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Seasonal oceanographic preferent ranges of jack mackerel habitat off the Peruvian coast between 1992 and 2023

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Seasonal oceanographic preferent ranges of jack mackerel (*Trachurus murphyi*) habitat off the Peruvian coast between 1992 and 2023

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Abstract

This research focuses on the investigation of oceanographic preferences of jack mackerel (*Trachurus murphyi*) off the Peruvian coast, using catch data from artisanal and industrial fleet over an extended period, from 1992 to 2023. The aim of this study was to describe the preferred oceanographic ranges of sea surface temperature (SST), sea surface salinity (SSS), sea surface height (SSH), chlorophyll concentration (CHL) and Eddy kinetic energy (EKE) for jack mackerel in different climatic of austral seasons using Principal Component Analysis (PCA) and Generalized Additive Models (GAM). In light of our results we observed that the preferred ranges found for summer were: (SST: 19.33-25.62°C, SSS: 34.57-35.38 PSU, SSH: -0.001-0.177 m, CHL: 0.07-7.08 mg/m^3 and EKE: 0.005-0.464 cm^2/s^2), autumn (SST: 14.83-24.96°C, SSS: 34.69-35.31 PSU, SSH: -0.012-0.213 m, CHL: 0.06-5.91 mg/m^3 and EKE: 0.007-0.351 cm^2/s^2); winter: (SST: 13.84-21.04°C, SSS: 34.66-35.35 PSU, SSH: -0.013-0.168 m, CHL: 0.09-0.84 mg/m^3 and EKE: 0.013-0.401 cm^2/s^2); and spring: (SST: 14.57-23.25°C, SSS: 34.67-35.39 PSU, SSH: -0.020-0.179 m, CHL: 0.16-1.61 mg/m^3 and EKE: 0.007-0.351 cm^2/s^2). GAM results showed that all variables were significant (p-value<0.05) for all seasons with exception of chlorophyll in summer. In the results of the PCA for all seasons it was found that the variables that have the greatest contribution to dimension 1 were SST, SSS and SSH; SSS ranges were not significantly different. In the biplot analyses it was observed that both summer and autumn have the same correlations between the same group of variables oceanographic, in the same way it happened for winter and spring.

I. Introduction

Jack mackerel is a straddling pelagic species and it´s finding from Ecuador to the central coast of Chile and along the Pacific to New Zealand (Serra, 1991). Due to its large spatial distribution in the South Pacific, it's associated with wide ranges of environmental parameters (Alegre et al., 2015). Several authors have defined ranges of oceanographic variables for their spatial models for example Bertrand et al. (2014), who found that for the surface temperature a minimum value of 8.7 °C and maximum of 26 °C in south-central Chile: Regarding chlorophyll, the minimum value was 0.016 mg/m^3. Regarding surface salinity, values of 34.0 PSU were found in the southern zone due to the influence of Sub-Antarctic waters (Nuñez et al., 2009). In the case of Peru, a temperature range between 14 and 24°C and more discreet for salinity of 34.95 to 35.10 PSU has been observed with information taken *in situ* from IMARPE surveys (Dioses, 2013).

The seasonal fluctuation of marine resources, including jack mackerel, is influenced by several oceanographic factors that affect their distribution and abundance in different marine areas. Thus, the aim of this study was to identify the oceanographic seasonal preferential ranges of jack mackerel habitat in the jurisdictional waters of Peru using data from fishing hauls of the artisanal fleet and the industrial fleet of three decades, differentiating the conditions by austral season. With results obtained, it is expected to improve the modeling of the habitat of jack mackerel, which will be useful for the management of the Peruvian State, fisheries companies and artisanal fishermen.

II. Materials and methods

Area of study and fishing sets data

The study area was the entire Peruvian coast between latitudes of 3°-19°S and longitudes of 70-83°W (Fig. 1). Records of fishing hauls (Catches) from artisanal vessels provided by the artisanal fishing area of the Instituto del Mar del Perú (IMARPE) between 1992 and 2023 were used, while data from the industrial fleet were collected and provided by Sociedad Nacional de Pesqueria (SNP), in total 9,693 fishing hauls were collected; The compilation of all this information has expanded the spatial coverage of the study area (Fig. 1).

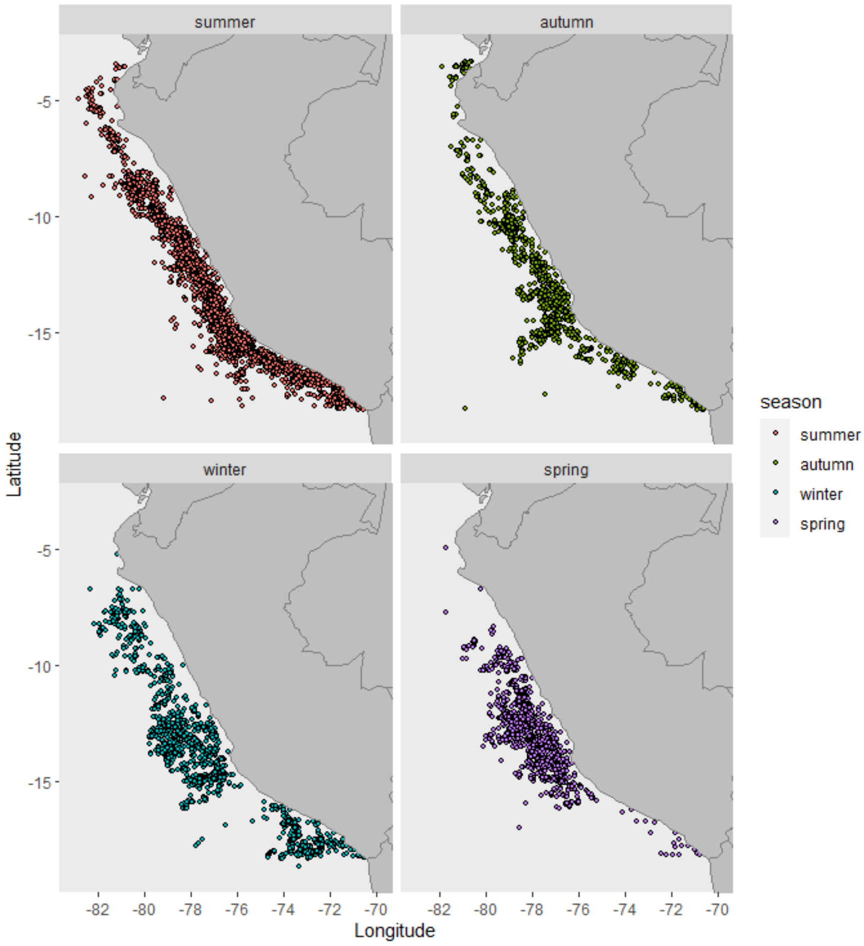

Figure 1. Spatial coverage of jack mackerel fishing hauls by four seasons between 1992 and 2023.

Satellite oceanography

The fishing hauls or catches were assigned satellite oceanographic variables according to their date and geographical position. The variables used were: SST (°C), SSM (PSU), SSH (m), CHL (mg/m^3), and EKE (cm^2/s^2). These satellite oceanographic data were obtained from Copernicus Marine Service (https://marine.copernicus.eu/).

Analysis

The first step of our analysis was grouped the data seasonally according to the climate of the southern zone; for summer (4856 catches) the months were considered: January, February and March, for autumn (1424 catches): April, May and June, for winter (1780 catches): July, August September and for spring (1633 catches): October, November and December.

Minimum, mean and maximum calculations were performed without out-of-range data in order to find the preferred ranges and to avoid outliers. Rstudio with the *mgcv* was used and package Gaussian family GAM models were performed to determine the significance level of the variables, as well as a PCA with the *FactoMineR* package to determine which are the most important variables for each season. The GAM model used was as follows, for each of the 4 seasons:

$$Log(Catch) \sim s(SST) + s(SSS) + s(SSH) + s(CHL) + s(EKE)$$

III. Results

Preferential ranges of habitat

Preferential ranges for jack mackerel have been found according to the season and are associated with the trend of each season (Table 1 and Fig. 2, Fig. 3):

Table 1. Oceanographic preferential range of jack mackerel by season.

Oceanographic variable		**Season**			
		Summer	**Autumn**	**Winter**	**Spring**
SST (°C)	Min	19.33	14.83	13.84	14.57
	Mean	22.45	19.81	17.44	18.46
	Max	25.62	24.96	21.04	23.25
SSS (UPS)	Min	34.57	34.69	34.66	34.67
	Mean	34.96	34.99	35.02	35.03
	Max	35.38	35.31	35.35	35.39
SSH (m)	Min	-0.001	-0.012	-0.013	-0.020
	Mean	0.087	0.096	0.080	0.080
	Max	0.177	0.213	0.168	0.179
CHL (mg/m3)	Min	0.07	0.06	0.09	0.16
	Mean	2.71	2.13	0.43	0.88
	Max	7.08	5.91	0.84	1.61
EKE (cm2/s2)	Min	0.005	0.012	0.013	0.007
	Mean	0.193	0.176	0.164	0.145
	Max	0.464	0.420	0.401	0.351

- **SST (°C).** During the summer the average temperature had been found at 22.45°C and a minimum range of 19.33°C and maximum of 25.62°C, while for autumn the average decreases to 19.81 °C and the ranges were between 14.83 and 24.69°C. The winter had the lowest average with 17.4°C in turn the minimum range was 13.8°C, while for the spring a low average was also found with 18.5°C. In the GAM graph the highest concentration of catches was observed was between 14.83 and 25.62°C.

- **SSM (UPS).** During summer the widest range of salinity had been found from 34.57 to 35.38 PSU and with an average of 34.96 PSU. In autumn the average was 34.99 PSU while in winter and spring the averages were around 35.02 PSU. The minimum and maximum ranges were similar in all seasons, but it could be observed that the highest concentration of fishing hauls was between 34.69 and 35.39 PSU.
- **SSH (m).** The average SSH had a positive trend between all seasons between 0.080 and 0.096 m. The minimum range does not exceed -0.020 m in spring and the maximum value in autumn up to 0.213 m. On the other hand, in the GAM graph it was observed that the largest number of hauls was between 0 and 0.200 m.
- **CHL (mg/m3)**. The chlorophyll ranges have been wide in summer between 0.08 and 30.18 mg/m^3 in turn the average was also higher with 2.71 mg/m^3. Autumn is another season where the range is wide (0.06 – 26.53 mg/m^3) and medium high (2.14 mg/m^3). During the winter it is the season with the lowest range and lowest average (0.43 mg/m^3). For spring the range is extended, however, this average double the value of the summer average with 0.88 mg/m^3. With respect to the GAM graph, it was observed that the general range was between 0.06 and 5.91 mg/m^3.
- **EKE (cm2/s2).** During the summer the highest range of EKE was found, between 0.005 to 0.464 cm^2/s^2, with a higher average value of 0.193 cm^2/s^2. For the following seasons the maximum values decreased consecutively for autumn, winter and spring with values of 0.176, 0.164 and 0.145 cm^2/s^2 respectively. Like salinity, there was no significant variation between the minimum and maximum ranges compared between seasons, but it was observed that the largest number of hauls was between 0.012 and 0.401 cm^2/s^2.

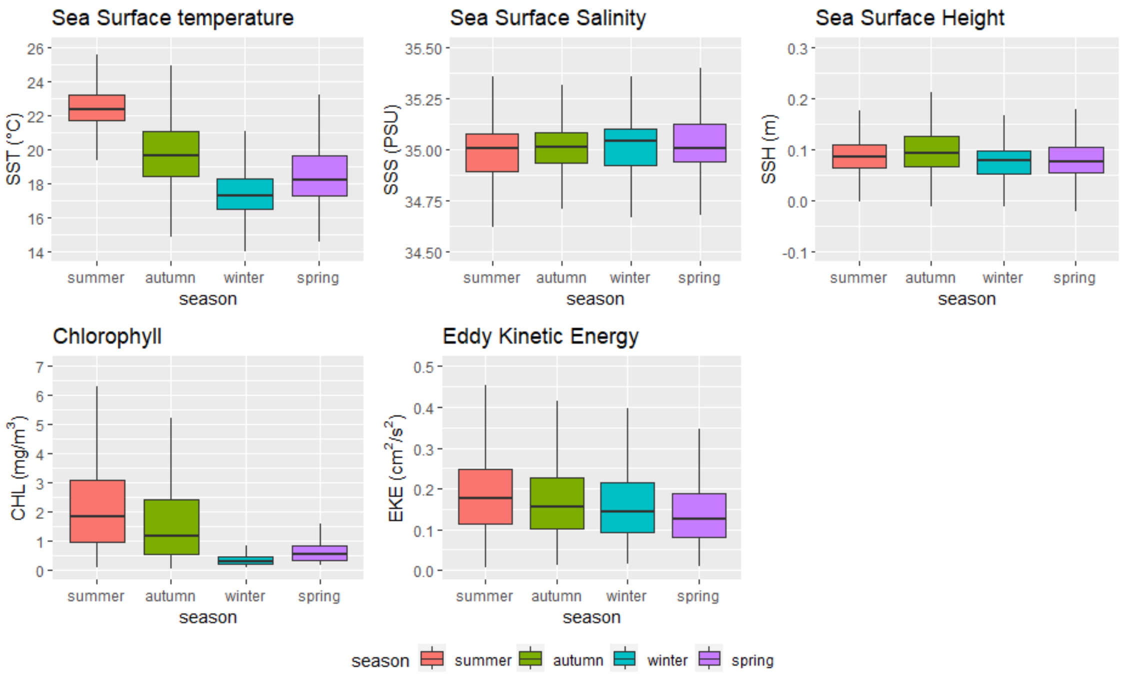

Figure 2. Boxplot of variables differentiated by seasons.

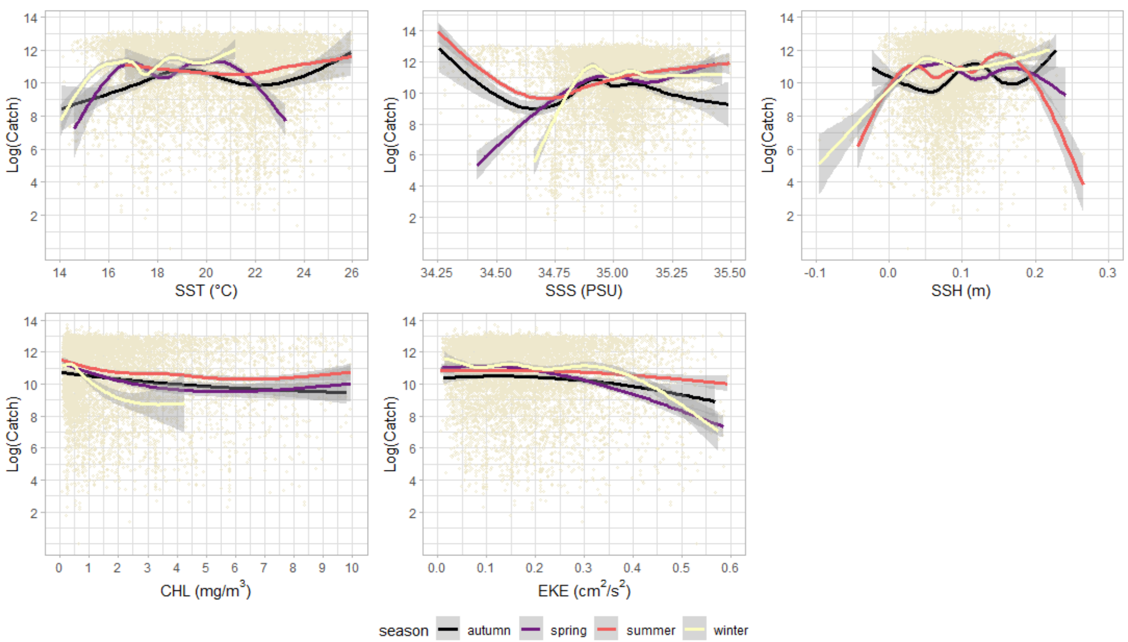

Figure 3. GAM charts of oceanographic variables.

Interaction between oceanographic variables and its importance

In the results of the PCAs observed in Figures 4 and 5, it has been observed that SST is the variable with the greatest contribution (>20%) in Dimension 1 in all seasons, followed by SSS and SSH. On the other hand, EKE and CHL are the ones that contribute the least.

- **Summer.** In the GAM analysis was found that the model explained 14.1% of the deviation and R-sq (adj) of 13.5%; all variables had a p-value significance level (p-value<0.05) with the exception of the EKE which was higher than 0.05. In the results of PCA it was obtained that three components explain 73% of the variance, being SST and SSH those that have the greatest contribution in the first dimension of this season. In the summer biplot it was observed that both SSH and SST have a positive relationship, and SST inverse relationship with CHL.
- **Autumn.** In the GAM the model explained 20.9% of the deviation and R-sq (adj) of 18.9%, all variables had a significance level (p-value<0.05). With the PCA it was possible to identify that the first three components explain 76% of the variance, these being SSH and SST in the first dimension. In the biplot it was observed, as in the summer, that SST and SSH have a positive correlation and SST with CHL a negative correlation.
- **Winter.** In the winter GAMs, the greatest explained deviation (~30.9%) and R-sq (adj) of 29.4% were found; and all variables had a significance level p-value<0.05. For the winter PCA, a greater explanation of variance was observed (84% of the first three components). At the same time, three variables were the ones with the greatest contribution; the first and most important was the SST, then the SSS and finally the SSH. In the biplot it was observed that SST, SSS and SSH have a positive correlation and CHL and EKE also positive correlation.
- **Spring**. In the GAM the model explained 27.7% of the deviation and R-sq (adj) of 29.2%; All variables had a significance level p-value<0.05. In the spring PCA, the first three components explained 84% of the variance. The variable with the highest contribution in dimension 1 was SSS, followed by SSH and SST. In the biplot chart the same winter trend was observed: SST, SSS, SSH, that is, positive correlation and CHL and EKE also positive correlation.

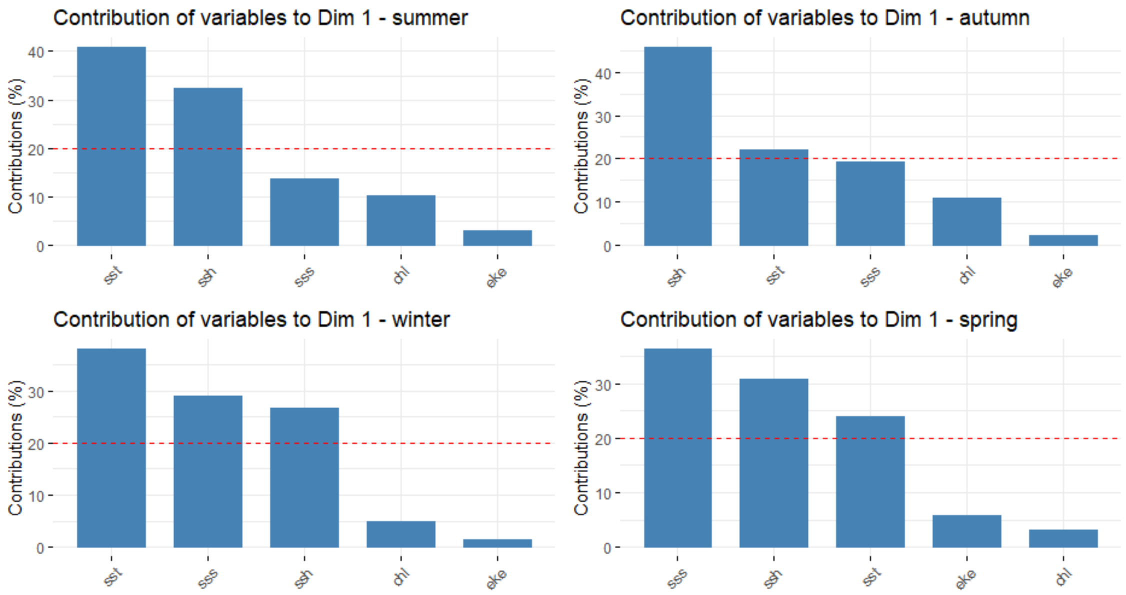

Figure 4. Contribution of variables to dimension 1 by season.

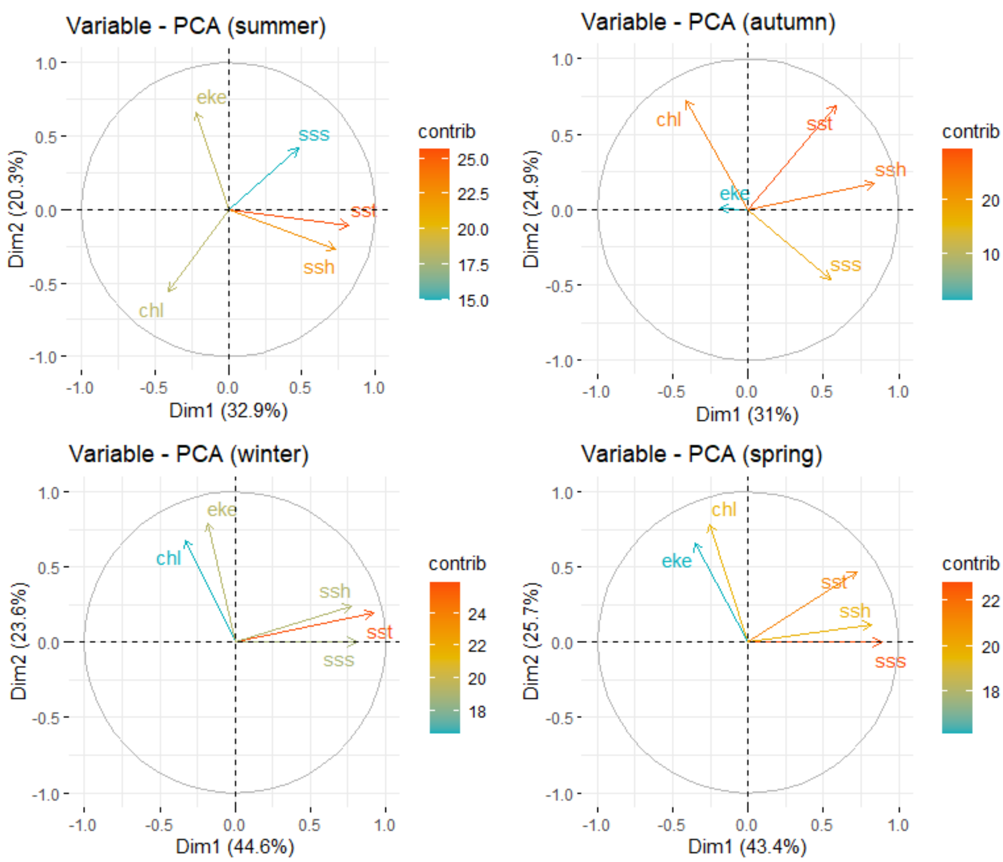

Figure 5. Biplots of PCAs (Dim1 vs Dim2) by season.

IV. Discussion and conclusions

In this study, it has been possible to compile three decades of fishing hauls of the artisanal and industrial fleet between 1992 - 2023. Likewise, catches of jack mackerel were associated with satellite oceanographic variables. The results showed different ranges of preference of each oceanographic variable according to the season, which represents a continuously changing habitat. These findings are relevant for the understanding of jack mackerel ecology and the modelling of its distribution, as well as for fisheries management and conservation of this important fishery resource.

Results from the SST ranges showed significant seasonal variations. We make the comparison with the work carried out by Li et al. (2016) in the southeastern Pacific area (25-47°S and 74-120°W) where the lower ranges of SST found have been colder; the minimum values found range from 11.4°C in summer and 9.1°C in winter, and its maximum ranges have been 22.5°C and 20.8°C in summer. In the case of the ranges found in Peruvian waters, it is observed that the minimum value found in summer has been 19.33°C, which is 8 degrees more than that observed by Li et al. (2016) and in winter the minimum value found was 13.84, that is, 4 degrees above what was found by Li et al. (2016). The average values of SST found in this work range from 17.44 to 22.45°C, which means that jack mackerel in Peruvian waters is adapted to warmer conditions. In the study by Bertrand et al. (2016) on the 3D habitat model for jack mackerel covering the entire Southeast Pacific, a wider range (9-28°C) was used.

The preferred ranges of SSM showed no significant variations between seasons. The minimum ranges were between 34.57 (summer) and 34.69 (autumn) PSU, whereas in Chile values of around 34 PSU associated with sub-Antarctic waters are used (Nuñez et al., 2009).

The SSH of this study found that the minimum ranges were from -0.001 (summer) to -0.020 m (spring), while what Li et al. (2016) found was between -0.153 (autumn) and 0.032 m (spring), that is, they are higher values than those found in this study. On the other hand, our maximum values were between 0.168 (winter) to 0.213 m (autumn), and what was observed by Li et al. (2016) were notably higher with maximums between 0.353 (autumn) and 0.465 m (spring), that is, there is a lower height off the Peruvian coast compared to the southeastern Pacific area compared to Chile.

The CHL levels showed wide seasonal variability, being highest during the summer and fall. It should be noted that this variable is affected by the high cloudiness that exists on the Peruvian coasts. That is why during winter and spring it is observed that the maximum values were 0.84 and 1.61 mg/m^3 respectively. On the other hand, the minimum value (~0.07 mg/m^3) found in previous studies (Hintzen et al., 2013; Bertrand et al., 2014) coincide with the minimum values found for summer and autumn (0.07 and 0.06 mg/m^3 respectively) and, otherwise, the minimum values observed by Li et al. (2016) were lower between 0.01 and 0.04 mg/m^3. With respect to the maximum ranges in summer, the maximum was observed 7.08 mg/m^3 without outliers and the maximum value with outliers was 30.18 mg/m^3 and according to the minimum required for the model of Bertrand et al. (2016), which was 26 mg/m^3. Our result showed little contribution of chlorophyll to the variables, however, the study by Grados et al. (2021) positioned chlorophyll as the most important variable apart from spring.

The EKE did not show seasonal variations which matches with the work carried out by Grados et al. (2021) where it was found that there is no seasonal pattern, in addition the contribution in dimension 1 of the PCA also indicates a low importance of this variable.

In the analysis of biplots of the PCA it has been observed that during summer and autumn the oceanographic variables have the same tendency except for EKE that did not present correlations with other variables. In the same way, similarities were observed for winter and spring seasons.

In conclusion, the results of this work provide valuable information on the ranges of the main seasonal preferred oceanographic variables of jack mackerel habitat on Peruvian coasts within a period of three decades. These findings are essential to continue efforts to model jack mackerel habitat, which is a tool for fisheries management and conservation of this important fishery resource.

References

Alegre, A., Bertrand, A., Espino, M., Espinoza, P., Dioses, T., Ñiquen, M., Navarro, I., Simier, M., Ménard, F., 2015. Diet diversity of jack and chub mackerels and ecosystem changes in the northern Humboldt Current system: a long-term study. Progress in Oceanography, 137, 299–313.

Bertrand, A., Dragon, A.C., Habasque, J., Lehodey, P., 2014.Hydrography/biogeochemistry and Chilean jack mackerel stock structure interactions. The Second Meeting of the Scientific Committee of SPRFMO.

Bertrand, A., Habasque, J., Hattab, T., Hintzen, N. T., Oliveros-Ramos, R., Gutiérrez, M., … Gerlotto, F. (2016). 3-D habitat suitability of jack mackerel Trachurus murphyi in the Southeastern Pacific, a comprehensive study. Progress in Oceanography, 146, 199–211. doi:10.1016/j.pocean.2016.07.002

Dioses T. (2013) Distribution patterns and abundance of Trachurus murphyi jack mackerel in Peru. In: Csirke J., R. Guevara-Carrasco & M. Espino (Eds.). Ecology, fisheries and conservation of jack mackerel (*Trachurus murphyi*) in Peru. Rev. peru. Biol. Special number 20(1): 067 – 074.

Grados, D., Csirke, J., Valdez, C., Peraltilla, S., & Gutierrez, M. Interannual variability of the habitat suitability of jack mackerel in the Northern Peru Current System, 2011-2019. South Pacific Regional Fisheries Management Organisation, 9th Meeting of the Scientific Committee, Held virtually, 27 September - 2 October 2021.

Hintzen, N.T., Corten, A.A.H.M., Gerlotto, F., Brunel, T.P.A., 2013. Hydrography and jack mackerel stock in the South Pacific, IMARES (Report/IMARES C156/13).

Li, G., Cao, J., Zou, X., Chen, X., & Runnebaum, J. (2016). Modeling habitat suitability index for Chilean jack mackerel (Trachurus murphyi) in the South East Pacific. Fisheries Research, 178, 47–60. doi:10.1016/j.fishres.2015.11.012

Nuñez E., Ramírez, M. C., & Pastene, S. V. (2009). Variability of the Chilean jack mackerel fishing habitat in the southeastern Pacific Ocean. Eighth International Meeting: SWG: Jack Mackerel Sub-Group SP-08-SWG-JM-06. 2-6 November 2009, New Zeland.

Serra, R., 1991. Important life history aspects of the Chilean jack mackerel, Trachurus symmetricus murphyi. Investigación pesquera, 36, 67-83.

SNP, (2013). The fourth S.N.P. Workshop on diagnosis on the status o the SouthPacific jack mackerel (*Trachurus murphyi*) in the Peruvian fishery. 26 June–3July 2008, Lima, Peru.