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Review of the comparison between the early paralarvae stages of three squid species of the family Loliginidae (Cephalopods: Myopsida): fishery Oceanographic variability between Cabo de Sao Tome and Cananeira in Southeastern Brazil

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ABSTRACT

Cephalopod fishing in Brazil has been on the rise as a result of the growing demand for high-quality food. Therefore, for the sustainable exploitation of this resource, adequate evaluation, and scientifically supported management strategies are necessary. Notably, the squid which belongs to the family Loliginidae is a fishery resource of increasing importance in the marine ecosystem of the Continental Shelf Southeast and South of Brazil. However, information about stock status, knowledge of life history, ecology, and the distribution of the early stages of its life cycle is still very insufficient. The present review analyzed more than 100 scientific articles, related to the history of life and ecology, the identification of the occurrence of cephalopods of the Loliginidae family in the region between Cabo of Sao Tome (RJ) and Cananeia (SP), the patterns of family distribution to oceanographic processes that were identified from horizontal and vertical maps of abundance, temperature and salinity in plankton sampling collected by 11 oceanographic cruises conducted by the Oceanographic Institute of the University of Sao Paulo (USP) and published in 2013. Respectively, Generalized Linear Models (GLMs) were used to detect the factors that would explain the occurrence and abundance of Loliginidae, which indicated the depth and sea surface temperature (SST), the height of the sea surface (HSS), the salinity of the sea surface (SSS), chlorophyll-a concentration Sea Surface Temperature (SST) and plankton density (PD). Also, a Redundancy Analysis (RDA) revealed the main distribution patterns observed for the three main species of Loliginidae about the oceanographic variables. *Doryteuthis sanpaulensis* predominated in the northern region of the sampling area, associated with cold waters and resurgence events. *Doryteuthis plei* occurred mainly in the southern region of the study area in warmer waters. *Loliguncula brevis* was found only in the estuaries' region of Santos, i.e. in the shallow and less saline waters. The results obtained represent a relevant contribution to sustainable management for the exploitation of these resources and also contribute to the knowledge about squid fishing oceanography in the regional marine ecosystem.

1. INTRODUCTION

Cephalopods are important components of marine

ecosystems around the world, playing a significant role in interspecific trophic relationships and sustaining industrial and artisanal fisheries (Rodhouse & Nigmatullin, 1996; Boyle & Rodhouse, 2005). These mollusks occupy several trophic levels and are considered the main intermediaries in the energy flow between primary, secondary consume, and top predators (Santos & Haimovici, 2002; Gasalla et al., 2010). However, the annual squid catch fluctuates most likely due to the

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influence of inter and intra-annual oceanographic variability in their feeding and spawning areas (Boletzky, 1986; Boyle, 1990; Piatkowski et al., 2001; Rodhouse, 2001; Rocha et al., 2001; Guerra, 2004; Boyle and Rodhouse, 2005). This is because the abundance and distribution of squid populations are highly susceptible to climate change and environmental conditions at a variety of Spatio-temporal scales (Pierce et al., 2006). Immense studies have found that there is a strong relationship between the abundance of squid in the Loliginidae family and marine environmental conditions at different scales.

Loliginidae is a widely distributed squid family of economic importance which is widely used as fishery products and with an important role in an intricate marine food web, and it is composed of 47 species distributed in 10 genera of which all are pelagic (Fields, 1965; Pierce et al., 2006; Vecchione & Young, 2010a; Granados-Amores et al., 2014). Generally, Loliginids have the posterior end of the fins connected to the mantle and four rows of suction cups in the tentacle (Vecchione & Young, 2010).

These characteristics make the cephalopod populations respond quickly to environmental changes, with consequent internal fluctuations in recruitment and catch rates (Pierce et al., 2006; Jackson, 2008). These characteristics also bring complexity to the population structure, making the application of conventional methods of assessment and management of stocks limited (Rodhouse, 2005; Perez et al., 2006). Thus, it is essential to understand their population strategies and mechanisms for environmental variability (Araújo, 2013). Previously, two of the most common species on the Brazilian coast including *Doryteuthis pleii* (Blainville, 1823) and *D. sanpaulensis* (Brakoniecki, 1984), were placed in the genus *Loligo*, a genus that is now restricted to the Eastern Atlantic (Vecchione et al., 2005).

The main species of squid exploited commercially which belong to the Loliginidae families presented peculiar characteristics such as; a short life cycle (less than one year), semi-parity (single reproductive event, followed by death), and high-growth rates, characteristics that significantly affect their availability for fishing (Rodhouse & Nigmatullin, 1996; Boyle & Rodhouse, 2005).

Generally, survival strategies in the early stages of the squid's life cycle are fundamental to the biological production of these organisms. The factors responsible for successful recruitment depend mainly on the interactions between the early stages of the life cycle and biotic and abiotic factors (Rodhouse et al., 1992).

Therefore, they need to develop several studies to better understand the mechanisms that occur in the early stages of development of these cephalopods in the South and Southeast regions of Brazil, as they are essential for understanding the distribution, biology, spawning and recruitment areas, the structure of the population, and fishing strategies (Piatkowski, 1998). The initial phase of the life cycle of most cephalopods such as squid is called paralarvae, as it does not present morphological differences about adults, as occurs with fish larvae and other organisms (Piatkowski, 1998; Young & Harman, 1988). They differ from the adults is only in their planktonic way of life (Barón, 2003b). Squid flanks are efficient predators of zooplankton, and active fins using jet propellers, however, their distribution is particularly dependent on ocean circulation (Barón, 2003b).

According to Röpke et al. (1993), the vertical structure of the water column, especially the occurrence of the monoclinal and the variable depth of the mixing layer, is an important factor in the distribution patterns of the paralarvae. In the southeastern region of Brazil, until now, the relationship between the occurrence of Loliginidae (*Doryteuthis pleii*, *Loliguncula brevis*, and *Doryteuthis sanpaulensis*) and the oceanographic characteristics was observed only by; (Castellanos, 1967; Juanicó, 1979; Gonzalez-Rodriguez, 1982; Haimovici & Andriguetto, 1986; Costa & Haimovici, 1990; Andriguetto & Haimovici, 1991; Costa & Fernandes, 1993^a, Costa, 1994; Barón, 2003b; Vidal et al., 2010), where the seasonal resurgence can increase local productivity, providing adequate conditions for the growth of paralarvae. Paralarvae survival depends on specific oceanographic characteristics, being particularly responsible for the success of stock-recruitment (Rodhouse et al., 1992; Moreno et al., 2009).

The mapping of catches of Loliginidae species was typically carried out using the cruise ship's onboard map system, indicating that the

best yields were associated with the areas of higher productivity originated from the coastal resurgence of Cabo of Sao Tome (RJ) and Cananea (SP), (Costa & Haimovici, 1990). Thus, most of the efforts and accumulated data on the biology and fishing potential of this species were related to the South and Southeast (Haimovici & Andriquetto, 1986; Andriquetto, 1989; Andriquetto & Haimovici, 1991), which mostly is used to refer to the area around the Brazilian coast. It is known in several aspects of the fishing and ecological distribution of squid in the family Loliginidae. Consequently, several studies that have been already published on Loliginidae indicated that many species belonging to the benthic and nektonic communities of the South and Southeast are subject to the influence of oceanographic phenomena (Costa & Fernandes, 1993a; 1993b; Vidal et al., 2010).

In this review, we summarize the life history of squid of the Loliginidae family on the Continental Southeast Platform about population structure, distribution of the paralarvae, abundance, age and growth, and the migratory behaviors, and spawning areas. These factors are fundamental for understanding the larval dispersion and mechanisms responsible for recruitment variability. In addition, we discuss the impacts of oceanographic variability on squid Loliginidae at regional scales. Given this, we propose a mathematical modeling technique to describe the relationship between oceanographic characteristics and conditions with an understanding of relevant physical-biological processes and mechanisms. Our tests will contribute to developing the ability to predict the population dynamics of Loliginidae and improve the sustainable management of squid fishing resources.

In addition, the perception of recruitment and spawning were taken into account in the assessment of fisheries stocks and fisheries management measures (Pierce et al., 2008; Moreno et al., 2009). And just as important, we note that Loliginidae squids are limited to productive coastal regions on the continental shelf, in all oceans, except the Arctic and Antarctica, extending to a depth of 200 meters (Boyle & Rodhouse, 2005). The representatives of this family have a characteristic that is dependent on the fund for the deposition of their eggs and also the preference for demersal prey as well

as the water column (Boyle & Rodhouse, 2005; Rodhouse, 2005).

Life history of the squid in oceanography

The hydrographic conditions of the Southeast region of Brazil between Cabo of Sao Tome (22°S, Rio of Janeiro) and Cananea (25°S, Sao Paulo), depend primarily on the spatial displacement of two bodies of water that touch the Continental Shelf: The Current of Brazil (CB) and the Central Water of the South Atlantic (CWSA), (Castro et al., 2006; Brazil, 2006). Given this, the spatial and temporal alternation of these bodies of water is directly dependent on the topography of the submarine floor and the prevailing wind regime (Costa, 1994).

The region of the Continental Southeast Platform (CSP) has a width of 50 to 230 km and the depth of the platform break varies between 120 and 180 meters (Castro et al., 2006; Araujo, 2013). About sediments, the CSP is mainly covered by sand and mud (Brazil, 2006; Araujo, 2013), with low water salinity, which comes from the mixture of tropical, hot, saline water ($T > 20^{\circ}\text{C}$ and $S > 36.40$). This is then transported via the superficial layer of the Current of Brazil (CB) and the Central Water of the South Atlantic (CWSA) which is relatively cold ($T < 20^{\circ}\text{C}$ and $S < 36.4$). Additionally, the CSP is as well transported in the lower layer of the CB and Coastal Water (CW) that results from the mixture of continental freshwater discharge with those from the continental shelf, with the lowest salinity ($S < 34$) of the waters of the CSP (Castro et al., 2006; Brazil, 2006).

Thus, given these hydrographic conditions in the South and Southeast of Brazil, we can find a large variety of squid representative of the Loliginidae family that has more than 40 species already described (Haimovici & Andriquetto - Filho, 1986), with great prominence within the group by its economic importance and the morphological diversity and body sizes (Haimovici et al., 1989). Therefore, the representatives who are part of this Family have as a characteristic the dependence on the fund for the deposition of their eggs and also the preference for demersal prey and the water column (Boyle & Boletzky, 1996; Boyle & Rodhouse, 2005).

In Brazil, five species of squid from the

family Loliginidae were reported between Cabo de São Tomé (RJ) and Cananéia (RGS) shown in (Fig.1): *Doryteuthis plei* (Blainville, 1823), *Doryteuthis sanpaulensis* (Brakoniecki, 1984), *Pickfordioteuthis pulchella* (Voss, 1953) *Lolliguncula brevis* (Blainville, 1823) and *Sepioteuthis sepioidea* (Blainville, 1823). Importantly, it should be noted that the last two species mentioned above are known to be restricted to estuarine regions and coral reefs (Palacido, 1977; Juanicó, 1979; Haimovici & Andriguetto - Filho, 1986; Haimovici et al., 1989; Haimovici & Perez, 1991; Jereb et al., 2010). *Doryteuthis sanpaulensis* differs from other species by the relative proportion of the fins, with a common feature of always exceeding 50% of the mantle length (Haimovici & Perez, 1991).

Among the representations of Loliginid squids, typically neritic, (*Doryteuthis plei* and *Doryteuthis sanpaulensis* formerly known as *Loligo*) is relatively more abundant in the southern region of Brazil (Haimovici & Perez, 1991; Haimovici & Andriguetto, 1986; Andriguetto & Haimovici, 1991; Costa & Fernandes, 1993a), as well as in northern Argentina 35 °S (Castellanos, 1967; Costa, 1994), sustaining a significant volume of catches (Costa & Haimovici, 1990; Perez, 2002; Gasalla et al., 2005), Cape Hatteras (36 ° N) which is usually associated with the Brazilian hot current. It also includes the Gulf of Mexico as the dominant tectonic invertebrate species during some seasons (Dragovich & Kelly, 1967; Livingston et al., 1976), the Caribbean Sea, Bermuda, and the islands of the Bahamas and the Caribbean (Migliavacca et al., 2020). The increase in catches may be a natural consequence of the decline in traditional fishing resources, which leads to increased availability and effort for capturing the potential of non-traditional species (Rodhouse, 2005).

According to Rodhouse (1998) and Gasalla et al. (2010), there is some evidence that the populations of Loliginid Cephalopods have increased in regions where their predators are overfished, which can be considered an ecological indict. In the case of *Doryteuthis plei*, their commercial catches occur between Cabo Frio (Rio of Janeiro) and Cabo of Santa Marta Grande (the Rio Grande of the South), being the most important species of Loliginidae in the States of Sao Paulo (SP) and Santa Catarina (SC), as it serves as food for cetaceans, pinnipeds, penguins, as well as several species of demersal

and benthic teleost fish (Santos & Haimovici, 1998). Its distribution occurs widely in the Western Atlantic, associated with hot water currents, such as the Current of Brazil (Haimovici & Perez, 1991). On the other hand, the distribution of *Doryteuthis sanpaulensis* is concentrated further south of Brazil (in Argentina) and is captured mainly in the states of the Rio Grande south and Rio of Janeiro (in the Cabo Frio region) in association, respectively, with Subtropical Convergence and cold waters local resurgence (Haimovici & Perez, 1991; Costa & Fernandes, 1993). Both species are captured as fauna accompanying pink shrimp trawling and seasonally by artisanal fishing for squid in coastal regions. Given the ecological and commercial importance of these species, their biology on the southeastern-south Brazilian coast is relatively well known (Juanico, 1979; Haimovici et al., 1989; Costa & Haimovici, 1990; Haimovici & Perez, 1991a; Perez & Haimovici, 1991; Costa & Fernandes, 1993; Santos & Haimovici, 1998; Perez & Pezzuto, 1998; Perez, 1999; 1999; Perez, 2002a; b; Perez et al., 2002; Gasalla, 2005; Perez et al., 2006; Araujo, 2013).

The species *Lolliguncula brevis* has a wide distribution on the Brazilian coast of the states of Pernambuco, Rio de Janeiro, São Paulo, Paraná and Santa Catarina (Juanicó, 1979; Haimovici & Perez, 1991; Haimovici & Andriguetto Filho, 1986; Zaleski, 2010), being abundant in shallow waters (Zaleski, 2005; 2010). The small size species has shown its distribution along the west coast of the Atlantic from Delaware (39°N and 76°W) to southern Brazil (27°S and 48°W) (Vecchine et al., 1982). This species is also captured as fauna accompanying the fishing of the seven-bearded shrimp (Perez, 1999), but different from squids of the genus *Doryteuthis* and has no commercial value (Zaleski, 2010). This loliginid differs from other Loliginidae species as it is often found in estuaries and bays, where the waters are less saline (Vecchione, 1991, Bartol et al., 2002). Further, it has respiratory pigments with a high affinity for oxygen and little sensitivity for a wide range of salinity conditions which is due to low the pH dependency, which constitutes characteristics responsible for the ability to explore hypoxic and euryhaline environments (Vecchione, 1991b), with an increase in abundance in salinity. In the Apalachicola estuary (Florida, USA), the most appropriate habitat for *Lolliguncula brevis* was found to be channels or passages with high-

speed currents and salinity of 20-30 ‰ (Laughlin & Livingston, 1982).

According to Bartol et al. (2002), comparisons of combinations between temperature and water salinity revealed that capture increases with increasing salinity and about depths only at low temperatures (5 to 9°C), and the highest abundances are usually registered between 5.0 and 15.0m. Due to its adaptability to brackish waters, small size, and easily capture, this species has been used in biomedical studies, especially in the Northern Hemisphere (Boletzky & Hanlon, 1983; Brismar & Gilly, 1987; Magnum et al., 1994; Hanlon et al., 1999; Bartol et al., 2002).

Studies that focus on reproductive aspects in cephalopods have indicated that the physiological and behavioral changes resulting from the reproductive process (gonad development, decreased or loss of food activity, and somatic growth) are not reversed after spawning. Consequently, cephalopods (with a few exceptions) are considered Semelparous animals (have only a single reproductive period), more or less prolonged and dying afterward (Costa, 1984; Costa et al., 1994; Haimovici, 1991).

The reproductive cycle of Loliginidae was studied from the monthly changes in the gonadosomatic indexes (GI = gland index; TI = testis index) and the relative proportions that appeared in different reproductive stages. For each individual, a stage of sexual maturation was assigned based on a macroscopic scale composed of four phases: (J) Juveniles (undetermined sex); (A) Immature; (B) Maturing (C) Mature and (D) Spawning. The scale was initially proposed by Juanicó (1979, 1983), and later changed and perfected by Brakonietcki (1984) as well as Andriquetto (1996). We observed that the average length of the first sexual maturation was defined in 50% of the population found in the reproductive process, where the estimate was based on the adjustment of the gonadosomatic indexes to a logistic function based on the model described by Pauly (1984).

The reproduction and spawning of squids of the genus *Doryteuthis* and *Loligunculla* were continuous events throughout the year, with their peaks related to seasonality and the production of several micro-cohorts. (Costa & Fernandes, 1993b; Andriquetto & Haimovici, 1996; Perez et al., 2002;

Zaleski, 2005; 2010; Rodrigues & Gasalla, 2008). The observed extensive pattern of reproduction and spawning suggests that these populations invest in seasonal spawning, allowing them to experience different environmental conditions during the year, and increasing the chances for successful recruitment (Boyle & Boletzky, 1996). With the growing commercial interest in the species of Loliginid, there is a need for studies on their biology and population dynamics, which will subsidize sustainable management of these peculiar fishing resources (Pierce & Guerra, 1994).

In the South and Southeast regions of Brazil, many studies have been carried out on the cephalopod fishing industry (Haimovici & Andriquetto-Filho, 1986; Costa & Haimovici, 1990; Perez, 2002; Gasalla et al., 2005b; Postuma & Gasalla, 2010; Zaleski, 2010), biology and population dynamics (Costa & Fernandes, 1993a; Perez et al., 2002; Gasalla et al., 2005a), ecology and trophic relationships (Andriquetto-Filho & Haimovici, 1991; Haimovici & Perez, 1991; Santos & Haimovici, 2001; Santos & Haimovici, 2002; Martins & Perez, 2007; Gasalla et al., 2010), reproduction (Costa & Fernandes, 1993b; Andriquetto & Haimovici, 1996; Rodrigues & Gasalla, 2008), growth (Perez et al., 2006) and occurrence of paralarvae (Andriquetto et al., 1996 & Vidal et al., 2010). However, in the study area between Cabo of São Tomé and Cananeia, studies on the biology and population dynamics of these species are still quite scarce, with the contributions based on the works of Palacio (1977), Juanicó (1979), Gasalla et al. (2005a; 2005b), Perez et al. (2005), Rodrigues & Gasalla (2008) and Postuma & Gasalla (2010).

The study of coastal cephalopods, in particular, Loliginid occurring in tropical regions has revealed a new relevance in times of climate change and global warming. Since these Loliginids tolerate and even thrive in warm water conditions. This group can thrive favorably when there is a rise in temperature caused by climate change (Santos & Haimovici, 2001; Jackson et al., 2008). Therefore, understanding how these organisms respond to environmental changes can help us to predict what kind of transformations will occur in ecosystems resulting from global warming.

In this sense, this review aims to provide some key information for the management of Loliginid

family fishing, specifically the ones commercialized in the South and Southeast regions of Brazil (i.e. *Doryteuthis plei*, *Doryteuthis sanpaulensis*, and *Loliguncula brevis*, which presents both industrial and artisanal expansion. In addition, providing an understanding of the strategies for the early stages of the squid's life cycle and the mechanisms responsible for availability to fishing is fundamental for the application of catch prediction models including the assessment of the impacts of climate change on fishing and consequently for planning adaptation and mitigation measures, as highlighted by (Costa & Fernandes, 1993b Santos & Haimovici, 2001; Jackson et al., 2008; Rodrigues & Gasalla, 2008).

squid from the Loliginidae family, distribution and abundance are strongly influenced by oceanographic conditions (Boyle & Rodhouse, 2005). In the present review, we have discussed the different patterns of distribution and abundance of the main species of the Loliginidae family. Climate variability over Northeastern Brazil (NEB) is modulated by large-scale atmospheric and oceanic patterns that occur (together or not) over the Tropical Pacific and Atlantic Oceans (Pezzi and Cavalcanti, 2001). So the classic example of interaction between the atmosphere and ocean is the phenomenon known as *El Niño* / Southern Oscillation (ENOS). *El Niño* (EN) is characterized by anomalous heating of the superficial and

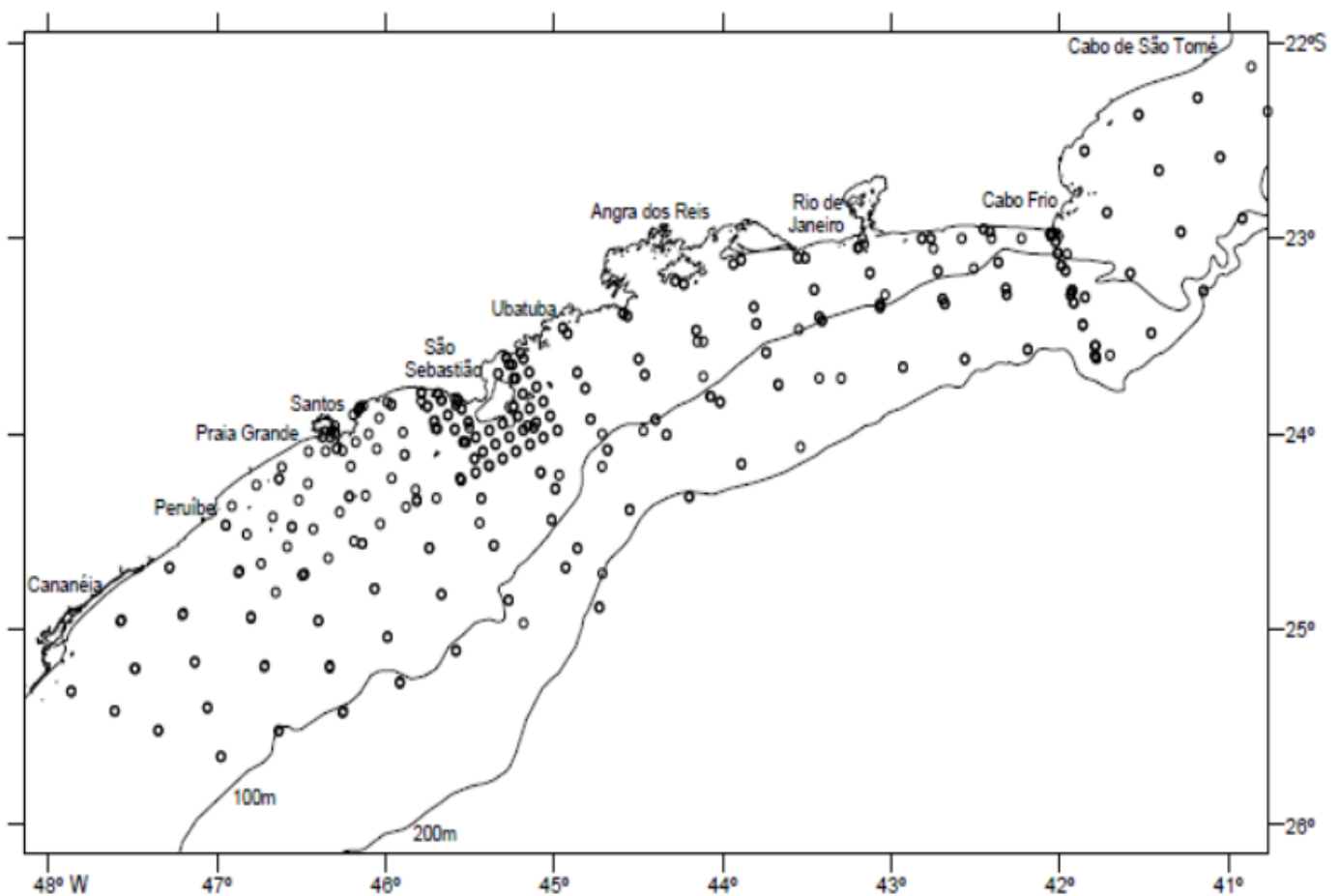


Fig.1. The migration pattern of squid from the Loliginidae family and the circulation of the oceanographic stations of the 11 Atlantic Ocean cruises between Cabo of Sao Tome (RJ) and Cananéia (SP)

Impacts of Large-Scale Oceanographic Variability

Years of *El Niño* and *La Niña* Events

For species with a short life cycle, such as

sub-superficial layer of the Central and Eastern Pacific Ocean (Rasmusson and Carpenter, 1982; Pezzi and Cavalcanti, 2001). The opposite condition characterizes the *La Niña* (LN) events. The Southern Oscillation (SO) is an anomalous variation in tropical atmospheric pressure, being an air response of the EN which is associated with the change in the general circulation of the atmosphere (Rasmusson and Carpenter, 1982; Kayano and Andreoli, 2004). This interaction has been considered one of the causes of climatic variations on the NEB (Kayano et al., 1988; Pezzi

and Cavalcanti, 2001).

This connection between the EN and the NEB occurs through atmospheric circulation, just as the drought-related to the event is attributed to an eastward displacement of the Walker circulation, with anomalous upward movements over the central and eastern equatorial Pacific. This also includes the downward movements (inhibition of convection) over the Tropical Atlantic (TA) and the continental NEB area (Iizumi, Toshichika, Luo, Jing-Jia, Challinor, Andrew J, Sakurai, Gen, Yokozawa, Masayuki, Sakuma, Hirofumi, Brown, Molly E, & Yamagata, Toshio, 2014). Contrary to anomalous patterns in atmospheric circulation, Sea Surface Temperature (SST) and precipitation in NEB are observed in LN episodes (Kayano et al., 1988). However, the abundance of squids in the Loliginidae family usually fluctuates as influenced by normal and/or extreme environmental conditions with particular reference to the *El Niño* and *La Niña* events that begin with an unusually hot and cold temperature range developed in the central and eastern equatorial Pacific (Wolter & Timlin, 2011). The evolution of *El Niño* and *La Niña* can be identified in the space-time changes in SST, Chl-a concentration, primary productivity, zonal wind, and anomalies of 20 °C isothermal depth a proxy for thermocline depth) of the TAO / TRITON matrix data along the equator (Wei et al., 2015).

ENSO (*El Niño* / South Oscillation) is the phenomenon best known as the large-scale variability of the oceans, due to the ocean-atmosphere coupling, especially in the face of the current global warming scenario (Philander, 1985; Gigliotti et al., 2009; Wolter & Timlin, 2011; Faccin, 2019). This phenomenon can provide insight into the possible effects of climate change on squid fisheries (Jones et al., 2014).

The events *El Niño* and *La Niña* have an impact on the distribution and abundance of Loliginidae (Cephalopod: Myopsida). For example, Zaleski, 2010; Araújo, 2013; Jones et al., 2014) also reported on the fundamental consequences of the interannual variability of the *La Niña* / *El Niño* of Loliginidae events in the Southeast Atlantic. Chen et al. (2009), analyzed data from Chinese commercial fisher concerning environmental variables and suggested that the *La Niña* / *El Niño* events could cause differences in squid recruitment as a result

of the influence of environmental conditions on the spawning areas. In addition, a *La Niña* event would result in a decrease in squid recruitment in the spawning area with displacements to the north of the fishing area, while an *El Niño* event could yield a favorable habitat for Loliginid in the spawning area with displacements to the south fisheries (Rasmusson and Carpenter, 1982, Wei et al., 2015).

Furthermore, the relationship between *El Niño* / *La Niña* with other squids or long-lived species has been studied. According to Nevárez-Martínez et al. (2000), an *El Niño* event would cause a sharp decrease in the resources of *D. gigas*, and the forces of the resurgence currents were strengthened in a year of *La Niña*, which translated into an increase in the abundance of squid. In the view of Jackson and Domeier (2003) they observed that the sizes of the marketed *Loligo opalescens* squid emerged and grew in an *El Niño* year and found that the squid was notably smaller with a slower growth rate than in a *La Niña* year.

Based on the findings of Sugimoto et al., 2001 and Wei et al., 2015, there are several impacts of *El Niño* events on climate regime changes on living resources, including short- and long-lived species in the western North Pacific. However, existing studies are mainly focused on determining the correlation between squid abundance/distribution and *El Niño* / *La Niña* and have only described how the recruitment, abundance, and distribution of squid populations can change correspondingly with the environmental variability in their spawning and food grounds. Our understanding of the mechanisms by which the *El Niño* / *La Niña* events lead to Spatio-temporal variability in the abundance and distribution of squid is still limited.

Wang (2012) revealed that the seasonal index in the *El Niño* region of *El Niño*, the evolution and seasonal intensity of events such as SON, DJF, MAM, and JJA can be observed. This study also states that each EN event has its characteristics, and does not have the same start and end month, in which positive SST anomalies can be observed in the first two quarters of the SON and DJF event, which correspond to the development phase including the maturity of the EN as described in the literature. Therefore, the seasonal indices for the North Atlantic and South Atlantic in the years

of EN may also be perceived as a sign of positive anomalies which is in line with other studies that reveal that the ATN is influenced by EN (Sugimoto et al., 2001).

The currents of Brazil and the Guianas Current

The oceanographic environment in the South and Southeast Atlantic Ocean is dominated by the equatorial southern current, which flows from east to the west, by finding the northeast coast of Brazil, bifurcates, originating from the Current of Brazil, which runs in the south, and the current Das Guianas, which follows northwest toward the Caribbean. Both are hot superficial chains moving near the coast. On sunny days, in most tropical regions of Brazil, as in the North, Northeast, and Southeast regions during the summer, the existing air on the continents is constantly heated during the day, becoming less dense and rising in the atmosphere and being replaced by marine air which is described to be relatively colder and consequently giving rise to the marine breeze (Gasalla et.al., 2011; Pena et.al., 2021). This double process interferes significantly in the variation of the weather conditions of coastal regions, determining the wind regime and in certain situations localized storms (Castro, 2008; Pena et.al., 2021).

In this sense, the chain that dominates the whole region near the edge of the continental shelf on the coast of Brazil is the current of Brazil, which takes the south direction, beginning from approximately 10°S, in the proximity of the Northeast coast, and extending to approximately 35-40°S, in northern Argentina. This chain carries heated waters denominated by waters from tropical water between 18°C and 28°C and has mean values of salinity between 35.1 to 36.2 ppm (Martins, 2006 p. 20-27; Faccine, 2019).

On the southeastern coast, especially in Cabo Frio (RJ), there is a decent sea wastewater temperature of up to 14 °C and greater density, in January and February, which circulates low from the currents of Brazil and Malvinas. This happens due to the wind, which in the summer constantly blows from the northeast direction (Miranda, 1985; Araujo, 2013).

Thus, this constant wind pushes the waters of the surface which had suffered insolation and

therefore were heated (around 26°C) for the open ocean (Pena et.al., 2021). Therefore, it causes a water gap next to the coast, which is filled by deep, much colder waters, which rise and reach the surface. In any case, this rise of cold waters is rich in nutrients, a phenomenon is known as a resource known, and occurs mainly in the summer due to the winds coming from the Northeast and Southeast, where it is usually observed in places of great fishing activity of Loliginidae (Pena et. al., 2021). In terms of Loliginidae larvae that appeared in the northern region of the area of Cabo Frio (23°S) between 20 and 80 meters and were associated with distinct oceanographic characteristics, the paralarvae identified as *D. Plei* occurred in warmer superficial waters, on the other hand, *L. Brevis* paralarvae were associated with surface waters with fewer salinity conditions (Martins & Perez, 2006; Gasalla et.al., 2010; Araujo, 2013). Regarding salinity, we observed that Brazil's current was in the North region, evidenced by salinity values > 36, characteristic of AT. From the vertical distribution maps of the water masses, the intrusion of CWSA was evident in the study area, close to the coast, and mainly in the northern region. Based on the diagram, it was also possible to identify the presence of CW, TW, and PW (platform water, from the mixture of the water mass).

Based on previous studies (Vecchione, 1981.1991; Martins & Perez, 2006; Gonzales et al., 2005; Baron, 2003 and Vidal et al., 2010; Moreno et al., 2009; Rodrigues & Gasalla, 2008), we can conclude that the winding standard of Brazil's current and the strength of the gulf chain do not affect the spatial distribution of Loliginidae squid fisheries. The seasonal variability of Brazil's current causes different behavior of water masses due to the formation of vortices and meanders induced by the changes in the pattern of the winds, thus causing the rise of waters and dispersion of nutrients (Campos et al., 1995; Brazil, 2006). In the summer, Ekman transport generated by the dominance of northeast winds and vortex training in the chain of Brazil moves from the superficial stratified water column, promoting intrusion and resurrecting with the presence of CWSA below 15 meters deep, which is rich in nutrients and responsible for increasing primary productivity and favoring the survival of meroplanktonic larvae. The penetration of CWSA during the summer causes a stratification with the formation

of a strong thermocline. Conversely, the water column becomes homogeneous during the winter due to its indent to the slope (Borzzone et al., 1999; Brazil, 2006). During the new spring thermocline period, a maximum gradient is recorded in February, when the temperature falls from 26°C to 7m to 16 ° C to 14m deep (Borzzone et al., 1999).

Synthesis of the occurrence and distribution of Loliginidaeparalarvae

For short-term cycle species, as is the case of Loliginid squid, distribution and abundance are strongly influenced by the oceanographic conditions (Boyle & Rodhouse, 2005). In the present review, it was possible to observe different patterns of distribution and abundance of the main species of Loliginidae. In this review, although paralarvae have occurred throughout the study area, they were mainly found close to the coast, but concentrated in distinct regions. Given the oceanographic variation caused by the complex and dynamic hydrography of the study area (Young & Harman, 1988; Piatkowski, 1998).

Paralarvae distribution standards may also be related to the distribution of adults, since mature individuals in the Loliginidae family move to more shallow areas for reproduction and spawning (Rodrigues & Gasalla, 2008), thus becoming the target of the fishing activities (Postuma&Gasalla, 2010). More so, Lipiski (1998) found that the distribution and abundance of ripe cephalopods deterdeterminedistribution and abundance of paralarvae. However, Loliginidaeparalarvae in coastal waters are often rare, even in situations where there is an incidence of reproduction and spawning aggregations (Hatfield & Rodhouse, 1994; Piatkowski, 1998). Regarding the horizontal distribution, the paralarvae occurred along the sampling area and approximately to a depth of 100 meters, standard verified for various species of Loliginidae (*Doryteuthispealei*Vecchione, 1981; *Lolligunculla Brevis*Vecchione, 1991b; *DoryteuthisGahi*Rodhouse et al., 1992; *DoryteuthisOpalescens*Zeidberg and Hamner, 2002; *Loligo vulgaris* Gonzalez et al., 2005; *Doryteuthis Plei* Martins & Perez, 2006; *Loligo vulgaris* Moreno et al., 2009; *Doryteuthis sanpaulensis* Vidal et al., 2010).

As for the vertical distribution, the paralarvae were collected to the stratum of 40 meters deep, and the

largest abundance was found between 20 and 40 meters. However, few works were described for the vertical distribution of paralarvae, the surface temperature of the sea (STS°C), surface salinity of the sea (SSS), depth (M) for Loliginidae, and can cite (Vecchione, 1981; Zeidberg&Hamner 2002; Young, 1998; Gasalla at al., 2011; Araujo, 2013), who analyzed higher abundances on the surface, for *Doryteuthispealei*, and up to 30 meters deep for *DoryteuthisOpalescens*, respectively.

Paralarvae of the species, *Doryteuthis Sanpaulensis* were the most abundant in the sampling area, distributed between Cabo Frio and the island of São Sebastiao. As well as in Barón (2003b) and Vidal et al. (2010), the paralarvae were found only on the internal platform, up to 60 meters. The greatest abundance occurred during the summer wide of Cabo Frio.

In addition, the largest abundance of *D. Sanpaulensis* may be vigorously related to the occurrence of a coastal resurgence in this region. During the summer and spring, the wind prevails in the east and northeast direction, causing removal from the surface waters of the chain of Brazil toward the open sea, through the transport of Ekman, allowing the outcrop of the CWSA, cold and rich water in nutrients (Miranda, 1985; González et al., 2005). The relationship between *D. Sanpaulensis* and the resurgence phenomenon was based on the evidence of the abundance of paralarvae observed in the Cabo Frio (González et al., 2005), which is the increase of the abundance of *Loligo vulgaris* in periods of a resurgence in the Galicia, Spain was also observed.

From the perspective of Vidal et al. (2010), the resurgence phenomenon can be one of the main regulators of food availability for the early stages of cephalopods and their growth, survival, and recruitment. The relationship between the abundance of paralarvae and the resurgence shows that this phenomenon can offer favorable conditions for the survival of the beginning stages of squid (Moreno et al., 2009; Gonzalez et al., 2005). However, low temperatures may lead to a reduction in growth rates, extending the period of the initial stages, exposing them to higher mortality rates, and consequently harming the recruitment process (Postuma, 2010).

In the meantime, Baron (2003a) verified that the

embryonic development of *D. Sanpaulensis*, South Atlantic, is usually at temperatures between 12 and 23°C, proving with the results obtained in the study which owes to the fact that the paralarvae of *D. Sanpaulensis* were found in seasons where STS ranged from 14.7 to 23.8° C and SSS between 34.5 to 35.5. Regarding the vertical structure of the water column, paralarvae were found in homogeneous waters, dominated by stratified waters and characterized by the presence of CWSA and TW.

DoryteuthisPlei was the most frequent species in the samples analyzed which can be found mainly in the southern region of the sampling area between the island of Sao Sebastiao and Cananeia. In the cruises carried out in the summer, paralarvae occurred between 25 and 65 meters in depth which can be associated with warmer STS (24.8° C to 27.8° C). Regarding the vertical structure of the water column, the paralarvae were found mainly in stratified waters with the presence of CW, CWSA and TWA found in the winter inhomogeneous waters, characteristic of the sampling area (Baron, 2003a). The highest frequency of occurrence and plenty of *Doryteuthis Plei* were found around the island of Sao Sebastiao and Cananeia during the summer. Therefore, these results come according to the peak of reproductive activity already observed (Martins & Perez, 2006; Rodrigues

&Gasalla, 2008; Postuma, 2010). Significantly, the paralarvae of *D. Plei* were associated with warmer waters compared to Sanpaulensis. A characteristic was also observed for adult populations of these two species (Juanico, 1979; Costa & Fernandes, 1993b) but the squid of *D. Plei* has preferences for warmer waters than the squid of *D. Sanpaulensis*. However, during the summer and spring, the paralarvae of *D. Plei* were found in stations with a laminated water column which is similar to the observations by Martins & Perez (2006) in Santa Catarina, and Gasalla et al. (2011) in Sao Sebastian. *Lolloguncula Brevis* are exclusively distributed in Santos bay during the summer and only a single occurrence has been recorded near the coast in the Santos region during spring. Individuals belonging to this genus have peculiarities in their habitat since is the only genus of the Loliginidae family that tolerates environments with low salinity water (Castellanos, 1967; Bartol et al., 2002).

According to Vecchione (1991b), in the coastal and estuarine region of Louisiana, in the United States paralarvae of this species are associated with low salinity waters. From our search of the literature, we observed that the paralarvae are most often found in shallow salinity waters, inhomogeneous waters, and characterized by the presence of AC which is also associated with SST around 25°C.

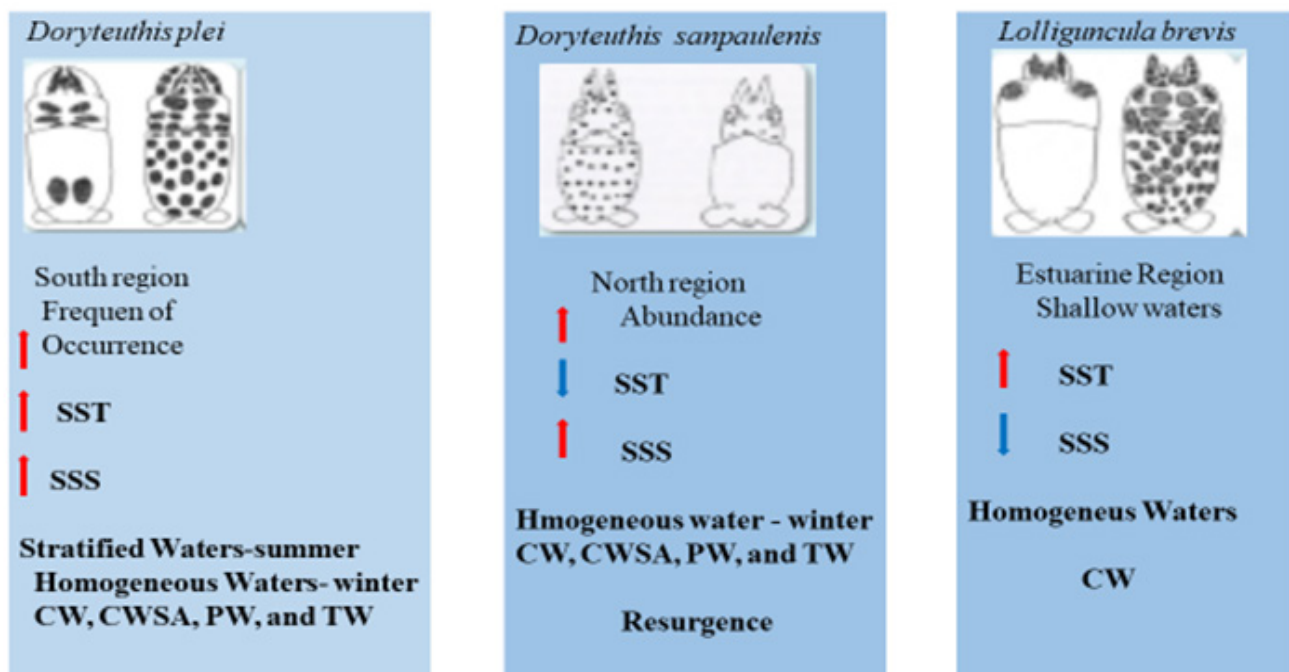


Fig. 2. Synthesis of the distribution patterns and oceanographic conditions associated with the Loliginidae sands, collected in the region between Cabo of Sao Tome (RJ) and Cananeia (SP). SST = sea surface temperature; SSS = surface salinity of the sea; CW = Coastal Water; CWSA = Central Water of the South Atlantic; PW = Platform Water; TW = Tropical Water (Araujo, 2013).

Moreover, Loliginidae species were associated with stratified waters with distinct oceanographic characteristics for paralarvae identified as genus *Doryteuthis* and occurred in warmer superficial waters. However, the paralarvae of *L. Brevis* were mostly associated with less saline surface waters. It is worth stating that, the results observed and obtained in the study represented an important contribution to the knowledge of the fishing oceanography of Loliginid squid in the regional marine ecosystem. The identification of essential habitats for the initial stages of the life cycle of commercially significant species for fishing has relevance to the evaluation and management of inventories, as well as for their conservation.

The paralarvae identified only down to the Family level alone represented 51% (N=125) of the total, down to the species level *Doryteuthis sanpaulensis* 30.6% (N=75), *Doryteuthis plei* 15.9% (N=39) and *Lolliguncula brevis* 2.4% (N=6) (Fig. 3). It is worth mentioning the occurrence of only one individual of the species *Pickfordiateuthis pulchella* during the OPISS-2 cruise, carried out in the spring cruise in the region of São Sebastião. The three identified species showed a higher frequency of occurrence in the cruises carried out in the summer months. *Doryteuthis plei* had the highest frequency of occurrence (23.3%). The paralarvae identified as *D. sanpaulensis* were more frequent (1 than %) and the paralarvae of *L. brevis* (27.3%).

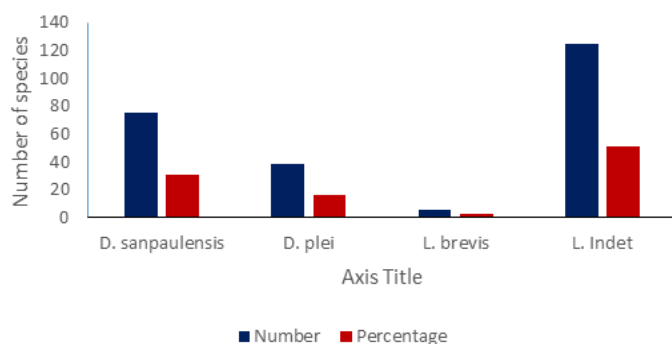


Fig. 3 Taxonomic composition of the paralarvae of Loliginidae paralarvae collected between 1991 and 2005 in the region between Cabo de São Tomé (RJ) and Cananéia (SP).

In addition, we can also observe that there was a positive correlation between abundance and the TSM interval, which were approximately between 21.5 to 22.5°C. Regardless of the influence of the Pacific Ocean, the variability of SST in the South Tropical Atlantic Ocean also presents its

importance and impact on the climate of the NEB region (Hastenrath and Heller, 1977; Moura and Shukla, 1981; Andreoli, 2002; Kayano et al., 2004). Some studies such as those by Hastenrath and Heller, 1977; Hastenrath, 1978; Moura, and Shukla, 1981, show that in years of drought, TWSS in the Tropical Atlantic show a positive GRADM behavior (positive TAP in the north and negative TAN in the south of Ecuador), for rainy years this behavior is reversed and GRADM is negative. For years in agreement on the Pacific and Atlantic, that is, EN and GRADM positive or LN and GRADM negative, the relationship between TWSS in the Tropical Atlantic and NEB precipitation is stronger and the amplitudes of precipitation anomalies are larger and more significant, with drought and rain conditions being observed, respectively, around or greater than the average. Generally, in divergent years (EN and negative GRADM or LN and positive GRADM) this relationship is weaker, since the Tropical Atlantic behaves in the opposite direction to the event in the Pacific, limiting or even reversing the sign of precipitation anomalies over the NEB (Pezzi and Cavalcanti, 2001, Moura and Shukla, 1981).

Pacific Decadal Oscillation

The Pacific Decadal Oscillation (PDO) is a pattern of climate variability on at least an inter-decadal time scale, reflecting the long-term environmental background in the Pacific Ocean. The variability in PDO coincides with the dynamic of some fisheries resources, such as Pacific saury (*Cololabis Saira*) (Tian et al., 2004) and skipjack tuna (*Katsuwonus pelamis*) (Lehodey et al., 2013). Mantua and Hare (2002) reviewed the impacts of inter-decadal changes in Pacific climate on many marine fisheries in the North Pacific. However, previous studies were focused on long-lived demersal fish stocks, whereas less work investigated PDO-squid interactions.

Recently, Wei et al. (2015) have indicated that the seasonal occurrence of *D. gigas* in the northern California Current was related to PDO, whereas the density of the squid coincided with the amount of juvenile hake, corresponding to the same trends in the SST and PDO indices. Paralarval abundance of *L. opalescens* was found correlated to both the El Niño-Southern Oscillation (ENSO) and PDO indices, which could be used in the development of adaptive management of market squid fishery

(Koslow and Allen, 2011). In the Northwestern Pacific Ocean, the significant influence of PDO combined with temporal variations in the Kuroshio changed the latitudinal distribution of *O. bartramii* (Chen et al., 2012), whereas the CPUE of albacore (*Thunnus alalunga*) was positively correlated with the PDO index with a lag period of 13 months (Zhang et al., 2011).

The PDO pattern provides an inter-decadal climatic background for ENSO, El Niño/La Niña, and Kuroshio/ Oyashio Currents, which is likely to continuously exist during the 21st century (Yatsu et al., 2013). Previous studies proposed the interactive relationships among the large-scale oceanographic factors above (Lu et al., 2005). The El Niño events tend to occur with high intensity in a warm phase of PDO, while the La Niña events occur more frequently with strong intensity in a cold phase of PDO (Lu et al., 2005). The SST in the Kuroshio extension has significant temporally-lag correlations with the PDO and ENSO indices, which can be used to forecast SST variations in the Kuroshio (Wang et al., 2012b).

Based on the relationships among the large-scale ocean climate variables and their influences on marine fisheries, the following hypothesis can be formulated: the recruitment, migration, distribution, and abundance of *O. bartramii* change with SST variations in the Kuroshio and Oyashio Currents under the El Niño/La Niña events in the corresponding PDO phase; the SST affects the primary YU et al. / J. Ocean Univ. China (Oceanic and Coastal Sea Research) 2015 14: 739-748 743 productivity and further influences the survival of prey; and the whole preprocess for several months, resulting in an observed time lag in the effects of oceanographic/ climatic conditions on the population dynamics of squid. To better describe the fishery's geography and relevant mechanisms, more field observations and numerical modeling studies on the relationship between *O. bartramii* and PDO are needed.

Impacts of Environmental Conditions on a Regional Scale in the Atlantic Ocean and South Pacific

In the Atlantic Ocean and South Pacific, the main squid species exploited commercially for the fishing fleets of Brazil, Ecuador, Peru, Chile, and Argentina, especially the Loliginidae, have peculiar

characteristics such as a short life cycle (less than one year), semi-parity (single reproductive event, followed by death) and high-growth rates, characteristics that significantly affect their availability for fishing (Rodhouse&Nigmatullin, 1996; Boyle & Rodhouse, 2005). In essence, many studies have described the distribution and abundance of the Loliginidae family about environmental conditions on a regional scale. Therefore, in comparison with other local oceanographic variables, SST is generally considered the most suitable indicator for the search for Loliginidae fisheries, which also has a superior predictive power for estimating squid abundance (Chen and Chiu, 1999).

Loliginid fishing is usually formed in areas with a dense distribution of isothermal surface water layer, the convergence of hot and cold water, and the thermal layer. According to Valentin (1984), the average phytoplankton biomass throughout the year is 0.4 mg /m³ of chlorophyll to 3.25µg / L, with the peaks occurring during the summer, when it reached up to 6.0 mg /m³ of chlorophyll a. Valentin et al., 1990, estimated the average zooplankton biomass at around 66 mg /m³ over the year, with the highest values recorded in February and November, with more than 200 mg /m³.

The favorable period for resurgence (October to April) corresponds to the period in which the presence of subtropical waters (CWSA) and the passage of E-NE winds are more frequent and intense. Both water temperature and Chl-a concentration have a major influence on the distribution and abundance of Loliginids throughout their life cycle (Zaleski, 2010, Wei, et al., 2015).

According to Andriguetto&Haimovici (1996) and Araujo (2013), the abundance estimates for *Doryteuthis sanpaulensis* in the Costa do Sao Sebastian reveal similarities to that found in Cabo Frio, where average catches (n/h and kg/h) were significantly higher in summer and the stock was concentrated at depths ranging from 7 to 113 meters, at temperatures between 14.7°C and 28.4°C.

In this sense, several relevant studies are based mainly on remotely detected ocean surface data, whose accuracy and reliability are considered

questionable because Loliginids of the genus *Doryteuthis* are often found in estuaries and bays in warmer and less saline surface waters. Essentially, the parallel *L. brevis* were associated with surface water with a temperature of 25°C, salinity in the range of 27 to 32.1, the pH was 7.6 ± 0.07 and the oxygen saturation was greater than 96% (Andrighetto & Haimovici, 1996). Even so, studies on the recruitment of *D. sanpaulensis*, *D. andplei*, *L. brevis* based on variations in the concentration of SST and Chl-a in the spawning areas are considered reasonable because the planktonic squares of the squid inhabit the surface waters of the sea (Goçalo, 2008; Pena et al., 2021). The abundance of Loliginidae is also associated with the height of the sea surface (HSS, also expressed as the height from sea level (HSL) or sea level anomaly, SLA) is another useful environmental indicator to assess the interannual variation in the distribution of Loliginidae during spawning and nursery periods in the subtropical frontal zone (Costa et al., 1993). The ideal ranges for squid habitats are between -20 and -4 cm SSH (Costa, 1994).

However, zooplankton biomass estimation can provide an effective way of exploiting the fisheries of *D. sanpaulensis*, *D. plei*, and *L. brevis* based on field research in the Southeast Atlantic and South Pacific. *D. sanpaulensis* appears to have a life cycle quite similar to that of other Loliginid species (Dragovich, 1967; Arnold, 1977; Andrighetto et al., 1996; Araújo, 2013; Bartol, 2002), see also Boyle (2005) who classified these species as annual spawners but with peak activity at the population level. Young squids generally migrate to deeper waters along the continental shelf towards the slope while feeding and maturing. Adult animals migrate back to coastal areas to spawn and die (or emigrate) from the area afterward (Dragovich, 1967).

In this way, the life cycles of cephalopods can be classified into two phases: the passive phase, when moving to areas with more favorable environmental conditions, and the active phase, when using ideal environmental conditions to reach certain life stages at different stages of life process between generations (Pierce et al., 2008). For commercial fishing purposes, most studies are focused on the active phase of adult Loliginids, while fundamental research focuses on the early stages of life, especially the passive planktonic

phase of juvenile and paralarvae. It should be noted that both the physical environment and biological factors (swimming behavior and depth and spawning areas of the water) affect the transport and recruitment of fish early in life (Andrighetto, 1991).

The squid from the Loliginid family is characterized by a short life cycle and dies immediately after spawning, the abundance of which depends entirely on recruitment. Due to the high natural mortality in the embryonic and larval development stage of *D. sanpaulensis*, *L. brevis*, and *D. plei*, any minor variation in the marine environment can affect the growth, survival, and recruitment in the stocks of this species of squid (Andrighetto, 1991, 1996).

CONCLUSIONS AND FUTURE RESEARCH

According to the above reviews, the abundance and distribution of squid from the Loliginidae family showed sensitivity and were strongly affected by changes in oceanographic conditions. The population dynamics of Loliginids in the North and Southeast Atlantic Ocean off Brazil are mediated mainly by medium-scale and large-scale climatic-oceanic phenomena (for example, Brazilian currents and Guyana Current) rather than small-scale environmental phenomena (for example, concentration of SST and Chl-a) because all oceanographic influences are imposed in the context of large-scale climate change.

Therefore, it should be noted that the Loliginidae analyzed showed differences in the horizontal distribution, concerning depth and latitude, and also in oceanographic conditions, whose variability varies over time and location with seasonal and geographical characteristics. Existing studies that reveal significant relationships between environmental factors and the populations of *D. sanpaulensis*, *L. brevis*, and *D. plei* can explain the mechanism of oceanographic influences to a certain extent. However, difficulties persist in the use of environmental variables that accurately predict the abundance and distribution of squid, which can be attributed to the uncertainty and outdated effects of the climate. In response to climatic changes in marine environmental conditions, Loliginid species are usually subject to large fluctuations in their abundance (Valentin, 1984; Gonzalez-Rodriguez et al., 1992). However,

it is urgent and necessary to draw a rational trajectory for the assessment of the stock of *Doryteuthis sanpaulensis*, *Doryteuthis plei*, and *Lolliguncula brevis* to achieve better sustainable management of these resources and fisheries.

In addition to the analysis of short and medium-term variability in the environment, long-term changes in marine ecosystems associated with decadal-scale variations in the structure and abundance of *Doryteuthis sanpaulensis*, *Doryteuthis plei*, and *Lolliguncula brevis* should be studied. The fluctuation of the Atlantic decade oscillation (ADO) in the abundance of *D. sanpaulensis*, *D. plei*, and *Lolliguncula brevis* was demonstrated by the evaluation of the response to the interference of climatic and oceanographic variations on fishing activity in the south and southeast of the Atlantic in Brazil where these changes may have effects under the reallocation of the capture potential at global levels (Cheung et al., 2010).

Given this, we can consider that the life cycles of a cephalopod can be classified into two phases: the passive phase which describes the movement to areas with more favorable environmental conditions, and the active phase, when they rely on ideal environmental conditions to reach certain stages of life at different rates of growth between generations (Pierce & Guerra, 1994; Pierce et al., 2008). For economic purposes of fishing, most studies are focused on the active phase of *D. sanpaulensis*, *D. plei* adult, as fundamental research for the early stages of life, especially the passive planktonic stage of juvenile and paralarvae.

Therefore, the environmental, physical, and biological factors events (spawning areas of the water, swimming performance, and depth) have shown that they can affect the transport and recruitment of fish early in life (Juanico, 1979; Andriguetto, 1996). We can exemplify that the distribution and settlement of fry in the nursery during its four stages of pelagic life depend on the biological and physical environment of the location in the Middle Atlantic Bay, where the flow conditions and climatic forces play significant roles in the transport of parapet from *D. sanpaulensis*, *D. Plei* and *Lolliguncula brevis* (Vidal et al., 2010; Vecchione, 1991b). For species with a short life cycle, such as Loliginid squids, distribution and abundance are strongly influenced by oceanographic conditions (Boyle &

Rodhouse, 2005).

However, low temperatures can lead to a decrease in growth rates, prolonging the period of the early embryonic and larval development stages, exposing them to high natural mortality rates, and consequently hindering recruitment in species stocks, (Pierce, 1994; Postuma, 2010). About the vertical structure of the water column, the parapets were always found in homogeneous waters which are dominated by CWSA and in stratified waters, with the presence of CWSA, PW, and TW (Goçalo, 2008; Pena et al., 2021).

Knowledge of the history of the Loliginid family life and the interaction between its parallel and the physical environment are of big importance for predicting the abundance of squid. Therefore, fundamental studies must be carried out constantly to better understand the potential impacts of oceanic weather events on the biological behavior of the squid. It is also important to point out that physical forces that drive the variability of the stocks of *D. sanpaulensis*, *D. Plei*, and *Lolliguncula brevis* need to be addressed.

Therefore, for future research, it will be necessary to emphasize the following approaches:

1. Fully master the basic biology and life cycle of *D. sanpaulensis*, *D. Plei* and *Lolliguncula brevis*. Depending on growth and age, the entire life cycle of the squid should be divided into two phases: the passive stage, including floating eggs, and planktonic parasites, and note active stage, including juvenile, sub-adult, and adult. Biological equations as a function of length and temperature should be used to parameterize the growth and mortality processes precisely for the passive processes of early life. Additionally, a Generalized Linear Model (GLM) should also be used in individuals to detect the factors that would explain the occurrence and abundance. Finally, a Redundancy Analysis (RDA) should be carried out to show the main distribution patterns of these Loliginidae species.
2. Connection of physical and biological models, interacting with the dynamics of the squid population (growth, transport, abundance, distribution, and mortality), identifying true dynamic factors that affect the passive drift life cycle processes, and conducting various

modeling tests to evaluate the influence of physical-biological processes on the *D. sanpaulensis*, *D. Plei*, and *Lolliguncula brevis* populations.

3. Define physical fields with time series, high-resolution three-dimensional flow fields, temperature and salinity, mixed diffusion coefficient, and optional vertical turbulent closure schemes in the South and South Atlantic Ocean by using the appropriate ocean dynamics models.
4. Evaluate the survival rate and the distribution pattern of larvae and parasites of *D. sanpaulensis*, *D. Plei*, and *Lolliguncula brevis* and predict the distribution and abundance of squid in the future.
5. In summary, this review elaborates on the life history of some representative species of the Loliginidae family and discusses the occurrence, distribution, and variability of the paralarvae and abundance of squids related to large-scale oceanic weather phenomena (*El Niño*, *La Niña*, currents of Brazil Guyana Current, ODA, OMA and PDO) and sea surface height (SSH), sea surface salinity (SSS), Chl-a concentration sea surface temperature (SST) and plankton density (PD). The stocks of *D. sanpaulensis*, *D. Plei*, and *Lolliguncula brevis* are believed to be driven by large-scale oceanic weather events. Therefore, it is hereby recommended making of population dynamics by coupling physical and biological models to simulate the initial squid life cycle process based on an accurate understanding of its initial life history.

AUTHOR CONTRIBUTIONS

conceptualization, W.B.M.Z., and R.K.; methodology, W.B.M.Z.; software, W.B.M.Z.; validation, R.K., and X.D.; formal analysis, W.B.M.Z.; research, W.B.M.Z.; resources, X.D.; data curation, W. B.B.M.Z.; draft writing preparation, W.B.M.Z.; writing—review and editing, R.K.; proofreading and editing, R.K.; G.W.; supervision, R.K.; project administration, X.D. All authors have read and agreed to the published version of the manuscript

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CONFLICTS OF INTEREST

The authors declare no conflict of interest.

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