E-ISSN: 2347-5129
P-ISSN: 2394-0506
(ICV-Poland) Impact Value: 76.37
(GIF) Impact Factor: 0.549
IJFAS 2023; 11(5): 42-50

www.fisheriesjournal.com
Received: 10-05-2023
Accepted: 12-06-2023

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Mapping of potential fishing areas of *Sardinella aurita* in the Ivorian exclusive economic zone (EEZ) from 2010 to 2020

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DOI: https://doi.org/10.22271/fish.2023.v11.i5a.2849

Abstract
The study we are conducting relates to the Exclusive Economic Zone fishing activities for small pelagic fish (EEZ) Ivorian. This zone is prone to strong in particular the *Sardinella aurita* whose localization is sometimes difficult because of their strong migration. The methodology used is based on combined analysis of remote sensing data variables ocean biophysics and *Sardinella aurita* fishing data. The implementation of all these data in a GIS from multi-criteria analysis by linking variables oceanic and fishing data has made it possible to show that the most influential oceanic biophysical parameters in determining the availability zones of *Sardinella aurita* are temperature (SST), salinity (SSM) and Chlorophyll-a. In addition, the great cold season is the period of the year most predisposed to a better availability of *Sardinella aurita* in the Ivorian EEZ.

Keywords: *Sardinella aurita*, Remote sensing, EEZ, Potential fishing area, chlorophyll-a, temperature

1. Introduction
The coastal regions of the Gulf of Guinea (GG) constitute one of the major marine ecosystems, producing living marine resources, in this case *Sardinella*, essential for the populations of West Africa (Sherman and *al.*,1991) [1]. However, the lack of spatio-temporal information on environmental conditions leads to a lack of knowledge of the marine environment (potential fishing areas). Faced with the challenge of declining fishing, do more modern and more effective methods of understanding fishery resources deserve to be tested (Djagoua and *al.*,2006) [2].

The use of spatial remote sensing could be a holistic alternative in determining the spatiotemporal variability of pelagic species availability zones. It is in this context that the CURAT (University Center for Research and Application in Remote Sensing) through the FONSTI (Fund for Science, Technology and Innovation) initiated this study The Ivorian Exclusive Economic Zone (EEZ) is an integral part of the entire marine ecosystem of the Gulf of Guinea located in West Africa and is between 1°0' and 5°5' North latitude and 3°30' and 7°5' West longitude. The Ivorian EEZ is bounded to the east by the Cape of Three Points on the Ghanaian border and the Cape of Palms on the Liberian border bordering the 520 km long Ivorian coastline.

2. Materials and methods
2.1 Data
2.1.1. Optical satellite data for detecting ocean biophysical variables.
Level L3 chlorophyll concentration data were acquired using the Seawifs sensors (1998-2002) from the Orbview 2 satellite on the one hand and the Modis sensor (2003-2020) from the Aqua satellite on the other. They will allow us to estimate the seasonal variability of the sea surface chlorophyll concentration. The wind and temperature data come from the reanalysis products of ERA 5 from ECMWF which replaces the ERA-Interim reanalysis. The estimate of the sea surface temperature (SST) will make it possible to observe the upwelling of cold water while

the U and V components of the ERA 5 wind will make it possible to assess the turbulence of the sea and to characterize the Upwelling phenomenon. The data downloaded covers the period from 1998 to 2020. Salinity data are from the SMOS (Soil Moisture and Ocean Salinity) satellite of the European Space Agency. They will make it possible to estimate the seasonal variability of sea surface salinity for the period 2010-2020.

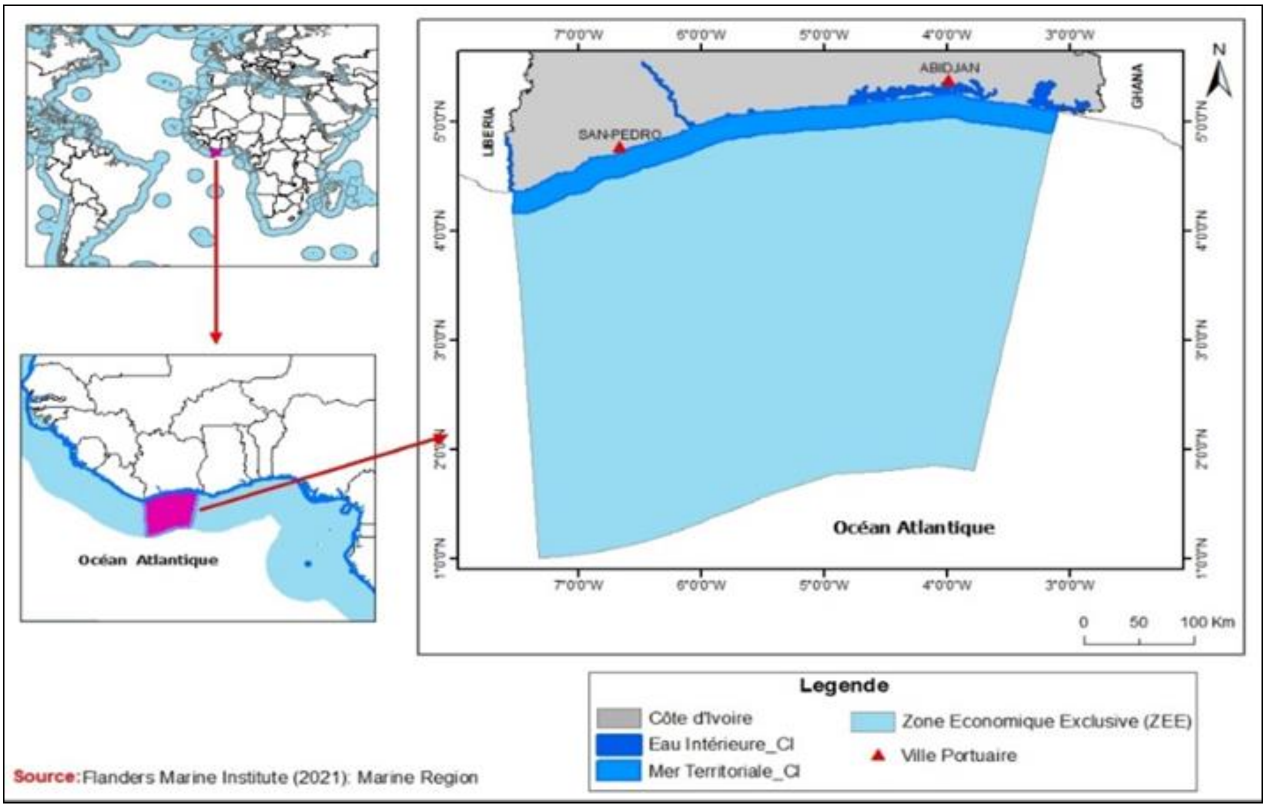

Fig 1: Location of the Ivorian Exclusive Economic Zone (EEZ)

2.1.2. Fishing data

Fishing data on *Sardinella aurita* were obtained from the Department of Aquaculture and Fisheries (DAP). These fishing catch data will allow us to make a comparative analysis between them and the satellite data of ocean biophysical variables.

2.2. Methodology

2.2.1. Estimation of ocean biophysical parameters influencing the distribution of *Sardinella aurita*

2.2.1.1. Estimate of there chlorophyll-a concentration, temperature and salinity

All images underwent pre-processing and bias removal prior to acquisition and use. The values of these variables were calculated and averaged according to the study periods in order to determine the monthly spatio-temporal variability of these images. The calculated monthly average values were extracted with the limits of the EEZ and proceeded to their interpolation for the production of monthly average maps.

2.2.1.2. Turbulence estimation

For the estimation of turbulence variability, wind data consisting of its U and V components from Era 5 were used. The turbulence calculation method follows that of (Bakun and Parrish, 1982) [3] which predict that the wind mixing index in the surface layer is usually calculated by the cube of the wind speed. The Ivorian coasts having a West-East orientation, implies that we will use the U.
Component of the wind for the calculation of the turbulence.

2.2.1.3. Upwelling estimate

The calculation of the upwelling index is based on that of (Bakun, 1973) [4] which according to the previous study by (Ekman, 1905) [5] believes that the volume of up flow and its transport depends on latitude and wind stress. To this end, the upwelling index summarizes the flow towards the ocean of surface water per km of coast (in m3 s-1 km-1) in two main directions:

- A direction Qx (West-East) according to

the equation $Q_x = \frac{\tau_y}{f.\rho} * 10^3$

- A direction (North-South) according to

the equation: $Q_y = \frac{-\tau_x}{f.\rho} * 10^3$

Of these two directions, being that the Ivorian coasts present a West-East direction, we used the equation of the direction Qx (West-East) following:

$$Q_x = \frac{\tau_y}{f.\rho} * 10^3$$

τ_y, the wind stress factor is estimated at from the wind speed according to the equation:

$$\tau_y = \rho_a . Cd . \sqrt{u^2 + v^2} . v$$

Where,
ρ_a = 1.2 kg m -3 (air density)
Cd = 1.4 · 10 -3 (empirical resistance coefficient)
u and v are the components of the wind in m·s -1

2.2.4. Mapping of potential areas of availability of *Sardinella aurita*

The mapping of pelagic species such as *Sardinella aurita* depends on environmental factors that influence their distribution. The criteria selected are derived from various oceanographic parameters favoring the availability of nutrients (Kassi, 2012) [6]. Each parameter, having a more or less significant influence on recruitment, will be related to the fishing data in order to see its weight and its influence on them. This will allow us to proceed to a reclassification of the values of the oceanic variables on the basis of three retained classes: Low, Medium and High. A multi-criteria analysis will be carried out in a GIS by merging the reclassified variables according to their weight in order to produce the map of the potential fishing zones of *Sardinella aurita*.

3. Results and discussion

3.1. Results

3.1.1. Estimated spatiotemporal variability of ocean biophysical parameters from 1998 to 2020

3.1.1.1 Seasonal variability of sea surface temperature from 1998 to 2020

Figure 2 shows that the entire ocean surface of the Ivorian EEZ is warm during the months of March to May and November to December with temperatures reaching 28° to 30 °C. On the other hand, the entire EEZ is colder during the months of July to September characterizing the great cold season with temperatures ranging from 23° to 24°C. Finally, the months of June and October appear as transitional periods between the passage from the hot season to the cold season for the month of June on the one hand and the passage from the cold season to the hot season on the other hand for the month of October. During these 23 years (from 1998 to 2020), the hottest month was April with 29.53 °C while the coldest month was August with 25.56 °C.

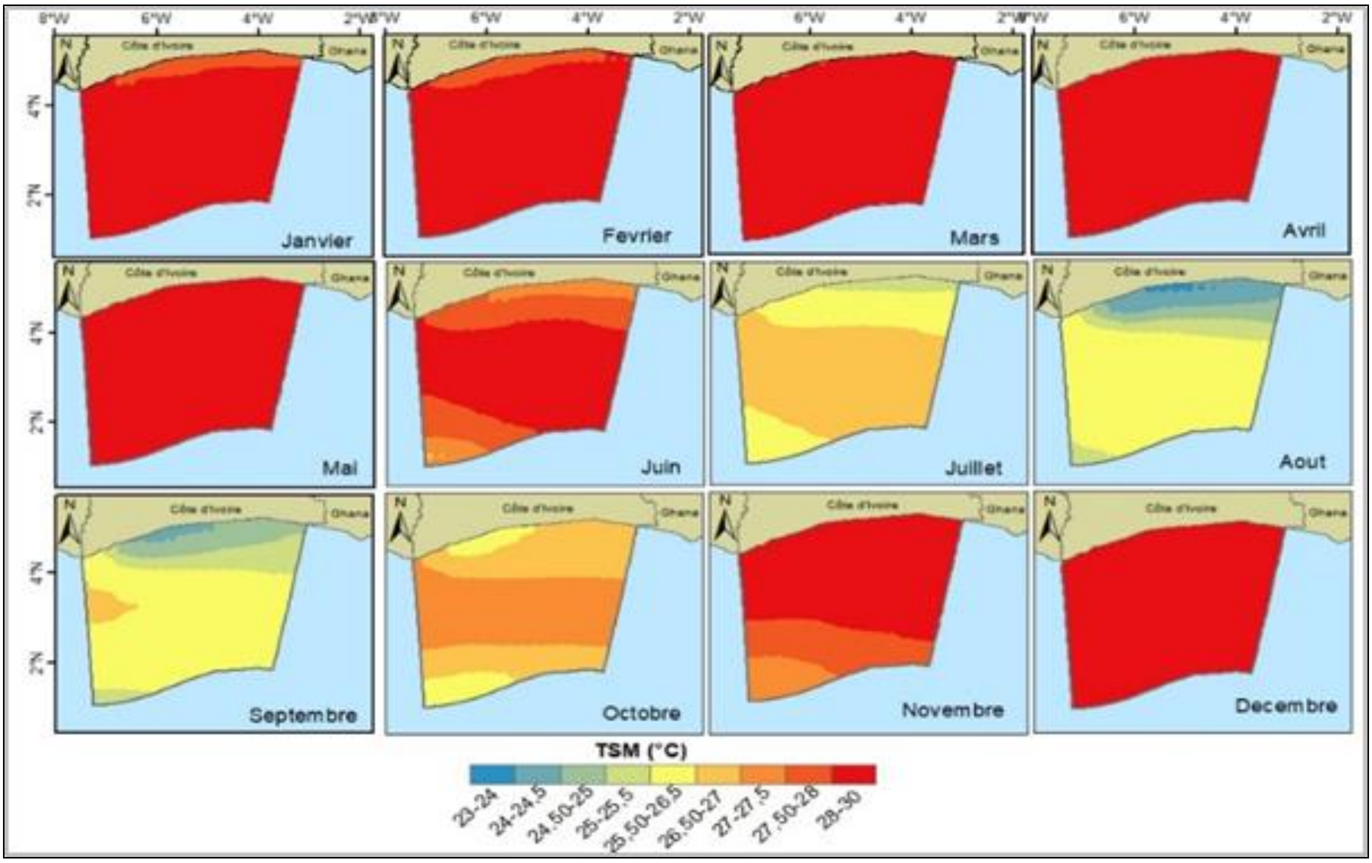

Fig. 2: Seasonal spatial distribution of sea surface temperature from 1998 to 2020

3.1.1.2 Seasonal variability of sea surface chlorophyll concentration from 1998 to 2020

The analysis of Figure 3 reveals that the planktonic bloom with strong chlorophyll activity is observed during great cold season during the months of July to October on the entire Ivorian coast. During this period, the highest values of Chl. a sometimes reaching 17 mg/m3 are located at the level of the coasts and gradually decrease seaward. It is clearly observed that the peak of the chlorophyll concentration is observed in August.

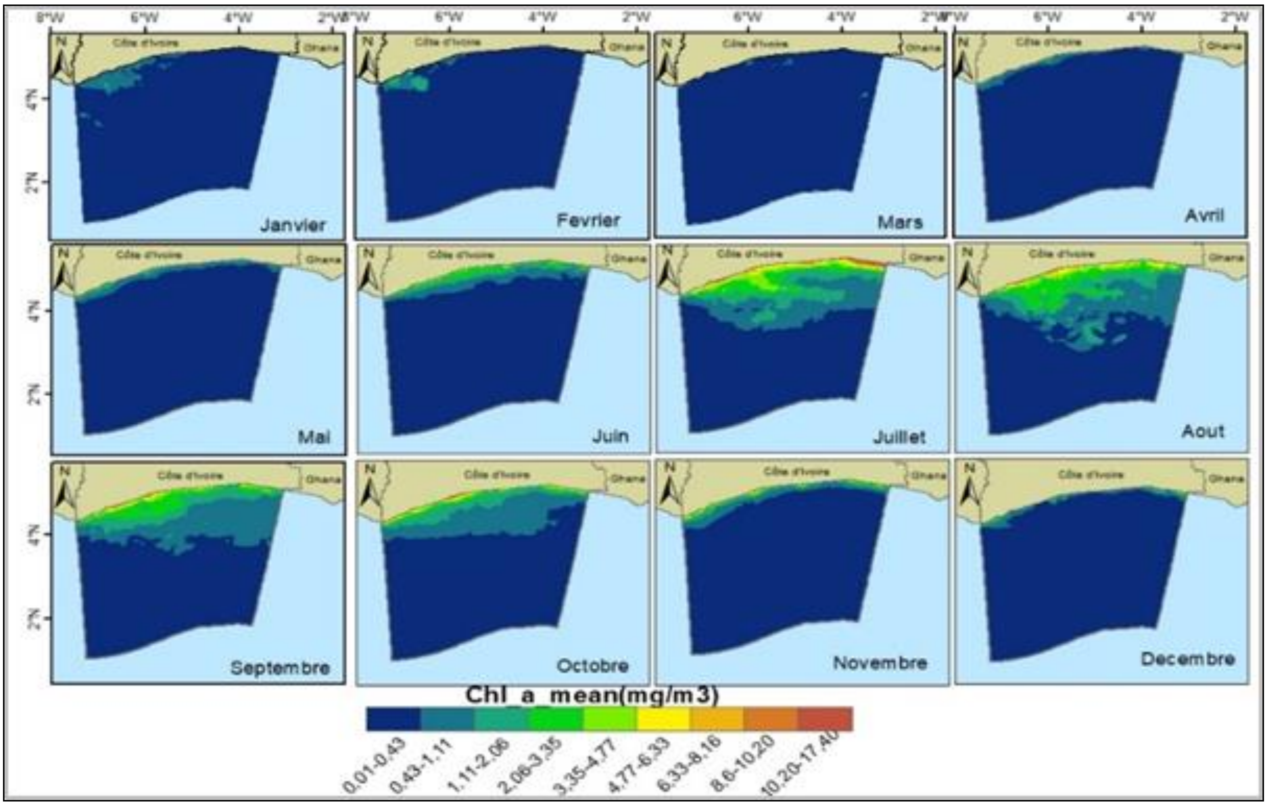

Fig 3: Spatio-temporal distribution of Chlorophyll-a concentration from 1998 to 2020

3.1.1.3 Seasonal variability of sea turbulence from 1998 to 2020

Strong turbulence is observed on the central coasts of the Ivorian plateau, gradually decreasing seaward to beyond 4°N between February and March until April (Fig. 4). During the great cold season from July to September, the strongest values of the turbulent mixing are located in the East where it originates to spread seaward beyond 4°N latitude and over the entire coastal zone to the West. We observe two turbid periods. The most important period is between February and March with values of 7.88 m3/s3 at 8.79 m3/ s3. The second less important period is between August and September, where the values of turbulent mixing are almost constant ranging from 7.71 m3/s3 at 7.72m3 /s3.

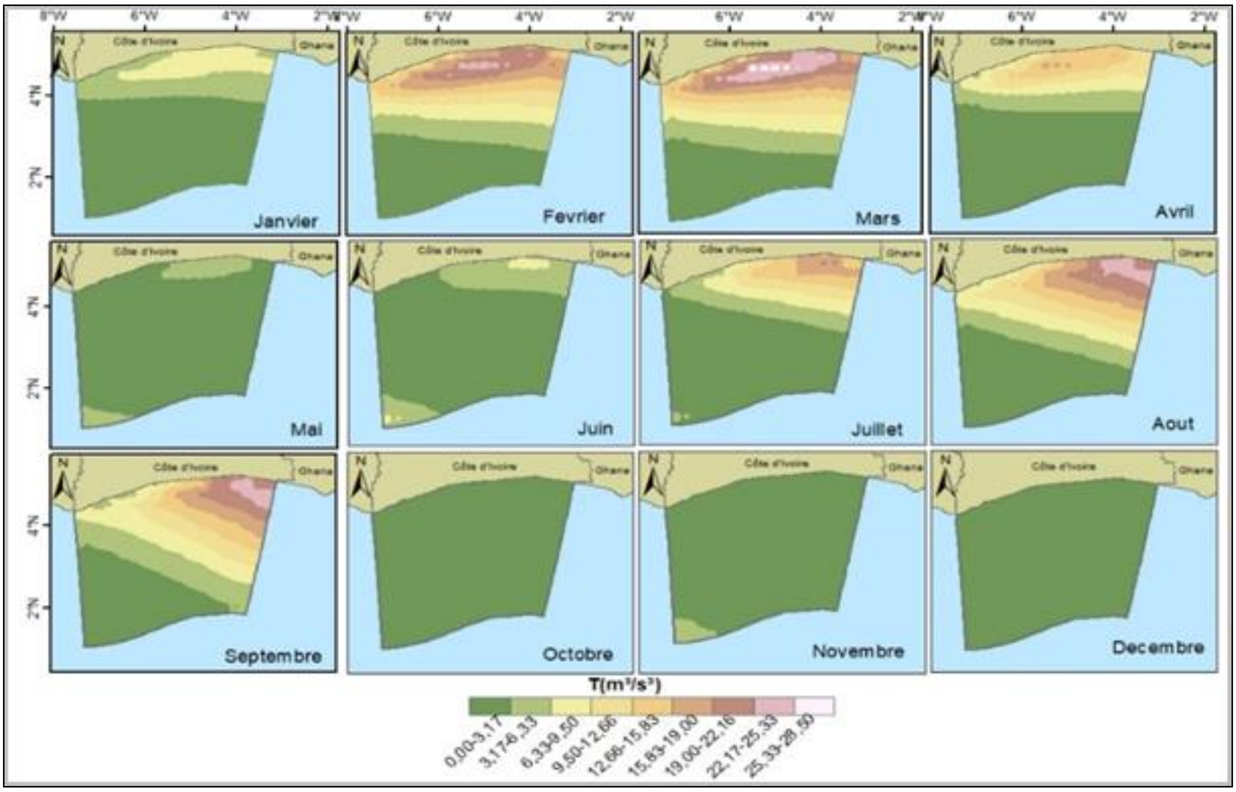

Fig 4: Seasonal spatial distribution of sea surface turbulence from 1998 to 2020

3.1.1.4 Seasonal variability of the upwelling from 1998 to 2020

Over the entire ocean surface of the EEZ, the upwelling phenomenon is more marked and more important during the months of June to September (i.e. the severe cold season). At this level, the mean values of the order of 20,000 m 3/s/km are observed on the coast above 4°N, becoming more significant offshore to reach the maximum threshold of 55,000 m 3/s/km. The upwelling of cold water during this season cool the coastal waters by also enriching them with nutrients.

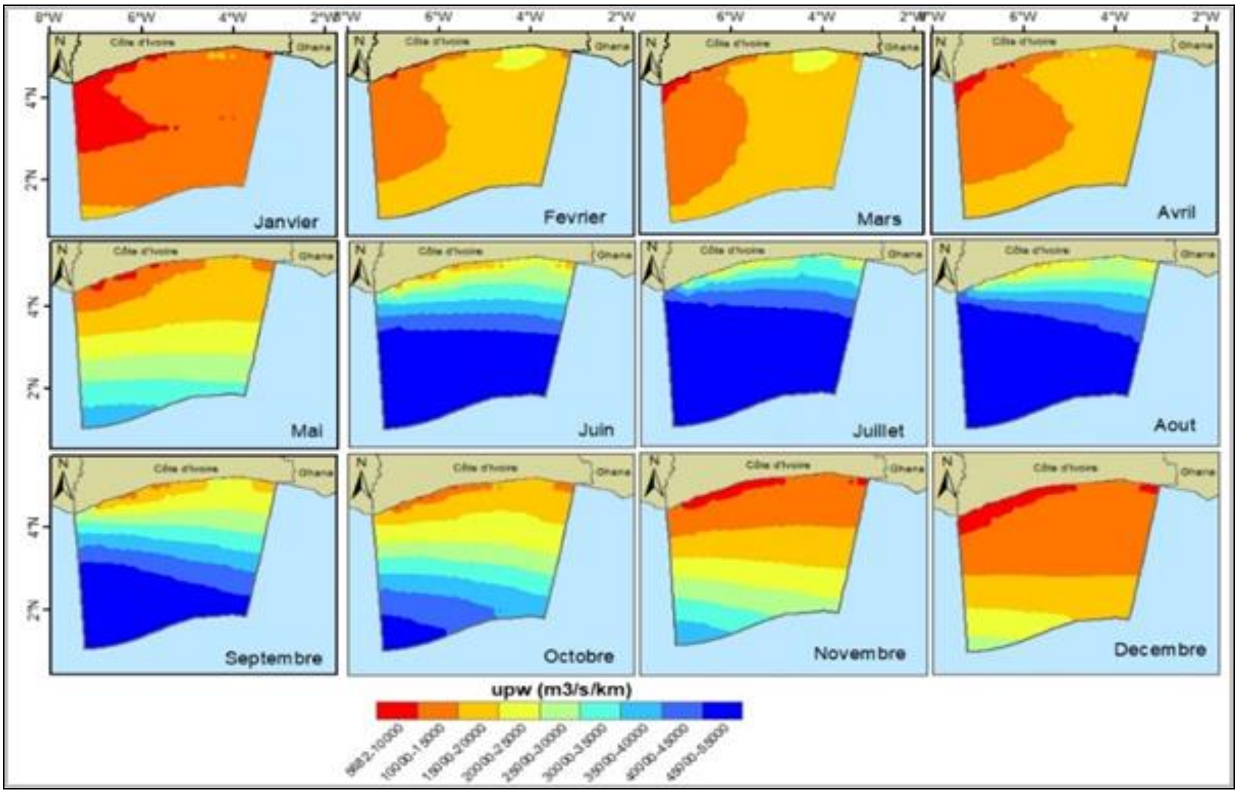

Fig 5: Seasonal spatial distribution of the upwelling index from 1998 to 2020

3.1.1.5 Seasonal variability of sea surface salinity from 1998 to 2020

The entire sea surface shows relatively low salinity from December to June with values around 34.5‰. The period from July to September marking the great cold season is the most saline with values oscillating around 35‰ to 35.5‰ from the coast to 36‰ off shore.

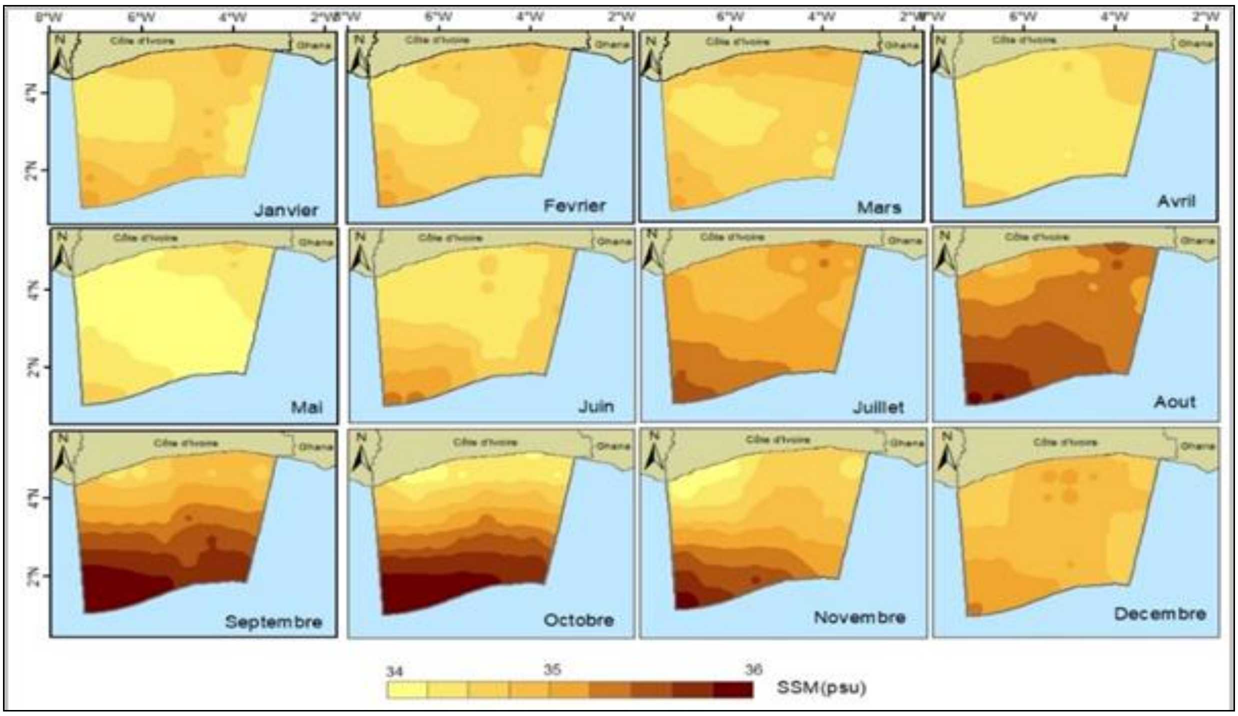

Fig 6: Seasonal spatial distribution of sea surface salinity 1998 to 2020

3.1.1.6 Relationship between fish stocks and ocean biophysical parameters

Chlorophyll and fish stocks

The evolutionary trend of the two curves (chl_a and *Sardinella*) is almost similar. When the chlorophyll concentration increases, fishing catches also increase and in the opposite way. The correlation coefficient between chl-a and *Sardinella* being 0.72% shows that there is a strong relationship between the two variables.

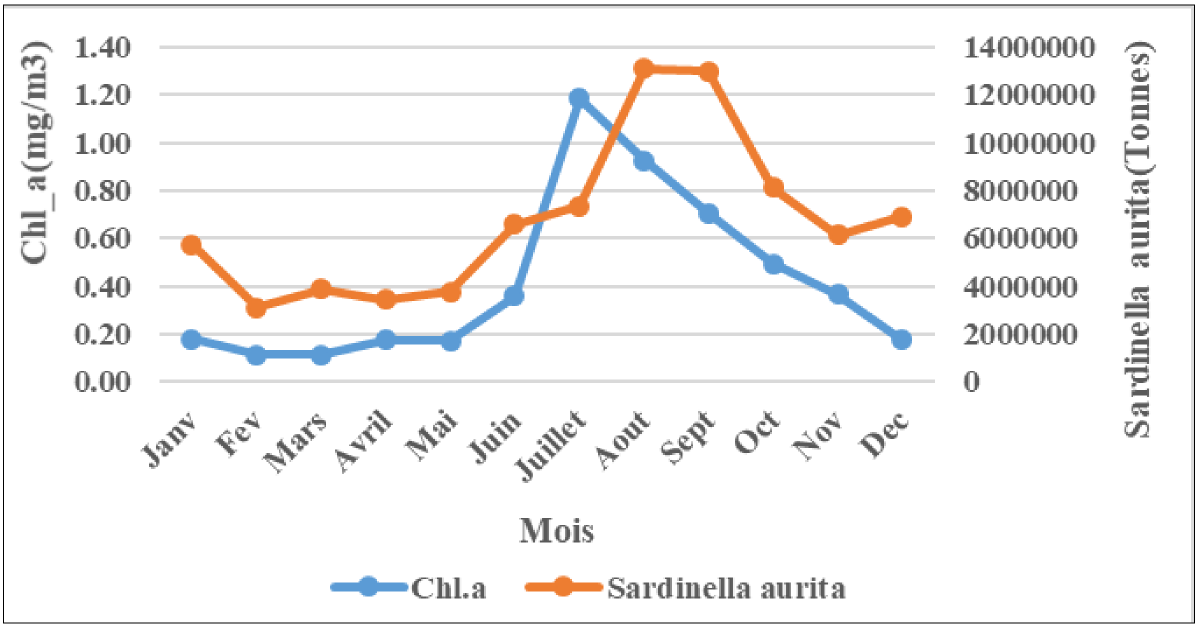

Fig 7: Relationship *Sardinella aurita* and Chlorophyll-a

Temperature and fish stocks

On analyzing Figure 8, we generally observe an inverse evolution between the two variables. We note that the higher the temperature becomes, the lower the fishing catches become and conversely when the temperature is low there is an increase in fish stocks. The correlation coefficient of -0.93% reflects a perfect negative relationship between temperature and *Sardinella aurita*.

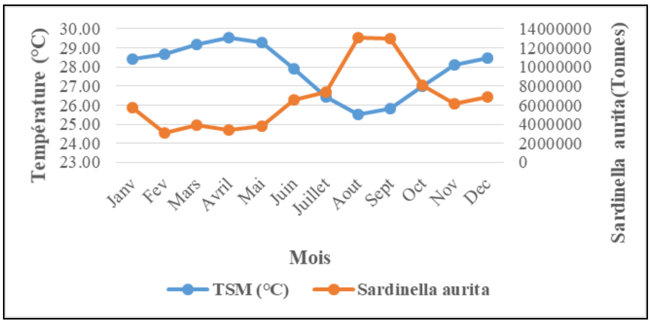

Fig 8: Relationship *Sardinella aurita* and Temperature

Salinity and fish stocks

The analysis of the relationship between stocks of *Sardinella aurita* with the seasonal variations of salinity shows a perfect evolutionary similarity between them. In general, the months when the salinity is low, there are low values of the catches of *Sardinella aurita* and the months when the salinity is high there is an increase in the stocks of *Sardinella aurita* in occurrence between August and September. The correlation coefficient which is 0.89% testifies to the strong relationship between salinity and *Sardinella aurita*.

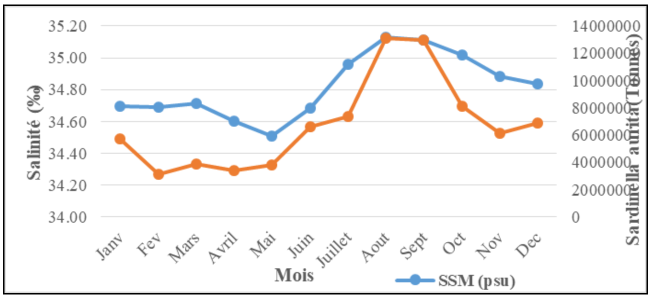

Fig 9: Relationship *Sardinella aurita* and salinity

Turbulence and fish stocks

The comparative analysis of the curve of seasonal evolution of the turbulence of the surface of the sea and the fishing catches of the *Sardinella aurita* reveals two trends: on the one hand, from January to April, fish catches become low when turbulence increases. On the other hand, from July in September, a medium or moderate increase in turbulence leads to large increases in fish quantities. The correlation coefficient between the two variables being 0.06% shows that there is a weak relationship between turbulence and the availability of fish.

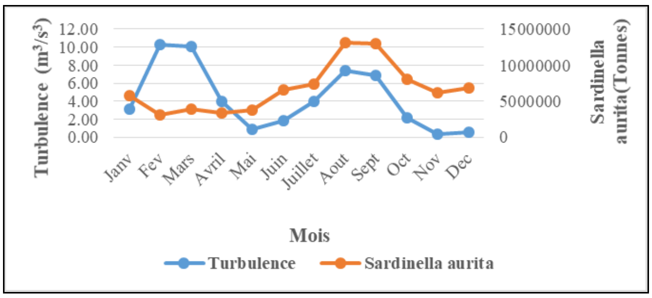

Fig 10: Relationship *Sardinella aurita* and turbulence

Upwelling and fish stocks

Observation of seasonal variations in upwelling and monthly Sardinella catches reveals an evolving proportionality between the two variables. Low upwelling values lead to low *Sardinella* catches and seasons of high upwelling values correspond to strong *Sardinella* recruitments. The correlation coefficient of 0.63% between the two variables indicates a good relationship between them.

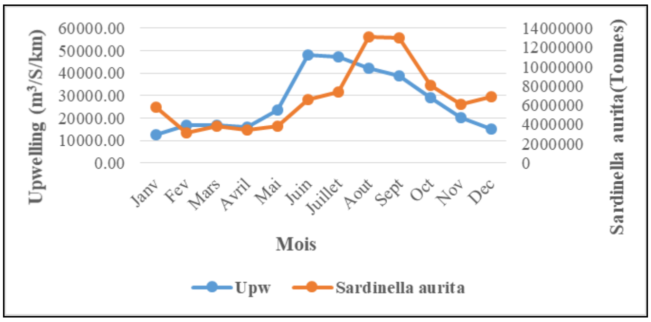

Fig 11: Relationship *Sardinella aurita* and upwelling

3.1.2.6. Correlative Synthesis of Ocean Biophysical Variables and Fish Stocks

Table 1 shows us the correlation coefficient of each oceanic variable and its weight, which allow us to gauge its level of influence on fish stocks. On analysis, we notice that except for the turbulence has a low coefficient. This testifies to its weak influence on fish stocks. On the other hand, a hierarchy of the weight of these variables allows us to establish the following order of importance of influence: temperature first, salinity second, chlorophyll third, then upwelling and finally turbulence.

Table 1: Synthesis of correlation coefficients and weights of ocean biophysical variables according to fish stocks from 2010 to 2020.

Variables	*Coefficient. Correlation*	**Weight of variables**
Temperature	-0,93	0,29
Salinity	+0,89	0,28
Chlorophyll-a	+0,72	0,22
Upwelling	+0,63	0,20
Turbulence	+0,06	0,02
Total	3,24	1

3.1.4. Mapping of potential fishing areas for *Sardinella aurita*

In order to determine potential fishing areas for *Sardinella aurita* in the Ivorian EEZ, several manipulations were made. But finally, it is the first three most influential variables (SST, SSM, Chl.a) which were merged which allowed us to obtain a convincing result represented by figure 12. This figure below indicates the spatiotemporal distribution potential zones of availability of *Sardinella aurita* in the Ivorian EEZ from 2010 to 2020. In general, the areas of average and high potential availability of pelagic species are located on the coasts. Also, most of the surface of the EEZ is characterized by a low potential for the availability of species, especially between latitudes 4°N and 2°N. The optimal period when we observe a better availability of pelagic species is that of the cold season from July to September. We note that the months of August and September (in this case the great cold season) are the most predisposed to a better availability of *Sardinella aurita* in the Ivorian EEZ. This could be explained by the higher fishing catches observed during these months (see DAP fishing data). In view of these results, we note that the satellite imagery has undeniable potential in the precision mapping of potential fishing areas in Ivorian marine waters.

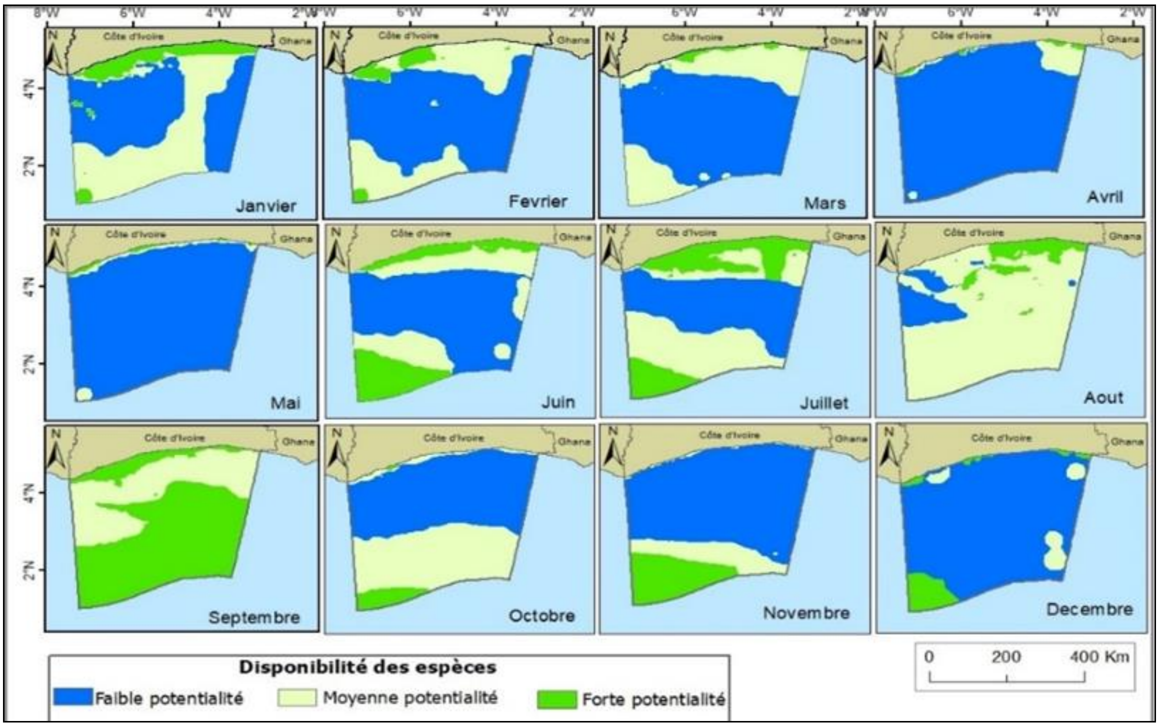

Fig 12: Location of potential fishing areas for *Sardinella aurita* in the Ivorian EEZ from 2010 to 2020

3.2. Discussion

3.2.1. Variability spatiotemporal of the ocean biophysical parameters

Temperature

The seasonal variability of the sea surface temperature showed a small cold season from January to February and a large cold season between July and September on the one hand as well as a large hot season from March to May and a small hot season from November to December on the other hand. These results confirm those of (Kassi and *al*., 2018) [7], by (Morliere, 1970) [8] quoted by (Kouakou, 2014) [9] which determine four marine seasons in Ivorian marine waters. The cold zones being the favorable place for the recruitment of pelagic species are more concentrated in the coastal zones while progressing offshore during the long cold season which corroborates the results of (Kassi, 2012) [6].

Chlorophyll

The analysis of the spatio-temporal variation of the concentration of chlorophyll in the Ivorian EEZ made it possible to show that the planktonic bloom with a strong activity chlorophyll is observed during the great cold season during the months of July to October on the entire Ivorian coast. Meanwhile, the West of Côte d'Ivoire is marked by concentrations of chlorophyll in the area of Tabou, San-Pedro and at the mouth of the Sassandra River during the months of January and February. Our results are in line with those of (Kassi, 2012) [6], who estimates that a high concentration of chlorophyll at the mouths would be related to the discharges of the rivers that flow into the ocean and that the presence of high concentrations of chlorophyll during the Great Cold Season (GSF) is due to the phenomenon upwelling.

Salinity

In general, salinity increases as you progress from the coasts out to sea (Gougnon and *al.*, 2018) [10]. The period from July to September marking the great cold season is the most saline with values oscillating around 35‰ from the coast to 36‰ offshore. These results are similar to those of (Morliere, 1970) [8] which explains that during the great cold season (GSF) from July to September, sea surface salinity (SSM) values greater than 35% were observed between longitudes 3 and 2º W and values (SSM) between 34 and 35% for the rest of the Gulf.

Turbulence

From our results, it has been shown that during the great cold season from July to September, moderate or average values of the turbulent mixing are located in the East where it originates to propagate offshore beyond 4° N latitude and over the entire coastal zone to the West. This fact would be due to the counter-current of Guinea which generally occurs in depth and which carries towards the West in agreement with (Mobio, 2009) [11] which showed that the simultaneous presence of the Guinea Current which carries to the East and of the Guinea Counter-Current which carries to the West occurs during the second half of the year.

Upwelling

Regarding upwelling, study has shown that the upwelling phenomenon is more marked and more important during the months of June to September. Our results agree with those of (Arfi and *al.*, 1993) [12] whose studies have revealed that the seasonal intensities of the resurgence calculated during the Great Cold Season are high on the entire Ivorian coast.

3.2.2. Mapping of potential fishing areas for *Sardinella aurita*

The work that we carried out on the Ivorian EEZ from 2010 to 2020 makes it possible to determine the potential areas of availability of pelagic species considering has three classes: low, medium and high availability potential (Kassi, 2012) [6].

Our results showed that in general, the areas of medium and high potential availability of pelagic species are located on the coasts. However, the great cold season is the period of the year most predisposed to a better availability of *Sardinella aurita* in the Ivorian EEZ, which demonstrates the highest fishing catches observed during these months. Our results corroborate those of (Djagoua and *al.*, 2006) [2] on the availability of species by showing that the highest catches occur from July to September and even that the annual reproduction is more accentuated during the great cold season.

4. General conclusion

The study that we have just carried out on the Ivorian EEZ has enabled us to estimate the spatio-temporal variability of oceanic variables and their influences on recruitment, but also to map potential fishing zones. The study revealed that:

- In general, the areas of average and high potential availability of pelagic species are located on the coasts.
- Most of the surface of the EEZ between latitudes 4°N and 2°N is characterized by low potential for species availability.
- The great cold season is the period of the year most predisposed to a better availability of*Sardinella aurita*in the Ivorian EEZ, which demonstrates the highest fishing catches observed during this period.

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