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Identifying seasonal patterns in the 3d habitat suitability related to the dynamics of the artisanal fleet of D gigas in the Peruvian ANJ

Republic of Peru

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IDENTIFYING SEASONAL PATTERNS IN THE 3D HABITAT SUITABILITY RELATED TO THE DYNAMICS OF THE ARTISANAL FLEET OF JUMBO FLYING SQUID *DOSIDICUS GIGAS* IN THE PERUVIAN JURISDICTIONAL WATERS

by

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This report contains information on the jack mackerel stock and fishery in Peruvian jurisdictional waters that, we reiterate, the delegation of Peru, in use of its discretionary powers, voluntarily provides for the purpose of information and support to the scientific research work within the Scientific Committee of the SPRFMO. In doing so, while referring to Article 5 of the Convention on the Conservation and Management of High Seas Fishery Resources in the South Pacific Ocean and reiterating that Peru has not given the express consent contemplated in Article 20 (4) (a) (iii) of the Convention, Peru reaffirms that the decisions and conservation and management measures adopted by the SPRFMO Commission are not applicable within Peruvian jurisdictional waters.

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Abstract

The jumbo flying squid is widely distributed in the Southeast Pacific and is affected, like other marine resources, by climate variability at different scales. In the present work, a 3D seasonal characterization of this resource in Peruvian waters will be carried out. For this purpose, acoustic data from IMARPE's scientific surveys will be used, as well as data from the artisanal fleet. Based on the results, it can be observed that the environmental variability had important variations (Sea Surface Temperature (SST) variance) in the coastal, being more variable during the 1990-1999 and 2010-2022 than in the decade of the 2000-2009. In addition, decadal variations in the sea surface temperature are observed, with warm periods (1990-1999 and 2010-2022) compared to the decade between 2000-2009. In addition, based on the acoustic results, no clear seasonal pattern was observed in the depth of this resource, but a clear nictimeral pattern was observed, with this resource being found up to 400 meters during the day and in the first 50 meters at night. Additionally, it was observed that these decadal variations were also replicated in the dynamics of fishing, with a greater expansion of fishing areas for the last decade (2010-2022) and greater distance from the coast. This shows that environmental dynamics have an impact on fishing dynamics.

I. Introduction

Jumbo flying squid (hereafter JFS) *Dosidicus gigas* is widely distributed in the Southeast Pacific. Off Peru, JFS are found along the whole coast, at distances ranging from 10 to more than 500 nautical miles (nm) from the coastline (Csirke et al. 2015, 2018). The JFS have different patterns at different scales, it undergoes diel vertical migrations from 0 to more than 650 m depth, seasonal inshore-offshore ontogenetic migrations (Csirke et al. 2015, 2018). The JFS is an essential and important component of the marine food webs, the juveniles are consumed by different top predators such as large-size fishes, marine mammals and sea birds. On the other hand, JFS feeds on different species but predominantly small mesopelagic fishes, micro-nektonic squids and euphausiids (Markaida and Sosa-Nishizaki, 2003). Owing to its highly economic values, JFS supports an important fishery off Peru, Chile, Ecuador and the Gulf of California in the whole area of distribution.

In Peru, this fishery is an important economic activity after the anchovy fisheries. The Humboldt Current System (HCS) is an important habitat with comparatively high productivity, sustaining large fisheries such as the anchoveta (*Engraulis ringens*), jack mackerel (*Trachurus murphyi*), and JFS (Cahuin et al., 2015; Bertrand et al., 2016; Ramos et al., 2017). The HCS is a coastal wind-driven upwelling system who is impacted by complex oceanographic processes at different scales such as eddies, fronts and meanders. Interannual and seasonal variations in environmental conditions off the HCS is significantly affected by the large-scale climate variability (namely El Niño Southern Oscillation, ENSO). Previous studies have shown that the habitat of JFS has been suffering the effects of changing environments at different scales such as the global ocean warming (Yu and Chen, 2018). But there is still a lack of knowledge about the description of different patterns, mechanisms and others about the JFS habitat. To advance the efforts in understanding the squid-habitat interactions, it is key to evaluate the habitat quality for this squid on a seasonal timescale.

To understand how the impact of the environmental conditions affects to JFS is key to the management, for that in the present study, an integrated acoustic data and HS model were used to examine the 3D seasonal habitat patterns of JFS in the Peruvian jurisdictional waters using the artisanal fishing data and oceanographic data.

To achieve this objective, we used different sources of data, we used fisheries data from artisanal fleet, acoustic detection of *D. gigas* and vinciguerria, and satellite oceanographic data.

II. Materials and methods

Study area

The study area is located in the Peruvian jurisdictional waters between 1996 to 2022.

Jumbo flying squid fisheries data

Commercial fishery data of JFS during 1996-2022 were obtained from IMARPE Observer Program on board the artisanal fleet and information registered in ports. These data comprised detailed catch (tons), fishing date (year and month), fishing locations (latitude and longitude) and fishing effort (fishing days) per fishing operation. The fishery dataset included 18810 fishing operations. The total area was located in Peruvian jurisdictional waters.

In this study, the monthly CPUE within a 0.5°×0.5° grid cell was calculated based on the following equation (Cao et al., 2009):

Acoustic data

The acoustic information has been collected during the execution of the scientific surveys carried out by IMARPE, this information was obtained through the use of scientific echo sounders EK-60 and EK-80 which were equipped with five sound frequencies 18, 38, 70, 120 and 200 kHz. This information was obtained from calibrated echo sounders. For discrimination, Echoview software was used with multifrequency algorithms and check sets. For the acoustic index calculations, the 38 kHz frequency was used due to its greater vertical range compared to higher frequencies.

Oceanographic data

Sea Surface Temperature

The Sea Surface Temperature (SST) was downloaded from the NOAA at a 1/4° grid. This data is a Daily Optimum Interpolation Sea Surface Temperature (OISST) who is a long-term Climate Data Record that incorporates observations from different platforms (satellites, ships, buoys, and Argo floats) into a regular global grid. The dataset is interpolated to fill gaps on the grid and create a spatially complete map of sea surface temperature. Satellite and ship observations are referenced to buoys to compensate for platform differences and sensor biases.

ONI index

In this study, we focused our analyses on the effects of the ENSO (El Niño and La Niña events) on the suitable habitat of JFS. The Oceanic Niño 1+2 indices over 1951-2022 were achieved from the NOAA Climate Prediction Center. Based on the index we run a low-pass filter with a cutoff of 8 years to reveal the decadal patterns.

Methods

Vertical distribution

Was used the acoustic data to evaluate the vertical distribution of the resources in study.

Quantifying the preferred habitat distribution metrics of squids

The center of habitat gravity (CHG) has been proposed to understand and evaluate the presence of shifts in distribution. The CHG is the average location of grids in each month, where each location is weighted by the effort.

$$LatG = \frac{\sum\left(Lat_{mij} x Effort_{mij}\right)}{\sum Effort_{mij}}$$

where n is the number of grids for each stock, Effort_mij is the effort computed for each grid, and the unit for LatG is degrees.

III. **Results**

Using the JFS acoustic data, we showed the nictemeral vertical distribution for summer and spring. Besides that, we plotted the light fish acoustic data together to JFS (Fig. 3) and can observed a correlation between both of them. During night hours both species are observed in a shallower area, in contrast at day hours, when both species are deeper around the 300 meters.

Decadal average of the sea surface temperature

The decadal separation of the sea surface temperature (sst) in three decades, 1990-1999, 2000-2009 and 2010-2020, was carried out. In addition, the SST anomaly and finally the SST variability were plotted. Looking at the decadal sst, we can see that there is no strong pattern in the 3 decades. The same results are observed for the sst anomaly. In the case of the sst variability (variance calculation), it can be observed that the variability was higher in the decade 1990-1999, which is comparable to the decade 2010-2022. It is also observed that the variability between 2000-2009 was lower, indicating a greater stability of the marine ecosystem (Fig. 1).

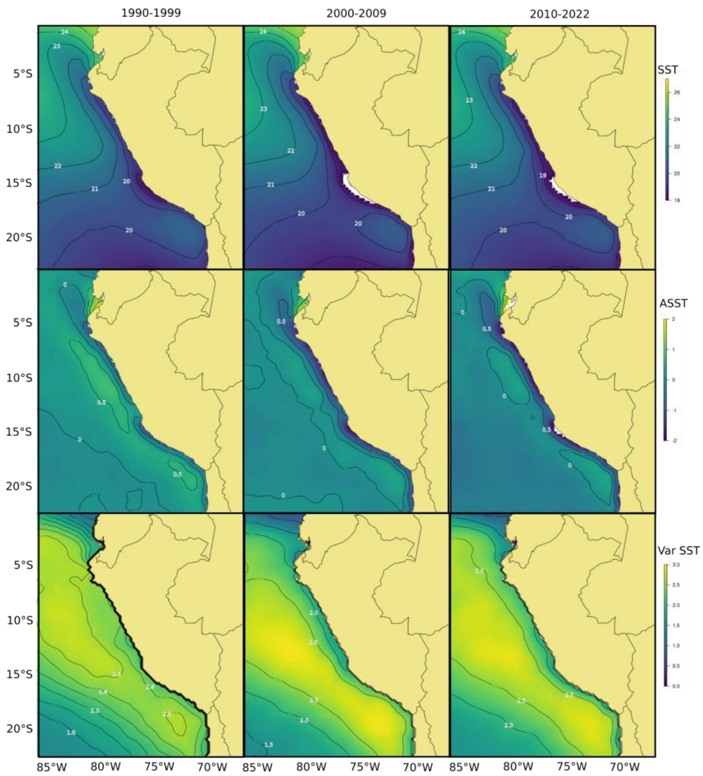

Figure 1. Decadal maps of (upper panel) sea surface temperature, (middle panel) sea surface temperature anomaly and (lower panel) sea surface temperature variability for tree periods i) 1990-1999, ii) 2000-2009 and iii) 2010-2022.

Decadal variability in the marine ecosystem

From the ONI data from 1951 to 2022, an 8-year low-frequency filter was performed, which allowed observing the decadal variability. It can be observed that for the decade between 1990-199 a positive pulse, followed by a negative pulse for the decade 2000-2009, then a positive pulse from 2010 to the end of 2018 and now a negative pulse, which may indicate decadal processes in the marine ecosystem (Fig. 2).

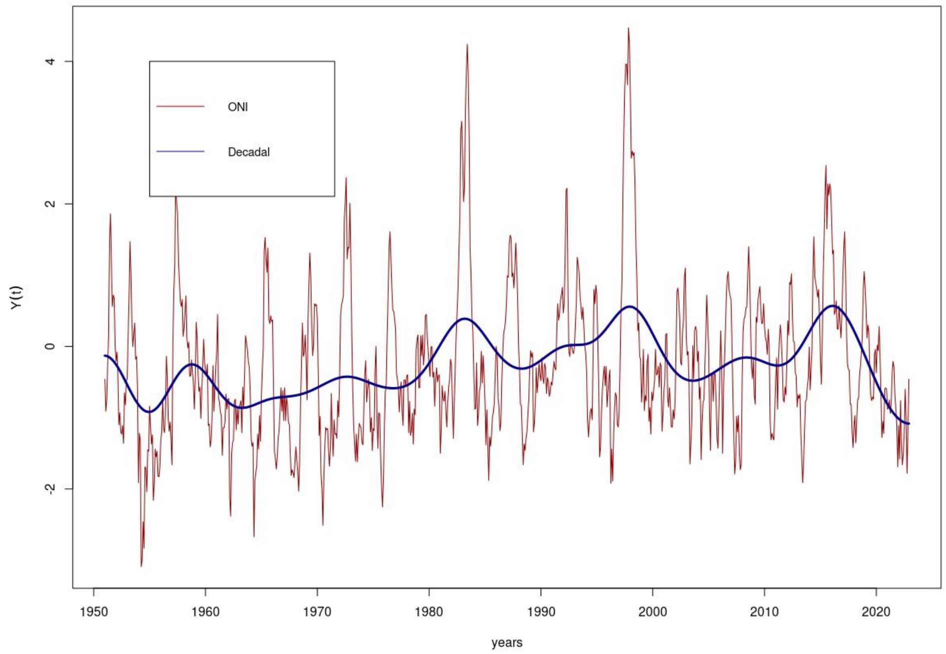

Figure 2. Low-pass filter with a cutoff of 8 years. We can observe the decadal variability from 1951 to 2022.

Nictemeral vertical distribution.

From the cruises carried out in summer and spring, calculations were made of the nictimeral distribution of the JFS, as well as of the vinciguerria, which is the JFS's prey. It can be observed that during the night hours the squid is found in the first 100 m of depth, during daylight hours the JFS goes up to 400 m deep. According to the results, no clear seasonal pattern is observed, since both summer and spring have similar vertical distributions (Fig. 3).

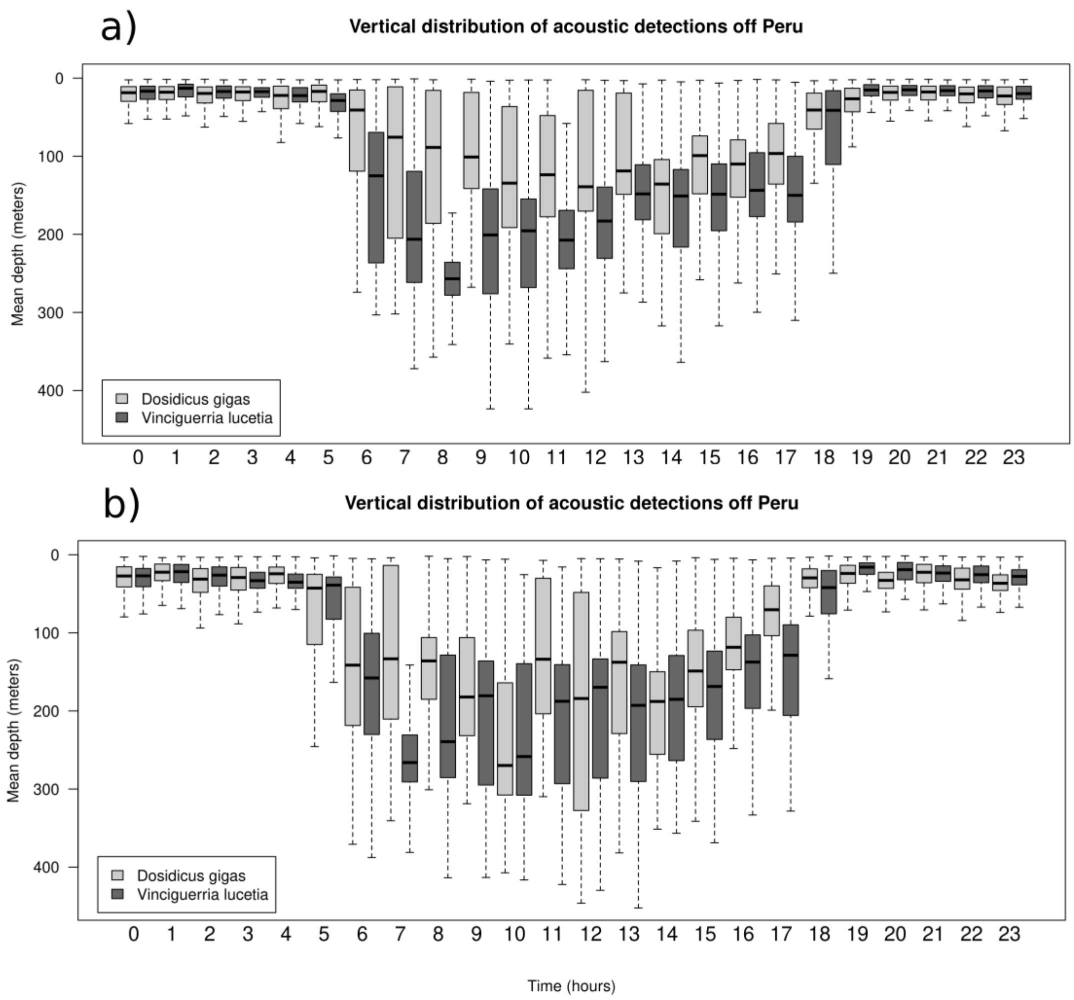

Figure 3. Nictemeral migration of jumbo flying squid and Vinciguerria, a) acoustic data for summer, b) acoustic data for spring.

Seasonal patterns

Using the temporal information of the artisanal jumbo flying squid fishery, we plotted the landing since 1996 (Fig. 4). We observed a negative trend or a reduction of the landings and, also, we observed three main patterns, the first one was selected before 2000, the second period was selected between 2000 and 2010, finally the last period was selected since 2011. For each period we computed the seasonal patterns.

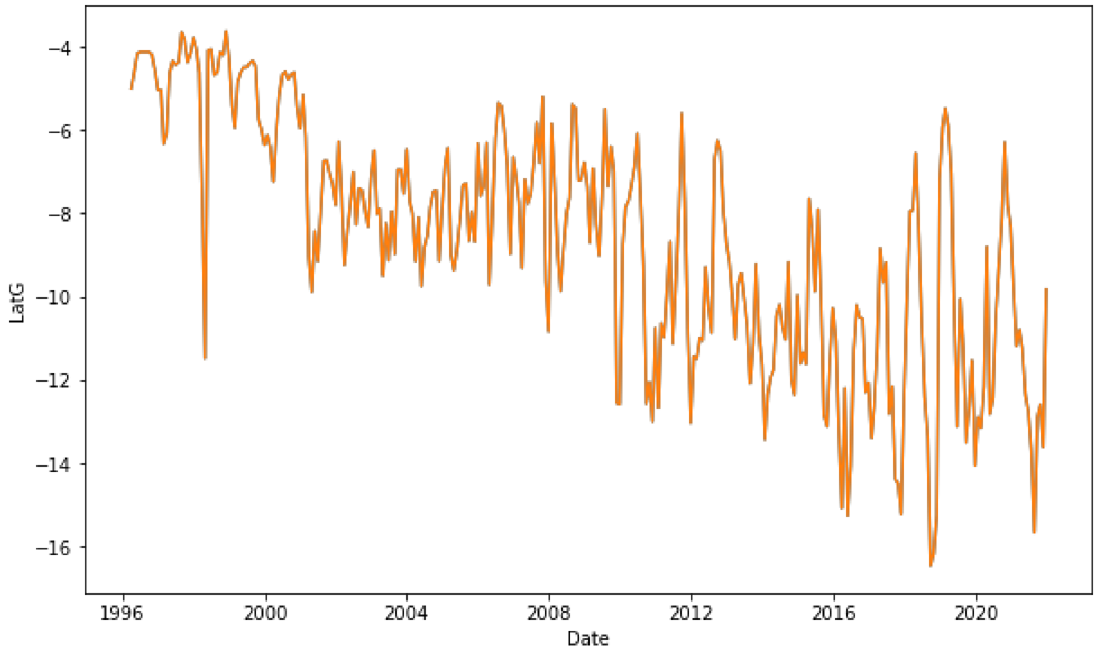

Figure 4. Temporal distribution of artisanal jumbo squid landing from 1996 to 2022.

During the first period we observed mostly all landing was reported in the north of Peru, in the 5°degree (Fig. 5).

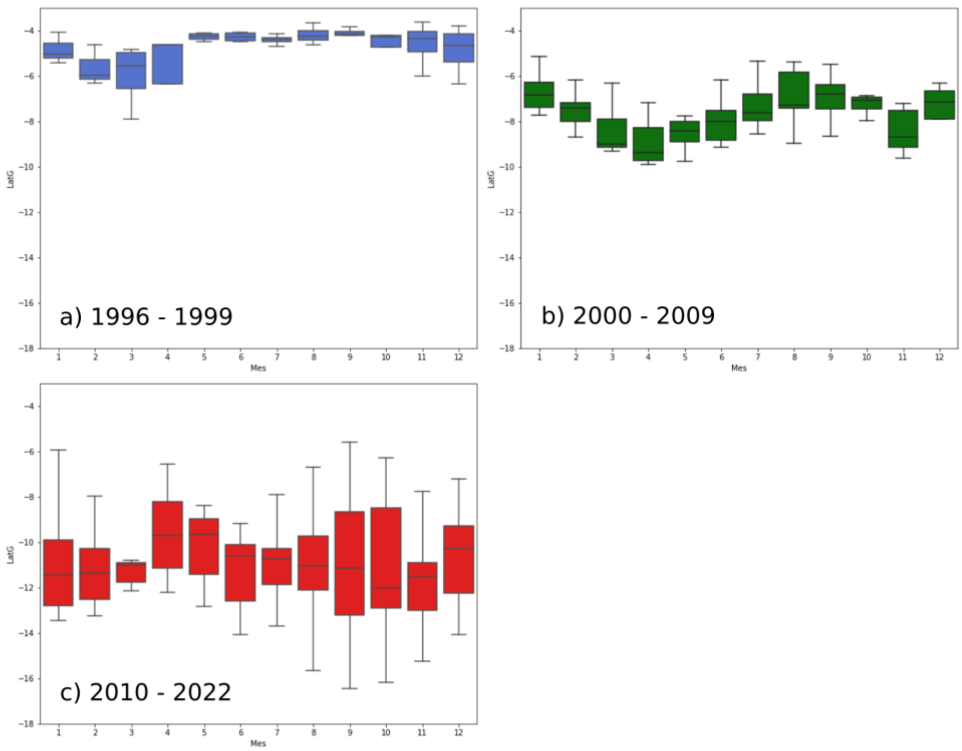

Figure 5. seasonal patterns of JFS landing for 3 decadal periods, a) 1996-1999, b) 2000-2009 and c) 2010 - 2022.

The second period ranged between 2001 to 2010, the seasonal patterns was different. A seasonal pattern was observed with in warm period (December to February). The landings were observed in the northern part (6°) but in April-May the landing core move to the south until the 10° (Fig. 5).

The last period since 2011, the seasonal pattern cores migrate to the central-south to Peru with a marked zone around to 11°, but with higher landing variability range between 8° to 14° (Fig. 5).

Patterns in the gravity center

We observe temporal patterns. In particular, we can observe two principal patterns. Before 2010, the principal fishing area were located in the north (around 5°S) and closer to the coast (in the first 10 nm). Since 2010 until now, we observed a movement of the fishing area, a movement to the south (~12°S) and far from the coast (50 nm) (Fig. 6)

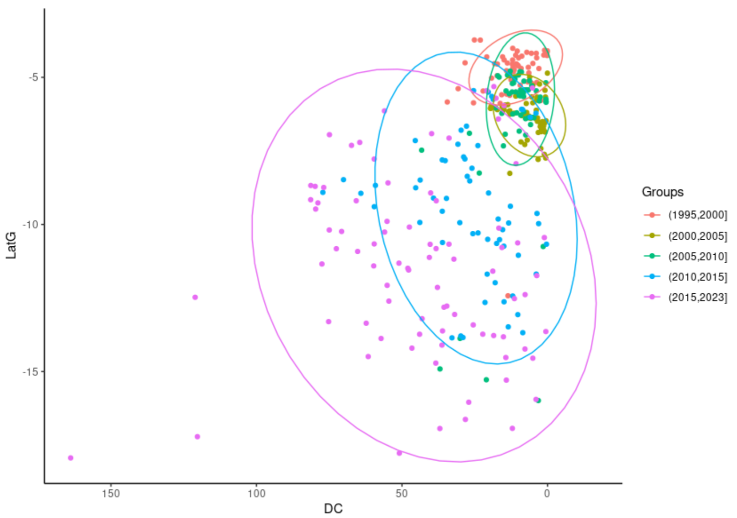

Figure 6. Gravity center of the fishing operation grouped each 5 years.

IV. Discussion

Using the oceanographic data, a decadal pattern can be observed, with a lower variability of the sst in the Peruvian coasts in the decade between 2000 and 2010, on the contrary, in the decade of the 90's and the decade from 2010 to 2022 the variability of the sst in the Peruvian coast are higher. These results of greater variability may be induced by the El Niño phenomenon of 1997-1998 and also by the coastal El Niño of 2017 (ref), both of which affected the Peruvian coasts. On the other hand, the decadal variability shows that in the 1990s (1990-1999) a warm period was observed, followed by a cold period (2000-2009) and then a warm decadal period again. This result is consistent with that shown in other work (Grados et al., 2018), where in addition to the decadal variability of the sst, the same pattern of behavior is shown in the depth of the 18ºC isotherm (Grados et al., 2018).

Seasonal patterns

The dynamics in the squid water column were mainly dominated by nictimeral variability, with squid in the daytime up to 400 m, while at night, JFS were found in the first 50 m of the water column. These results agree with other studies on the nictimeral behavior of this resource.

On the other hand, from the fishing data, a seasonal pattern was observed. A clear seasonal pattern was observed, in the warm months the fishery developed slightly further south, but in cold periods it developed further north, possibly in warmer environments. Another interesting result is the seasonality within each decadal period, during the first period studied, the dynamics of the fishery developed between degrees 5 and 6, then for the period 2000-2009, the fishery developed in degrees 6 to 10, with greater spatial coverage. Then, in the third period, the fishery dynamics expanded to cover higher latitudes, mainly from grade 8 to 15.

The aforementioned decadal periods observed in the environmental part are also observed in the data coming from the fleet, in the decade of the 90's the fishery was located in grade 5, in front of Paita. Then, in the 2000s (2010-2009) the fishery increased its dynamics covering a larger latitudinal area, as well as becoming a little more oceanic. Finally, in the third decadal period, 2010-2022, the dynamics developed further south and further offshore.

V. Conclusion

It is concluded that the behavioral pattern of artisanal squid fishing vessels would respond to decadent environmental periods with their own conditions. However, this could also be due to the fact that, in the early years when this fishery was developed, fishermen did not have sufficient knowledge to expand their fishing areas or to venture to areas farther away from the main port (Paita 5°S). Over the years, with the increase in navigational experience and the increase in size, greater autonomy and use of better vessel technology, fishing zones became more dynamic, reaching greater latitudes and distances away from the coast.

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