MACCALL, 2011) requires a series of historical catches, the natural mortality rate (M), the age of maturity (Imat) and the level of stock depletion in a recent year. A hybrid production model by Schaefer and Pella, Tomlinson & Fletcher provides a latent production function that allows total flexibility in the specification of Bmsy/B_0 (Bmsy: biomass in "*maximum sustainable yield*" and B_0: virgin biomass). The probability distributions of the parameters Depletion, M and Bmsy/B_0 for entry into the model were obtained via resampling procedure, called Monte Carlo chains. It is assumed that selectivity follows a standard logistic model (maturity warhead) at the age of maturity (Imat) that is used to divide immature and mature biomass.

DBSRA uses a simple production model with a time frame for recruitment and mortality, as follows:

$$B_t+1 = B_t + P\,(B_{t\text{-}imat}) - C_t$$

Where B_t is biomass at the beginning of the year *t*, $P\,(B_{t\text{-}imat})$ is the annual latent production based on adult biomass in the year t-Imat and C_t is the catch in the year t. The production function is partially derived from a standard inventory recruitment relationship (DICK & MACCALL, 2011). Biomass in the first year (B_0) is assumed to be equal to biomass without fishing. The DLMtool package version 5.4.2 was used to perform this analysis (CARRUTHERS & HORDYK, 2020). 1,000 simulations were performed for each of the estimated parameters.

The total allowed catches (TAC) for each scenario were calculated considering the exploitation rate that would allow the maximum sustainable yield (Fmsy / M), multiplied by the current estimated biomass, which, in turn, was calculated by multiplying the bio -virginal mass by the current level of depletion.

Results

The combination of life history parameters used to simulate the distribution of virgin lengths is shown in figure 5.

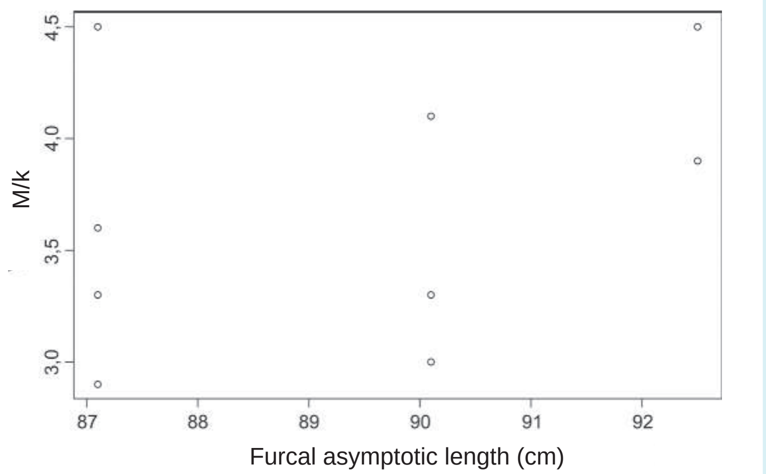


Figure 5. Combination of life history parameters used to simulate the distribution of virgin lengths of the stock of *Katsuwonus pelamis* in the Southwest Atlantic Ocean.

The resulting reproductive potential (SPR) fraction for 2017-2019 was 47% (36-71%) (Fig. 6). This value was used as representative of the current level of stock depletion in both scenarios. The resulting reproductive potential fraction for the early 1980s was 78% (Fig. 7), that is, close to a virginal value. In fact, it is assumed that the composition of lengths sampled at the beginning of the exploration, similar to the virginal one, demonstrates the good performance in estimating the level of depletion of the stock. Consequently, we can infer that the estimated SPR value for the current period can be considered a good indicator of the current level of stock depletion.

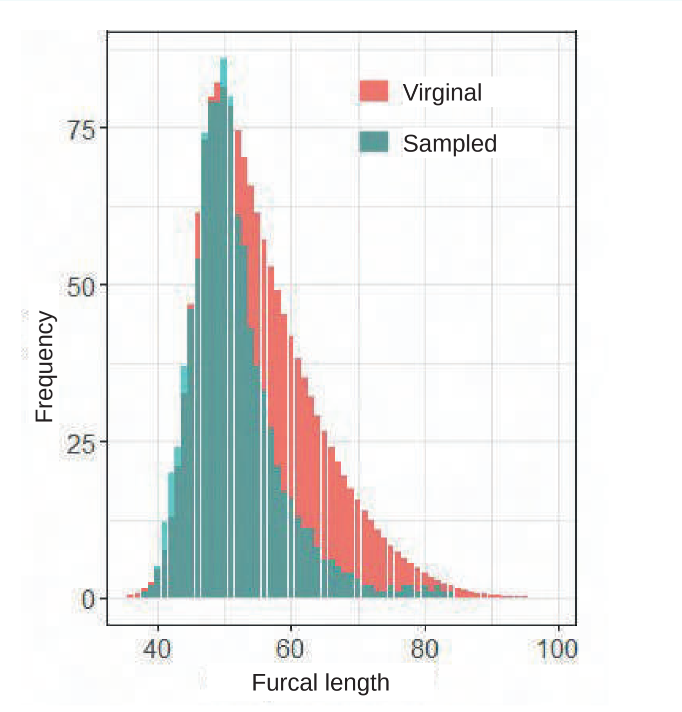


Figure 6. Illustrative figure of the comparison between the composition of lengths of skipjack tuna sampled in the 2017-2018 and 2018-2019 seasons, representative of the current stock situation in the southeastern and southern regions of Brazil and the virginal composition modeled from the combinations of parameters of life's history.

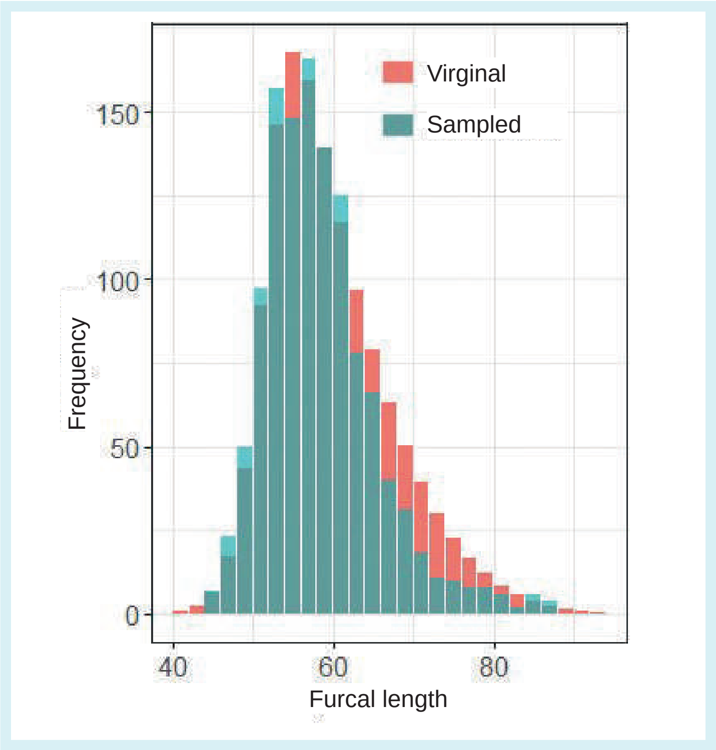


Figure 7. Illustrative figure of the comparison between the composition of lengths of skipjack tuna sampled in the early 1980s (data published by Vilella & Castelo, 1993), representative of the southeastern south region of Brazil in a period close to the beginning of industrial fishing in the region and the virginal composition modeled after combinations of life history parameters.

The uncertainties associated with the input parameters used in the DBSRA model for both scenarios are shown in the histograms in figure 8.

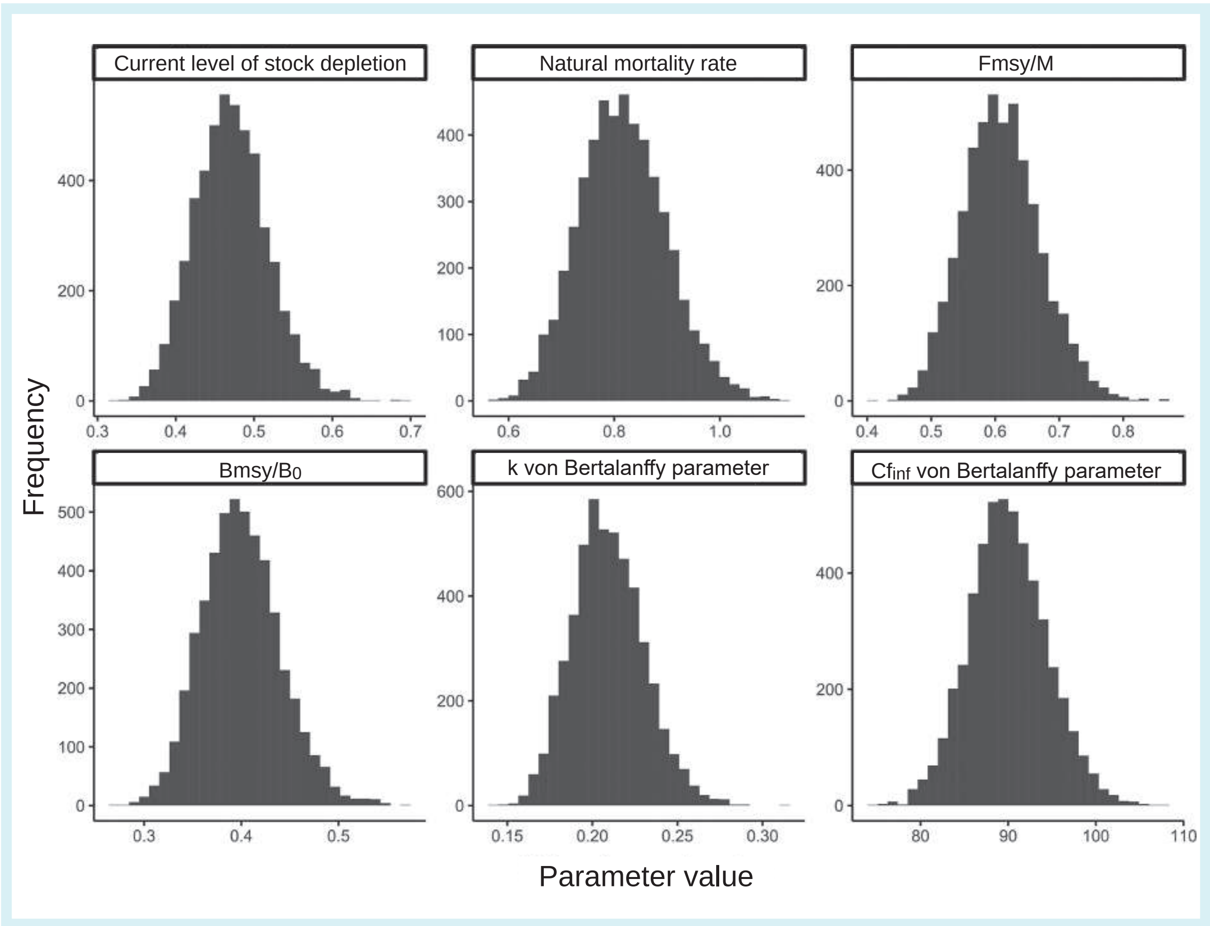


Figure 8. Probability distributions of the input parameters used in the DBSRA model for the skipjack tuna in the Southwest Atlantic.

West Atlantic Stock Scenario

For the scenario of a single stock in the West Atlantic, the modeled biomass mass temporal pattern estimates that the stock's virgin biomass was between 200,000 and 400,000 tons until the late 1980s. After a few years of the beginning of industrial fishing for pole and live bait in a new fishing area, in southeastern and southern Brazil, biomass decreased gradually until the end of the 1980s, when it stabilized between 80,000 and 200,000 tons, remaining at this level to the present day (Fig. 9). Each line in figure 9 represents one of the 1,000 repetitions of the model, so it is important to highlight that the initial value of each line must be compared only with the final value of the same line.

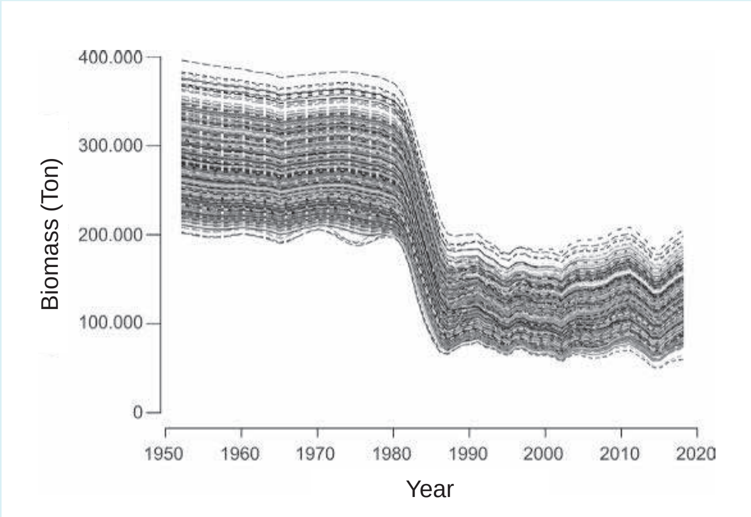


Figure 9. Estimates (1,000 repetitions) of the temporal evolution of the skipjack tuna biomass in the West Atlantic Ocean between 1953 and 2018 according to the DBSRA model.

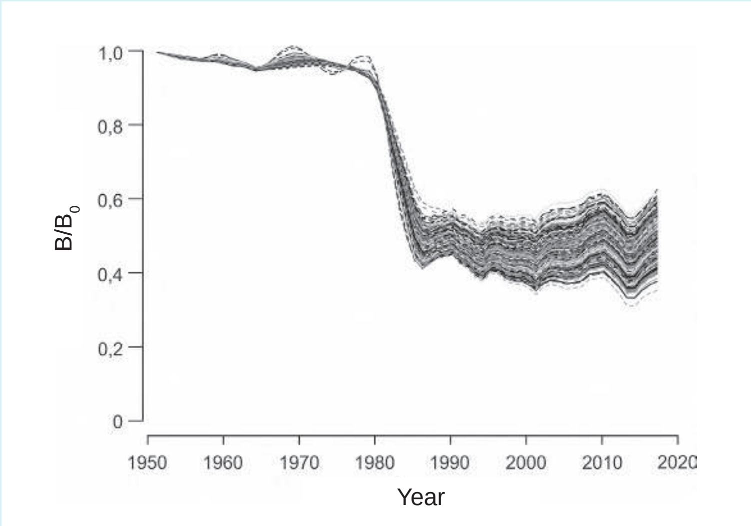


Figure 10. Estimates (1,000 repetitions) of the temporal evolution of the current biomass in relation to the virginal (B/B_0) of skipjack tuna in the West Atlantic Ocean between 1953 and 2018.

Currently (although the theory goes back to the 1930s), there are several studies showing that the biomass in which the stock increases its productivity is about 40% (a little more or less) of virginal biomass, depending on the species' life history (HILBORN *et al.*, 2003; THORSON *et al.*, 2010). At this level of depletion, the stock would maximize its surplus production, that is, biomass production above what is necessary to replace individuals lost to fishing mortality. Therefore, considering the results of the model, it can be said that the current biomass would be above the level of 40% of virginal biomass. With this, it can be said that the stock in the West Atlantic is not in an overexploitation situation and the maintenance of the current catch levels would ensure a sustainable exploitation of this resource in the long run.

The fraction of virginal biomass also decreased in the early 1980s, from 1.0 to 0.40 to 0.60, according to the model's results (Fig. 10). Each line in figure 10 means one of the 1,000 repetitions of the model, therefore, the initial values of each line should be compared only with the final values of the same line.

Thus, according to the model result and considering the input parameters, the total allowable catches for the stock were estimated at around 32,749 tons (28,000 and 38,000) (Fig. 11), slightly above the catches recorded for the past few years.

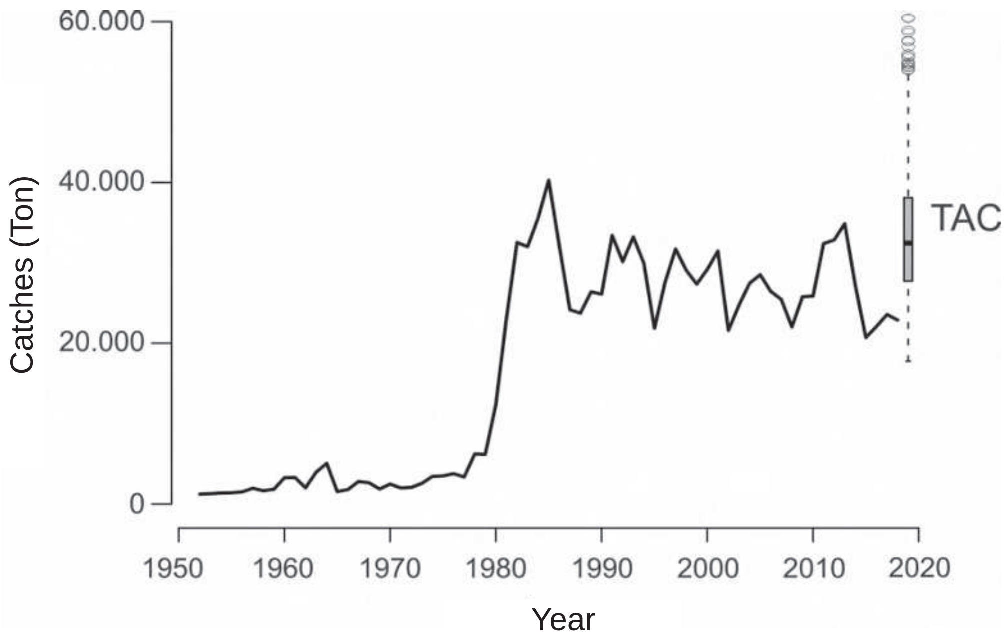


Figure 11. Temporal evolution of the registered catches of skipjack tuna in the West Atlantic Ocean between 1953 and 2018 and the total catches allowed for the stock (TAC = Total Allowable Catch).

Southwest Atlantic Stock Scenario

For the scenario of the existence of a stock in the Southwest Atlantic distinct from the Northwest Atlantic, the modeled biomass temporal pattern estimates that the stock`s virgin biomass was between 150,000 and 320,000 tons until the end of the 1970s. After the beginning of the industrial fishing for pole and live bait in southeastern and southern Brazil, biomass decreased gradually until the end of the decade of 2010, when it stabilized between 50,000 and 180,000 tons, remaining at this level until the present day (Fig. 12). Each line in figure 12 represents one of the 1,000 repetitions of the model, so it is important to highlight that the initial value of each line must be compared only with the final value of the same line.

With this scenario and considering the results of the model, it can be said that the current biomass would be above the level of 40% of virginal biomass. With this, it can be said that the stock of skipjack tuna Atlantic Southwest is being exploited at a sustainable level in the long run.

The fraction of virginal biomass has also gradually decreased since the beginning of the 1980s, going from 1.0 to values between 0.35 and 0.60, according to the model`s results (Fig. 13). Each line in figure 10 means one of the 1,000 repetitions of the model, therefore, the initial values of each line should be compared only with the final values of the same line.

Thus, according to the model result and considering the input parameters, the total allowable catches for a stock scenario in the Southwest Atlantic were estimated at around 27,000 tons (between 23,000 and 31,000) (Fig. 14). This value (27,000 t) is slightly higher than the catches recorded between 2014 and 2019 (Fig. 14), however below the maximum recorded in 2013 (32,400 t).

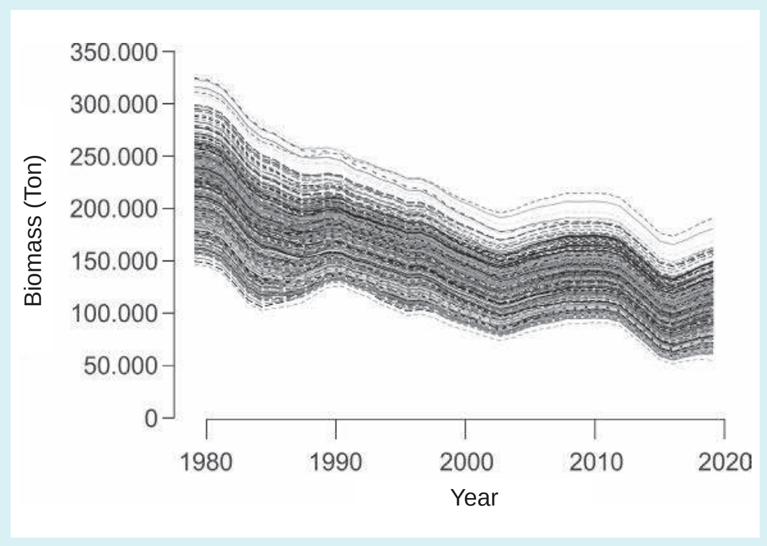


Figure 12. Estimates (1,000 repetitions) of the temporal evolution of the skipjack tuna bio-mass in the Southwest Atlantic Ocean between 1979 and 2018 according to the DBSRA model.

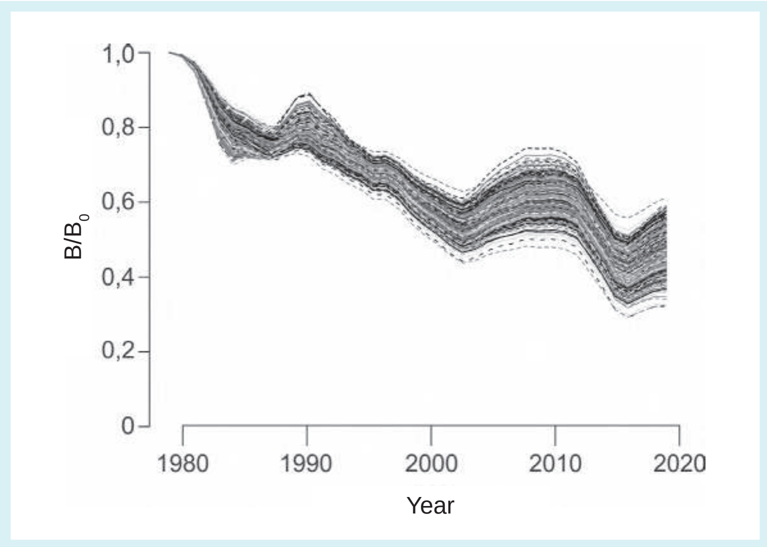


Figure 13. Estimates (1,000 repetitions) of the temporal evolution of the current bio-mass in relation to the virginal (B / B0) of skipjack tuna d in the Southwest Atlantic Ocean between 1979 and 2018.

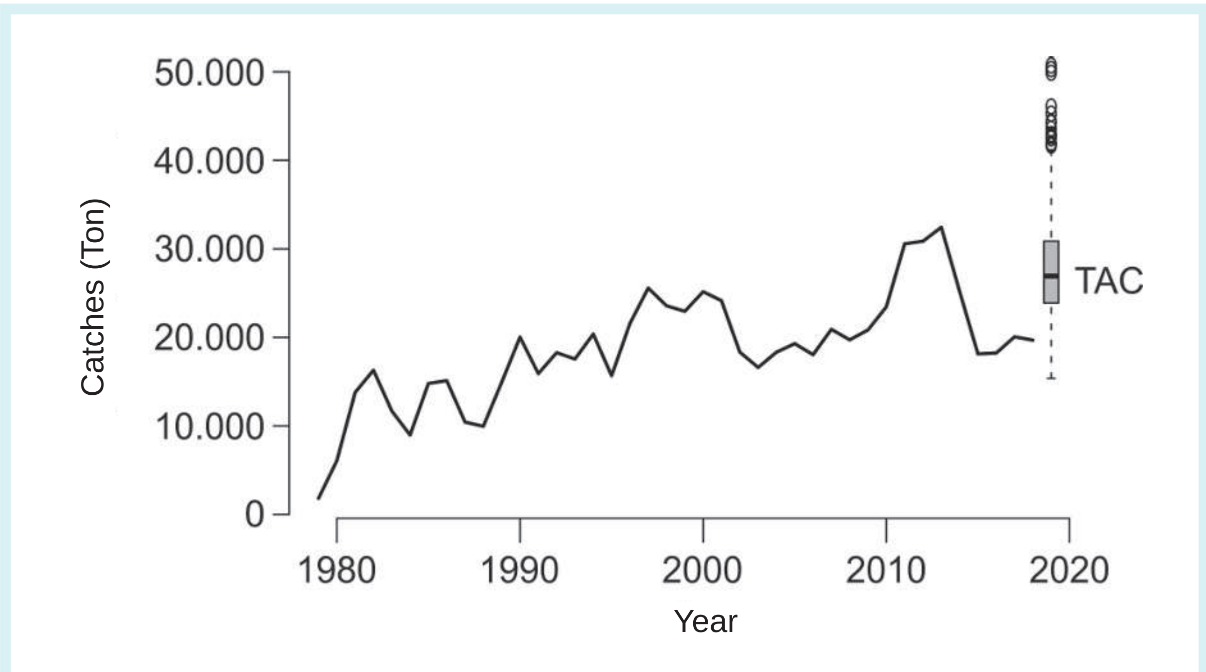


Figure 14. Temporal evolution of the registered catches of skipjack tuna in the Southwest Atlantic Ocean between 1979 and 2018 and the total catches allowed for the stock (TAC = Total Allowable Catch).

Final considerations

The stock valuation presented in this chapter results from the application of the possible methods in view of the available data. The length composition sampled in two harvests (2017–2018 and 2018–2019) represented a "photograph" of the current stock size structure, and was used to estimate the fraction of the remaining reproductive potential. This fraction was estimated at 47% of the virgin biomass. With fewer individuals of larger sizes removed over time by fishing, we can say that the stock loses spawning potential. However, it is important to note that the availability of stock for the fishing fleet is highly dependent on the oceanographic dynamics of the region (see Chapters 2 and 9). As reported in Chapter 9, the year 2018 was considered "atypical" and may represent a year of low availability of skipjack tuna for the fleet. Thus, the reproductive potential could be underestimated. On the other hand, the lack of a continuous sampling program, makes these the best available data.

The use of this parameter as a proxy for the current level of depletion can be questioned, since it does not consider the capture of immature individuals. However, considering the lack of representativeness of the catch rates per unit of effort to estimate the drop in abundance over time, this was the best possible alternative. With that, we can say that the stock, in both scenarios, is not overexploited and that the current catch levels mean a sustainable exploitation of the resource in the long run. The estimated values of biomass over the years and total allowed catches (TAC) showed a wide variation resulting from the uncertainties considered in the input parameters of the DBSRA model (Fig. 8). The estimated TAC values for this fishery indicate that the level of catches maintained over the past few years would be satisfactory and leave no room for large increments in the removed biomass, as it is necessary to reserve a safety margin due to natural stock fluctuations due to variability oceanographic. This means that any increase in fishing effort, which means an increase in the number of boats, or even through new technologies that increase fishing power, can result in a situation of over-exploitation of the stock. The use of TAC values of 32,700 for the West Atlantic and 27,000 for the Southwest Atlantic as a management measure necessarily involves the construction of a management strategy. This strategy should include continuous data collection, effective monitoring of compliance with the rules and objectives of the bodies responsible for managing this resource, as well as users and representatives of civil society. We believe that establishing a management strategy is fundamental for the sustainability of this important fishery and, for that, it is necessary to have a constant flow of data and scientific information.

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Overview of skipjack tuna fishing with pole and live bait in the Southwest Atlantic

11

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Introduction

The purpose of this chapter is to present an overview of the skipjack tuna fishing with pole and live bait, based on publicly available data and official data. The research was carried out in the period from 2017 to 2019, within the scope of the skipack tuna Project, meeting the specific objective of characterization of the population dynamics of skipjack tuna and the fishing fleet of pole and live bait[1].

The initial guideline was to understand the circumstances that marked the introduction of fishing for skipjack tuna with pole and live bait in Brazil. Then, identify the main factors that influenced the results of fishery production, from its beginning to the present day. The databases searched and used here are statistical yearbooks and government reports. Although those are official data published through the years, there were some discrepancies between nationals and regional reports in specific years, as well as gaps in the available statistics. In addition, since 2011, a synthesis of national data on the Brazilian production is not available. In other words, there is no unified national data system on fisheries production in Brazil. Facing these problems, the alternative was to resort to several regional sources to verify the result of the fishing production of skipjack tuna with pole and live bait. We also found that the data from official departments, both federal and regional, do not match the data presented in other chapters of this same thematic unit. This is a worrying factor, which makes difficult the understanding of the situation as a whole, and which can affect the management of the species in Brazil.

Despite these discrepancies and the impossibility of establishing a common database, given the great diversity of information and the specific needs of the researchers, we proceeded with the selection of data from the institutions responsible for monitoring marine fisheries in Brazil. It is a choice with the purpose of, first, getting to know the organization of our databases better, and, second, assuming that to build a data valorization policy, it is necessary to verify its flaws and gaps, understand what are the limiting factors, and then propose innovation programs to develop models, methods and languages that transparently express all actions related to natural resources. However, considering the information from Chapter 10 of this unit, where researchers have chosen to use the ICCAT database, we present through the text comparative values of the total skipjack tuna national production, especially in the most recent years when a national consolidated statistics is nonexistent.

For the construction of this overview on the skipjack tuna fishing with pole and live bait, the research was organized in three stages: the *first stage* of the work was the search for historical statistical data on the skipjack tuna fishing production with pole and live bait,

[1] The research was developed in the period from 2017 to 2019, by the ECOPESCA Laboratory - Biology of the Nécton and Fishing Ecology of the Federal Fluminense University - UFF in partnership with the Postgraduate Program in Sociology and Law PPGSD-UFF.

since its introduction in Brazil, in 1979, until 2018. On the website of the Fisheries Institute – Secretariat of Agriculture and Supply of the State of São Paulo –, we can find the *Historical Series of Data on Marine Fisheries in Brazil*, available in an electronic spreadsheet. This series are compiled information from 1950 to 2011, which includes the commercial fishing statistics (artisanal and industrial) included in the national bulletins published by the different institutions that have taken on the responsibility of recording and consolidating fishing data in Brazil over the years[2]. This database consolidates information on all species caught by different fishing gear in Brazilian waters, including fishing for skipjack tuna with pole and live bait.

Using the spreadsheet tools, it was possible to select the records of annual catches from three main ports[3], which are available in the general database from 1979 to 2011. From these records, a new electronic spreadsheet was generated, containing only the data of skipjack tuna caught with pole and live bait. We observed that in some years, information was lacking, especially in the production details of some regions.

Such as *Historical Series of Data on Marine Fisheries in Brazil* did not arrive until 2018, it was necessary to seek data directly from regional sources, both to complement the data already obtained and to update them from 2011 to 2018. However, investigating this specific period, from 2011 to 2018, became a challenge, considering that in order to find data that could establish the pattern of development of the skipjack tuna fishery, it was necessary to review and check the reports in detail to complement the information in the spreadsheet. With that, we tried to highlight the periods of growth, stability, or discontinuities in fishery production.

After this standardization of the annual records of fishing statistics of fishing with pole and live bait between 1979 and 2018, in the discharge ports of Rio Grande do Sul, Santa Catarina and Rio de Janeiro and the national total, we seek to highlight the main trends in fishing over the analyzed period. To smooth short-term interannual fluctuations and highlight long-term trends, annual moving averages of production were calculated, with a three-year interval[4], as recommended by King (2013). This analysis made it possible to identify four phases of development of skipjack tuna fishing with pole and live bait, which will be presented and discussed throughout this chapter.

In the *second stage*, the work consisted of verifying the technical and scientific production to identify the possible events that influenced the development of fishing with pole and live bait in Brazil. The starting point was the search in the library of the ECOPESCA-UFF Laboratory, then consulted the reports of the working meetings of the Permanent Group of Tuna and Related Studies and the technical research reports carried out by government agencies, available in the collection CEPSUL-ICMBio digital[5]. Finally, a search was made on the *Google* Scholar, which brings together indexed journals from different sources, using the keywords "*Katsuwonus pelamis*" and "Brazil". Even though it's not an exhaustive search on the subject, the result presents a scientometry[6] the performance of scientific production on the species in the Southwest Atlantic.

Finally, in *third stage*, which took place in the period from 2017 to 2019, qualitative indicators were sought that could clarify the meaning of some data and elucidate the functioning of the production chain. The methodological framework for qualitative analysis,

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[2] More information about the historical series reconstruction project is available at: http://www.propesq.pesca.sp.gov. br /35/ content. Accessed in: June 7 2018.

[3] There are three unloading ports where vessels unload their fishery products. In the case of fishing with pole and live bait, there are the ports of Rio Grande (RS), Itajaí-Navegantes (SC) and Niterói-São Gonçalo (RJ).

[4] A moving average is an estimator calculated from sequential population samples. Moving averages are commonly used with time series to smooth short fluctuations and highlight long-term trends. In the specific case of this study, the original sequence of annual fishery production was smoothed using the average between three years [(year-1 + year + year + 1) / 3] (KING, 2013, p.156).

[5] Available at: https://www.icmbio.gov.br/cepsul. Accessed on: 12 2018.

[6] Scientometry is the study of the measurement and quantification of scientific progress, the research being based on bibliometric indicators (SILVA & BIANCHI, 2001).

proposed by Haguete (2007), was the key incentive for the collection of qualitative data, carried out as follows: (i) **interviews** – 27 were held, six with managers involved in the fishing sector (three at the state level and three at the federal level), four with researchers from federal universities, two with fishing owners, two with members of the Union of Shipowners. Fishing in Rio de Janeiro – SAPERJ, one with an industrial manager, one with a consultant in the fishing sector, four with boat masters, four with fishermen and three with intermediaries in the commercialization of fish; (ii) **monitoring of discharges of skipjack tuna** – about 10 discharges of the industrial fleet of pole and live bait were followed at "cais da Sardinha 88" and at FRIDUSA, both located at Ilha da Conceição, and at Funelli, located at Ponta da Areia – Niterói (RJ); (iii) **technical visits** – in two processing industries; Camil, a large size industry, and Tours Conservas, a smaller company that produces canned tuna for a differentiated market.

With the data collected it was constructed and will be presented in this chapter an overview on the fishing of skipjack tuna with pole and live bait in the Brazilian coast, since its introduction to the present day, and the characteristics of this fishing gear in its different stages, from the capture to the industries.

1. The art of fishing with pole-and-line and bait boat

The skipjack tuna (*Katsuwonus pelamis*) and a cosmopolitan, pelagic and migratory species of great commercial importance, with increasing global production in recent decades and raw material for canning industries. In Brazil, catches are made by pole and live bait vessels, especially between spring and summer, and autumn. This fishery lands approximately 25,000 t / year, placing it in fourth place in the world catches of the species through this fishing method (GILLET, 2016).

skipack tuna fishing with a pole and live bait was introduced in Brazil in 1979, in Rio de Janeiro, by Portuguese immigrants from Madeira Island and other regions such as Cape Verde and Angola (LIMA *et al.*, 2000; CASTELLO, 2007). We can consider that fishing with pole-and-line and bait boat in Brazil is relatively recent. However, it is one of the most sustainable fishing gear, because it presupposes high selectivity, since it captures only the targets, removing the fish "one by one", thus minimizing incidental catches of other species (MILLER, 2017).

1.1 Capture of live baits

Juvenile sardines (*Sardinella brasiliensis*), anchovy (*Anchoa* spp.), cascada sardines (*Harengula clupeola*), manjuba (*Centegraulis edentulus*) and manjubão (*Lycengraulis grossidens*), used as live bait, are caught in shallow depths, in bays, inlets or around islands, between Cabo de São Tomé (RJ) and Cabo de Santa Marta Grande (SC) (LIMA *et al.*, 2000). Currently, the fleet of tuna vessels of the company Leal Santos, from Rio Grande do Sul, has been successfully using anchoíta (*Engraulis anchoita*), an abundant species in southern Brazil (MADUREIRA *et al.*, 2016).

The fishing gear used to catch the bait is the siege. Currently, it is mandatory that the tuna vessel itself performs this operation, for which it uses an auxiliary vessel (*panga*) and one or two *caiós*, usually manned by five fishermen (Fig. 1). After the sighting of the bait school, the *caió* remains stationary with one end of the network, while the *panga* surrounds the school and the siege begins. Upon completing the siege, the bottom of the net is closed, forming a large bag that is slowly collected. At the end of the collection, with the bait retained in the net bagger, the *panga* slowly approaches the tuna vessel to overflow the bait.

Figure 1. Tuna vessel in the coastal zone off Paraty (RJ), during the baiting process. The left observes the *panga* motorized towing two nets that will be used in the operation of the enclosure. Photos: Lauro A. Saint Pastous Madureira.

Once on the vessel, the baits are kept alive in vats with constant water circulation. Daily, the sardines are fed with a specific ration (OCHIALINI, 2013) and the tub is cleaned by removing the residues and fish that may die in storage.

1.2 Deep sea fishing

The fishing of skipjack tuna itself is practiced more than 60 miles from the coast, generally on the limit of the continental shelf, in depths that vary between 80 and 500 m (MATSUURA, 1982; COLETTO *et al.*, 2019). The continental shelf is the portion of the seabed adjacent to the continents that begins at the coastline and embankments towards the sea, with a gentle embankment towards the depths of the oceans. An abrupt change with an increase in the slope of the ocean floor establishes the outer limit of the continental shelf. In general, this change occurs at varying distances from the coast, at depths between 150 and 200 m (CASTRO, 2012, p. 33; COOKE *et al.*, 2007).

Upon arriving at the fishing area, experienced fishermen (scouts) assist the master in looking for schools (or "*manchões*"). Sea birds (or "little birds", a popular name given by fishermen) and floating objects are generally good indications of the presence of these aggregations. When approaching the school, the master activates the "shower", a curtain of water around the vessel, which serves to hide the silhouette of the boat and create turmoil on the water surface. Live baits are thrown into the sea, attracting fish to the vessel, when fishing begins. Fishermen positioned on the edge of the vessel use bamboo or fiberglass fishing rods, equipped with hooks without dewlap, to catch the fish (Fig. 2). The fish are quickly detached from the hook and directed to the hold, where they are stored. Most modern vessels use brine cooling. Each vessel takes between 20 and 25 fishermen on trips that last from 15 to 30 days, depending on the conditioning factors that are: the time spent in catching the bait and the time spent in locating the schools and catching the fish.

2. The development of skipjack tuna fishing in Brazil

The fishing of the pole and live bait fleet, since its introduction in 1979, concentrated its activities initially in the southeast region, later extending to the south, occupying a region between the latitudes of 18º S and 36º S (VILELA & CASTELLO, 1993; ANDRADE & SANTOS, 2004). Rio de Janeiro was the precursor in the art of fishing the skipjack tuna with pole and live bait. In 1978, two adapted trawlers made their first surveys to capture the skipjack tuna successfully. The success boosted the enterprise in the following year, and, from that date, began to operate in a commercial manner. According to the SUDEPE report (1980),

Figure 2. skipack tuna fishing moment. In the photo it is possible to observe the “shower” in operation and the fishermen catching the fish. Foto: Lauro A. Saint Pastous Madureira.

the fleet showed an increase in production of approximately 300%, in comparison with the catches made by liner and longline boats in previous years. The results were so encouraging that, in the period from June 1979 to June 1980, the fleet for the capture of skipjack tuna grew from 7 to 33 vessels. By April 1981 this number had reached 47 (SUDEPE, 1981).

From this success, this fishery developed as one of the main offshore fisheries, feeding an industrial park initially based in Rio de Janeiro and later in Santa Catarina and Rio Grande do Sul.

Figure 3 presents the results of the analysis of the annual fishing production of skipjack tuna with pole and live bait, between 1979 and 2018, for the states where the main unloading ports are located (Rio Grande-RS; Itajaí / Navegantes-SC; Niterói / São Gonçalo-RJ) and totals for Brazil. The analysis of the production showed that this fishery could be subdivided in seasonal phases, to be interpreted in the light of the models presented by Grangier and Garcia (1996) and more recently by Jennings *et al.* (2009), which define the different stages of fishing development. Thus, the overview on skipjack tuna fishing was organized in four phases (Phase I: 1979 to 1988; Phase II: 1990 to 1998; Phase III: 1998 to 2011; Phase IV: 2011 to 2018), which will be detailed at follow.

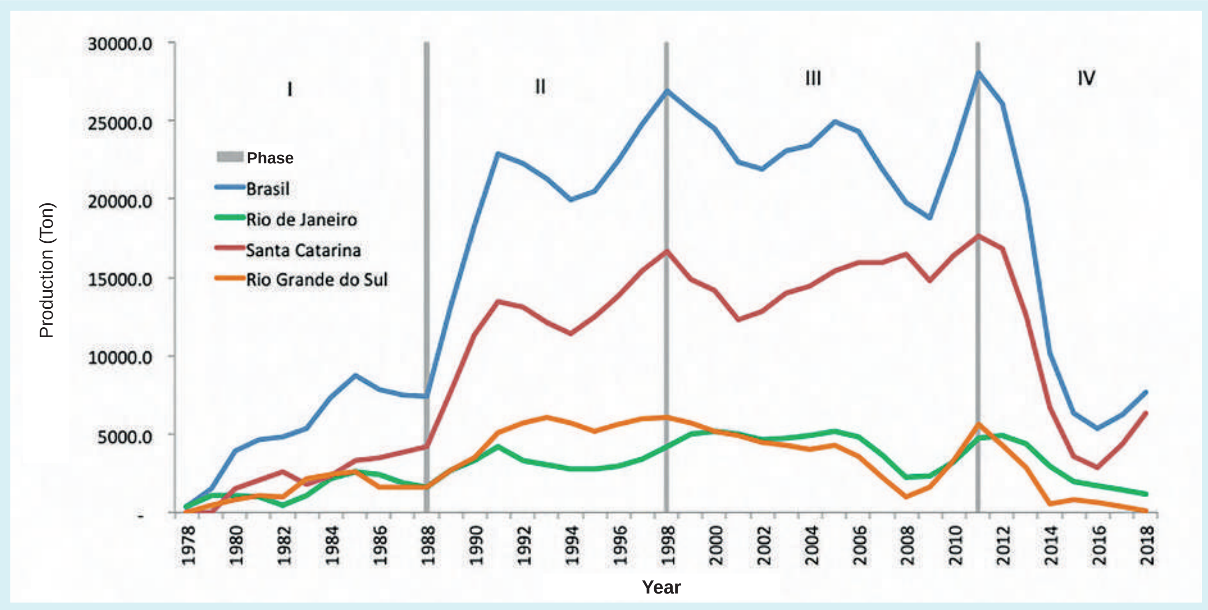

Figure 3. Fishery production, in tons, of skipjack tuna caught by pole and live bait fishing for the states of Rio Grande do Sul, Santa Catarina, Rio de Janeiro and national total in the period between 1979 and 2018, and the respective phases of development (I, II, III, IV).

In order to better understand the dynamics of each phase (I, II, III and IV) and to understand the route of skipjack tuna in Brazil, the following key themes were described for each period: *Fishing area* – presents the expansion of the fishing area in the Southwest Atlantic and the behavior of the fleets; *Fleets* – characterizes the development of fleets according to the number and size of vessels and their ports of origin; *Custom production* – compares the average production per port of discharge, as well as the contribution of this production in the national total; *Technology* – explores the historical process of modernization of the sector, especially in the fishing technology of vessels; *Industry and market* – is a synthesis of the main elements of the skipjack tuna economic cycle.

As a result of *second stage* of work, survey of scientific production, we will present in each phase, a Box of Scientific Production, whose objective is to highlight the role of scientific research in the construction of this activity. In the boxes, the information was organized by date of publication. The most recurrent themes were: a) *fish technology* – articles dealing with fish processing on board vessels and in industry; b) *fishing oceanography* – publications dealing with the relationship between oceanographic characteristics and fishing activity; c) *parasites* – dealing with the occurrence and identification of parasites in the skipjack tuna; d) *life's history* – scientific works addressing aspects related to the population and reproductive parameters of the species; and e) *fishing* – dealing with fishing production, fishing effort and models of fishing income.

2.1 PHASE I: Introduction and Expansion of skipack Tuna Fishing – 1979 to 1988

The data for this phase, from 1979 to 1989, are from the Fisheries Production Statistics Reports of the Brazilian Institute of Geography and Statistics - IBGE, which are available at the *Historical Series of Data on Marine Fisheries in Brazil*, from the São Paulo Fisheries Institute.

This fishing with pole and live bait started in the state of Rio de Janeiro in 1979, initially with a timid but promising production. Figure 4 above shows a marked increase in production in the first three years, reaching a level above 6,000 tons in 1988. In the first two years, Rio de Janeiro led the fishery production, gradually being overtaken by the fisheries discharged in Santa Catarina.

Box 1. Scientific production

The scientific production on the skipjack tuna and the fishing with pole and live bait was driven by the discussions that took place between 1978 and 1979, when they formalized the creation of the Permanent Group of Studies on Tunas and the like (GPE-Tunas and the like) . In 1979, the "International Year of the skipack tuna" was created, promoted by ICCAT - International Commission for the Conservation of Atlantic Tuna. This event marked the participation of Brazil. Thus, for four years there was an incentive to research on skipjack tuna which culminated in the presentation of the results at an ICCAT meeting in Tenerife (SAKAGAWA & SYMONS, 2011). During that time, studies on eggs and larvae (MATSUURA, 1982; 1984), reproduction, marking and estimates of fish stocks and yield (LIMA, 1984) were developed.

Also, in 1980, fishing research aboard the Malacostraca Ship began, under the responsibility of the Rio de Janeiro State Agricultural Research Corporation (PESAGRO-RIO), which lasted until 1991 (ÁVILA DA SILVA & VAZ DOS SANTOS, 2000).

Figure 4 shows the scientific production at this stage. The survey found 17 publications, highlighting 1983 as the year with the highest number of publications.

As shown in the graph, the predominant themes in these publications were: (i) aspects of the skipjack tuna biology, such as the occurrence and characterization of larval stages (e.g., MATSUURA, 1982) and eating habits (e.g., ANKENBRANDT, 1985) , weight and length relationships (AMORIM *et al.*, 1981); (ii) fishing, focusing on the analysis of exploitation rates and stock size (JABLONSKI & MATSUURA, 1985); (iii) only one article listing the oceanographic characteristics, and the susceptibility to capture the species (EVANS *et al.*, 1981).

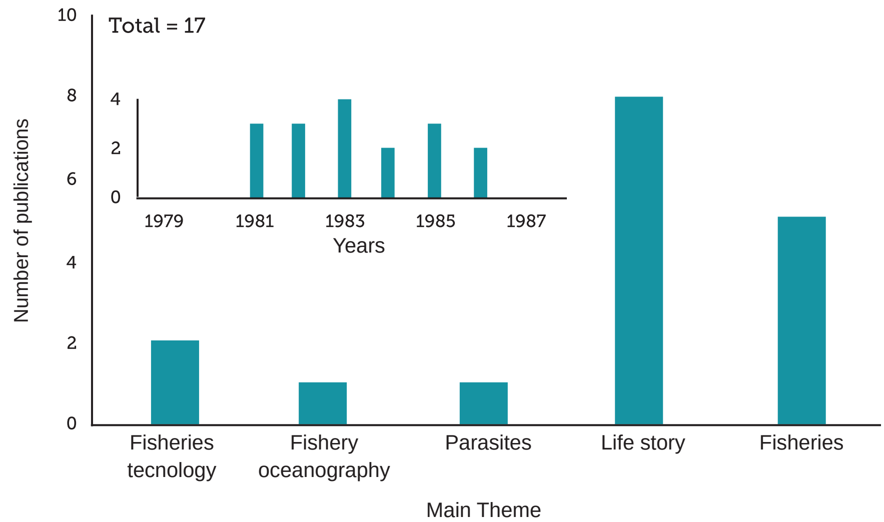

Figure 4. Number of publications in national and international scientific journals on skipjack tuna (*Katsuwonus pelamis*) by year of publication (minor figure) and main theme (major figure), during Phase I (Prepared by the authors).

Phase I is defined as an exploratory phase. It marks the introduction of fishing with pole and live bait in Brazil. The few vessels presented an adventurous, innovative fishery, with significant results in catches and great profitability.

The following key themes will present an overview of Phase I that characterizes the introduction and expansion of skipjack tuna fishing with pole and live bait in Brazil.

Fishing Area

The first fisheries recorded occurred in two areas on the southeast coast: (i) Pesqueiro Norte, off the Cape of São Tomé, in the state of Rio de Janeiro; and (ii) Pesqueiro Sul, off São Sebastião, in the state of São Paulo. Both areas are located on the edge of the continental shelf.

From 1980, the records show the occurrence of a third area - Pesqueiro Sul 2, off Itajaí, in the state of Santa Catarina. This fishing area was also registered at the edge of the continental shelf. In these early years, fishing took place mainly close to the platforms for prospecting and extracting oil, which functioned as major attractors of schools (SUDEPE, 1980; 1981; 1988). However, for security reasons, SUDEPE published Ordinance Nº. 002/80, which prohibited fishing near oil platforms in the northern area of Rio de Janeiro (LIMA *et al.*, 2000). This regulation had consequences for the composition of the fleet, as will be seen below.

At the end of Phase I, the total fishing area was established between the latitudes of 20° S, off Vitória, and 35° S, on the Brazil and Uruguay border (SUDEPE, 1980; MADUREIRA *et al.*, 2016).

Fleet

One of the characteristics that marked the national pole and live bait fleet in Phase I, was the great diversity of vessels adapted from various fishing modalities, with an average size around 20 m (SUDEPE, 1980; 1983).

Initially, the fleet rapidly increased in number. Vessels from siege fishing (sardine and mackerel), shrimp trawling and bottom line fishing were quickly adapted, with the removal of the original structures and installation of live bait tanks, pump system for water renewal and other adaptations necessary to fishing with pole and live bait. Among the first vessels adapted for fishing for the skipjack tuna in Rio de Janeiro were Ave Maria, Brastuna, Novo Rio, and Ferreira and Taí (SUDEPE, 1983). The number of registered vessels jumped from seven, in 1979, to 100 vessels in the beginning of 1982, considering the vessels that made at least one fish discharge during those years (Tab. 1). However, the effective number of vessels in operation at the end of 1982 was only 45 (SUDEPE, 1983), suggesting that smaller vessels have ceased to operate in this fishery. The limitation of fishing around the platforms, as shown above, restricted the operation of smaller vessels (10-15 m) to periods when schools were found closer to the coast (LIMA *et al.*, 2000). In fact, after 1982, these vessels, unable to transport large amounts of bait and make significant trips on the high seas due to the lack of equipment, returned to their original fisheries. From this moment onwards, larger vessels remained in fishing, but new vessels entered, also of larger size and better adapted to fishing conditions. These changes reflected a relative stabilization in the number of active vessels, however, with an effective increase in the average gross tonnage of the fleet over the years, as shown in table 1 (SUDEPE, 1988).

As the fishing activity consolidated, the vessels became more suitable, both in model and size. As of 1988, the establishment of a new national fleet of vessels began, with the construction of the tuna vessel "Vô David", in Santa Catarina, considered, at the time, the largest boat in the country, resembling the leased vessels. This vessel was launched to the sea in 1990, starting to operate in the next phase.

Table 1. Average gross ton (t) and number of vessels registered in the fishery with pole and live b ait between 1979 and 1987 (SUDEPE, 1988).

Year	Average gross (Ton)	Vessels
1979	32.0	7
1980	47.0	39
1981	73.0	69
1982	85.0	100
1983	95.0	57
1984	94.5	48
1985	99.1	50
1986	101.7	45
1987	103.2	40

Also, in 1981, fisheries carried out by Japanese leased tuna vessels were initiated in Santa Catarina, vessels considered to be large in relation to national boats (LIMA *et al.*, 2000). Since it is a pelagic species, the skipjack tuna fishery requires that vessels have autonomy and better safety conditions, thus, it is likely that the decrease in vessels from 1983 (Tab. 1) is related to the conditions required for deep sea fishing (SUDEPE, 1988; LIMA *et al.*, 2000), due to low yields.

Fishery Production

Although Rio de Janeiro took the first steps in the implementation of fishing with pole and live bait, already in the middle of the period that composes Phase I, Santa Catarina surpassed Rio de Janeiro. The production of the state of Rio Grande do Sul also started to be expressive. However, Santa Catarina production was considerably higher (Fig. 5). There are possibly two factors that led to the good result of production: first, due to access to the new fishing area - Pesqueiro Sul 2; and second, the leasing of tuna boats from the Japanese fleet, which, because they are larger and more suitable, allowed to achieve the best results (LIMA *et al.*, 2000).

According to the SUDEPE report (1988), at the end of Phase I, in 1987, Itajaí became the main port of landing for fishery production, due to various conditions, such as the best availability of live bait; the implantation of canning industries, buyers of fish; and the better proximity to the canned- skipjack tuna consumer market.

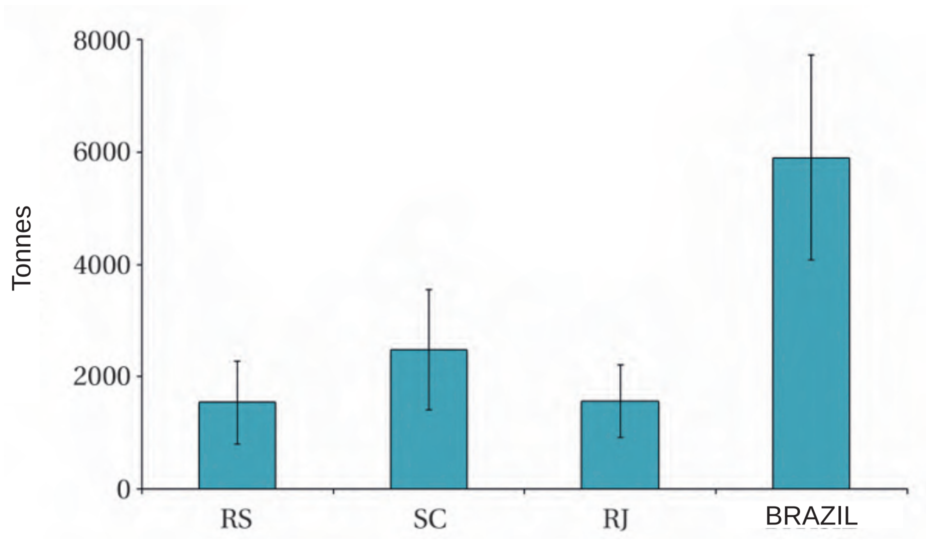

Figure 5. Average (blue bar) and confidence interval (95%) of fishery production in Rio Grande do Sul (RS), Santa Catarina (SC), Rio de Janeiro (RJ) and total for Brazil during Phase I, from 1979 to 1988. The average confidence limits indicate the variability of annual production during this phase (Elaborated by the authors).

Technology

Vessel technology at the beginning of fishing for skipjack tuna with pole and live bait was very limited. Also, as it is a new fishery in Brazil, there were no national fishermen qualified in this fishing gear. This scenario favored Portuguese immigrants with experience to enter the labor market. They acted as fishermen, masters of vessels and fishing owners.

In 1985, more modern foreign tuna boats were leased, equipped with navigation equipment (satellite navigator, radio goniometer), echo sounders and thermometer for measuring surface water temperature (LIMA *et al.*, 2000). The modernization of boats has become essential to achieve better results.

Industry and Market

The first canning industries emerged in Rio de Janeiro in the 1950s, producing canned sardines, centralizing a large part of the canned fish industrial park. In the 1980s, these companies started canning tuna, with Santa Iria emerging in the first half of 1980 as the largest tuna canner in the state of Rio de Janeiro. Other companies, such as Beira Alta and Jangada, also used all fish production for canning, while Fridusa and Mantuano, through GP - Gelo e Pescado, exported frozen fish (SUDEPE, 1980; 1988).

As already mentioned in the themes *fishery production* and *technology* (above), from 1987 onwards, Itajaí became the main port for fisheries production.

2.2 PHASE II: skipack Tuna Fishing Consolidation - 1990 to 1998

The data for this phase, in the period from 1990 to 2003, are from national fisheries statistics from the reports of the Research and Management of Fisheries Resources of the Northeast Coast, Brazilian Institute of the Environment and Renewable Natural Resources – CEPENE / Ibama (currently Centro Nacional of Research and Conservation of Marine Biodiversity in the Northeast, Chico Mendes Institute for Biodiversity Conservation – CEPENE / ICMBio). These data are available at the *Historical Series of Data on Marine Fisheries in Brazil*, Institute of Fisheries of São Paulo, which informs that, in the period of four years, 1990 to 1994, there was an absence of statistical data. However, in 1995, the data returned, through the annual reports of Fisheries Statistics by CEPENE / Ibama.

At this stage, the standard of the Brazilian fleet was consolidated. The term *Standard fleet* indicates that most vessels have similar characteristics in relation to the size, technology and fishing gear used (FONTELES-FILHO, 2011). As a consequence, there was a considerable increase in fishing production. According to available data, the period marked significant growth in all states, as shown in figure 3.

In addition to the standard of vessels becoming more appropriate to the fishing modality, there was also an increase in cargo capacity. These adjustments made it possible to achieve significant results. But it was also in Phase II that there was a drop in the national production of the sardine fleet. This fact can be interpreted as the cause of conflicts related to the capture of juvenile sardines as bait for the pole tuna fleet with live bait (OCCHIALINI, 2013). In order to limit fishing and trade in juvenile sardines, Ibama instituted Ordinance 120-N / 1992, prohibiting the trade in sardines - true with a length of less than 17 cm, and forcing vessels operating in the capture of tunas by the rod and hook system, with live bait, to capture their own bait (Portaria Ibama 120-N, Art. 4, 1992).

It is possible to infer that new research was driven by the conflicts caused by the limitations of access to the sardine as a live bait. For example: studies were carried out to verify the percentage of sardines used by skipjack tuna fishing. The percentage of removal of live baits was calculated to evaluate the effect on the stocks of sardines (LIN, 1992). The study showed that the drop in the production of sardines was more related to other factors, such as the increase in fishing effort and the increase in the occurrence of sardines - true juveniles in the catches of the sardine fleets. In addition, the amount of sardines used as live bait represented about 12% of the total catch of young sardines caught by the sardine fleet.

The box 2 shows the research records that sought innovations for the live bait issue.

Box 2. Scientific production

Seven publications were registered for this phase. The most frequent themes were fishing and the skipjack tuna life story. The annual scientific production in this phase was low, with only one scientific article published each year (Fig. 6). Much of the information on fisheries and the biology of the species was made available in restricted circulation reports, which often do not appear in the bibliographic database of the *Google* Scholar.

Another topic addressed by scientific production was the use of the sardine (*Sardinella brasiliensis*) as live bait. Other studies have tried to try other species for live bait, such as anchovy (*Engraulis anchoita*) and the potbellied (*Jenynsia multidentata*) (PALUDO *et al.*, 1987; LIMA *et al.*, 2000; MADUREIRA *et al,* 2016).

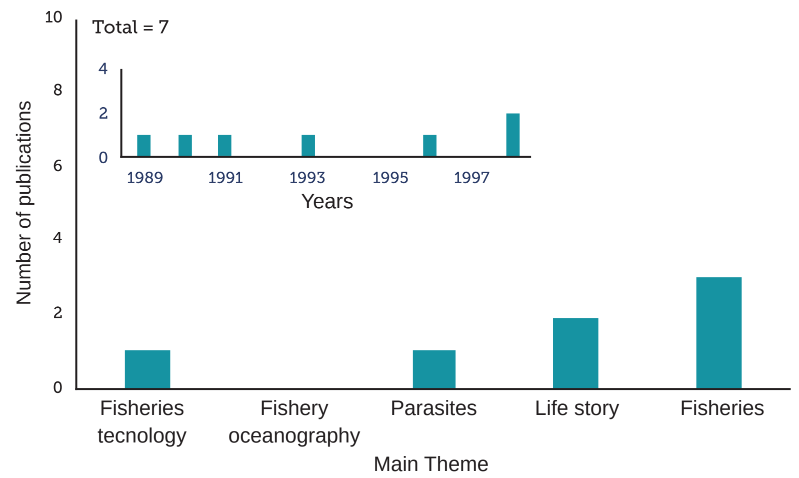

Figure 6. Number of publications in national and international scientific journals on skipjack tuna (*Katsuwonus pelamis*) by year of publication (minor figure) and main theme (major figure), during Phase II (Prepared by the authors).

Fishing Area

In this phase and in the following years, the skipjack tuna fishing region extended between the latitudes of 20° S, off Vitória, up to 35º S, Brazil-Uruguay border. In late spring and summer, due to seasonal migrations of the species along the coast, fishing took place further south, close to the Uruguayan border, and in the autumn and early winter months, the fleet, in search of the skipjack tuna, moved north, often reaching Espírito Santo (see Fig. 1 of Chapter 2).

Fleet

One of the main characteristics of the fleet that marked Phase II was its modernization, adapting to the needs for offshore fishing, which added autonomy and agility for large movements. New boats measuring over 25 m and gross tonnage from 105 t onwards entered the fleet, some with a cold hold on board and preserving the fish in brine, in addition to the nationalization in 1993 of the leased Japanese boats (measuring 42.4 m in length and gross ton of 284.8 t).

In the early 1990s, tuna vessels were forced to adapt fishing structures to capture their own bait, an activity that until that moment was carried out by a fleet of small trawlers in bays and sheltered coastal areas.

The fleet suffered a stratification by size by port of unloading, where the smaller boats were concentrated in Rio de Janeiro, the larger ones in Santa Catarina and a third segment of the fleet, consisting only of the larger vessels of these two states, which started to land in Rio de Janeiro, between April and September, and in Santa Catarina, from October to April (LIMA *et al.*, 2000).

Fishery Production

According to data from the sources consulted, national production in Phase II reached its maximum, with an approximate result of 26,000 tons in 1997. ICCAT data for 1997 indicate 25,821 tons. Based on national data, fishing production maintained an average production of 21,107 t / year during the period. The average unloaded production in Rio de Janeiro was much lower than in Santa Catarina and Rio Grande do Sul (Fig. 7).

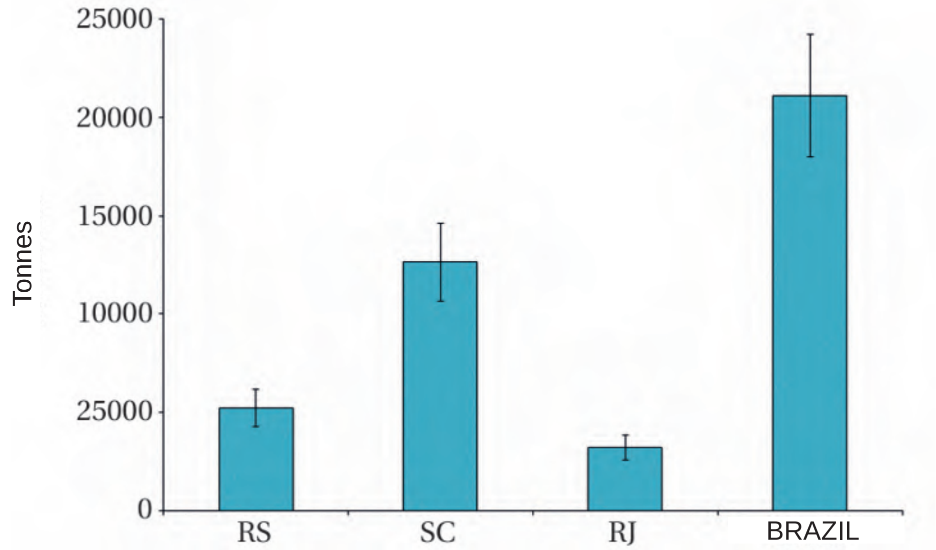

Figure 7. Average (blue bar) and confidence interval (95%) of fishery production in Rio Grande do Sul (RS), Santa Catarina (SC), Rio de Janeiro (RJ) and total for Brazil during Phase II, from 1989 to 1998. The confidence limits of the mean indicate the variability of annual production during this phase (Elaborated by the authors).

Technology

From a technological point of view, the new boats entering the fleet were already equipped with satellite positioning instruments and echo-probes. Another important aspect concerns the technology for preserving fish on board, with the introduction of boats where the fish was stored in vats containing chilled brine, which improved the quality of conservation (OLIVEIRA, 2015).

Industry and Market

During this phase, with the stratification of the fleet by size for unloading and the port facilities available in Santa Catarina, industries moved to the south. Canning industries in Rio de Janeiro experienced a crisis associated with declines in the production of sardines, added to the closure of the warehouse at Praça XV, a traditional place for the direct sale of fish to consumers, which was deactivated in May 1991 (SAPERJ, 1991). This fact significantly worsened the situation of the fish market in Rio de Janeiro. As of this date, the discharges started to be carried out in precarious conditions at the quay of the old Mantuano Canning Industry (JABLONSKI, 1997), in Ilha da Conceição (Niterói-RJ), also known as the "pier of Sardinha 88" . The provisional structure lasted until the end of 2018, when the oil industry took over the area[7].

[7] During the monitoring of discharges between 2017 and 2019, the authors were able to verify the precarious conditions of the site.

2.3 PHASE III: skipack Tuna Fishing Stability - 1998 to 2011

The data for this phase, specifically from 2004 to 2007, are from the National Fisheries Production Reports, which are the responsibility of the General Coordination of Authorization for Use and Management of Fauna and Fishery Resources, Directorate for Sustainable Use of Biodiversity and Forests - CGFAP-DBFLO -Ibama. In the period from 2008 to 2011, the data are from the Fisheries and Aquaculture Statistical Bulletins, under the responsibility of the then Ministry of Fisheries and Aquaculture. All of these reports were accessed through the *Historical Series of Data on Marine Fisheries in Brazil*, on the São Paulo Fisheries Institute website. However, the data close in 2011.

The box 3 shows a significant result of scientific production in Phase III. Many productions in this period were driven by research carried out by the Program for the Evaluation of the Sustainable Potential of Living Resources in the Exclusive Economic Zone – REVIZEE, which began in 1996 and extended until 2006. However, the volume of themes related to the marine environment were fundamental to boost scientific research.

Box 3. Scientific production

The years 2000 and 2010 showed the best results, with about 21 articles listed in national and international journals.

The main topics covered were divided into nine articles on catch estimates (e.g. MENEZES *et al.*, 2010); five articles on the presence of parasites (e.g., CÁRDENAS & KOHN, 2009); four on life history (e.g., ANDRADE & CAMPOS, 2002); and, three articles on fishing oceanography (e.g., ANDRADE, 2003) (Fig. 8).

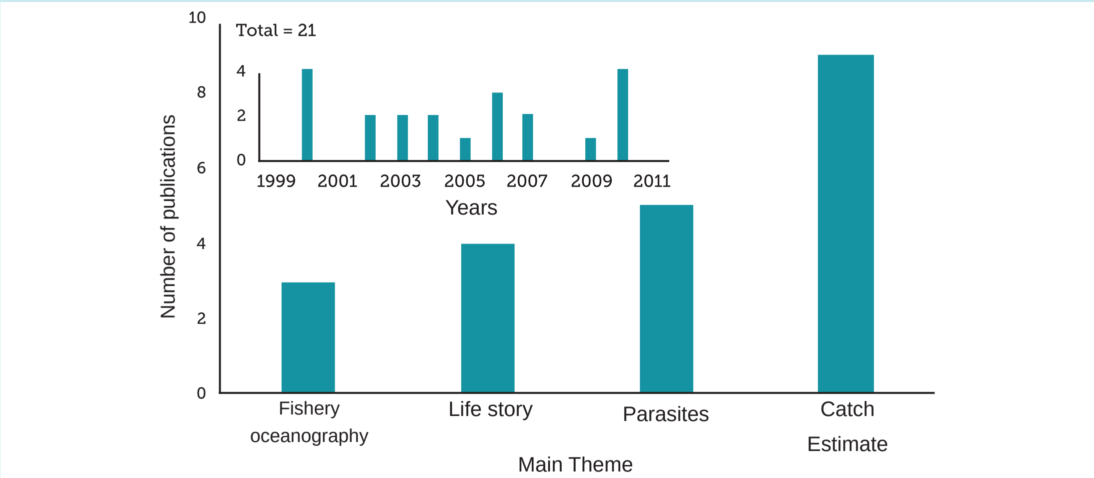

Figure 8. Number of publications in national and international scientific journals on skipjack tuna (*Katsuwonus pelamis*) by year of publication (minor figure) and main theme (major figure), during Phase III (Prepared by the authors).

This phase is characterized by the Brazilian fishing production reaching the highest values, varying around 20,000 to 25,000 t / year, for a period of more than 10 years. It was 12 years of stability of this fishery in Brazil, except in Rio de Janeiro, where most of the canning industries were closed. In addition, there were records of conflicts between the live bait fleet, the sardine fleet, and artisanal fishermen, due to the restrictions related to the sardine, especially in coastal areas.

The data records in this phase indicated that the fishing of skipjack tuna in Brazil was fully developed and stabilized. The following topics describe the characteristics of Phase III fishing dynamics.

Fishing Area

In Phase III, new questions about fishing areas were introduced in the skipjack tuna fishing arena. These are the areas where the live bait is caught, considering that the problem of the availability of the live bait is directly related to the art of fishing for the skipjack tuna.

That said, it is also important to emphasize that the conflicts are related to the restrictions of the new rules instituted by Portaria Ibama 120-N / 1992, as presented in Phase II. This infralegal normative instrument, which aims to ensure the recovery and stability of the sardine shoals, prohibited the trade in juvenile sardines, and forced tuna vessels to capture their own bait. In addition, Conservation Units were created in Rio de Janeiro and Santa Catarina, presumably in areas where real sardines were fished as live bait. For this reason, the owners of boats that fish skipjack tuna claim that the areas of fishing for live bait became more restricted with the creation of these spaces of federal scope, including here the Extractive Marine Reserves.

However, it is essential to remember that the objective of creating a Conservation Unit is the protection of rare, endemic species and, especially, threatened species of extinction. An Extractive Reserve also has the objective of ensuring the sustainable use of natural resources by the local populations or traditional communities. To this end, contracts for the concession of the right to use the area are signed with a series of obligations, including the responsibility to safeguard biodiversity within the limits of Extractive Reserves.

Therefore, the schools of sardines that are found in an Extractive Reserve are the responsibility of this traditional population that lives there, they are legally responsible for the entire area. Therefore, fishing for sardines for live bait is not understood as a subsistence activity for the population. In addition, skipjack tuna fishing is considered a mode of industrial fishing. It is not practiced by community fishermen, it is not part of the local subsistence fishery, and for that reason the fishing for real sardines for live bait is not allowed in any Conservation Unit.

Fleet

Phase III consolidates the trend presented in Phase II, that is, the development of larger vessels in Santa Catarina, which used modern equipment, achieved very significant results, and remained stable. On the other hand, vessels in Rio de Janeiro have undergone little modernization (IBAMA, 1998) and little innovation (VIANNA, 2009).

During this period, specifically in 2006, the National Program for Satellite Fishing Vessel Tracking - PREPS was launched, through Interministerial Normative Instruction No. 2 of September 2006, under the responsibility of the Special Secretariat for Aquaculture and Fisheries of the Presidency of the Republic, Ministry of Environment and Navy of Brazil. This is satellite monitoring, which was an important instrument for managing and controlling the operations of the fishing fleet. In this way, it became mandatory that all fishing vessels with gross tonnage (AB) equal to or greater than 50, or with total length equal to or greater than 15 meters, including fishing research vessels, must be tracked by the system. The system also aims to increase the safety of on-board fishermen, improve marine surveillance and minimize conflicts between industrial and artisanal fishing, related to the fishing area. However, according to the masters and shipowners interviewed, with the exception of the physicalization that has been used in the application of infractions, few improvements have occurred, both for safety at sea and to minimize conflicts. For example, vessels considered artisanal, especially the “Itaipava fleet”, are not required to join the system, however, they catch tuna in the same fishing areas, competing with the licensed fleet without being noticed in the re-tracking system.

Fishery Production

The data obtained from the official national banks regarding the average production of fish in Phase III was approximately 23,187 t / year. Having reached a maximum production of 29,445 t in 1999 and 29,445 t in 2011 (Fig. 4). The ICCAT data for 1999, on the other hand, showed 22,948 tonnes, the best result was in 2011, which reached the result of 29,322 tonnes.

Phase III was the period in which the national result remained stable and in high productivity. The last year of this phase, 2011, was the one that achieved the best result. Average production in Santa Catarina was around 15,000 t, and in Rio de Janeiro it was slightly higher than in Rio Grande do Sul (Fig. 9).

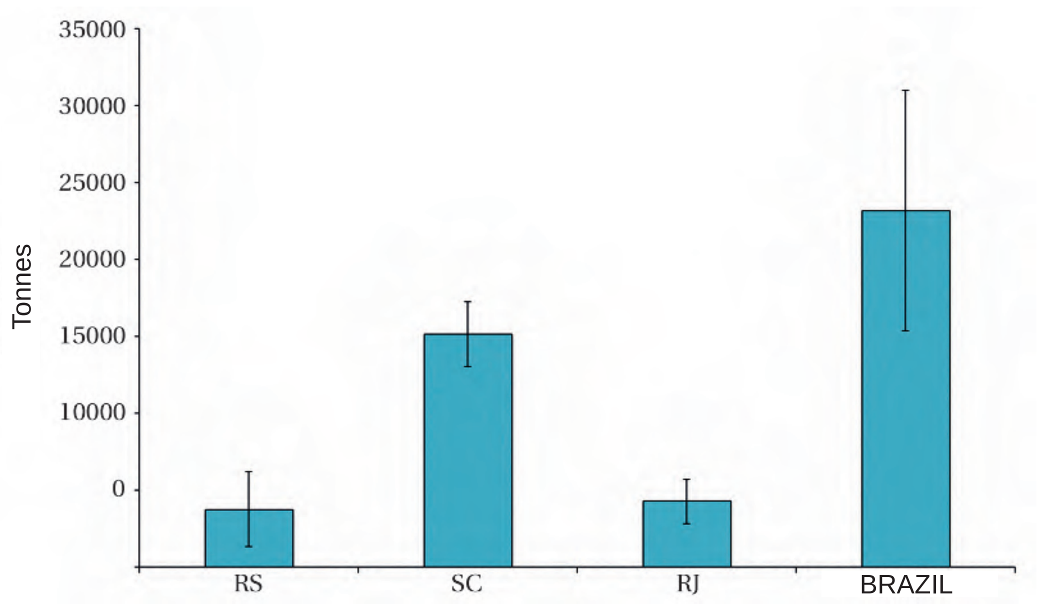

Figure 9. Average (blue bar) and confidence interval (95%) of fishery production in Rio Grande do Sul (RS), Santa Catarina (SC), Rio de Janeiro (RJ) and total for Brazil during Phase III, from 1999 to 2011. The confidence limits of the average indicate the variability of annual production during this phase (Elaborated by the authors).

Technology

This satellite tracking technology was used for the first time in 2001 to monitor foreign fishing vessels, as part of a Federal Government program aimed at occupying the exclusive Brazilian economic zone, exploring areas deeper than 200 m and passing on technology to national companies.

Based on the good results obtained with monitoring and the potential benefit for management, PREPS was developed and instituted.

Industry and Market

The states of Santa Catarina and Rio Grande do Sul already performed well, while the scenario in Rio de Janeiro showed the opposite. The lack of an adequate port structure to carry out unloading was one of the main obstacles. Vessel owners and masters showed dissatisfaction with the provisional quay on Conceição Island, known as the "Sardinha 88 quay", which was initially the place available for handling discharges after the closing of Praça XV.

However, as there was no state investment to serve the vessels, it ended up becoming the definitive unloading site[8]. With most canning industries deactivated, all unloaded fish was removed from the site in trucks, washed and frozen in FRISA and later transported to the large industries, now located in the south, as described in more detail in Chapter 12 , which addresses the socioeconomic dynamics and social conflicts in the skipjack tuna productive chain in Rio de Janeiro.

2.4 PHASE IV: From the height to the scarcity of skipack tuna fishing - 2012 to 2018

Since national data on the Historical Series of Data on Marine Fisheries in Brazil from São Paulo Fisheries Institute ends in 2011, to verify the data in Phase IV, it was necessary to consult directly several regional institutions. The sources were: (i) Santa Catarina - from 2012 to 2018, the UNIVALI[9] database; (ii) Rio Grande do Sul – for the period from 2011 to 2013, the CEPERG[10] reports, and for the period from 2014 to 2018, the reports of the Statistics Project for Fisheries Landing RS[11], from the Institute of Mathematics, Statistics and Physics of the Federal University of Rio Grande (IMEF- FURG), under the coordination of Prof. Paul Gerhard Kinas; (iii) Rio de Janeiro – period between 2011 and 2017, data from FIPERJ[12] reports, and for 2018, data from the Fishing Activity Monitoring Program – PMAP[13], also carried out by FIPERJ.

It is possible that the results in this period present more inconsistencies, if compared to the ICCAT data. A national data collection and information system is not available to inform Brazilian society about the situation of marine resources, not even fishery production. Despite this, the data collected regionally indicates that the results in the years 2012 and 2013 were quite encouraging, however, followed by an abrupt decline until the year 2016. The following years, both 2017 and 2018, showed better results, obviously, not as the level of the year 2012 (Fig. 4). ICCAT data for this period also indicates a decrease, however, less abrupt, with 2013 having the best result, with 32,127 t, and 2017 with the worst result, with 14,577 t. For the year 2018, the result was 14,886 t.

The box 4 shows the increase in the volume of publications that address oceanographic aspects for the years 2016 and 2017. The most likely explanation for this phenomenon is in Case Study 2, Chapter 2. The publications presented that date from 2016 are from studies started in 2013. Case Study 2 presents the integration process between a private company and the University, which, through technology and innovation, added by the FURG Oceanography Institute, carried out a detailed analysis of oceanographic conditions, combined with constant monitoring.

Phase IV is extremely important due to the abrupt differences that occurred within the period. It is possible that the drop in fisheries production is related to the effects of climate change, which affect the ocean dynamics and, consequently, the dynamics of marine biodiversity. The following topics describe the characteristics of the fishing dynamics at this stage.

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[8] Shipowners and masters, interviewed in 2017 and 2018, expressed dissatisfaction with the lack of structure on the “Sardinha 88 pier”, indicating that an adequate warehouse was lacking in Rio de Janeiro to meet the fish discharges from different fishing fleets, including the pole and live bait.

[9] Available at: http://pmap-sc.acad.univali.br/. Acessed on: Mar. 12 2020.

[10] Available at: https://www.icmbio.gov.br/cepsul/acervo-digital/37- download/estatistica/111-estatistica.html. Acessed on: Jul. 16 2020.

[11] Available at: https://imef.furg.br/o-que-e-o-projeto-estatistica-pesqueira. Acessed on: Jul. 16 2020.

[12] Available at: http://www.fiperj.rj.gov.br. Acessed on: Jul. 16 2020.

[13] Available at: http://www.fiperj.rj.gov.br/index.php/publicacao/index/1. Acessed on: Jul. 16 2020.

Box 4. Scientific production

Seventeen publications were found (Fig. 10) in the period of Phase IV, with special emphasis on the years 2015 and 2018, which presented the largest number of publications. One of the topics that appeared among the most researched was about the occurrence of parasites in the skipjack tuna. The other topic that had a good result from publications was about aspects of fishing oceanography (e.g., MADUREIRA *et al.*, 2016; MADUREIRA *et al.*, 2017) and oceanographic parameters in the area of distribution of the species in the Southwest Atlantic.

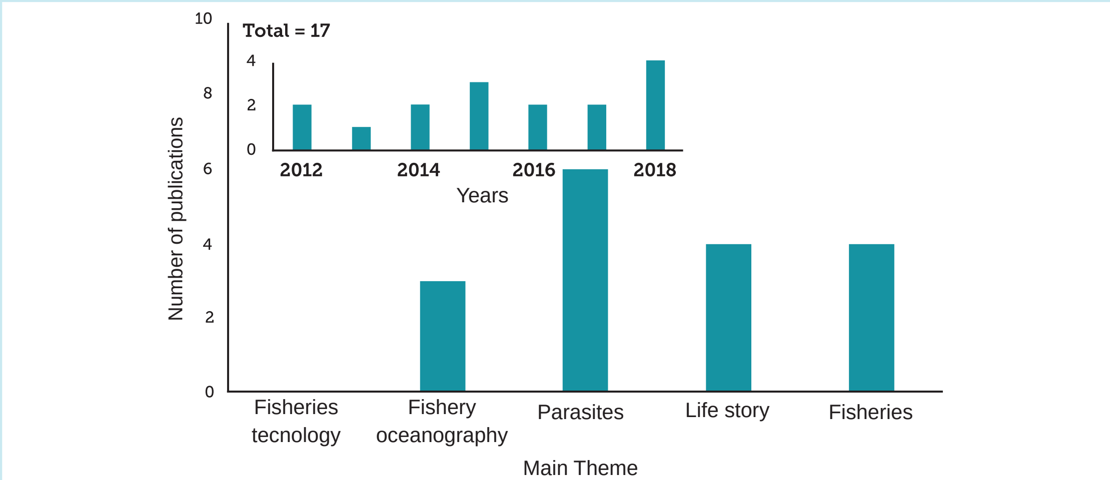

Figure 10. Number of publications in national and international scientific journals on skipjack tuna (*Katsuwonus pelamis*) by year of publication (minor figure) and main theme (major figure), during Phase IV (Prepared by the authors).

Fishing Area

In the state of Rio de Janeiro, the conflicts mentioned in Phase III, continued in Phase IV. The central issue that sustained the conflicts are those presented in Phase III, related to the access limitations for fishing for sardines for live bait in Conservation Units, which is prohibited.

However, the problems related to the fishing and fishery production areas for Phase IV can be explained through the results in table 4. The increase in the number of publications on oceanographic aspects of the species' distribution areas in the Southwest Atlantic highlights the complex interplay of climatic issues that affect the dynamics of marine currents, altering the dynamics of biodiversity, and that, consequently, alter the behavior of skipjack tuna schools. Thus, the pre-established fishing areas, commonly known, are in a constant state of change.

Fleet

According to the interview with the SAPERJ representative, in 2018, the Rio de Janeiro fleet operated with seven boats, considered the smallest number of vessels in operation of all time. The data monitored by FIPERJ indicate that ten boats unloaded in the same year in Niterói. However, in table 1 of Chapter 9, the total number for 2012 was 15 tuna vessels in general, including skipjack tuna. For 2018, the total number was nine vessels (table 1, Chapter 9), that is, the information provided, both by the SAPERJ representative and the data made available by FIPERJ, do not match.

According to the analysis carried out in Chapter 9, the drop in productivity of skipjack tuna in 2018/2019 motivated "the modification of the catch composition of the Rio de Janeiro fleet".

Fishery Production

The data gathered from the official regional databases indicate a record catch in 2012 and 2013 for national production. However, there was an abrupt drop to reach the lowest value of 3,316 t in 2016. This data does not coincide with data reported by ICCAT, which presented the result of 16,418 t in 2016. However, the construction of figure 11 was based on regional data, indicating the greatest annual variability in national catches, mainly due to the disparity between the production landed in Santa Catarina, in relation to the other states.

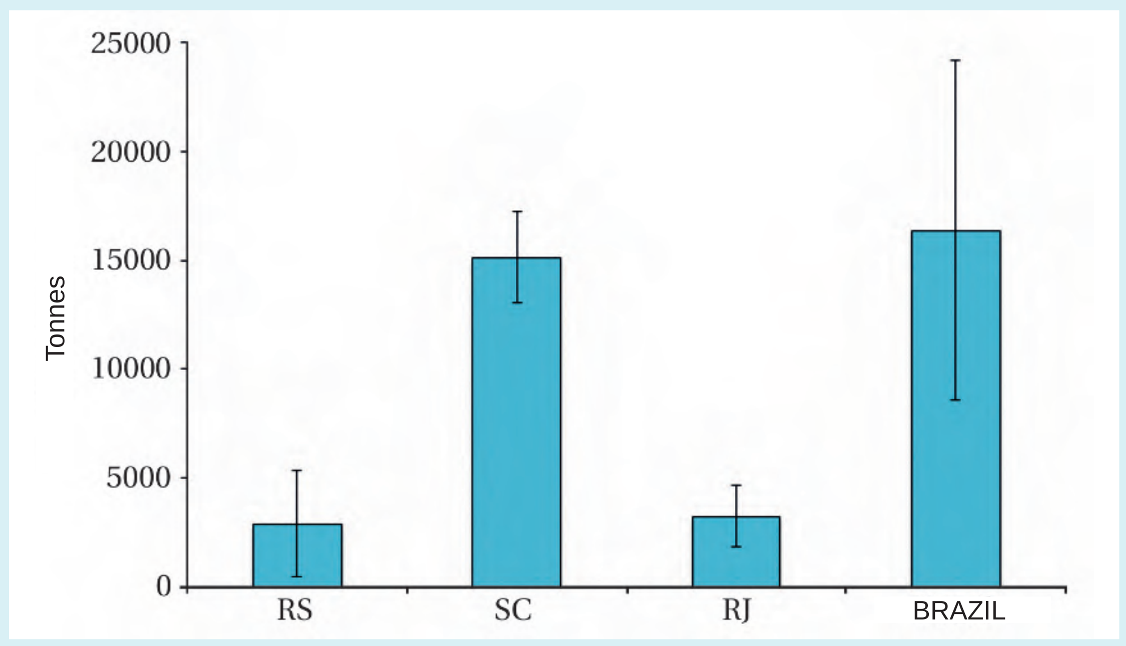

Figure 11. Average (blue bar) and confidence interval (95%) of fishery production in Rio Grande do Sul (RS), Santa Catarina (SC), Rio de Janeiro (RJ) and total for Brazil during Phase IV, from 2012 to 2018. The confidence limits of the average indicate the variability of annual production during this phase (Elaborated by the authors).

Technology

Phase IV can also be considered as the period of innovation. The crisis spurred new experiments, such as, for example, replacing the sardine with anchoíta for live bait, as did the Leal Santos do Rio Grande (RS) industry fleet. This study is presented in Chapter 2, in Case Study 2. The innovation resulted from the transfer of knowledge acquired in previous studies carried out by the FURG Oceanography Institute (IO-FURG) (MADUREIRA *et al.*, 2016). It is important to highlight actions of this partnership - private company-public university -, because knowledge transfer is one of the guidelines that the Intergovernmental Oceanographic Commission recommends for promoting the sustainability of marine resources. These are guidelines agreed during the Conference on the Oceans[14], of 2017, which aim to "strengthen and promote effective and transparent partnerships between multiple stakeholders, including public-private partnerships [...]" (item 12.c), which should be applied as a matter of urgency.

The partnership also boosted detailed analysis of available data, both from the company and from the Institute, in order to refine knowledge about the behavior of schools of skipjack tuna. In addition, this same fleet has used a software that provides oceanographic and plankton productivity data that help in the definition of areas more conducive to catches.

[14] Available at: https://nacoesunidas.org/wp-content/uploads/2019/05/conferencia-oceanos-2017.pdf. Acessed on: Jun. 30 2020.

The Institute assisted in the interpretation of the letters provided by the software. The vessels have a license to use the software and the masters, in possession of the information, can make their decisions regarding the most suitable areas for fishing. Innovation and technology have made the fleet of the company Leal Santos more efficient in terms of fuel economy (see Case Study 2, Chapter 2). Therefore, if diesel oil is saved, it means that the activity has reduced the emission of greenhouse gases into the atmosphere (MADUREIRA *et al.*, 2016).

Industry and Market

With the closure of the main canning industries in Rio de Janeiro, the industrial park ended up being centralized in Santa Catarina, with Camil and Gomes da Costa as the main buyers of fish for canning. Another important hub is represented by the food industries Leal Santos LTDA, in Rio Grande (RS).

Until 2017, at Ilha da Conceição, in Niterói (RJ), companies bought skipjack tuna discharged mainly at the "pier of Sardinha 88". All fish was removed from the vessels and taken to the distribution center of FRISA - Frigorífico Rio Doce SA (Niterói-RJ) for freezing, and later transported by ACM-Pescados by truck to companies in the south. At the end of 2017, discharges at the "Sardinha 88 pier" were disabled due to unsanitary conditions. Part of the discharges were transferred to the Friduza pier, also on Conceição Island, while another part was transferred to the Funelli Comércio de Pescados pier, located in Ponta D`Areia, in Niterói. At the end of 2019, all downloads were transferred to Funelli.

In 2020, only one tuna vessel continues to unload in Rio de Janeiro, due to the continuity of the contract with the fish processing industry. However, all other vessels unload in Santa Catarina or Rio Grande do Sul, where the largest canners in Brazil are located. Only Gomes da Costa, the largest canner in the industry, produced, in 2017, 500,000 cans of 170 g per day[15]. Other large companies (Camil, Leal Santos) also produce large quantities, while the company Tours Conservas, located in Itajaí (SC), produces "artisanal" canned products on a smaller scale, destined for a market gourmet the São Paulo-Rio de Janeiro axis[16]. A more detailed analysis on the topic is presented in Chapter 14.

3. Discussion

The purpose of this chapter was to understand the conditions that enabled the development and consolidation of the skipjack tuna fishing with pole and live bait in the southeastern and southern regions of Brazil, based on national and regional data. The organization of the data in four distinct phases: (i) introduction, (ii) expansion, (iii) stability and (iv) heightened scarcity, allowed the construction of an overview of this fishery.

Perhaps the greatest difficulty has been to reconcile comprehensive statistical data with data from discontinued periods or released only in publications other than national annual reports, such as, for example, data made available by ICCAT. Although the Brazilian government, as a member of ICCAT, is committed to providing this body with annual statistics on the fishing production of all species of tuna and the like caught in Brazilian jurisdictional waters, this has not always been the case[17]. Without the provision of data, gaps are formed, in addition to the fact that, often, the data obtained do not always inform the catches by port of discharge, which makes comparative analyzes between states difficult.

[15] Available at: https://g1.globo.com/sc/santa-catarina/noticia/maior-empresa-enlatadora-de-pescados-da-america-latina-paralisa-producao-em-itajai.ghtml. Acessed on: Apr. 4 2018; Available at: https://g1.globo.com/sc/santa-catarina/noticia/maior-empresa-enlatadora-de-pescados-da-america-latina-paralisa-producao-em-itajai.ghtml. Acessed on: Apr. 4 2020.

[16] Information obtained from interviewing managers of the Industries: Leal Santos (Apr. 2018); Camil and Tours Conservas (Nov. 2019).

[17] In 2017, the Brazilian delegation arrived at the ICCAT meeting with news of the collective resignation of the Scientific Subcommittee of the Standing Committee for the Management of Tunas in the country, not presenting any statistical information on fisheries for 2016. Under these conditions, due to Recommendation 11-15 adopted by ICCAT in 2011, Brazil would be automatically prohibited from fishing any species of tuna under the mandate of the Commission as of January 1st 2018. Available at: http://conepe.org.br/editorial/30. Accessed on: Aug. 25 2017.

In this chapter, it was also shown that national fisheries statistics, before being a State policy for the sector, have been driven by local or regional monitoring programs and projects, often dependent on financing with definite time for closure. Therefore, retrieving and consolidating this information was not an easy task. However, it was relevant to point out the obstacles that hinder the appropriate application of fisheries management methods.

The geographical changes in the production centers are the result of investments in the sector and logistical facilities for the operation of the fleet and installation of industries. In the 1970s, Rio de Janeiro was the pole of the canning industry in Brazil, especially canned sardines. At that time, there were practically 13 to 15 companies canning sardines in the state. Coqueiro emerged as the leader during the 1980-90s, but lost market share, being finally acquired by Camil, in 2011, and transferred to Itajaí. Gomes da Costa, Brazil's current leader, also left Rio de Janeiro for Itajaí (SC), having been acquired by the Spanish group Calvo (MARTINS, 2006), and currently holds 55% to 60% of the market in the Sardine and of Tuna[18], respectively. It produces more than 2 million cans (500,000 tuna) daily and generates more than 2 thousand direct and 7,500 indirect jobs[19].

The park installed in Itajaí offered logistical support in the construction and maintenance of vessels, specialized technical services for the nautical industry, as well as suitable industrial facilities that provided facilities for the flow of production to the main consumer centers. The precarious unloading facilities in Rio de Janeiro gradually promoted the movement of activities to the south, culminating in the almost complete halt of activity in the state, at least for pole and live bait.

Since the 1990s, the capture of the bait has been a bottleneck and a point of conflict between the live bait fleet, the sardine siege fleet and artisanal fishermen. Periods of scarcity increased conflicts, as the sardine siege fleet attributed the lack of adult sardines to the capture of juveniles for use as live bait. Artisanal fishers also complain that tuna vessels, when capturing juvenile sardines in coastal areas, are breaking a link in the food chain, since many other species feed on juvenile sardines in these environments (OCCHIALINI, 2013).

The use of alternative baits is a reality for the Leal Santos fleet in Rio Grande (RS). According to a report by the company's commercial director, this represents a major innovation, with important economic consequences. Anchoíta is a very abundant species and little used as a fishing resource in Brazil and can be an alternative to minimize the impacts on the sardine, at least in the southernmost fishing areas. Another potential field of research would be the cultivation of alternative species for be used as live bait in this fishery. It is true that experiments in this regard date back to the 1980s, and that, despite this, scale production at costs compatible with the fishing operation has not yet been achieved.

Responsible fishing, carried out within premises that minimize aggression to the environment and keep stocks within their limits of sustainable exploitation, has been sought as a standard of excellence for national and international products. Certifications are evaluation processes, which attest to products through detailed analysis of all processes, from fishing to the final product, checking whether the industries follow internationally recommended protocols and procedures[20]. This way, consumers will be guaranteed to be

[18] Information obtained from interview in 2018, with a consultant of the fisheries industry.

[19] Availabe at: http://g1.globo.com/sc/santa-catarina/sc-que-da-certo/noticia/2016/09/setor-pesqueiro-de-sc-se-reinventapara-evitar-que-crise-chegue-mesa.html. Acessed on: May 20 2020.

[20] The Marine Stewardship Council promotes the sustainable fishery through a program of certification for fisheries and companies that go under an evaluation promoted by independent certifiers. Available at: https://www.msc.org/species/tuna. Acessed on: May 20 2020.

purchasing a product captured in a sustainable way. According to the International Seafood Sustainability Foundation and International Pole & Line Foundation (2019), fishing with pole and live bait is considered sustainable fishing, since it catches the fish one by one, with the lowest incidental catch rates and interactions with other species. In addition, the international market has been more demanding, suggesting that certified products, from responsible fishing, can achieve a more competitive and differentiated market value.

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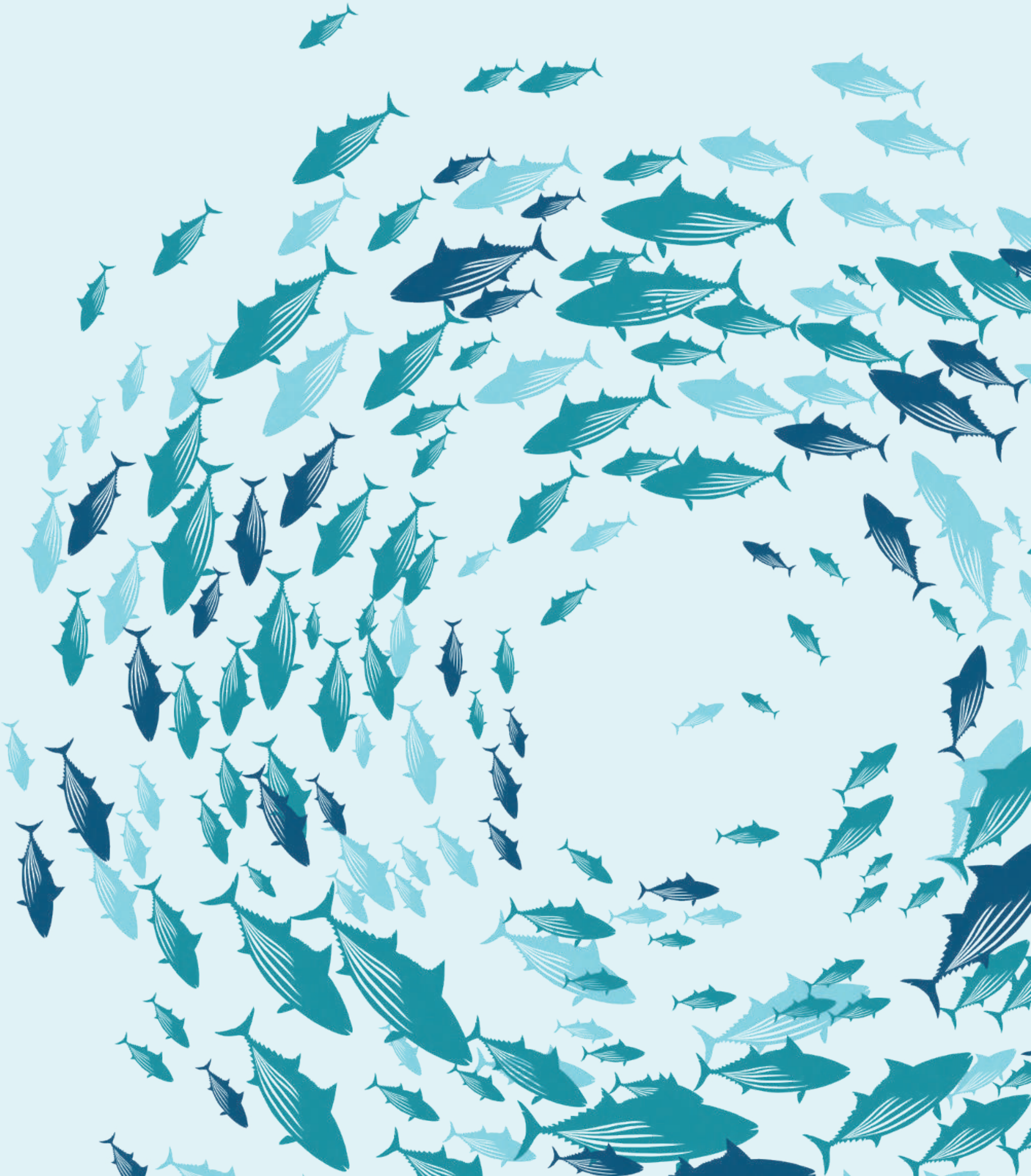
Unit IV

SOCIOECONOMY IN SKIPJACK TUNA FISHERIES



Socioeconomic dynamics and social conflicts in the skipjack tuna production chain in the state of Rio de Janeiro

12

José Eduardo Viglio,
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Introduction

The skipjack tuna (*Katsuwonus pelamis*) is an important tuna species for the Brazilian fishing industry, in addition to being the tuna that occurs most frequently on the coast of the country. The development and dynamics of the skipjack tuna productive chain are conditioned by parameters that impose risks and uncertainties, arising not only from socioeconomic, political and technological factors, but also by biological, ecological, climatic and environmental variables (SOARES, 2009). Changes in these variables may reflect the availability, seasonality and rate of capture of the fishing resource in certain regions. Given the complexity of the variables involving natural and social systems, the conditions necessary for the economic performance desired by the partners in the chain are not always subject to control.

This chapter presents the results of the research carried out by the Center for Environmental Studies and Research at UNICAMP, between mid-2017 and the end of 2018, which sought to understand the structure, socioeconomic dynamics and social conflicts of the skipjack tuna productive chain in the state of Rio de Janeiro (RJ). The analytical emphasis fell on the economic activities of the chain in the state of Rio de Janeiro, in the main restrictive aspects, from an environmental and safety point of view, involved in the capture of the skipjack tuna and the live bait, and in the conflict relations between the different partners in the chain. The continuous fall in the capture of live bait and skipjack tuna in the last five years has intensified the tensions and disagreements between the different stakeholders chain, compromising cooperation between them. This could be seen, for example, in the relationship between research/management and the productive sector.

The skipjack tuna chain in Brazil basically boils down to what is produced in the states of Santa Catarina, Rio Grande do Sul and Rio de Janeiro. The development of fishing with a pole and live bait and the necessary technology on the vessels for this began in Rio de Janeiro, in the late 1970s and early 1980s. At that time, also in Rio de Janeiro, the first canning industry of skipjack tuna appeared. However, despite the fact that the state has become a leader in production throughout the 1980s, Rio de Janeiro has been losing prominence to the two southern states of the country over the past few decades. This trend, as will be shown below, is noted not only by the drop in the volume of fish, but also by the decrease and technological obsolescence of its industrial fishing fleet, when compared to those of Santa Catarina and Rio Grande do Sul, and, still, by the closure of the fish canning industrial units in Rio de Janeiro, finally ending this industrial activity in the state in the 2010s.

In order to characterize and analyze the socioeconomic dynamics and social conflicts of the skipjack tuna productive chain in the state of Rio de Janeiro, the research work sought to identify and describe its different partners and moments, as well as to problematize some factors that condition its performance.

The theoretical instruments and methodological procedures used in this analysis are described in item 1 of this chapter. Bibliographic and documentary research was carried out, followed by field research that included interviews with various social factors and variables that involve the skipjack tuna chain in general and, in particular, the state of Rio de Janeiro. In field research, the method of direct observation of the activities developed in the Rio de Janeiro chain and the social dynamics that underlie them was also used.

In item 2, which deals with the structure and dynamics of the production chain in Rio de Janeiro, the economic segments that are part of the chain are described, according to the National Classification of Economic Activities (CNAE), and, specifically, those that are developed in Rio de Janeiro. The different activities that are part of these segments are analyzed, their flows and dynamics, the profile of the workers involved, the characteristics of the industrial and artisanal fleets, and the volume of skipjack tuna captured over the years.

Item 3 discusses the social conflicts between the productive sector, fisheries and marine management and science in the skipjack tuna chain, mainly around restrictions from the legal point of view, which condition the capture of skipjack tuna and live bait. in the state of Rio de Janeiro, with emphasis on the institutionalization of marine protected areas, the closed period for sardines and the restriction of fishing in areas of oil platforms, which are very present in the Campos Basin and which are attractors of the skipjack tuna.

Finally, some final considerations are outlined and the importance of social and institutional dimensions in interdisciplinary research on fishery resources is signaled.

1) Theoretical instruments and methodological procedures

The research sought to understand the different aspects of the chain that are related to strictly economic activities as defined by the National Classification of Economic Activities - CNAE. Thus, for a broader perspective on the dynamics of the skipjack tuna chain in the state of Rio de Janeiro, we sought to identify the role and performance of social and institutional actors linked to the productive sector, research, management and oversight. To this end, the notion of conflict and negotiation arena was adopted to treat the production chain as a social space for interaction between multiple actors in dispute for access and control of the natural resources involved (FERREIRA *et al.*, 2017). Conflict, here, is understood as manifestations of open gaps between two or more individual or collective actors, who present historical or momentarily incomparable interests, as to the appropriation or control of goods considered rare, scarce (FERREIRA, 2012, p. 3). In these conflicts, interests, needs, rationalities, power, costs and benefits are at stake (BOBBIO *et al.*, 1992).

The concept of chain can be understood as stages of production and distribution, as a set of interconnected links between material suppliers and the transformation processes of the final product (RITZMAN & KRAJEWS, 2004, p. 30). It starts, therefore, from a systemic view, which highlights the connection of these stages by flows of materials, capital and information (CASTRO *et al.*, 2002).

Study field

The research focused on the municipalities of Niterói, São Gonçalo and Rio de Janeiro to analyze the activities, social actors and institutions related to the skipjack tuna chain in the state of Rio de Janeiro. Niterói and São Gonçalo concentrate almost all of the skipjack tuna landing in the state (FIPERJ, 2013a; 2013b; PMAP-RJ, 2018a; 2018b; 2019).

Data collection

Data were collected through documentary research, semi-structured interviews and direct observation (BAYLEY, 2008; BERNARD, 2013) of activities in the production chain, between the periods of July 2017 to December 2018.

Documentary research

The documentary research consisted of the analysis of the following documents and information: Regulatory and normative devices related to the capture of live bait, specifically of sardines and skipjack tuna in relation to fishing in oil platform areas; Minutes and reports of meetings linked to the extinct Technical Working Group on Live Bait – GTT, Brazilian Tuna Fisheries Association and the scientific subcommittee of tuna and the like; Official Gazette of the Union with the list of vessels authorized in the skipjack tuna fishery, with data of the owners and registration number; Reports and information produced by the Rio de Janeiro State Shipowners' Union (SAPERJ); Reports and statistics published by the Rio de Janeiro State Fishing Institute Foundation (FIPERJ); Journalistic texts from Jornal O Globo about the skipjack tuna chain; Official bases of employment and unemployment of the federal government, such as RAIS (Annual List of Social Information) and CAGED (General Register of Employed and Unemployed; National Classification of Economic Activities (CNAE); and bibliographic production on skipjack tuna fishing in the period from 1978 to 2018.

Semi-structured interviews

Twenty-three (23) interviews were conducted during the research period. We sought to interview a group of people who represented the breadth of the social and political-institutional actors involved in the skipjack tuna chain in the following categories: academic researchers (4 interviewees); fishing owners (3); SAPERJ representatives (3); representatives of the Rio de Janeiro Fish Industry Union (SIPERJ) (2); representatives of landing, transport and freezing services (3); Ibama's environmental analysts related to fisheries inspection and monitoring (3); representative of RESEX Marinha de Itaipu in Niterói (1); fishing master (1); representative of the Brazilian Navy (1); technical representative of the Union of Shipowners and Fishing Industry of Itajaí and Region (SINDIPI) (1); former industrial director and currently a consultant to the fishing industry (1).

Direct observation

In the field work, it was possible to follow two skipjack tuna landings, one in the municipality of Niterói, from an industrial vessel, and the other in São Gonçalo, from an artisanal vessel from the Itaipava fleet. It was possible to observe, for example, the different internal and external structures of these vessels, and the practices of collecting and transporting the fish that were employed.

Data analysis

This set of materials, including the transcribed interviews, was analyzed using the content analysis technique, whose purpose is the objective, systematic and qualitative description of the manifest content (BARDIN, 1977). To this end, it was sought to identify, in the analysis of the material surveyed, the social and institutional context of the authors and informants, the timing, the arguments, approaches and views placed there. The set of information collected and analyzed allowed, later, the establishment of different interpretations and interests among the actors of the skipjack tuna production chain in Rio de Janeiro.

2) Structure and dynamics of the skipjack tuna production chain in the state of Rio de Janeiro

Taking as a reference the National Classification of Economic Activities (CNAE), as used by Soares (2009), the skipjack tuna productive chain in the state of Rio de Janeiro is constituted by the following economic segments:

1 – Fishing and related services (class 05118-CNAE), which includes the activities of catching, gathering and transporting fish.

2 – Fish preparation and preservation (class 15148–CNAE).

The canning / preserving activity, which is also part of the 15148-CNAE class, ceased to be developed in the state of Rio de Janeiro in 2011, when the company Camil, belonging to the Pepsico group, acquired the old company Coqueiro. With this change, the processing and canning of skipjack tuna, which also occurred in São Gonçalo, in the state of Rio de Janeiro, was transferred and concentrated entirely on the industrial plant of the state of Santa Catarina[1]. At the São Gonçalo industrial plant, only sardine processing and canning remained. Before that, in 1998, the company Gomes da Costa transferred its manufacturing unit that operated in Rio de Janeiro to the city of Itajaí, in Santa Catarina. Currently, without canning, most of the skipjack tuna caught in Rio de Janeiro, after washing, storage and freezing, is sent to the Gomes da Costa Group (GDC), in Santa Catarina.

Therefore, in a higher level of detail, the production chain of the skipjack tuna in Rio de Janeiro can be divided into three main moments, involving: catch, landing and conservation, each of which is conducted by different companies and actors, as it can be seen in figure 1.

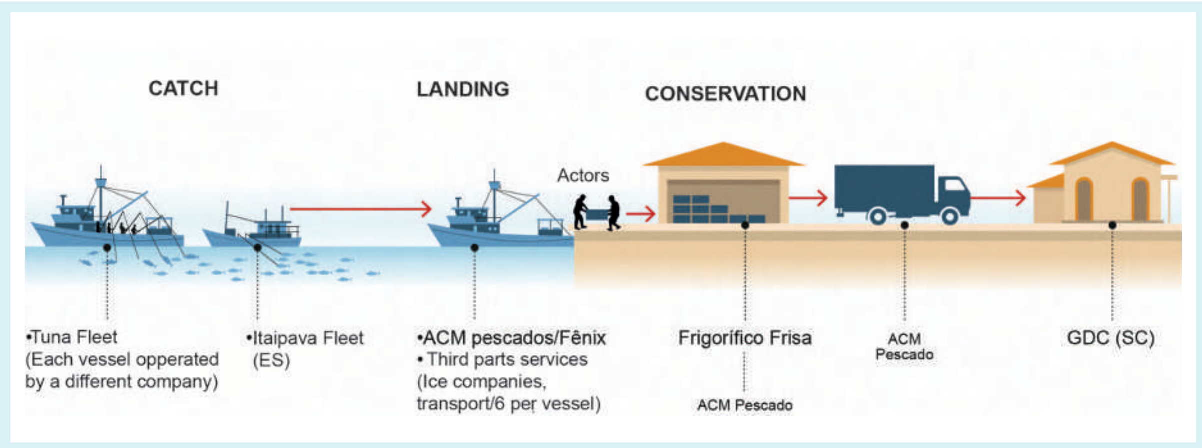

Figure 1. Flowchart of the skipjack tuna production chain in the state of Rio de Janeiro.

Capture

During the analyzed period, skipjack tuna fisheries were carried out by tuna vessels from Rio de Janeiro specifically aimed at industrial fishing for skipjack tuna, none of which has a freezing system on board[2], and by smaller vessels in the Itaipava fleet (SOUSA, 2009; MARTINS *et al.*, 2014).

Over the past two decades there has been a steady decline in the tuna industrial fleet in Rio de Janeiro. MENEZES *et al.* (2010) and SAPERJ showed that in 2003 there were about 17 large vessels operating in Rio de Janeiro, while in 2018, that number dropped to around 7 vessels[3] (Fig. 2).

[1] For a better understanding of the restructuring process, marked by mergers and new acquisitions in the fisheries sector, see MARTINS, 2006.

[2] For more details on this type of vessel, see VIANNA, 2009.

[3] Although SAPERJ indicates only 7 vessels for 2018, the monitoring of fishery production, Chapter 9 of this volume, registered the movement of 10 vessels in Rio de Janeiro for the period.

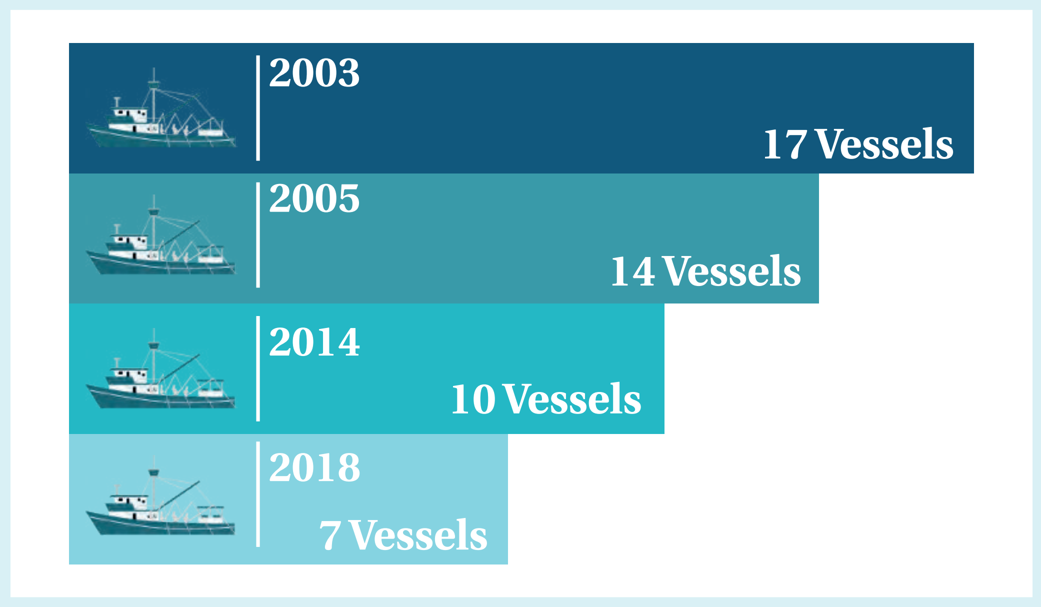

Figure 2. Evolution of the number of skipjack tuna industrial vessels in Rio de Janeiro.

The vessels of the Itaipava Fleet are so named due to the fact that most of the boats are built in the municipality of Itaipava (ES) and identified from the singularities of naval carpentry, as they are adequate to the needs of performance in the open ocean, and, mainly, due to the origin of its fishermen, recognized for their ability to catch fish of significant commercial value, with a national scale. This fleet has more than three hundred medium-scale boats (an average of 12 meters) and uses competitive artisanal techniques in ocean fishing, providing unique fisheries when compared to the other national fleets focused on tuna fishing and the like (SOUSA, 2009).

Some of these vessels fish and land the skipjack tuna in the state of Rio de Janeiro. Depending on their size, they are classified as artisanal and present great diversification in the use of oil and habitats used in a single fishery (multiple), and various fishing modalities also targeting pelagic fish, that is, those swim, preferably, on the surface and half water (MARTINS *et al*., 2005; *et al*., 2014). Due to these characteristics and due to the large volume caught, the research identified the existence of questions and distrust on the part of some players in the arena regarding the artisanal status of this fleet.

Collection

Upon disembarkation, the fish are collected and transported by a subcontractor of the company Gomes da Costa (GDC) based in the municipality of São Gonçalo, ACM Pescados, which is a division of Fênix Pescados to serve the GDC.

As for the disembarkation infrastructure in the state of Rio de Janeiro, specifically for the case of the skipjack tuna in Niterói and São Gonçalo, there is no public terminal for disembarkation. The landing points active in these municipalities are private, as in the case of the ports of Friduza and Fênix Pescados. According to Macedo and Viana (2009), for the state of Rio de Janeiro, the structures that are part of the support to the activity of the fishing sector are under various forms of pressure, such as real estate and oil and gas generation, which they occupy areas previously used by the sector, making access to the sea more difficult or more expensive. For the authors, the drop in the supply of logistical support on land makes the setting up, unloading and maintenance of fishing vessels more expensive, which may reduce the quality of the fish and make it more expensive.

Fish preparation and freezing

In Rio de Janeiro, only a single company carries out these activities, Frigorífico Frisa, which is not specifically aimed at fish and which also focuses on beef. At Frisa, blood and waste separation, washing and freezing of fish are carried out. After freezing, the skipjack tuna and other tuna are fully shipped to GDC, in Santa Catarina, by ACM Pescados. Therefore, canning, which is part of the skipjack tuna chain, has, in recent years, been entirely carried out in Santa Catarina, by GDC.

2.1) The workers in the skipjack tuna production chain in the state of Rio de Janeiro

The federal government's official employment and unemployment bases, such as RAIS (Annual Social Information List) and CAGED (General Register of Employed and Unemployed), did not allow us to reach a sufficient level of data disaggregation to capture the information for these specific workers. The maximum level of disaggregation refers to "Formal jobs in saltwater fishing". In order to collect specific data on workers in the skipjack tuna production chain in the state of Rio de Janeiro, it was necessary to call directly on representatives of the economic segments that make up this chain. Field research and articulations with stakeholders they were crucial to acquire information of that order, although without further sociodemographic details.

Figure 3 shows the data on the fishing workers involved in catching the skipjack tuna. They are highlighted according to the type of vessel: Tuna fleet, considered industrial, and Itaipava fleet, technically considered artisanal.

As can be seen in the figure, in each unit of the industrial fleet, around 25 workers embark, per trip, distributed in a hierarchical occupational structure composed vertically, by order of command of the boat and income, from top to bottom by: master, machine personnel, foreman and fishermen. The profile of these workers is men, aged 20 years or more, and fluctuating average income, which varies according to the amount caught and the division by parts, previously defined by the owner or the master of the vessel. In 2017, SAPERJ estimated that the total number of workers in industrial fishing was 150, since only 10 tuna boats went to the high seas to fish.

Also, according to figure 3, in each boat of the Itaipava Fleet between 10 and 12 fishermen worked, theoretically distributed horizontally in the occupational structure.

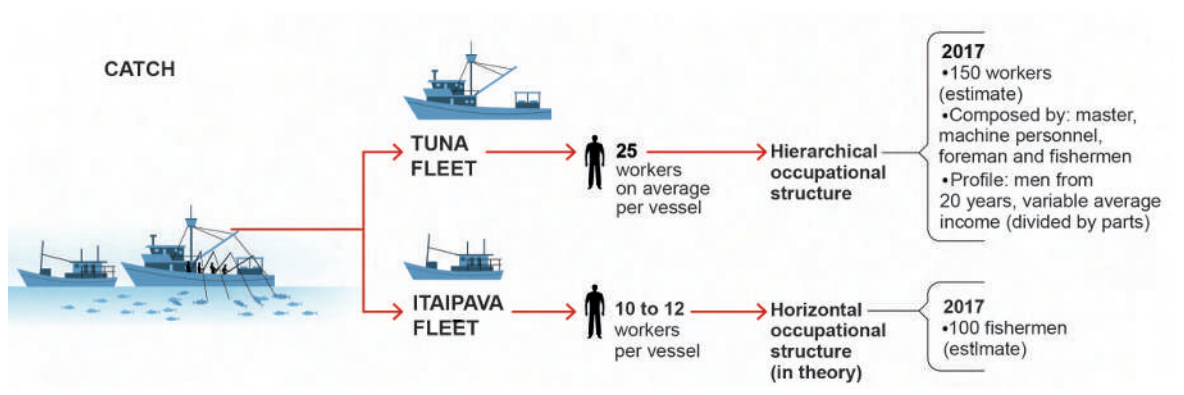

Figure 3. Workers in the skipjack tuna productive chain in Rio de Janeiro involved in catching fish.

From information collected in the field, it is suggested that at least 10 vessels from the Itaipava Fleet landed skipjack tuna and other species in Rio de Janeiro in 2017[4]. Therefore, a total of around 100 to 120 workers was estimated for this fleet. Considering the two types of vessels, in 2017, there were around 250 workers involved in the capture of skipjack tuna in Rio de Janeiro.

Regarding the Itaipava Fleet, it is noteworthy that actors in the chain accused by the research problematized the term craft to designate it, as previously stated. One of the issues raised by them is that the occupational division of workers on these boats, even if theoretically appears as horizontal, and therefore without a functional hierarchy, in practice follows exactly the same standards as the vertical distribution of the industrial fleet, implying the same income division. Thus, the boats of the Itaipava Fleet would not be subject to the burden of industrial vessels, such as being subject to the fiscal controls imposed by environmental inspection bodies, such as Ibama, while their owners would be enjoying financial advantages. of a micro-enterprise, as is the case with industrial boats.

In relation to the information in Figure 4, workers involved in activities related to landing (gathering) and fish conservation are represented. As can be seen in the diagram of the figure, there is only one company responsible for each of these two activities. In activities related to disembarkation, ACM Pescados is the responsible company. Fênix Pescados directly employs 35 employees, of whom only 4 work exclusively at ACM, and mobilizes around 100 individual microentrepreneurs (MEIs), including truck drivers, ice companies and other third party services. However, it should be mentioned that many landings of skipjack tuna and tuna and the like also occur in Porto da Fênix, and on these occasions, Fênix employees as a whole are mobilized. The company did not provide socio-economic data on its employees or on outsourced workers.

Regarding the workers involved in conservation activities, all are employees of Frigorífico Frisa, whose number of employees decreased consecutively between 2013 and 2017, from 50 to just 12. All men, with an average age of 35 and with an average monthly income of around two minimum wages.

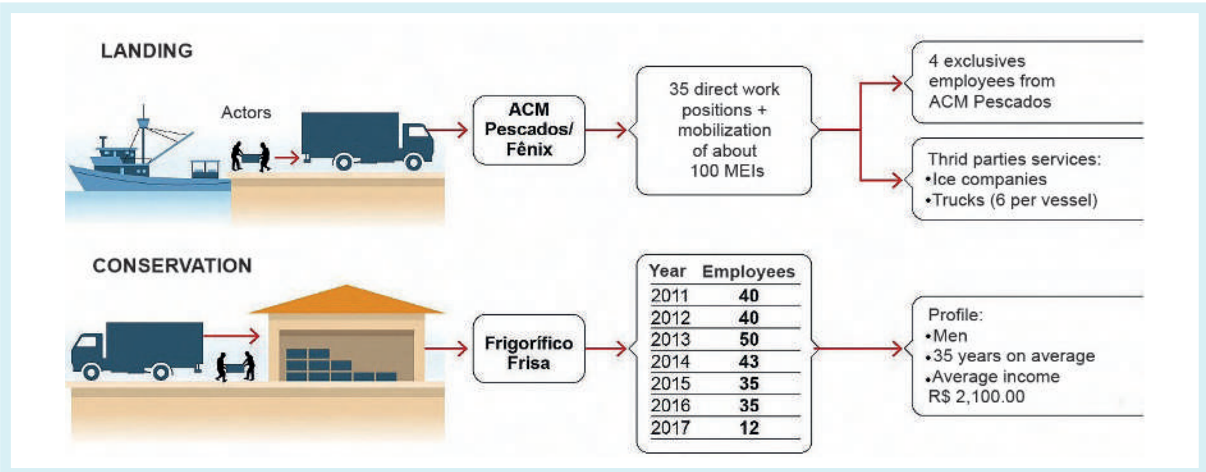

Figure 4. Workers in the skipjack tuna production chain in Rio de Janeiro involved in collection and conservation.

In numerical terms, not considering the Itaipava Fleet, Rio de Janeiro employs about 200 workers directly involved in the activities of the skipjack tuna chain. As noted, this number has been decreasing each year in all activities or moments in the chain. As there is no official data on the Itaipava fleet and its workers operating in Rio de Janeiro, it is not yet

[4] Information obtained through interviews, in 2018, with the owners of a landing point in the municipality of São Gonçalo.

possible to understand how much of this economic niche[5] left by the model of large tuna boats has been occupied by the model of smaller boats in the Itaipava fleet, whose workers, most likely, do not reside in the state of Rio de Janeiro.

2.2) Average annual volume of skipjack tuna caught and processed in the state of Rio de Janeiro

Historical data on the average annual volume of skipjack tuna landed in the state of Rio de Janeiro were collected from documentary, bibliographic sources and directly from actors in the chain, specifically SAPERJ. The researched sources were: i) Regional Coordination of SUDEPE in the state of Rio de Janeiro (1980), which brings data for the period from 1976 to 1978[6]; ii) Castello (2000), which brings data from the period 1979-1985 in the document "Assessment of the Sustainable Potential of Living Resources in the MMA Exclusive Economic Zone. REVIZEE Analysis / Refinement of Past Data on Fisheries Prospecting"(estimate based on the published graph); iii) Jablonski (1996), who brings data from 1986 to 1996 in the document "Note on marine fishery production in the South and Southeast Regions"; iv) Rio de Janeiro Fisheries Shipowners Union (SAPERJ), data provided for the period 2000-2014; v) Menezes *et al.* (2010), which brings data for 2007; and vi) FIPERJ that brings data for 2011-2015. In addition to these, data were collected for the period from 2015 to 2017 with Frisa Frigorífico, which concentrates the washing and freezing of the skipjack in the state of Rio de Janeiro.

Based on the above sources and data, the graph in figure 5 shows the volume (in tons) of skipjack tuna landed in the state of Rio de Janeiro in the specified periods, covering the period from 1976 to 2017, with no data for the period from 1997 to 2000. According to the graph (Fig. 5), the data point to a general downward trend in the volume of skipjack tuna landed in Rio de Janeiro between the years 1986 and 2017. Disregarding the early years of the late 1970s – which were the years of fishing – and the early 1980s – for which there is no data, but it is known, according to the literature and the testimony of stake-holders, which was a period of consolidation and great growth in pole and line fishing live bait in Rio de Janeiro – the highest capture peak of the entire period was reached in 1981 and 1982, when the catch reached 15 thousand tons. Since then, until 1995, the tendency was for an abrupt fall, reaching 2,500 tons in 1993. As of 1996, the trend changes and small increases in catch are verified year by year until reaching 5.8 thousand tons in 2006. In the following three years for which data are available (2007, 2010 and 2011), the total captured is around 4 thousand tons. However, in 2012 a new high was reached, reaching close to 6 thousand tons of skipjack tuna captured. Since then, according to the data obtained by this research work, until the end of 2018, the drop in the catch volume has been constant and abrupt until 2017, when the lowest historical mark since the consolidation of fishing in Rio is reached de Janeiro in the early 1980s, reaching no less than 1.6 thousand tons. The data collected by the PMAP-RJ for the year 2018 confirm this situation of free fall of the skipjack tuna landed in the state of Rio de Janeiro. According to this survey, as summarized in table 1, the production of skipjack tuna was around 720 tons (PMAP-RJ, 2019).

There are uncertainties about the causes of scarcity, as different factors may be involved, including cyclical weather phenomena, climate change, overfishing, increased legal restrictions and decreased availability of live bait.

[5] It is important to note that this economic niche resides in yellowfin and goldfish that are also captured by the industrial fleet when it does not find the skipjack tuna The masters of the industrial fleet prefer the skipjack tuna because it has a price and a certain purchase. If the master captures yellowfin or gold, for example, he will have to negotiate price and buyer at the port. As they are not specialized in catching fish for fresh consumption (something that the Itaipava Fleet specializes in), they often do not reach satisfactory prices with other cargo.

[6] The data for this period represents catches from fisheries other than pole and live bait, which was introduced in Brazil in 1979.

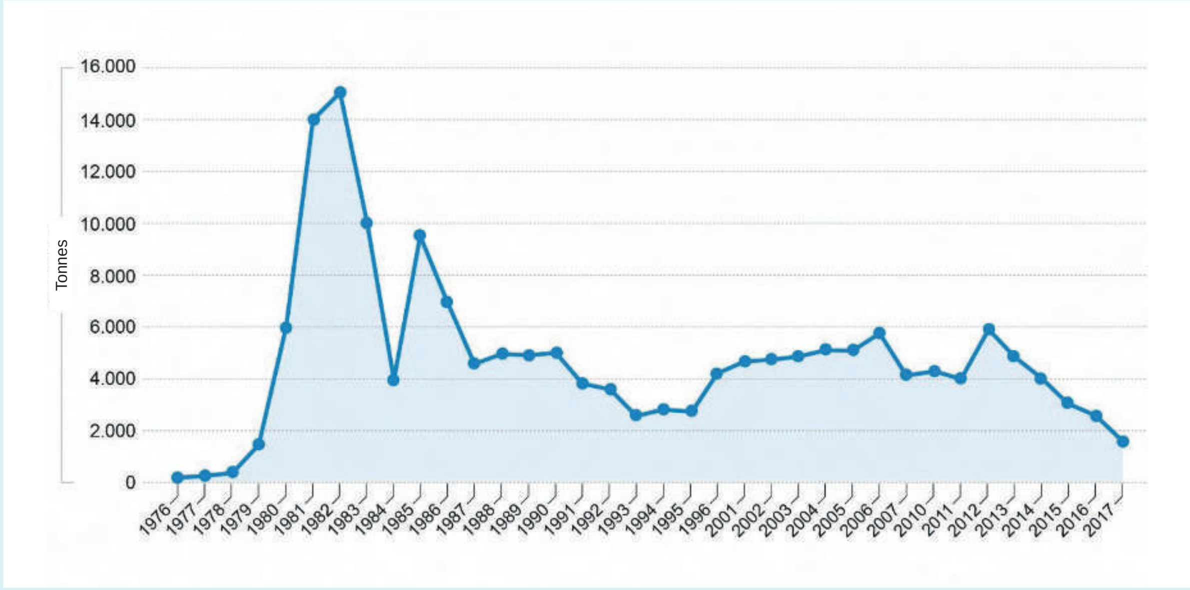

Figure 5. Evolution of the skipjack tuna capture in the state of Rio de Janeiro - 1976-2017 (Sources: 1. 1976-1978 data – SUDEPE (1980); 2. 1979-1985 data - estimate based on Castello (2000); 3. 1986-1996 data - Jablonski (1996), taken from FIPERJ, Ibama / SUPES-RJ; 4. Data from 2000-2014 - SAPERJ; 5. Data from 2015-2017 - FRISA (2018)).

Table 1. Table with the total of skipjack tuna landed in Niterói and São Gonçalo (total RJ) for 2017 (only 2nd semester) and 2018 (1st and 2nd semesters) for the industrial and artisanal fleet (in tons).

FLEET	2nd qtr/2017	1st qtr/2018	2nd qtr/2018	Total 2018 (Not specified)
Niterói industrial	148.40	664.80	54.20	719.00
São Gonçalo industrial	Not specified (less than 34.00)	40.10	29.70	69.80
Niterói artisanal	8.58	Not specified (less than 17.5)	3.26	11.84
São Gonçalo artisanal	9.80	9.80	Not specified (less than 3.20)	19.60
Total/quarter (Not specified)	166.80	714.70	87.10	820.20

Source: PMAP-RJ / FIPERJ (2018; 2019).

In general, the data show little stability in the volume captured over the years, however, with a few exceptions, as is the case of the surveys carried out by FIPERJ for the years 2011 and 2012 and by PMAP-RJ from 2017, it is known that the data are of little reliability. As a rule, the inconsistency and lack of regularity in fishing statistics in Brazil, and more specifically in the state of Rio de Janeiro, compromise the results and hinder a reliable picture of reality. There are gaps in annual series in the survey of the period as a whole and there is a lack of sample standardization. These statistics do not have regular human and financial resources, either by governmental administrations or by the productive sector itself. Therefore, FIPERJ, the state institution responsible for research, is dependent on external resources and specific programs that are uncertain. An example of this is the Fishing Activity Monitoring Project in the State of Rio de Janeiro – PMAP-RJ (PMAP-RJ / FIPERJ, 2018; 2019), which evaluated fishery production for the second half of 2017 and for 2018, with resources from conditions of environmental licensing of the oil and gas sector[7].

In the next topic, some aspects will be discussed that, in some way, are restrictive for the productive chain of the skipjack tuna in the state of Rio de Janeiro.

3) Social conflicts between production, fisheries management and science in the skipjack tuna productive chain in Rio de Janeiro

The fishing of skipjack tuna with pole and live bait is highly dependent on natural stocks of small pelagic fish, which, in the case of the state of Rio de Janeiro, has the sardine as the main bait (OCCHIALINI, 2013). The success of the fishery depends, therefore, on the positive relationship between the capture of live bait and the capture of skipjack tuna (SCHWINGEL *et al.*, 1999). The lack of enough bait to supply the demand of the tuna fleet is a limiting factor to the expansion of these fisheries in various parts of the world (LIMA *et al.*, 2000). In the case of Rio de Janeiro, the creation of marine protected areas, such as the Itaipu Extractive Reserve (RESEX) in Niterói in 2013 (which prohibits the baiting of the industrial fleet in the area), the creation of the sardine closure period – true in 2009, together with a greater fishing effort, mainly from 2016, due to a possible scarcity of the resource, it has been pointed out by connected partners of industrial fishing as one of the bottlenecks for a better performance of fisheries in the state[8]. The excerpt below, obtained through an interview with one of the shipowners, highlights this perspective:

> *I spent 10 days baiting in Cabo Frio; here, Itaipu, it's forbidden, in Botafogo there isn't, sometimes the boat leaves here to go there in Florianópolis to bait, sometimes there is fish and can't get bait, sometimes there is bait and there is no fish. (Interview with Shipowner in 2018)*

On the other hand, the partners linked to research and management partly question the shipowners' arguments, as explained above, specifically with regard to the magnitude of the negative impacts, both of the creation of the aforementioned extractive reserve and of the closed period. A study carried out by FIPERJ, between 2011 and 2012, identified that, in this period, the Itaipu area was used as baiting point only 3 and 9 times over the years, respectively. Jurujuba, also in Niterói, was the area with the largest number of baits in those years, with 61 and 29 occurrences, respectively (FIPERJ, 2013b). For a member of FIPERJ interviewed, this study, whose data were collected from information from the tuna boats themselves, was considered by the institution in discussions about the creation of the Itaipu RESEX, by the State Environmental Institute of Rio de Janeiro (INEA).

The first attempt to create the Itaipu RESEX, according to Simon (2017), took place from 1998 to 2004, without a conclusion due to numerous conflicts, among them, among artisanal fishermen themselves. In 2012, this demand was taken by a group of artisanal fishermen from Itaipu to the Secretary of State for the Environment who, together with the State Environment Institute and in partnership with the Federal Fluminense University (UFF), decided to resume the process of creating the Reservation (SIMON, 2017).

Due to such partnership relationships between university, environmental and fisheries management institutions, exemplified by the case of the creation of the Itaipu RESEX, it was possible observe the existence of tension in the relationship between the productive sector and the research and management sector in Rio de Janeiro.

[7] For a more in-depth look at the skills and transformations of the institutional arrangement in fisheries management in the country, as well as the problems of implementing programs and policies, including monitoring, see Ramos (2016).

[8] According to Occhialini (2013), the industrial fleet employs around 30% of the trip in obtaining this input, and has sardines - true as the preferred species of live bait (82% of the baits captured in 2010-2011). However, in times of scarcity or unavailability, such as that observed between 2011-2012, the manjubas or boqueirão supply the demand of the fleet. Also according to the author, if the search and bait time is counted, tuna vessels employ 4.3 ± 3.13 days on average in the process, varying from a minimum of 2 to a maximum of 12 days.

These conflicts occur when there is competition between different sectors to use the same marine area. As the research and management sectors also propose and implement conservation measures that totally or partially exclude or restrict the activity of the productive sector, this type of conflict is a worldwide phenomenon (BESS & RALLAPUDI, 2007).

The partners in the productive sector repeatedly reproduced the argument that they do not see positive returns from scientific research and management for this sector. In fieldwork, it was possible to verify situations of lack of cooperation between these partners, through direct observation, when, for example, a skipjack tuna industrial boat did not communicate the landing in advance, thus preventing the statistical survey of that boat. In the conception of members of the productive sector of Rio de Janeiro who were interviewed, previous situations of cooperation resulted in restrictive devices to them, thus associating management and research activities with legal restrictions.

For an interviewed researcher, this view of research and management as restrictions on fishing is common among the productive sector due to the absence of systematic research on stocks, fisheries biology and on technologies with the potential to bring practical results to the sector. For this interviewee, the absence of a continuous system of obtaining information is what makes the policy restrictive:

> *Whenever the result that appears is a dangerous result, we can say, that resource has decreased and the fault lies with fishing, and then the control and management bodies, when they exist and want to work, the first measure is restriction, so what appears is the restriction. It is not that the research work that is carried out will ultimately lead to restrictive measures, but the absence of a continuous system of obtaining information is what makes the policy restrictive. It is that old story that you know very well, when in doubt do not go beyond, precautionary principle. (Interview with researcher, June 2018)*

Regarding the closed sardine period, the species' capture is suspended for practically five months in the year, following Ibama's determination. This prohibition was frequently questioned among the players in the productive sector, because, in their opinion, this restriction lacks scientific basis and compromises the operation and investments in the sector, as summarized in the excerpt of an interview with a consultant from the fishing industry:

> *So how will you progress, if you have the most sustainable method [fishing with pole and live bait], but on the other hand, the fundamental that is the supply of live bait, for this methodology, we lock its supply, we cut its supply, we prohibit its supply. Same point: slowly the economic agents that invest in the area, stop investing. He falls, falls, until a point comes in which we lock and for worse. There is a successful project like that of [company] Leal Santos who is anchoita. But in the region of Rio de Janeiro that does not have an easy anchoita alternative as it has in the south, it is affected, it has a very big impact, right? Associated with this, the regions where they captured the live bait, more and more areas of preservation, prohibition of captures etc. were created, you know, already made it more difficult to access this bait. (Interview with former industrial director and current fishing industry consultant in November 2018)*

In summary, the current perception among partners in the productive sector is that there has been an increasing creation of legal restrictions on fisheries, supported scientifically, but with questionable arguments, which compromise the performance of the productive chain of the skipjack tuna. There is also an understanding, not only among the productive sector, that conflicts over the appropriation of these natural resources have become more acute in recent years in the face of the growing scarcity of resources. In this context, one less area for baiting, such as the creation of the Itaipu RESEX, gains a more critical dimension, according to the understanding of the FIPERJ representative who was interviewed.

Another restrictive aspect for the capture of the skipjack tuna refers specifically is specifically to the banning fisheries in oil rig areas. According to the rules of the Brazilian Navy (NORMAM-DPC), fishing is prohibited within a radius of 500 meters around the oil platforms. This restriction becomes more problematic for skipjack tuna fisheries in the state of Rio de Janeiro, since Petrobras alone has at least 40 oil production units, operating 546 wells and 80 installed, exploration and production in the Campos basin (BRONZ, 2009). At the same time, a set of works has pointed out these areas as attractors for fish, and more specifically for the skipjack tuna (KIM, 2015; MENEZES, 2010; JABLONSKI, 2003; 2008; BRONZ, 2005; 2009).

According to Jablonski (2003), in 1998 and 1999, 60% and 38% of the tuna landed in Rio de Janeiro, respectively, came from these prohibited areas. Recently, in 2018, there were changes in NORMAM-08 and NORTEC-08, which deal with restrictions on fishing and navigation in the areas of safety of oil platforms and other offshore and navigation units.[9] According to a representative of the Brazilian Navy who was interviewed in the research, the new text aims to increase the rigor on fishing vessels that invade the areas of safety of platforms and other offshore units.

Throughout the research, it was possible to observe that the practice of fishing in restricted areas of 500 meters around the platforms is recurrent in the speech of the fishing partners interviewed, and not treated as a veiled subject. This situation is highlighted, for example, in the speech of one of the shipowners, when he says: “from time to time we have a fish problem, they all touch the platform and, on the platform, I either starve to death or get a ticket to try pull that fish off the platform”. This picture suggests that some fishing players already account for the risks and costs of illegality in their fishing decisions.

Final Considerations

The skipjack tuna chain in Rio de Janeiro, which was a pioneer and experienced peak moments in capture and processing in the country, has been undergoing transformations in recent decades, a direct result of a set of political-institutional, social, economic and environmental. It is observed, mainly, the shortening of the stages of this chain in the state of Rio de Janeiro and a consequent decrease in its socioeconomic contribution.

As seen in this chapter, some factors listed, of a political-institutional, economic and natural nature, in addition to the conflicts pointed out, explain the situation of the skipjack tuna chain in the state of Rio de Janeiro, mainly: seasonality in availability of live bait and fish marked by a moment of severe scarcity, the process of industrial restructuring of the industry, the reduction and technological obsolescence of vessels, and the instability and gaps in management and policies to promote the fishing sector.

At the same time, the constitution and strengthening of an environmental agenda in the country in recent decades, with norms and new players at stake, it has imposed restrictions on the chain, specifically in obtaining real sardines as live bait for fisheries. One of the consequences of this, especially in times of scarcity due to conditions beyond

[9] An excerpt inserted in the standard follows: “The Maritime Authority, after carrying out a qualitative analysis of the data, will forward the complaints received to the Police Authority and the Federal Agency controlling the fishing activity, for the adoption of applicable sanctions. CP/DL/AG shall reduce the validity of the dispatch by period for the offending fishing vessels”.

these restrictions, is the explanation of conflicts and questions, and even delegitimization of environmental rules, management and science, by the actors. It is practically unanimous in the fishing sector in Rio de Janeiro that there is a prevalence of a conservative approach to the detriment of a productive approach to fishing. There is, therefore, an environmental and a productive-fishing arena. A possibility for a better articulation between them would be the creation of institutions and methods – largely of negotiated resolution - as a way to better process the demands or even prevent them (VIÉGAS, 2016).

At the federal level, the same problems are reflected due to the successive changes and instabilities in the institutional arrangement of fisheries management in the country. Since the extinction of the former Fisheries Development Superintendence (SUDEPE) and incorporation in the newly created Ibama in 1989, the ordering of fisheries resources as an integral part of biodiversity has come under the competence of both bodies concerned with conservation issues, as well as production bias. In line with Ramos (2016), it is possible to affirm that the diffusion of power and lack of coordination compromise the decision-making and effectiveness of fisheries management, since conflicts have been exacerbated and the formation of subsystems (or subareas) has been facilitated, with well defined technical and political perspectives in each set of actors and institutions involved.

Finally, it is necessary to reaffirm the importance of social and institutional dimensions in interdisciplinary research on natural resources. If we do not look at these dynamics, it becomes difficult to understand aspects related to the management, availability, seasonality and rate of capture of the fishing resource in certain regions.

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Analysis of the acceptability of skipjack tuna by public school students in the municipality of Macaé

13

Laís Buriti de Barros

Introduction

The skipjack tuna (*Katsuwonus pelamis*) is a migratory pelagic cosmopolitan species of great commercial importance, with increasing global production in recent decades, and a raw material for canning industries.

Currently, fish production contributes significantly to the supply of food and employment worldwide, accounting for 15 to 20% of all animal protein consumed by the human population. This figure may be over 50% in some countries. Fish is highly nutritious and serves as a valuable supplement in diets low in essential vitamins and minerals (HLPE, 2014).

The ranking published by Food and Agriculture Organization of the United Nations (FAO), in 2018, registered the capture of approximately 3,000,000 tons of skipjack tuna, which guaranteed it the 3rd place worldwide, that year. The report The State of World Fischeries and Aquaculture (FAO, 2018, p. 12) highlights the importance given to the issue of food security, especially in developing countries, since the nutritional conditions of fish caught in the sea are different from fish reared in captivity.

Promoting the increase in fish consumption and its addition to the diets of low-income populations are important means of improving Food and Nutritional Security (SAN) for the following reasons: (i) protein bioavailability is approximately 5 to 15% higher than that in plant sources, containing several amino acids essential for human health, especially lysine and methionine; (ii) the lipid composition of the fish is unique, both long-chain and polyunsaturated acids (LC-PUFAs), with potential beneficial effects on adult health and child development. Many low-cost pelagic fish, such as sardines, are some of the richest sources of LC-PUFAs. In addition, fish is an important source of essential micronutrients such as vitamins D, A and B, and minerals.

The FAO report also points out that when production and / or stock ecosystems are degraded or overexploited, the capacity of the productive sector to guarantee Food and Nutritional Security (SAN) is limited or reduced.

Population and income growth in developing countries, together with the accelerated urbanization process and the diversification of the diet, are factors that should create an additional demand for products of animal origin, including fish. Thus, the future of the fishing sector depends on actions and decisions taken at various levels of social organization and at different scales (BRASIL, 2010).

The inclusion of fish in school meals was evaluated in 2011 by the extinct Ministry of Fisheries and Aquaculture, in partnership with the National Education Development Fund (FNDE), and presented by the Ministry of Education in a Technical Note, recommending the inclusion of fish in food school. The survey indicated that 34% of the 1,884 municipalities surveyed claimed to have included fish in school meals.

The difficulties pointed out were the low acceptance / lack of habit by the students and the high cost, followed by the risk of pimples present in fish meat, difficulty in access and lack of suppliers/absence of products on the market. Despite this, 31% of the municipalities did not claim to encounter difficulties in including fish in school meals (BRASIL, 2013b).

In Brazil, the National School Feeding Program (PNAE) aims to contribute to biopsychosocial growth and development, learning, school performance and the formation of healthy habits of students, through actions of food education and nutritional and the provision of meals that cover their nutritional needs during the period they remain in school (BRASIL, 2013a).

FNDE, responsible for PNAE, when publishing Resolution/CD/FNDE nº 15, of 25/08/2000 and, later, its revision by Provisional Measure nº 2178-36 of 2001, established it as one of the procedures for the control from the quality of the food served to the students, the application of acceptability tests by the executing entities (BRASIL, 2013a).

The acceptability test is indicated by the PNAE for the inclusion or alteration of the supplier of a certain food or brand of a product defined in the menus approved by the Technical Coordinators of School Feeding in each municipality. It is also considered that the acceptability test should be done for each municipality, considering that the acceptability of students may vary between regions of the country. Therefore, in order to assess the acceptability of tuna *Katsuwonus pelamis,* this study, within the scope of the skipjack tuna Project, aimed to carry out the test with public school students located in the city of Macaé, Rio de Janeiro, according to the methodology proposed by PNAE with students, children and adolescents, aiming to encourage and promote their consumption in school meals.

Methodology

Preparation of the recipe

The recipe defined for the tuna acceptability test was a tuna salad (tuna loin in pauch, spaghetti fusilli and natural spices). This preparation was chosen because it allows the pre-preparation with a smaller number of steps and transportation under controlled temperature (cold), contributing to the safety of the food. The ingredients were weighed separately (Tab. 1).

Table 1. List of ingredients of the preparation evaluated in the acceptability test.

Ingredients	Quantity
Tuna pieces[(1)]	40 g
Macaroni type *fusilli* cooked	40 g
Cherry tomatoa	10 g
Extra virgin olive oil	10 ml
Salt	2 g
Parsley	0,5 g

[(1)] Tuna in edible pieces in oil with vegetable stock produced by Cellier Alimentos – Federal Inspection Seal No. 3699 (Ministry of Agriculture, Livestock and Supply).

The tuna salad was prepared at the Food Technology Laboratory of the Ajuda do Polo *Campus* Macaé at the Federal University of Rio de Janeiro by the responsible team (Fig. 1). The pre-preparation for the test days was carried out on the eve of each date, and stored under refrigeration for 12h until the time of the test.

Figure 1. Finishing the tuna salad. Photo: Laís Buriti de Barros.

The ingredients served in raw form were washed under running water and cleaned in a hypochlorite solution for 20 minutes. The pasta was cooked in the time recommended by the manufacturer with 0.5% salt and then cooled with cold filtered water to stop cooking and reduce the temperature of the pasta. Then, tuna pieces, cherry tomatoes, chopped parsley, salt and, finally, olive oil were added.

When finished, the tuna salad was packaged and had its temperature measured and recorded on its own form for control. It was transported in thermal boxes, and the temperature was maintained with the aid of recyclable ice to the location of the events.

Acceptability Testing

The acceptability test is an instrument to verify the average preference of the foods offered in school lunches. According to the Manual for application of acceptability, published by PNAE (BRASIL, 2017), the objective is to "measure the acceptability index of the food offered to students" in order to offer "an accepted and healthy food", which improves the development of the student in the classroom and promotes the formation of good eating habits.

For the application of the test, it is necessary to ask the taster to evaluate how much he likes or dislikes the sample. The test consists of a scale of "n" points by which the taster indicates his impression on the sample, where the ends of the scales indicate the maximum or minimum of an impression or an attribute, such as taste, for example. The type of scale must be appropriate to the age group of the target audience, and it can be a facial hedonic scale, suitable for children up to 6 years old, or verbal or unstructured hedonic scale, for teachers over 7 years old (PALERMO, 2015).

For this study[1], a form with questions was prepared using a five-point verbal hedonic scale (1 = disliked; 2 = disliked; 3 = indifferent; 4 = liked; 5 = loved it).

[1] The project was approved by the Research Ethics Committee of the Universidade Federal do Rio de Janeiro – *Campus* UFRJ Macaé, registered under No. 9555119.3.0000.5699.

This question also contained two questions about what the participant liked the most and what he disliked the most in preparation, according to the Manual for application of acceptability tests in the National School Feeding Program (BRASIL, 2017) (Fig. 2).

Name: ______________________________ Age: ______ Series: ________

Check the answer that most represents what you think of the tuna salad:
( ) I loved it
( ) I Liked it.
( ) Indifferent
( ) Did not like it
( ) Hated

Tell us what you liked best about the preparation: ______________________________

____

Say what you liked least about the preparation: ______________________________

____

Figure 2. Verbal hedonic scale model that can be used by students from the 6th year onwards.

The descriptive categories presented on the hedonic scale were transformed into the corresponding numerical values, with values of 1 and 5 being assigned to the categories “detested” and “loved”, respectively, for data analysis. For the acceptability test, samples are considered accepted if at least 85% of the tasters assign a grade ≥ 4 in terms of global assessment, according to Resolution/CD/FNDE No. 26 (BRASIL, 2013a).

During the tasting, the tasters were arranged in individual cabins in a place with a controlled room temperature (25ºC). It is worth noting that these conditions contribute so that the tasters, in this case, the students, do not talk to each other, as shown in figure 3, below.

Figure 3. Cabin with untrained tasters during the acceptability test. Photo: Laís Buriti de Barros.

Acceptability Test Results

For this study, acceptability tests were applied to two different groups of students, with different age groups, on different occasions (both in the year 2019): (i) the first took place on “World Oceans Day”, an annual event held at the Biodiversity and Sustainability Institute – NUPEM, in *Campus* Macaé at the Federal University of Rio de Janeiro; (ii) the second, during the “Week of Extension and Research” event, held at the Instituto Federal Fluminense (IFF) *Campus* Macaé.

The standard procedure that preceded the application of the tests, for both the first and the second, was the distribution of the Term of Free and Informed Commitment (ICF) to all participants and the Term of Commitment and Assent for Minors (TCAM) to the participants. responsible for underage participants to authorize their participation in the tests. Participants are called untrained tasters.

First Test – TCAM and TCEL were delivered to 500 responsible students from public schools[2] who were previously invited to participate in the event “World Oceans Day”. Among the invited schools, elementary school students were delimited, from 6th year, aged 10 to 16 years. Of the 500 guests, only 242 students were authorized. But, effectively, the tuna salad was evaluated by 229 untrained tasters. The result was 86.5% acceptability (198 tasters accepted the preparation); of these, 32% (64 tasters) highlighted tuna as the most preferred ingredient, and 8% (16 tasters) as the least preferred ingredient. These data are summarized in figure 4.

Results

198 tasters **accepted** the preparation
86.5% acceptability

32% pointed out the tuna as the **preferred** ingredient

8% pointed tuna as the **least preferred** ingredient

Invited tasters (students between 10 and 16 years old)	500 students
Authorized tasters by those responsible	242 students
Tasters who effectively participated in the test	229 students

Figure 4. Results of the first acceptability test.

In order to popularize the nutritional benefits of fish, the team responsible for the test also presented recipes with various forms of preparation to encourage fish consumption and organized an educational activity entitled “Path to healthy eating”, based on 10 steps to healthy eating according to Food Guide for the Brazilian Population (BRASIL, 2014).

[2] Amil Tanos Municipal School, Fluminense Federal Institute, Journalist Álvaro Bastos State School, Joffre Frossard Municipal School, Matias Neto State School, Zelita Rocha Municipal School and Doutor Cláudio Moacyr de Azevedo Municipal School.

The participation of students from public schools in Macaé was very positive, mainly due to the participatory and joyful interaction with scholarship students and volunteers from the Nutrition Course at the Federal University of Rio de Janeiro - *Campus* UFRJ Macaé. In a healthy and fun competition among students, the groups answered questions previously elaborated to reach the goal of completing a circuit, reaching the end in first place.

Second Test - With the same procedure as the first test, initially, delivered to the guardians of minors the TCAM and the TCLE and the older students only signed the TCLE. For the second test, 300 students from the 1st year of high school were invited, aged between 14 and 25, all students from IFF *Campus* Macaé. The objective of the second test was to increase the number of tasters and, with that, improve the final result data for the same recipe. For the acceptability test, a 50g portion of the tuna and pasta salad was served, which was evaluated by 168 tasters. Of these tasters, 157 accepted the preparation, indicating 93.5% acceptability, with 36% (56 tasters) indicating tuna as the most preferred ingredient, and 6% (10 tasters) as the least preferred ingredient. These data are summarized in figure 5.

Results

157 tasters **accepted** the preparation
93.5% acceptability

36% pointed out the tuna as the **preferred** ingredient

6% pointed tuna as the **least preferred** ingredient

Invited tasters (students between 14 and 25 years old)	300 students
Tasters who effectively participated in the test	168 students

Figure 5. Results of the second acceptability test.

The objective of applying the two tests was to improve the number of tasters of the recipe (sample number) and have a more reliable result on the impression of the tasker on it. Although the result of the first test exceeded the minimum percentage of 85% (see figures 4 and 5) required by the PNAE, the researchers decided to apply a second test to confirm the percentage of acceptability. Adding the number of effective tasters in test 1 (229) with that of test 2 (168), there were a total of 397 students who tasted the tuna salad. Of this total, 355 accepted the preparation. The result was positive, because the final percentage was 89.9%, improving acceptability.

Innovation for other fish flavors

It is known that fish provides essential nutrients for the health of children and young people. It is also known that food culture is a process under construction, with constant learning, above all. In this sense, innovative multidisciplinary research is fundamental to try new foods and develop new flavors. In the state of Rio Grande do Sul, an innovative research was developed, from 2009 to 2014, with the aim of introducing anchoita, *Engraulis anchoita*, a small and abundant pelagic species, in school feeding. The study aimed to evaluate the possibility of including that fish in school meals, considering acceptability and adherence, and also the factors that interfered in its consumption by students from public schools in Rio Grande do Sul. The acceptability of the product, in the form of canned with tomato sauce, reached the rate of 75%, being below the index indicated by the PNAE, of 85% (MADUREIRA *et al*., 2009; SILVA *et al*., 2012; CARBONERA *et al*., 2014).

Fonseca *et al.* (2017), continuing the analysis of that study, indicated that fish is not a usual food in infant feeding, especially in the state of Rio Grande du Sul, which made it difficult for students to accept it (68.7% liked the preparation "pasta with anchovy sauce"). The authors evaluated that in the municipality of Porto Alegre (RS) the acceptability was 81%, although the adherence was the lowest (45%), suggesting that the greater acceptability can be attributed to the presence of fish in the school menus of that County.

The authors mentioned advanced in the studies and, in a second stage of the project, evaluated the adherence to different preparations with anchovy fish, with the observation that "pasta with anchovy sauce" was the option most chosen by the schools, possibly due to the its practicality of preparation, although it was the one with the lowest adherence (68.5%). The preparation that showed the greatest adherence was "pizza" (92.1%), being the second most chosen option by schools to serve students. The high adherence to this preparation, according to the authors, can be explained by the fact that it is a food traditionally incorporated into children's preferences.

In any case, the anchoita project showed that there is a field to be explored to increase school feeding with products from marine fisheries, especially those that are easy to prepare and have high acceptability by students.

The place of tuna in school meals

In 2011, the report with the results of the research "Nutritional composition of school meals in Brazil: an analysis based on a sample of menus" was carried out by CECANE at UFRGS. The objective of this research was to know the nutritional composition of the food offered in schools. The researchers analyzed 1,064 school cards in Brazil, with 54.4% of urban areas, 38% of rural areas, 3.2% of indigenous communities and 4% of remaining quilombo areas, taking Resolution/CD/FNDE nº 38/2009 as a basis for comparison. The analysis organized the nutritional composition by frequency of food supply in the analyzed menus. The foods mentioned in the menus were separated into groups, for example, fish was shown in table 3 in the meat and egg group (BRASIL, 2011, p. 5-6), divided into two categories: (i) fish and seafood ; (ii) canned fish (tuna and sardines). The frequency in menus throughout Brazil of canned fish, including tuna and sardines, presented the percentage of 92.5% for "No time" (see table 2).

Table 2. Frequency of canned fish (tuna and sardines) on the school menu.

Food	Frequency (%)	Brazil	Mid West	North	Northeast	Southeast	South
Canned fish (tuna or sardines)	No time	92.50	98.90	95.30	84.00	96.90	96.90
	1 or 2 times	7.50	1.10	4.70	16.00	3.10	3.10
	3 or 4 times	0	0	0	0	0	0
	5 times or +	0	0	0	0	0	0

Adapted from BRASIL, 2011.

The results of the survey on the frequency of food on school menus throughout Brazil indicate that the frequency of tuna is practically nil, with a 92.5% index of “No time” and 7.5% for 1 or 2 times. However, the results of the two sensorial analyzes presented in this chapter, with the participation of 397 tasters from Macaé public schools, within the scope of the Skipjack tuna Project, presented an **average of 89.42% acceptability** of the skipjack tuna.

Therefore, in the sphere of the Skipjack tuna Project, acceptability tests showed results above the percentage of 85% recommended by the PNAE. This result makes data available so that new preparations and/or products can be inserted in the menu of public schools, positively indicating their applicability to the sector of production and distribution of institutional meals.

Final Considerations

The composition of the recipe evaluated sensorially within the scope of the Skipjack tuna Project offers a satisfactory supply of protein and carbohydrates, and can be offered on the school menu as a main dish. Practicality from the point of view of pre-preparation and preparation of the recipe must also be considered. The skipjack tuna analyzed is marketed in packages that do not require refrigerated packaging and, in addition, the product is ready for consumption. In this way, the pre-preparation comprises only the cooking of the pasta, cleaning and cutting of the spices, and portioning of the ingredients, which can be served hot or cold.

Considering a Maximum Sustainable Yield of 27,000 t/year for the skipjack tuna in the Southwest Atlantic Ocean (see Chapter 10) this fish can be considered for inclusion in school meals to stimulate fish consumption in Brazil, especially due to its acceptability and its nutritional value. In addition to this aspect, storage and preparation facilities serve as alternatives for their consumption by schoolchildren in regions far from seas and rivers.

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Development and perspectives for the marine-fishing activity of the skipjack tuna

14

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Introduction

Since its beginnings, fishing has always been an important economic activity for tribes and civilizations, both because it is a relevant source of food and nutrition, and because it is the basis of livelihood and income for millions of people around the world (SAHRHAGE & LUNDBECK, 2012; FAO, 2016). Fishing (unlike aquaculture) is, even in its most advanced standard, an extractive activity. Whether it is marine (87%) or continental (13%), the fishing resource is defined as a common property resource for society, which is available and free in nature and can be extracted for common benefit (GORDON, 1954).

As a rule, marine fishing is divided into two forms of extraction: coastal and oceanic. While the coastal one is essentially focused on subsistence and leisure activities, focused on small or medium scale fisheries for shrimp and coastal fish, the oceanic one is mainly focused on pelagic fish, which consolidates it as a more elaborate economic activity., with larger species and higher market value (PINCINATO, 2010).

However, fishing is susceptible to several factors, such as dependence on nature and seasonality to access schools; fishing and storage techniques, given the product's perishability; the type of product, its selling price and the target market; and all the logic of resources and sustainability. In addition to the depletion of coastal fishing resources, the main alternative for the development of fishing activity in Brazil is precisely in ocean fishing, aimed at capturing, among other fish, tuna (HAZIN & TRAVASSOS, 2007).

Skipjack tuna is a pelagic species, cosmopolitan of tropical and sub-tropical waters (COLLETTE & NAUEN, 1983). It is characterized by being typically oceanic and highly migratory, forming large schools on the sea surface (LIMA *et al.*, 2000). In addition, the skipjack tuna is a commodity highly valued and widely traded globally with stocks distributed worldwide, especially for tied sale (FAO, 2014).

In Brazil, 90% of tuna catches are of the species *Katsuwonus pelamis*, the skipjack tuna. Considering the vast Brazilian coast and the confluence of the waters, it is known that the skipjack tuna is concentrated on the coast of the southeast-south region, configuring great commercial importance as a fishing resource. However, in Brazil, fish consumption in general does not exceed 10 kg per capita/year, since it encounters a series of barriers and challenges to become an alternative to other sources of animal protein, mainly poultry and pork (DURAN *et al.*, 2017; THE VILLAGE *et al.*, 2019).

In this context, the question is: why are other proteins consumed at the expense of fish protein? Why is the fish supply deficient? Why is the product variety low? Despite the aforementioned expectation of global growth, low Brazilian consumption is a cause and consequence of competitiveness problems for the industry (low variety of products, poor quality, etc.).

At the same time that the market does not make demands regarding the quality of products, the industry does not seek to increase the technological standard to stimulate a new demand. In addition to low technological intensity, logistical activities present serious obstacles, ranging from outdated vessels, storage failures and even precarious transport. The resulting low volume of consumption of this type of protein, combined with a deficiency in public policy and regulation, stakeholders (fishermen, shipowners, industry, among others). In this scenario, without greater incentive, those who could exercise governance and encourage the development of the skipjack tuna chain, do not get to do it.

Given the deficient characteristics of the market, as well as due to the different levels of technological intensity, the logic of organization and functioning of the skipjack tuna productive chain can be interpreted from “two scenarios”. In a first scenario, the current picture is described, with outdated technology, absent governance structure and low value-added market. However, the second scenario shows that, by offering knowledge and generating technological development, associated with concise governance and established in and by the skipjack tuna chain by leading companies, it is possible to create specific markets and add value to the product generating wealth.

This behavior of the skipjack tuna chain creates the need to know, understand and discuss different mechanisms so that it is possible to transform a natural source of resources (marine) into socioeconomic wealth and prosperity (fishery products). Therefore, it is necessary to analyze the dynamics of the marine-fishing activity, as well as the structure of the skipjack tuna chain, emphasizing its market, technological and institutional dimensions.

From this context, this chapter aims to propose development alternatives and analyze the prospects for the marine-fishing activity of the skipjack tuna. Thus, to achieve the proposed objective, a research with a qualitative approach, of the descriptive type, was used. Data collection was based on documentary (technical reports) and bibliographic (scientific articles) research, technical visits, in-depth interviews and the realization of a focus group, which allowed discussions between different partners in the marine-fishing chain of skipjack tuna.

Thus, the following section presents the dynamics of marine activity – fishing for the skipjack tuna, based on the relationship between the market, technology and the sector’s governance structure. The relationship between these three variables allows the definition of the structure of the skipjack tuna chain. Then, a development plan for the skipjack tuna chain in Brazil is proposed.

1) The Dynamics of Skipjack Tuna Marine-Fishing Activity

National tradition and culture do not treat fishing as an economic activity capable of generating wealth and prosperity. As it is an extractive activity, dependent on natural (climate change), anthropic (environmental degradation) and normative issues, the setbacks are almost inherent. However, it is necessary to understand that these impacts are the result of typical fluctuations in an activity that is dependent on natural stocks and, around this reality, it is necessary to structure and establish market dynamics (products and consumption), technological (chain) and institutional (sectoral governance).

To understand the dynamics of the marine-fishing activity of the skipjack tuna, the sections below report the results of the wide-ranging diagnosis carried out. For this, the following data collection techniques were used: bibliographic, documentary research, technical visit and in-depth interviews. Bibliographic and documentary research are based on secondary data obtained through scientific articles or widely accessible technical reports. The technical visit took place at the different companies operating in the sector, in order to analyze their activities and understand the transformation processes. In addition, in-depth interviews were conducted and workshop with different experts of the sector.

1.1) The Logic of Skipjack Tuna Marine-Fishing Activity

Among the different species of tuna, the skipjack tuna stands out as the third most produced tuna species in the world – on average, 3 million tons per year, which represents about 40% of the total world tuna catch (FAO, 2018). The tuna fishery in the Atlantic Ocean is less expressive than in the other oceans, but still the skipjack tuna occupies a prominent place when considering that about 20% of the total annual catch, approximately 25 thousand tons, comes from fisheries performed on the southeastern and southern coasts of Brazil (ICCAT, 2019).

In Brazil, 90% of the tuna catches are skipjack tuna, representing more than 95% of the raw material used in tuna cans (GONÇALVES, 2011; MOHAN *et al.*, 2015). The catch volume of skipjack tuna is mainly influenced by climatic variations such as El Niño and La Niña, where the increase in positive anomalies leads to the difficulty of obtaining bait (in this case, the capture of sardines), access to stocks and the consequent fall in catches (see Chapter 2 and SCHMIDT *et al.*, 2019).

As a result of these climatic variations, in a period of less than 10 years, production fell from 30 thousand tons in 2011 to 20 thousand tons in 2017, which represents a drop of one third (Fig. 1). The reduction in the volume of skipjack tuna caught in Brazil meant that there was a need to import tuna, which caused an increase in the price of the product and a decrease in consumption.

Figure 1. Skipjack tuna available for production in Brazil (Adapted from SCHMIDT *et al.*, 2019).

The increase in imports, in a way, due to the inherent lack of predictability of marine-fishing activity, generated a cascading effect. This market behavior ended up reflecting throughout the chain, considering that it compromised the income of the fisherman and his family, the supply-security the activities of the industry as a whole and even affected the quality of the product that reaches the market.

It is understood, therefore, that the dynamics of the marine-fishing activity of the skipjack tuna occurs from three dimensions: market, technological and institutional. The relationship between these three dimensions is what determines the different arrangements of the skipjack tuna chain.

1.2) The Skipjack Tuna Market in Brazil

The world production of fish has grown 3.2% per year, surpassing the population increase of 1.6% in the same period (FAO, 2014). In the period between 1980 and 2016, the worldwide consumption of fish per capita went from 12 kg/year to almost 20 kg/year (FAO, 2016), which is equivalent to a consumption of 400g per week (about 3 to 4 fillets).

The use of new production techniques has increased the availability of fish. In addition, the search for consumers for healthier foods that, in line with scientific discoveries, greatly influences the growth in demand for fish and the various benefits that this protein brings to health (TRONDSEN *et al.*, 2004; VERBEKE & VACKIER, 2005).

Fish plays an important role in the human diet, providing about 20% of the average intake of animal protein to 3 billion people and is rich in polyunsaturated fatty acids from the omega-3 family (FAO, 2014). In some developed countries, consumption per inhabitant reaches up to 1 kg per week. Portugal, Japan, Norway and Spain, for example, consume approximately 50-60 kg/year. On average, industrialized countries consume 500g per week (30 kg/year).

However, despite greater ease of access and greater concern for healthy habits, fish consumption in some developing countries, such as Brazil, is still below the level recommended by the World Health Organization (WHO), which suggests that people adopt a weekly portion of at least 250 grams of fish (around 12 kg/year) in your diet.

Although Brazil has a vast coastal area, 12% of the world's freshwater reserve, 2 million hectares of wetland, reservoirs and estuaries, the national average of fish consumption is 9.75 kg per inhabitant per year (DURAN *et al.*, 2017), below the WHO recommended. More than that, fish consumption is only 5% of the total protein consumption of Brazilians (Fig. 2).

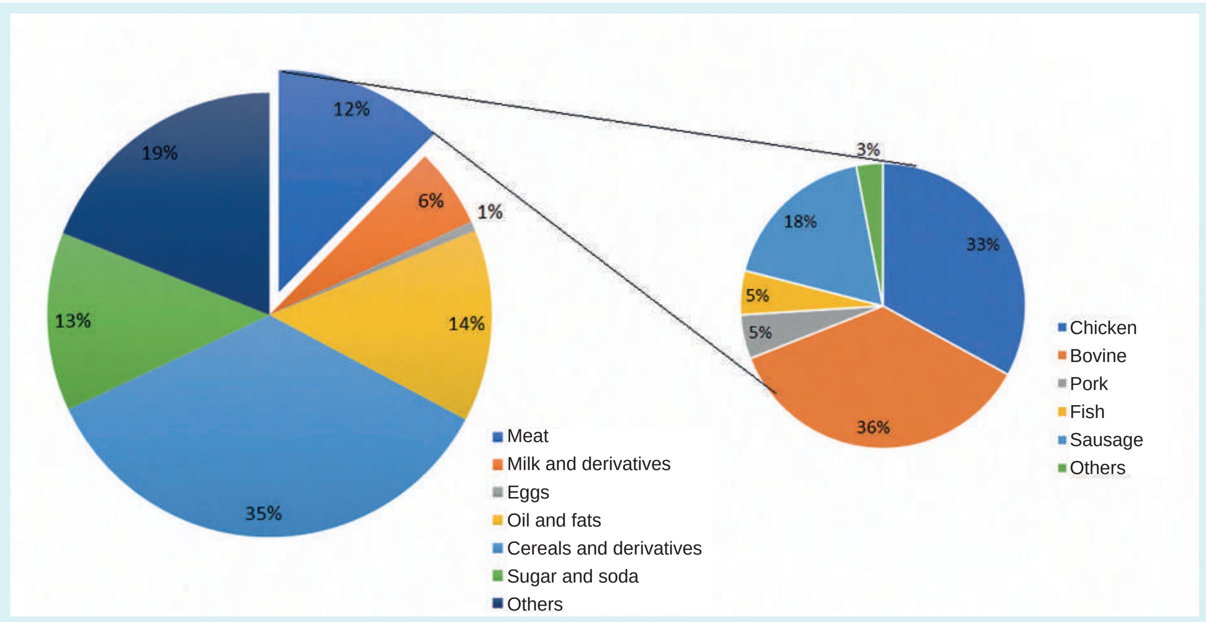

Figure 2. Protein consumption in Brazil (Adapted from LEVY *et al.*, 2012).

Low consumption can be linked to lack of availability, quality variation, precarious packaging and little variability of products that meet the needs of consumers (VERBEKE & VACKIER, 2005). In addition, the lack of preparation skill, the high price, the strong odor and taste, the lack of habit of consuming fish, the low convenience, the risks of contamination and the diseases associated with consumption, they are some of the main barriers that affect consumer behavior, and, consequently, low consumption.

Other factors, such as the existence of nearby substitute products, culture and place of origin, also influence the preference and consumption of the type of protein (CARLUCCI *et al.*, 2015).

In order to increase knowledge about the tuna consumption behavior in Brazil, a survey was carried out - carried out by NITEC / UFRGS, between January and February 2018, with 405 respondents at the national level. With the analysis of the sample profile, there was a predominance of female respondents (62%) who are in the age group between 20 and 39 years old (62.5%). In addition, the vast majority of the sample had, at least, completed high school (96.8%) and a family income above 3 minimum wages (76.3%). It is noteworthy that 61.5% of the respondents live with the family (with or without children) and approximately 58% live with 3 or more people in the same residence.

As for the relevant factors when buying fish (Fig. 3), the main characteristics highlighted by the respondents are: "flavor" and "texture and consistency". In the case of tuna, it is understood that the form of presentation – in a can – adequately resolves these factors as it is considered a safe food in terms of its composition and elemental concentration (NIEKRASZEWICZ, 2010).

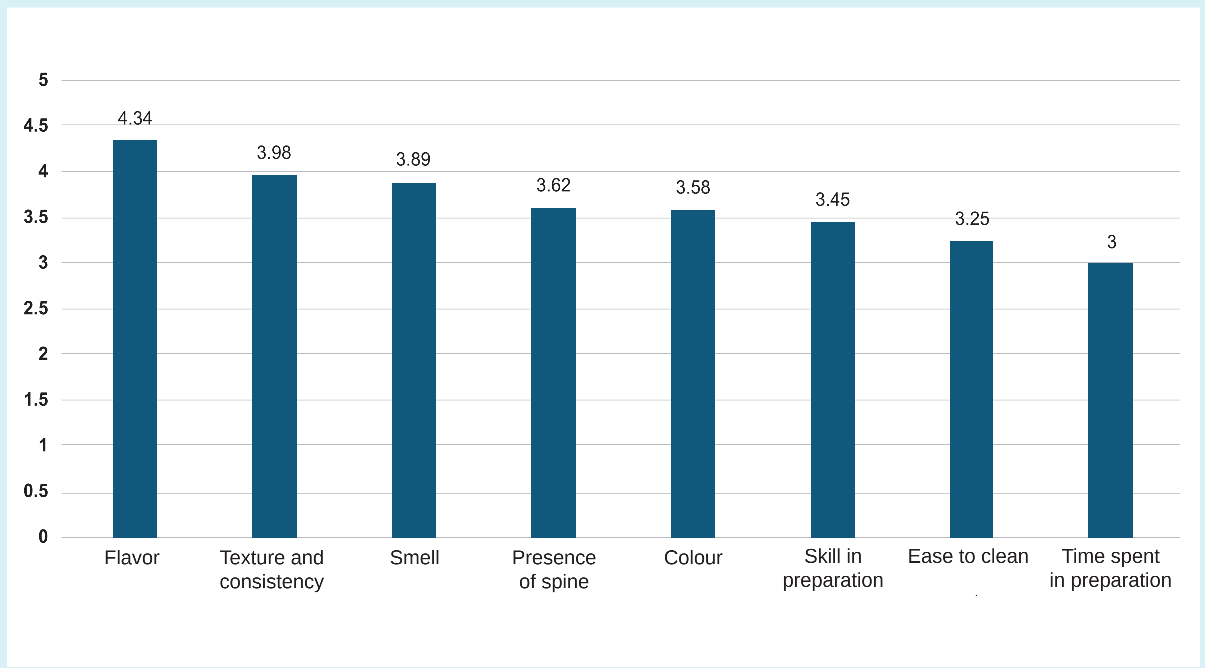

Figure 3. Important characteristics at the time of fish purchase decision. Source: NITEC, 2018.

However, characteristics such as "skill in preparation", "ease in cleaning" and "time spent in preparation" show how the consumption of fish is not a routine and natural activity for consumers, which reinforces the idea that Brazilians rarely consume fish. It is noteworthy that for tuna these three characteristics are supplied by the practicality and functionality of the can and sachet. Among the respondents, the purchase of canned tuna stands out (85.8% of respondents), which signals convenience as an important factor.

Consumer behavior in relation to tuna consumption is then governed by two different standards: convenience and healthiness. In terms of convenience, the canned tuna preservation technique allows, at the same time, to increase the shelf life and shelf life of the product, to have a product ready for consumption without the need for preparation, in addition to facilitating transportation, distribution and availability of the product for purchase. As for healthiness, recognition of the nutritional quality of the proteintuna are subject to extensive communication by health professionals. Its benefits make this type of protein highly accepted by consumers who are concerned with the "health, food and well being" trinomial.

Some markets, such as the European one, use the identified niche markets (convenience and healthiness) to increase their product and offer it to the market with a high added value. Factors such as presentation in transparent glass, recognition of stamps of origin in sustainability, and commemorative packaging guarantee the product a different perception of value by the consumer.

In this context, in order to understand the behavioral decisions behind the canned tuna market in Brazil, the reasons for low consumption, the factors for the limited development of the chain and its products, or, still, the regulatory restrictions present in any sector of economic activity, it is necessary to analyze the configuration of the skipjack tuna productive chain (section 1.3) and the different institutional governance standards of the sector (section 1.4).

1.3) The Skipjack Tuna Productive Chain

The technological pattern present in the structure of the skipjack tuna chain is represented from the analysis of the different stages that make up this chain: capture, processing and commercialization.

Capture of the Skipjack tuna

The capture of skipjack tuna has four different stages: vessel, bait (capture of live bait), tuna capture and storage.

Because it is a pelagic species, the skipjack tuna has migratory routes defined by water temperature and food availability, which causes the capture to occur along the coast of the southern and southeastern states of Brazil (RS, SC and RJ) in different seasons (see Chapters 2 and 9 of this book). Brazil has approximately 38 vessels in operation (Fig. 4), which are concentrated in the states of Rio Grande do Sul, Santa Catarina and Rio de Janeiro. In addition, 2 are under maintenance and 7 boats are deactivated or wrecked.

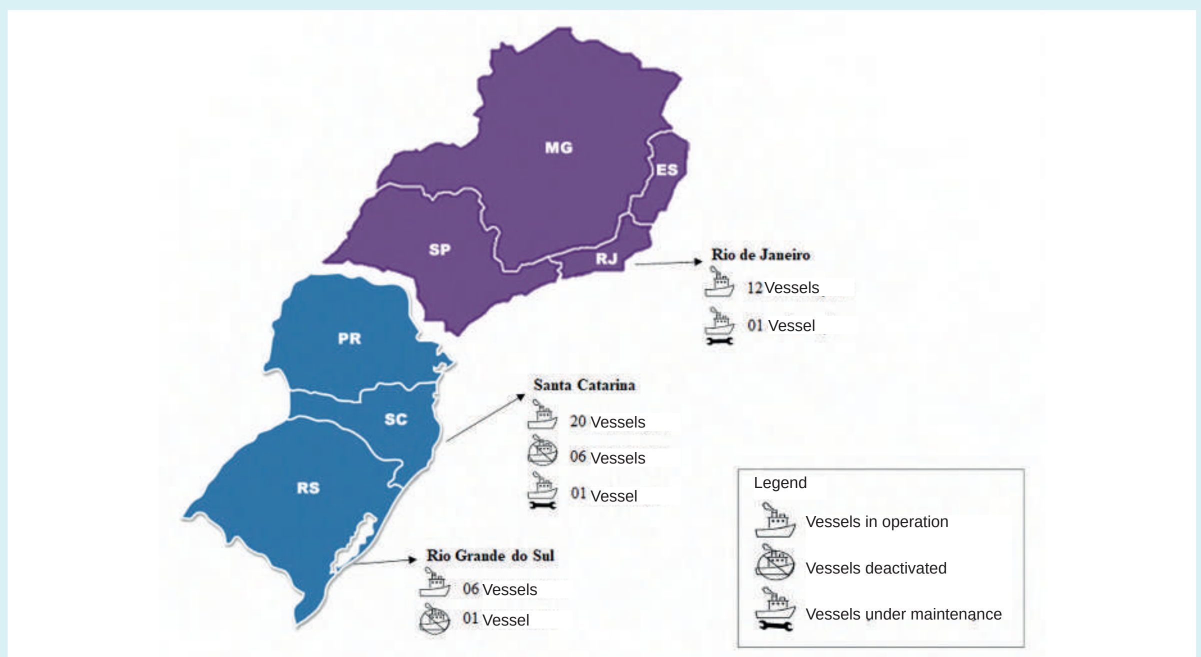

Figure 4. Number of tuna vessels in Brazil (Data aggregated based on the lists of companies used to the economic subsidy in the acquisition of diesel oil for fishing vessels (BRASIL, 2012) and their state of operation considering the numbers of vessels in the Captaincy of the Ports and in the General Record of Fishing Activity (SINPESQ, 2017)).

The vessels have different sizes, storage capacity and autonomy on the high seas. Most of them belong to shipowners who sell their production to the canning industry. The exception is the Leal Santos industry, which has its own vessels.

Regarding the capture process, there are different extraction techniques. For tuna fishing, the techniques of net fishing and pole and live bait stand out. The most used tuna fishing method worldwide is the seine (PARKER *et al.*, 2015). However, tuna fishing with pole and live bait, which corresponds to approximately 5% of the total volume of tuna caught worldwide, occurs mainly in developing countries (GILLET, 2016). In Brazil, the predominance is by the pole and live bait method, which places it in a prominent position in what is the most sustainable form of capture (ANDRADE, 2008).

This fishing modality has two distinct moments: bait fishing and tuna fishing. The bait traditionally used to catch tuna is the sardine. However, due to the possible collapse of the species, both due to the closed season (regular actions), as well as the fishing for sardines to operate at the limit of natural stocks, some researches point to anchoíta as a sustainable alternative to replace sardines as live bait for the capture of the skipjack tuna in southern Brazil (see Chapter 9 and COSTA *et al.*, 2016).

The method of fishing with a pole and live bait guarantees the lowest ecological impact in comparison to fishing with siege, as it ensures the preservation of stocks, since it avoids the capture of other species and juvenile individuals (Gilman, 2011). In addition, this type of fishing makes it possible to add value from environmental certifications and seals, such as, for example, Marine Steward Council and Friend of Sea .

After the capture, the skipjack tuna is stored on board the vessel. There are different techniques for conserving fish in vessels, the techniques traditionally used to inhibit degradation on board are refrigeration and freezing (GONÇALVES, 2011). Technologically advanced vessels use the super freezing method to inhibit degradation. This technique applies intermediate temperature to refrigeration and freezing (-3º C), in order to promote the transformation of part of the water into ice, which allows to increase the useful life of fresh fish.

Most Brazilian tuna vessels use the immersion cooling method. This method consists of freezing by directly immersing the fish in chilled aqueous solutions (brines) at a temperature below 0º C. However, as in the case of ice, where excess weight alters the physical structure of the fish, the use of brine alters other organoleptic properties, limiting its use to the canning industry.

Analyzing the process of capturing the skipjack tuna, it is clear that there are benefits of fishing with pole and live bait, given all the potential for adding value (in particular, its sustainable attribute) that this type of technique allows. Fishing with pole and live bait generates benefits both for companies, through the adoption of sustainable fishing seals and wealth generation, and for the consumer, due to the perceived quality of the product, and for the entire marine ecosystem, due to the preservation of species and conservation of stocks.

However, despite the benefits generated by the type of fishing adopted, the technological standard present in Brazilian vessels is low, its facilities are precarious. This technological gap is reflected, for example, in the way the product is stored on board.

The skipjack tuna caught by different Brazilian vessels is discharged in ports or directly at the canning companies' dock. When disembarked at ports or in markets, raw materials require transportation until processing, which occurs, in most cases, by land.

Skipjack tuna Processing

The skipjack tuna caught by different Brazilian vessels is discharged in ports or directly at the canning companies' dock. When disembarked at ports or in markets, raw materials need transport until processing, which occurs, in most cases, by land.

When the skipjack tuna is landed directly at the companies' dock, it is selected according to different technical-biological and operational criteria to be encased, by means of electric mats with water inflow on the product, for cold hyper-freezing chambers, precisely to maintain the physical-chemical properties of the protein.

After the cold chamber, the skipjack tuna has two different processes: primary and secondary. In the primary, the product will be sold exclusively frozen, so it leaves the cold room straight to the buyer. In the secondary, the product goes through 7 stages of manufacture (Fig. 5).

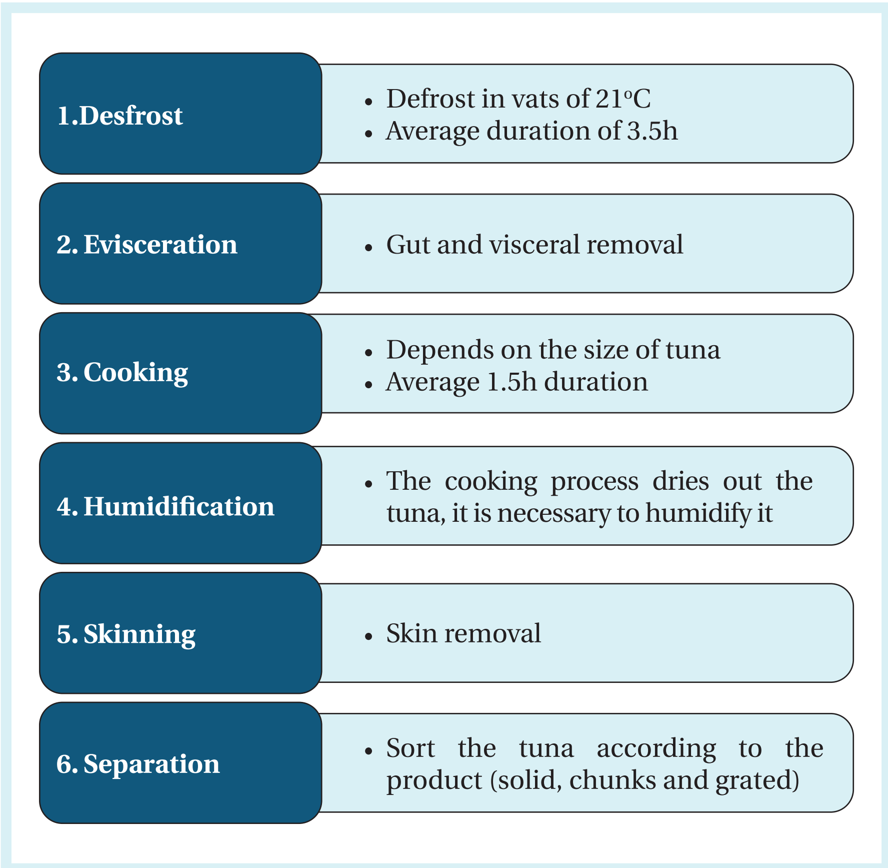

Figure 5. Stages of the skipjack tuna transformation process.

Finally, with the tuna already separated according to the type of product (solid, pieces or grated), it is sent to the packaging stage, where it will be filled, sterilized, labeled and packaged.

As a rule, this processing logic follows techniques and procedures long defined by the technology itself in use in the canning industry in general. Even with process news, this has a relative impact on the quality and variety of products. In this context, the major technical increment action is in increasing the volume produced – see, for example, the recent investment planned by Gomes da Costa, which aims to "double" the production capacity of its Itajaí/SC unit (SPAULTZ, 2018).

Commercialization of Skipjack tuna[1]

Brazilian production of skipjack tuna was around 20 thousand tons in 2017. Approximately 80% of this production was destined for the domestic market. Of these, 98% for canning and only a tiny part consumed fresh. The rest of the national production was exported in the form of frozen fish for further processing in the different countries of destination. Regardless of the scale of the market, it is possible to identify three types of markets for the skipjack tuna in Brazil (Fig. 6).

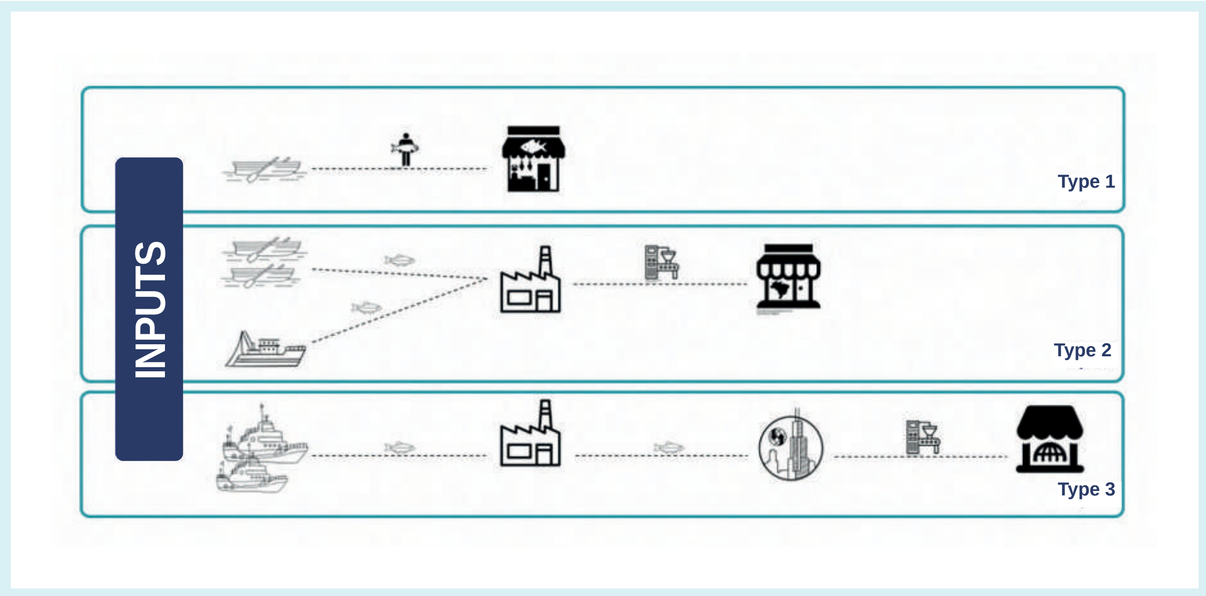

Figure 6. Types of skipjack tuna market in Brazil.

In the Type 1 market, the level of chain interaction occurs without intermediaries. The capture of the skipjack tuna fish takes place through artisanal vessels, where the fish au natural it goes on to retail sales (fish markets, fishmongers, supermarkets and fairs). In some cases, the product is destined directly to restaurants, mainly those of Japanese cuisine. s a rule, this Type 1 of marketing is the least expressive in terms of volume of capture, and is therefore based on cost.

In the Type 2 market, the level of interaction in the chain requires intermediaries for the tuna transformation process. The capture takes place both by artisanal and industrial vessels, which deliver their production directly to the industry. It is up to the industry to process the canned tuna input, which will reach the consumer through wholesalers and retailers.

The canned tuna market in Brazil is centralized in three major companies, namely: Camil (Itajaí/SC), Gomes da Costa (Itajaí/SC) and Leal Santos (Rio Grande/RS). The first two produce exclusively for the domestic market, and together they hold over 85% of the market share, serving a national consumption of approximately 180 million cans/year, which is equivalent to less than one can per capita/year.

This low consumption rate is directly related to the perception of value that the consumer has – wrongly, the canned product shows the idea of containing preservatives. Add to that the fact that a considerable part of the national production depends on "imported frozen cooked tuna", ready to be directly canned. Originating in Thailand, Ecuador and El Salvador, this raw material carries a strong participation fish muscle,

[1] During the research, on January 3, 2018, the Ministry of Agriculture, Livestock and Supply temporarily suspended the export of fish to the European Union due to the lack of sanitary conditions of the vessels in order to avoid a suspension unilateral.

which considerably reduces the quality of the product. Therefore, the low quality that ends up being perceived makes it difficult for the consumer to create the consumption habit.

Finally, in the Type 3 market, the level of interaction in the chain requires qualified intermediaries. In this case, the catch usually occurs via industrial fishing fleets – not excluding, in some cases, the use of other types of vessels. The industry is responsible for making it possible to transport the product for export, as is the case of the company Leal Santos, which supplies the frozen raw material so that the canning activity is completed in the foreign market. The product captured in Brazil, while the export channels were open, were sent to large canning industries, mainly in Spain.

In summary, the set of activities related to the production processes and their linking, as well as the different types of market, give light to the following map of the skipjack tuna chain (Fig. 7).

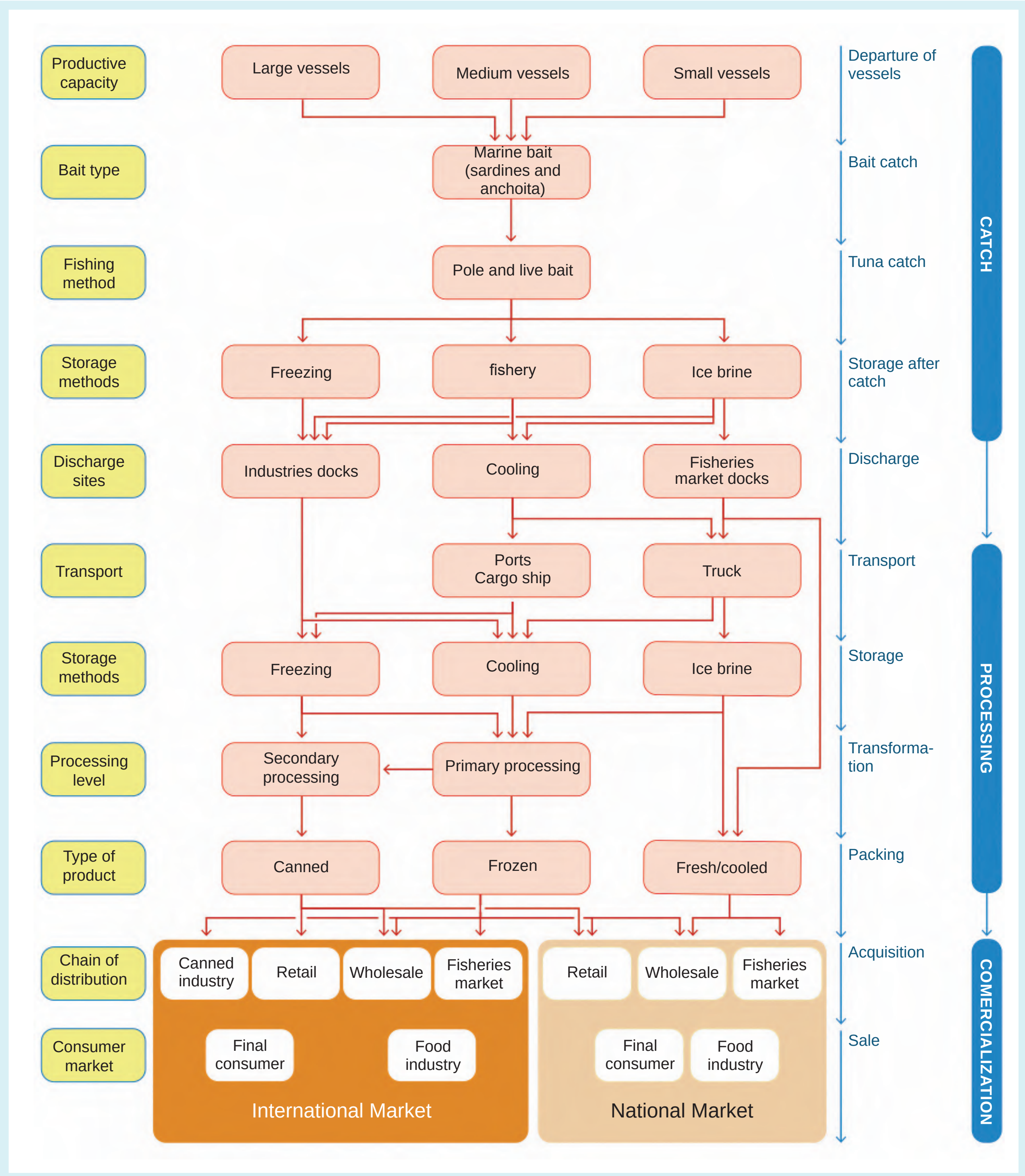

Figure 7. Map of the skipjack tuna productive chain in Brazil.

1.4) Skipjack tuna Sectorial Governance

As in all economic fishing activity in Brazil, skipjack tuna fishing suffered (and suffers) from the mismatch between the different institutions and regulatory bodies operating in the sector. Over the past 40 years, fishing activity has been the object of different organization and control agencies (Fig. 8).

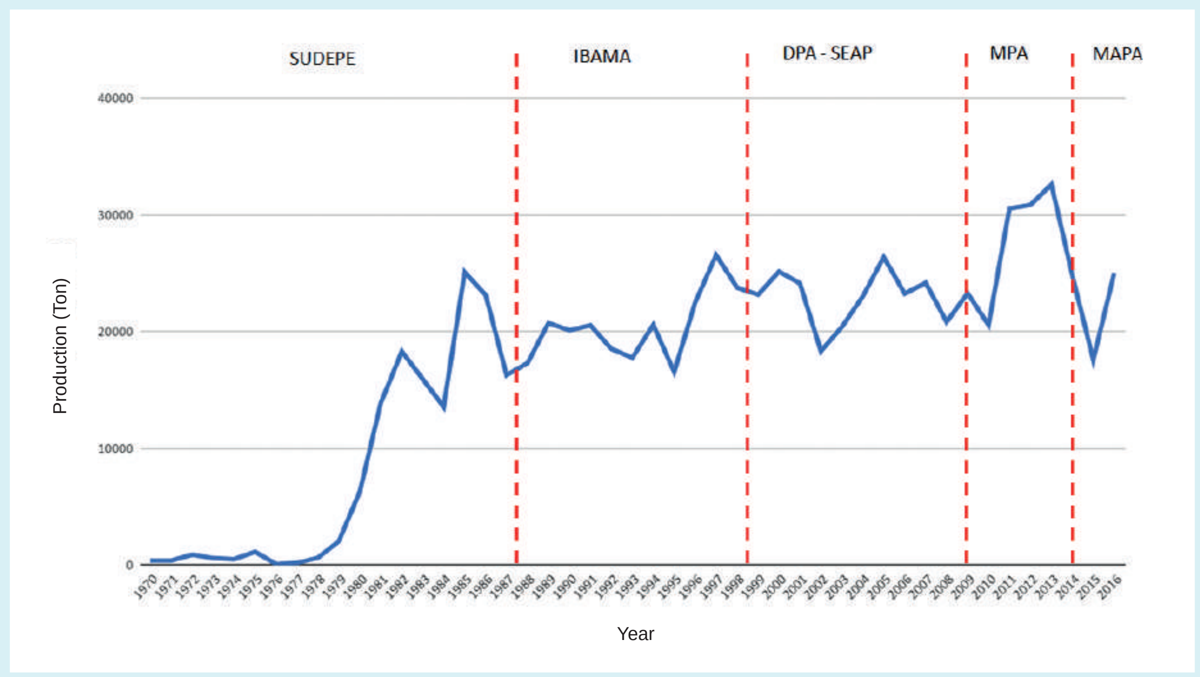

Figure 8. Evolution of fisheries production in Brazil according to the sector's governance. Source: GOULART FILHO, 2016; FAO, 2018.

The constant change of the governing body of the fishing activity in Brazil meant that the focus of work also changed. During the SUDEPE period, the focus was on industrialization based on technological development. With Ibama, the focus was on preserving and restoring the marine ecosystem. The dichotomy between the preservation of environmental resources and economic gains turns the fishing activity from "good guy" to "villain". In a way, over this period (and up to the present day), fishing is no longer seen as an economically prosperous activity with the potential to generate value and wealth for society, and has come to be perceived as a subsistence activity, associated with the exploration of the marine environment (MARTINS, 2018).

However, governance must be analyzed not as something "good" or "bad", but as something that frames economic environments in particular ways – facilitating (or not) the development of sustainable and profitable businesses (BARCLAY & CARTWRIGHT, 2007). According to Cavalcante (2018), the governance structure refers to the institutional framework of economic integrations responsible for defining the way decisions are made.

In this context, the governance of the fishing activity involves fishermen, shipowners, industry and other interested parties to manage not only fisheries, but the entire chain, from the transformation process to commercialization, so that they are sustainable and profitable (BARCLAY & CARTWRIGHT, 2007). The relationship between these different partners is an important bridge between the different levels of coordination, for example, linking local governance entities to national policies (COHEN *et al.*, 2012; ERIKSSON *et al.*, 2015). However, the social representation of the skipjack tuna chain is fragile, predominating leaders with little class identity, and who often end up for defending only their own interests (NETO, 2010). In this way, and knowing that the skipjack tuna chain in Brazil is poorly structured, the cost of its organization (mainly for technological development) is high. This becomes yet another obstacle to the generation of efficiency and productivity gains and its transformation into sustainability, generation of wealth and prosperity.

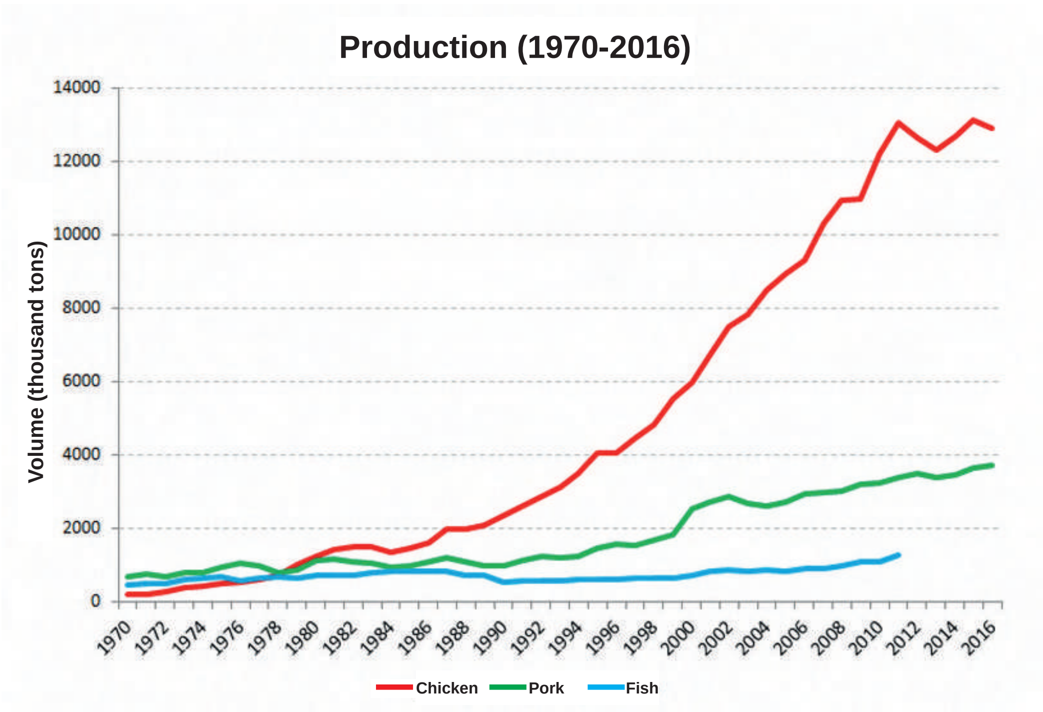

Figure 9. Production volume per chain. Source: AVILA *et al.*, 2019.

This lack of governance among fishermen occurs largely because it is a sector that extracts resources from common use, that is, each fisherman depends exclusively on himself. At the same time, the cost of a certain “disorganization of the sector” (largely due to the weakness of its governance structure) takes its toll daily on the myriad of inefficiencies that end up being transferred to products and, therefore, consequence, for the cost-benefit ratio of what is sold.

It should be noted, however, that, since the skipjack tuna chain is centralized in the production of canned tuna, two large companies – Gomes da Costa and Camil – concentrate, albeit in a restricted way, on commercial relations with different direct and indirect suppliers of inputs, the essence of coordination (governance) of their respective supply chains, especially in the control of supply and even prices practiced in the market.

The importance of chain governance, however, goes beyond the transactional/ commercial role played by one or another leading partner. Understanding the permeability of a governance structure throughout a chain is, long before merely commercial issues, aligning the capacity for innovation, production and the profile of the market. In this sense, the example of the chicken and pork chains serves as a reference for the skipjack tuna sector. These are real cases of transformation (not to mention revolution) of economic activities essentially handcrafted into real agro-industrial complexes of unparalleled importance in the generation of social and economic wealth for the country. Both segments established governance structures that could be based on the technical-operational content of their chains, the development potential of the consumer market.

1.5) From "hen" to "chicken", from "pig" to "pork"... from "fish" to "fishery product"?

When analyzing the production of chickens and pigs (alternatives to the traditional bovine protein), it is clear that the process of structuring their chains, carried out over the last 50 years, has allowed them to remove themselves from a level of informality and precariousness that, in much, remembers the stage of the fishing chain today. This is even more evident if we take into account that, until the mid-1980s, the production volume of the chicken, pork and fish chains were at the same level (Fig. 9).

So, what was done for these chains to develop? The consumption of chicken has increased over time as there has been greater control over the mode of production, from being a product of domestic breeding to becoming an economic activity that generates wealth (OLIVEIRA & COSTA, 2011; ABPA, 2019). Pork consumption was dependent on the stigma of meat that is harmful to health. However, by making the population aware of the benefits of consuming this type of protein, barriers were created in order to guarantee the quality of the products (ABCS, 2016; ABPA, 2019). In a relatively short time (15 years), while the "hen", from "Sunday hen", was elevated to the position of "chicken", the "pig", became "pork".

From the 1990s onwards, the technological increase in both chains was extremely important for their development. The import of poultry and swine breeding stock allowed an increase in productivity and quality of the products offered. In addition, technology transfer processes favored the competitiveness of companies (ABCS, 2016; ABPA, 2019), at the same time that sanitary control and control of the operation allowed for higher quality in production.

This transformative process was strongly based on the institutional structuring of the chicken and pork chains, properly orchestrated from the formalization of sectorial associations that allowed the development of policies and actions aimed at increasing the partners in the chains. In general, the chicken and pork chains have become more structured, technological and with superior coordination and governance standards, which has consequently led to an increase in product quality.

The increase in the quality of the products, coupled with the clarification and awareness of consumers about the benefits of consuming chicken and pork meat, allowed the development of new products and new markets. Consumer needs have meant that, for example, new cuts and new forms of presentation (packaging) are introduced to the market. This combination of quality and awareness can leverage the development of sectors.

Despite considerable success, the chicken chain appears to be at its growth limit. The chicken meat scandal in 2018, when "Operation Carne Fraca" was triggered by the Federal Police and the Public Ministry to identify irregularities in the frigorific, served, if not as an indicator of some form of exhaustion of the model, by least as a warning sign. At the same time, the pig chain still has potential for development. It is known that it is not possible to transform the market simply by imposing it, therefore, it is necessary to transform the industry so that it changes the profile of its products, offering a higher quality.

Analyzing these two trajectories, what needs to be done with "fish" so that it can become "fishery product"? What is needed for it to reach the same rates as the chicken and pork chains?

In a succinct way, the trajectories of the chicken and pork chains show that, in order to consolidate a market, it is necessary to: (a) a sectoral governance structure that acts as coordination and in a regulatory manner; to (b) present minimum levels of technical-operational structure that determine and control the different stages of the chain (capture, processing and marketing), as well as establishing minimum quality standards for the product. In other words, it is necessary to create a governance structure that organizes the chain as a whole – from technology to the market – allowing to deliver products of higher quality and perceived value.

However, structuring and coordinating the chain itself is not enough. For it to develop, it is necessary to pay attention to the potential for wealth generation. So, how can we add value to skipjack tuna to achieve the same growth levels as the chicken and pork chain?

1.6) From Healthy to Sustainable: potential for adding value to skipjack tuna

Both the tangible aspects, linked to the physical (service, quality, technology, comfort), as well as the intangible aspects, linked to the tag (meaning, values, identity, personality), give additional attributes to the product. Packaging, for example, plays an important role in the product's functionality and image. It serves as a reference of its quality, signaling to the consumer if it is justifiable to pay a premium price (LYONS & WIEN, 2018). Likewise, the consumer experience and exclusivity add value to the product and can justify this price.

Having seen how the marine-fishing activity of the skipjack tuna in Brazil is structured, how its market and consumer behavior are configured, as well as which the technical-productive structure of its value chain, what is the level of governance in the sector and, mainly, having compared it with the recent success history of the chicken and pork chains, two qualities can be observed for adding value in the marine chain – fishing of the skipjack tuna: healthiness (intrinsic) and sustainability (extrinsic).

The intrinsic quality is based on the "healthy" specificities of the skipjack tuna, which offers great nutritional benefits and at the same time presents minimal health risks (JENNINGS *et al.*, 2016). In the last few decades, the demand for food has been changing considerably. More informed consumers pay more and more attention to health, as is the example of functional and organic foods. According to Hamzaoui-Essoussi & Zahaf (2012), attributes such as healthiness and local economy, in addition to freshness and flavor, are considered important for the consumer.

In this context, the market with healthy products, with less or no sugar, salt and fat, and with more fibers, vitamins and nutrients, has grown a lot over the years. Among these, products with a high concentration of n-3 fatty acids stand out, which bring benefits in relation to the reduction of triglyceride levels, prevention of cardiovascular diseases, better brain and retinal development of the fetus, as well as greater probability of a full-term pregnancy, in addition to reducing the risk of developing neurodegenerative diseases such as Alzheimer's disease (OLIVEIRA & LUNA, 2014).

Among the source foods for the consumption of these nutrients are fish such as skipjack tuna. Fish, in addition to being composed of proteins with high biological value, is also an easily digestible food.

The extrinsic quality, on the other hand, is based on the sustainable specificities of the skipjack tuna chain: the sustainability potential of the production process using the pole and live bait method, which guarantees the preservation of the species (stocks) and the reduction of the environmental impact. The method of fishing with pole and live bait tends to be more selective, with the percentage of capture varying from 5 to 15% of the school, favoring the sustainability of the species (MATSUURA, 1982).

Although skipjack tuna is not considered a species at risk of extinction, the main species that is used as bait – the sardine – is exploited in large volumes, both by artisanal and industrial fishing, and it is observed the decreased availability, both for environmental reasons (climate change) and for fishing. In this context, the challenge to increase the exploitation of the fishing resource that is abundant, having as premise the effort to reduce the impact caused by the withdrawal of the sardine, is the use of alternative species such as live bait, in this case, the anchovy and the lambari.

These specificities – healthy and sustainable – generate alternatives for potential actions to add value to the skipjack tuna chain. Analyzing the different products generated by the chicken, pork and tuna chains (Fig. 10), it is evident that the tuna's wealth generation is superior to that of the other chains.

Segment	In Natura R$/Kg	Processed/Industrialized (R$/Kg)			Premium (R$/Kg)	In Natura > Premium
		Entire	Portioned	Portioned Processed		
Chicken	**3.20***	**9.85** (Frozen Seara organic chicken)**	**10.49*** (Frozen Sadia chicken drumstick)**	**12.71 (Frozen Nobre chicken breast fillet)**	**23.59*** (Frozen Korin chicken breast fillet with no antibiotics)**	**7.40**
Pork	**4.70***	**10.00 (Entire pig)**	**20.59** (Frozen pork rib Pamplona)**	**26.90** (Seara bacon in cubes)**	**55.90** (Frozen Seara pork rib with barbecue sauce)**	**11.90**
Tuna	**5.00**	**13.90** (Fresh entire tuna)**	**32.29** (Gomes da Costa grated tuna)**	**57.26** (Gomes da Costa spicy tuna pâté)**	**95.92*** (Gomes da Costa tuna fillet in olive oil)**	**19.20**

Figure 10. Generation of wealth in the chicken, pork and tuna chains.
* Values for 04/01/2020 - Source: https://www.noticiasagricolas.com.br/
** Values for 04/01/2020 - Source: https://www.angeloni.com.br/super/
*** Values for 04/01/2020 - Source: https://www.carrefour.com.br/

2) Development Plan for Skipjack Tuna Marine-Fishing Activity

The brief reports of the recent experiences of the chicken and pork chains, together with the clear advantages of the product's value, especially its health and sustainability attributes, open a horizon of potential development for the skipjack tuna chain. However, any development path depends on planning. And, to make such a plan, it is necessary to look, initially, at the obstacles that characterize the sector.

As seen, the marine-fishing activity of the skipjack tuna in Brazil presents obstacles in its key dimensions (market, technology and governance). The product quality limitations and the market's own behavior profile, as well as the low technological intensity expressed throughout the structure of the value chain, or the weaknesses of its governance structure, highlight the need to deepen the problems and bottlenecks in the sector so that, based on them, actions can be identified whose logical-temporal arrangement will establish the contours and embody a development plan.

In order to get into the details of the main obstacles and to propose a development plan for the marine-fishing activity of the skipjack tuna in Brazil, the diagnosis of the sector was carried out[2] and a workshop.

The workshop took place in November 2019 with the participation of 21 representatives from relevant companies, organizations and institutions in the sector. In order to be able to raise the set of information of interest (i.e., the obstacles), the activities were conducted so that the participants could expose their knowledge about the sector[3]. The sequence of activities was as follows: presentation of the diagnosis of the skipjack tuna chain; identification of current chain barriers; definition of actions to solve the obstacles; and, finally, systematization of the action plan, based on the organization of actions by urgency and the possibility of carrying them out over time.

[2] The results of this diagnosis are presented in detail throughout section 1 of this chapter
[3] The workshop used the focus group method, with which it is possible to obtain, economically and immediately, through the knowledge and perception of the different partners involved (companies, organizations and institutions) in the target reality, information relevant and current. The participants were arranged in the same place in order to discuss the market, technological and institutional dimensions of the marine-fishing activity of the skipjack tuna in Brazil.

2.1) Main Barriers and Challenges for the Marine-Fishing Activity of Skipjack tuna

From the perception of the partners that make up the marine-fishing chain of the skipjack tuna, it is evident that the different dimensions of analysis have different barriers (Tab. 1). However, despite this dimension-based interpretation, it was realized that the obstacles and challenges of this activity are interconnected, that is, one obstacle is the cause and consequence of another.

As expected (and identified in the diagnosis - section 1), the discussion in the workshop evidenced a great discontent among the partners with the lack of a consolidated governance structure, especially due to the lack of a clear definition of roles and responsibilities among the partners.

The lack of a stable governance model is reflected in the inadequate use of instruments and mechanisms, such as public policy, regulation, marketing actions and publicity. Precisely those that could serve to stimulate the creation of higher value-added products is for expanded consumption of tuna. Much of this is due the fact that the low quality of some products (e.g., grated canned tuna) and the lack of habit of the Brazilian population are barriers that restrict both increased consumption and supply, making the price of the final product higher and less competitive when compared to other sources of animal protein.

However, this scenario is difficult to change in the short term, since the interaction between the different partners (e.g., companies, universities, government and civil society) is low. With this, among other consequences, the amount invested in activities such as research, development and innovation (P, D & I) remains below what is necessary.

Table 1. Main obstacles of the skipjack tuna marine-fishing chain in Brazil.

	Market	Technology	Institutions
Barriers and Challenges	Economic Configuration	Outdated Technology	Lack of Governance
	Consumer and Marketing	Lack of investments in Research, development and innovation	Regulation
	Value Added Product	Lack of Interaction	Absence of Public Policies
	Publicity	Fishing Modalities	Fishing Invisibility
	Expansion of Consumption	Equipament Acquisition Cost	Lack of Fisheries Management
		On Board Quality Control	

Source: Action Plan Report for the Development of the Skipjack tuna Chain in Brazil (NITEC, 2020).

This low level of investment makes it difficult, for example, to make strategic decisions. The lack of detailed research and studies to generate reliable data and information affects the efficiency of fisheries management and, by deduction, the sustainable development of the sector. In addition to the potential environmental damage, this leads to economic losses, since the control and monitoring of inventories is a minimum condition for the export of products. Likewise, there is no full conviction among partners in the sector that the fishing modality in use (i.e., pole and live bait) is really the most sustainable from an environmental and economic point of view. Finally, the lack of collaboration between the partners to face all the problems and obstacles listed above results in the invisibility of fishing before the eyes of the market and the government, especially considering its representativeness in terms of wealth generation.

In reality, as noted, many of these traits are due to the fact that there are two technological standards in the different stages of the chain: artisanal and industrial. This technological gap in the sector leads to different institutional governance arrangements.

In the artisanal pattern, there is a set of marine-fishing activities that are sprayed on small partners. If, on the one hand, this suggests a socialization of the activity, on the other hand, it prevents minimum scales of profitability, especially for fishermen. As a result, the technological outdation of equipment and production processes, especially in this capture stage, becomes critical due to the lack of investment power. However, it is still necessary to expand the quality control on board to avoid losses and maintain the product standard. In short, the high cost of acquiring new equipment makes it difficult to renew the current tuna fleet and does not allow the technological improvement of artisanal fishing.

In the industrial standard, in contrast, there is an institutional governance arrangement structured around some large companies that benefit from final products (e.g., canned) that establish more rigorous technical-productive standards, based on more modern technologies and aimed at more modern markets. competitive. However, because the skipjack tuna is a commodity, the chain is naturally focused on costs. Any "startle" – such as lack of raw material, product perishability, foreign exchange variation, international price – generates fear. Lack of supply security invariably leads to an increase in the import of skipjack tuna, making the final product less competitive in the market when compared to other sources of protein (e.g., chickens and pigs).

In short, the fishing industry, in general, is still focused on the purely transactional pattern of the resource extracted from nature, that is, the production chain is organized in buying and selling relationships, with little or almost no incorporation of technological solutions (i.e., product or process) that could increase added value.

Extractive chains have technical-economic dynamics that are difficult to predict and complex in terms of their impacts. The skipjack tuna chain, being an extractive activity, is dependent on environmental conditions such as, for example, climatic variations (SCHMIDT *et al.*, 2019), availability of bait and the technological standard adopted.

As there are still barriers of a technological nature and also of a marketing nature, this industrial configuration does not allow the reduction of transaction costs inherent to this activity. This makes it difficult to add value to products from fisheries, as the technological gap from capture to final consumer does not allow the offer of new solutions to the market.

Therefore, the creation of policies and actions aimed at the technological increase of the chain and the formalization of sectorial associations can be mechanisms to stimulate the development of the skipjack tuna chain.

2.2) Development plan for the marine-fishing activity of skipjack tuna

Based on the obstacles and challenges identified in the action definition stage, the workshop participants proposed solutions to the different problems of each size. Each solution was detailed considering the necessary activities, form of execution, possible responsible persons and institutions involved, as well as the estimated value for its realization. After this stage, the suggested actions were presented and discussed in the large group and ordered in *a priori* the construction of the Development Plan for the marine-fishing activity of the skipjack tuna.

Institutional Dimension

In the institutional dimension, it was suggested as the first action **identify the partners representative** of the sector (i.e., government, business, universities and civil society) in order to structuring a governance model that facilitates decision-making regarding planning, programming and implementation of actions for the development of the skipjack tuna chain. Concomitantly, it was suggested to carry out a **project of positive institutional marketing** (e.g., endomarketing) in order to improve the visibility of the sector.

This action would have as main objective to explain to all partners in the chain the value of the product in economic, social and environmental terms. The third action would be to **presentation and consolidation of development proposals** defined by the new governance structure. The fourth refers to the creation of a continued data collection program, which lasts for a long term in order to better guide the fishing management of skipjack tuna. Finally, the fifth action is linked to the **review of rules and regulations**, being an essential action for monitoring and adjusting the regulatory framework and the governance structure of the chain.

Therefore, the proposed institutional actions make it clear that it is first necessary to bring visibility to the sector so that only then will it be able to involve the partners in the search to promote more assertive strategies and actions, including long-term data collection and review programs standards that support decision-making for governance partners.

Technological Dimension

In the technological dimension, the first action would be **mapping and diagnosis of products and processes**, that is, what is necessary both to improve the quality of products as for the improvement of production processes, going through aspects of infrastructure until process optimization. That done, the second action would be to implement **forums of discussion** that will be based on this diagnosis to then search for actions that can address any obstacles. The third action would be to conduct a specific **study for assessment of stocks and impacts of different fishing modalities**, in the case of the skipjack tuna, the comparison between pole and live bait and siege. Finally, establish a line of **financing to modernize vessels** in order to address some of the *priori* needs in the sector.

Therefore, the proposed technological actions show that there is a need to diagnose the technological level of the sector to identify development alternatives. This diagnosis would then be used as a basis for the development of new strategies and actions, requiring the implementation of a governance structure along the lines of discussion forums. The participants also stressed that it is important to define and monitor the stock, in order to determine the productive capacity so that the alternatives and synergies between the different fisheries can be expanded. They also reinforced that, for the modernization of the fleet to take place, there must be the possibility of leasing and licensing boats, considering the specificities of the fishing modalities and their impacts on the ecosystem.

Market Dimension

In this dimension, the first action refers to the promotion of a campaign on the benefits of the product in relation to other sources of protein. Then, the second action would be the development of a value-added product that is in line with the consumer's wishes and requirements. For that, thirdly, it is necessary to establish the product standard, including features, packaging and quality of the product itself. The fourth action, then, would be the definition of the portfolio of products that will be offered to the consumer. Finally, it is necessary to carry out advertising campaigns for this portfolio of new products in different channels to reach the consumer and increase consumption.

From the suggested actions, it is evident that in order to improve the market-logic dimension, an institutional and technological structure is needed as support to satisfy consumer demand. From advertising campaigns to the development of the new mix of products, it is necessary for all partners to be clear that the focus is on the consumer and that all actions must be interconnected.

The governance structure must jointly establish actions that aim to add value to all stages of the chain, which requires greater investments and also training. Specifically, in technological terms, it will only be possible to develop quality products if there is an established production standard that starts from the capture and reaches the commercialization. This could guarantee the certification of companies and their products, enabling them to enter new markets and, consequently, increase wealth generation throughout the chain.

Development Plan for the Skipjack tuna Chain

Figure 11 shows how the actions were arranged in their dimensions (clear blue boxes for institutional dimensions, medium blue boxes for marketing and dark blue ones for technology) and over time (short, medium and long term). Once having this temporal view in perspective, it was possible to identify the *priori* actions proposed in this activity.

Observing the plan, it is possible to visualize a coherence between actions for the development of the sector. The three dimensions analyzed in this report are multidisciplinary and, therefore, the most diverse knowledge needs to be integrated in order to obtain a broad understanding of how actions should be implemented. From figure 11 it is clear that it is necessary to carry out institutional actions first in order to be able to trigger actions from other dimensions.

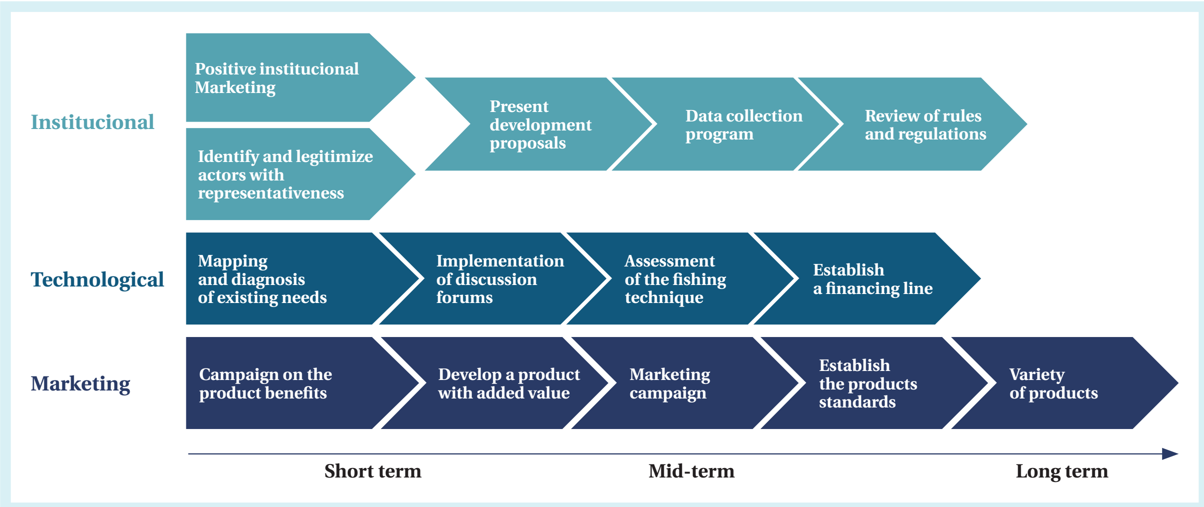

Figure 11. Skipjack tuna Chain Development Plan. Source: Action Plan Report for the Development of the Skipjack tuna Chain in Brazil (NITEC, 2020).

Final Considerations and Perspectives

The skipjack tuna fishing sector is at its crossroads. Years of technological and institutional lag are clearly reflected in the product profile and market behavior. Behind the good and bad attributes of fish quality, there is a whole “chain of events” that overlaps the “value chain” itself. From the technical-operational and logistical conditions of the fishing itself, especially the storage and transport of the fish, through industrial processing to the market shelves, the production chain is the result of technological and institutional problems.

Analyzing the obstacles pointed out in the skipjack tuna chain, it is evident that, for the institutional dimension, it is necessary to bring visibility to the sector so as to create conditions to involve the partners in the search for the promotion of more assertive strategies and actions that support decision making to the partners in the chain, mainly through a formalized governance structure.

To the **technical-operational dimension**, given the technological heterogeneity of the different stages of the skipjack tuna chain, it is necessary to develop new strategies and actions for technological development and increment in order to transform the productive structure.

To the **market dimension** an institutional and technological structure is needed to support it so that consumer demand can be met. From advertising campaigns to the development of the new mix products, it is necessary for the partner to be clear that the focus is on sensitizing the consumer and that all actions must be interconnected. The governance structure must jointly establish actions that aim to add value to all stages of the chain, which requires greater investments and also training.

From these considerations it is possible to identify the existence of **four major focus perspectives** for the development of the marine-fishing activity of the skipjack tuna in Brazil: costs, consumption, sustainability and value generation.

The focus on costs it represents the current scenario where the objective is to sell more of the same, so that any change generates fear, such as, for example, the seasonality and perishability of the product, or even, the exchange rate and the trade balance. However, high productivity processes tend to reduce inventories, that is, it generates sustainability problems in the medium and long terms.

The focus on consumption seeks to stimulate demand through education and awareness in order to change the culture of consumption. In addition, the development of new packaging communicating the benefits associated with the consumption of tuna and the development of new products would lead to market segmentation in niches. However, this type of approach can influence the volume of security stocks.

The focus on sustainability, mainly by the pole and live bait method, shows a great potential for the development of products with high added value, such as: "organic" production (even canned), international certifications and perception of "sustainable" value (30% of premium price). However, the problem is the unit cost that this approach has.

Finally, the **focus on value generation** seeks to transform the productive structure to impact the quality of the product offered. For this, it is necessary to technologically develop the mode of production, storage throughout the entire chain and diversify the offer. However, it is necessary to organize the chain as a whole, creating the necessary alternatives for the development of the marine-fishing activity of the skipjack tuna.

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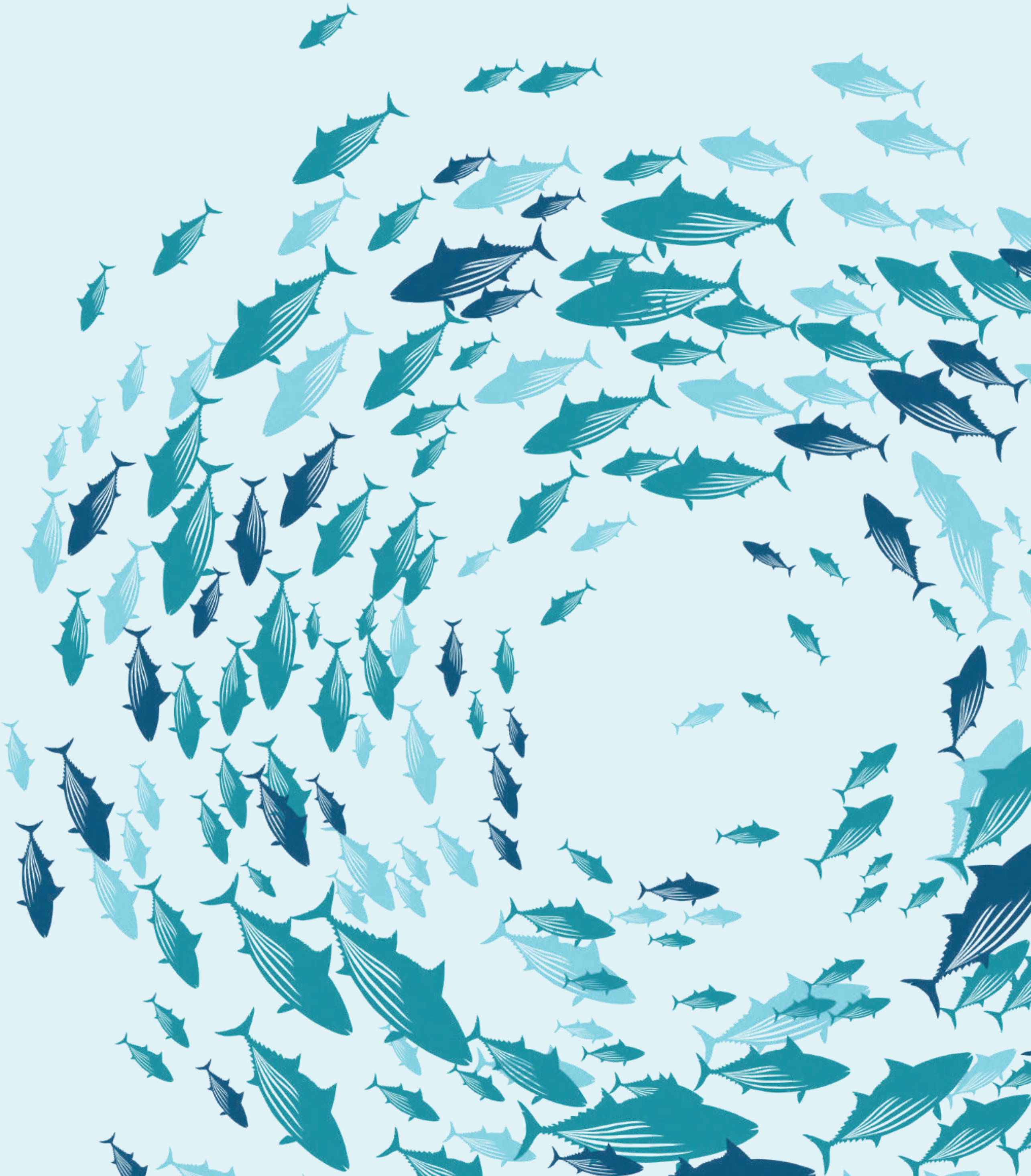
FINAL CONSIDERATIONS



Final considerations

The thematic units of this book were organized with the purpose of supporting the sustainability of the skipjack tuna fishing in Brazil, from the generation of new information. At the end of each chapter, the researchers presented their considerations. They are reflections that come from studies and analyzes carried out within the scope of the skipjack tuna Project, indicate deficiencies, point out conflicting instances, suggest ways to search for solutions, but, mainly, show the wealth of new themes for future research. The construction of this publication was essential to measure the power of research on the marine environment, in all its scope.

One of the most recurring notes was the need to implement a monitoring and communication system for fishing activity, on a national scale. It is a fundamental tool for management, which is governed by the precautionary principle, in order to prevent natural resources from reaching inflection points. In this context, we highlight the meaning given by Aragão (2013, p.24), a researcher in environmental law "the precautionary principle presupposes a scientific evaluation in all testable and verifiable aspects of risk before adopting any measures"[1]. That said, evaluations are carried out through continuous monitoring. In this way, it is possible to evaluate, for example, the sizes of fish caught and the impact of catches on reproductive cycles on the sustainability of the fishing stock.

Another issue that was widely commented on was the absence of a national database, capable of securely subsidizing the different methods of analysis and allowing the most plausible interpretation of the fishing history of this resource, since when it was little or nothing explored. This problem is also linked to the absence of an integrated monitoring system, taking into account that inefficient data take away the vigor of actions aimed at the sustainability of marine natural resources.

Sustainability is built mainly on three pillars, the environmental, the social and the economic. In relation to the social dimension, in the context of the Skipjack tuna Project, the analyzes showed that there is a vast field of research still unexplored in relation to industrial fishing in Brazil. Here, emphasis was placed on historical aspects in relation to fisheries and the social dynamics of the industrial fishing productive chain, from a multi-partner perspective and the interaction between society and the environment. These are complex issues, which concern an important highly migratory natural resource, exploited industrially, and whose decision, conflict and negotiation processes take place on a global, national, regional and local scale.

In this scenario, the social issue can be evaluated in a promising way with the theoretical and analytical perspective of multi-partner and multilevel decision-making arena, guided by conflicts (FERREIRA *et al.*, 2017)[2]. It is of great importance to use this theoretical and analytical framework to understand the meanings and values that are attributed to the legal norms and regulations that aim at the sustainability of skipjack tuna fishing in the national scenario, which have recent revisions and changes, regarding the orientation fisheries, which is the case, for example, Normative Instruction No. 14/2020, which allows seine fishing for complementary capture of skipjack tuna and other tuna species. In this sense, it would be opposed to conduct studies that consider language and its symbolic sets, to understand how conflicts are made explicit.

Another axis of social concerns, also evidenced in the scope of the skipjack tuna Project, refers to the absence and gaps of political-institutional actions related to fisheries management and the conditions of industrial fishing workers, as was the case of the study on the state from Rio de Janeiro. Initiatives that improve the professionalization of these workers are fundamental for the innovation and growth of the sector. The social principle of sustainability suggests that workers have adequate training through technical training and specialization courses, to make them more qualified professionals, in order to establish a safer and more efficient production process.

We recognize that, in order to promote sustainability, it is necessary to know. More than knowing, it is necessary to understand, because "understanding is based on knowledge and knowledge cannot advance without a preliminary tacit understanding" (ARENDT, 1994, p. 333). Based in Arendt[3], we believe that knowledge will only advance if it coincides with the interests of those who need to guarantee the future of fishing. It is important to emphasize that the demands of the international agendas for sustainability of the oceans emphasize the need to improve knowledge and scientific research, in the sense of developing "strategies to raise awareness about the natural and cultural relevance of the ocean"[4], therefore, sharing has become if required.

Among the themes of the book, the study on the biology of the skipjack tuna has involved the largest number of researchers. The researchers observed the skipjack tuna from the larval state until the adult phase, when they are captured. The scope of the studies involved their diet, to try to better understand the role of food in the life cycle and in the migratory routes of the species. Also, the types of parasites by which they are affected were investigated, as well as the genetic connectivity relationships between populations in the Atlantic Ocean. These studies showed an essential picture about the skipjack tuna, highly migratory oceanic natural resource, which moves a complex industrial productive sector, which integrates an important social arena and, objectively, begins in a tiny oocyte.

The studies examine the environmental aspects angled by sustainability, having as core the conservation of biodiversity and characteristics of the sea, aiming at the quality of the marine environment as the main source of life in the oceans. Recalling that, for a female to spawn and a male to fertilize, it is necessary that the environments are in ideal conditions of temperature, salinity, nutrition and sea current, so that the new individuals survive, grow and reproduce properly again.

The dynamics of biodiversity are integrated with oceanographic dynamics, and both are linked to climatic factors. However, climate change has increased uncertainties and generated or intensified anomalies in oceanographic interactions, affecting marine ecosystems. It is necessary to better understand the effects of these anomalies, because they have a direct impact on the results of fishing catches.

Studies indicate that, in order to face uncertainties, it is necessary that the analyzes be continued, as well as the search for solutions. An example is what was pointed out by one of the case studies, in which practical and positive results were demonstrated from partnerships with university centers of excellence, which provide technological innovation so that the productive sectors obtain competitive results in the international scenario.

[3] ARENDT, Hannah. *Compreender, formação, exílio e totalitarismo*. São Paulo: Editora Schwarcz, 1994.

[4] ONU. *Conference on the Oceans*, 2017, paragraph 12d, Available in: https://nacoesunidas.org/wp-content/uploads/2019/05/conferencias-oceanos-2017.pdf. Access in: 18 May 2020.

These processes are also part of corporate sustainability, spelled out by the economic development plans to strengthen the consumer market. It is a challenge that runs through the modernization concept, in the sense of seeking more energy efficiency in the reengineering of processes that overcome risks, and are supported by scientific research to face uncertainties. However, it is not only the productive sector that needs innovation and technology, science and all research fields also lack incentives. Scientific research needs support to undertake, to carry out more experiments, to improve its technologies, so that the results are more accurate, as, for example, was the unprecedented experience of electronic marking for satellite monitoring in skipjack tuna. Despite the limitations faced by the researchers, some hypotheses were confirmed, such as the case of the skipjack tuna susceptibility to variations in surface temperature and related to plankton concentrations in the marine environment.

Our considerations are guided by the principles of sustainability, in their social, economic and environmental dimensions. Through these principles we are able to understand what are the topics that need more research. Likewise, it is for these principles that multidisciplinary and interdisciplinary research are justified. At the end of all chapters, the result of three years of research by the skipjack tuna Project, we understand that here new studies are also proposed on one of the most important oceanic natural resources. It means, therefore, that the scope of future studies for the sustainability of fishing for skipjack tuna in Brazil should grow more and more.

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We hope that the results will effectively assist in the sustainable management of the species, ensure the activity of the productive sectors and mainly safeguard access to the fish for future generations.

Rio de Janeiro, September, 2020.

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Photo: Lauro A. Saint Pastous Madureira.

We present the book “Sustainability Skipjack Tuna Fishery in Brazil”, with 13 chapters containing the results achieved by a multidisciplinary team in three years of research. Organizing this volume was a joint effort by all researchers to share information and improve understanding on this important marine fishery resource. This was the result of interdisciplinary interactions enhanced by the project, which dealt with the early stages of the skipjack tuna life, its habitat and oceanographic dynamics, reproduction and biological growth, fishery, productive chain and socioeconomics. The purpose is that the information presented here can reach fishermen, administrators, students, the third sector and governance, as end users of the information, so that they can contribute to the effective sustainability in the scope of the skipjack tuna fishing.