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Seasonal Variability of Sea Surface Temperature and Chlorophyll Concentration and Its Correlation with Pelagic Fish Catch in Senegalese Exclusive Economic Zone (EEZ)

Jeanne Maffoué Kouadio[1, *], Waly Ndiaye[2], Ahon Jean-Baptiste Kassi[1], Tacko Niang[3], Eric Valére Djagoua[1], Abdou Aziz Diouf[3]

[1]Center for Research and Application in Remote Sensing, Felix Houphouët-Boigny University, Abidjan, Côte d'Ivoire

[2]Institute of Fisheries and Aquaculture, Cheikh Anta Diop University of Dakar, Dakar, Senegal

[3]Ecological Monitoring Center, Dakar, Senegal

Email address:

maffoue.kouadio@curat-edu.org (J. M. Kouadio)

[*]Corresponding author

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Abstract: Remote sensing data were used in this study to relate the biophysical characteristics of the ocean and their relationship with the coastal pelagic fish catches in the Senegalese Exclusive Economic Zone (EEZ) from 2003 to 2017. Level 3 (4 km) monthly sea surface temperature (SST), chlorophyll (Chl-a) data from the Moderate Resolution Imaging Spectroradiometer Satellite (MODIS-Aqua) and statistics fishing data were used. These biophysical parameters associated to coastal upwelling index and turbulence water index allowed to characterise availability of fish. The monthly average variation of the biophysical parameters shows a close relation between chlorophyll concentration, sea surface temperature and the pelagic species availability. The results showed that satellite variables are directly related, with high chlorophyll-a concentrations and high upwelling intensities corresponding to low ocean surface temperature. The analysis of intra-annual variations shows the identification of two distinct seasons. A cold season from November to May, marked by an intense upwelling, corresponding to a high concentration of chlorophyll and high upwelling intensity with very high landings of coastal pelagic species. A warm season from June to October corresponding to a low concentration of chlorophyll and a decrease in the intensity of upwelling with low landing values. A hot season extending from June to October, corresponds to a low concentration of chlorophyll-a and a decrease in intensity of upwelling with low landing values.

Keywords: Sea Surface Temperature (SST), Chlorophyll Concentration (Chl-a), MODIS Data, Small Pelagic Species, Senegal EEZ

1. Introduction

Senegal is one of the countries in the North West African sub-region with the highest catches. Coastal pelagic resources constitute more than 70% of the catches made in the Senegalese Exclusive Economic Zone (EEZ), mainly by artisanal fishing. The quality and diversity of these resources in Senegalese waters are due to several environmental factors, such as the variation in phytoplankton abundance and the upwelling of deep cold waters loaded with mineral salts. This physical and biological variability, as well as light conditions, strongly influence primary production. The latter, essentially linked to the development of phytoplankton, supports the whole food chain up to the exploited species and explains part of the spatio-temporal variability [1].

Senegal's exclusive economic zone (EEZ) is characterised by a well-defined, nutrient-rich upwelling, which supports one of the most productive ecosystems in the world. Small pelagic stocks make up the majority (tonnage) of all fish landings and are the most important marine resource. Small pelagics, consisting mainly of small pelagic fish, are the main source of animal protein for the majority of the population. Fish consumption of about 25 kg/year/capita exceeds the world average of 12 kg/year/capita and that of the rest of Africa, with 8.2 kg/year/capita [2].

This marine resource is vital for coastal populations that depend on artisanal fishing for their income and food security, as is the case in the coastal regions of West Africa. The Senegalese upwelling is marked by high seasonal and interannual variability, which is believed to affect small pelagic fish [3-6].

In recent years, marine ecosystems have undergone major changes due to the effects of climate change. Senegal is not immune to this phenomenon and the fisheries sector is the most affected. The management of fisheries in Senegal's exclusive economic zone must be conceived within the framework of coastal zone management. In this context, a study of the parameters of the coastal marine environment becomes crucial to know the effect of changes on the species living there. Advances in satellite remote sensing of environmental disturbances have become important for understanding variations in ocean productivity and catches of small pelagic fish. Small pelagic fish are the most abundant fish stocks in the CCAMLR area, and are mostly shared by several coastal states. They occupy a fundamental place in the upwelling ecosystem due to their intermediate position in the food chain and their abundance. Small pelagic stocks show strong natural variations in abundance. These species can control both the abundance of the zooplankton they consume (top-down control) and the abundance of their predators (bottom-up control) depending on the situation [3].

2. Material and Methods

2.1. Study Area

Senegal has an exclusive economic zone (EEZ) that is 718 km long and covers nearly 159,000 km^2 [1]. In surface area, Senegal's maritime territory ranks 85th in the world and 24th in Africa. It is divided into two large areas: the Great Coast, which extends from the mouth of the Senegal River in the North to the Cape Verde peninsula, and the Little Coast, which extends from the Cape Verde peninsula to the Saloum Delta in the South including Casamance (Figure 1). In fact, there is a clear ecological disparity between the Petite-Côte and the Grande-Cote, both in terms of the direct influence of upwelling and the enrichment processes that result from it [7].

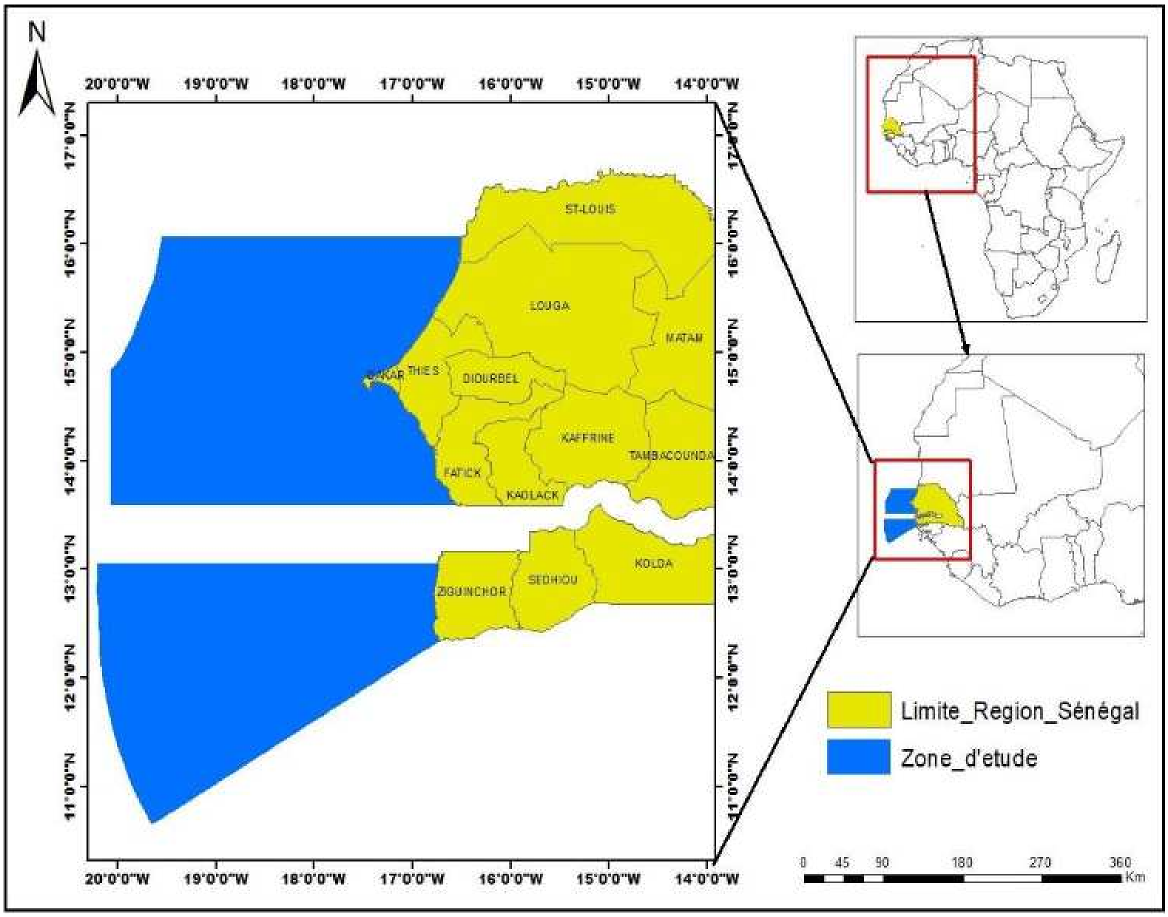

Figure 1. Study area of the Senegal has an exclusive economic zone (EEZ).

2.2. Satellite Data

The biophysical parameters (chlorophyll-a and sea surface temperature) used in this study are from the MODIS Aqua sensor that was used to determine ocean color. The wind data from ERA-Interim is a dataset that will be used to calculate the upwelling index and the turbulence index to characterize their phenomena. The landing data of coastal pelagic species from the Senegalese Directorate of Marine Fisheries allowed the analysis of the relationships between the biophysical parameters of the ocean and the pelagic species studied.

2.3. Ocean Biophysical Parameters

2.3.1. Chlorophyll-a and Sea Surface Temperature

A 4-km data set from 2003 to 2017 of chlorophyll-a and sea surface temperature from the MODIS sensor was used for this study. Monthly mean variations were obtained from satellite images for the spatial distribution of biophysical parameters as Chl-a and SST. The extraction of the study area was done from the shapefile of the study area, and all images of the series from 2003 to 2017 were averaged monthly. Finally, the seasonal variations will allow to see the seasonality of the chl-a concentration, sea surface temperature in the Senegalese exclusive economic zone.

Time series of chl-a concentration and surface temperature were generated. The curves obtained showed the temporal variability and the relationship between the concentration of chlorophyll and sea surface temperature in the exclusive economic zone of Senegal.

2.3.2. Coastal Upwelling Index and Turbulence Index

A 10-meter vertical component (V) wind data set from the ERA_Interim reanalysis was used to calculate the coastal upwelling index and the turbulence index.

2.3.3. Coastal Upwelling Index

The upwelling is a phenomenon of upwelling of deep and cold water to the coast accompanied by the contribution of nutritive salts in the euphotic zone. This availability of nutrients initiates the development of phytoplankton which is the first link in the food chain. The upwelling index was used in this study to determine the potential fishing areas in the Senegalese EEZ. It was calculated from the Ekman transport equation [8] in which the wind speed is replaced by its component parallel to the coast:

$$IUC = \frac{r*Cd*V2}{f}$$

Where r = air density, Cd = coefficient of roughness at the air-sea interface, V^2 = square of the wind component parallel to the coast, f = Coriolis parameter.

2.3.4. Turbulence Index

Turbulence was used in this study to see the variation of the stability of the water column over the exclusive economic zone of Senegal. Its formula is given from the energy transmitted by the wind to the ocean surface. This energy generates turbulence within the surface layers [9]. It is estimated from the cube of the wind speed [10].

$$TI = V^3$$

With TI is the Turbulence index and V is the wind speed in vertical component.

After calculating the coastal upwelling and turbulence indices, an interpolation was made by the Arcgis IDW tool to obtain the monthly average spatial variation maps of these two parameters.

2.3.5. Statistics of Satellite and Fishing Data

In this section, only statistical data from the four pelagic species (sardinella, bonga, mackerel and horse mackerel) were used. Monthly mean values of chlorophyll-a concentration and sea surface temperature were used to plot the relationship between chlorophyll-a and sea surface temperature. The monthly mean and average values of the turbulence index and the upwelling index were calculated in Excel and used to interpolate to obtain the maps of turbulence and upwelling variation.

These graphical representations of the monthly average satellite variables and the monthly average variation of the coastal pelagic species allow us to obtain the relationship curve of the coastal pelagic species and the satellite variables. These statistical data also allow the evaluation of the satellite variables and the quantity of stocks of pelagic species.

3. Results

3.1. Ocean Biophysical Parameters

3.1.1. Seasonal Variability of Chlorophyll-a

The general trend described in Figure 2 showed a high concentration of chlorophyll-a at the coast, which gradually decreases towards the open sea.

The spatial distribution of chlorophyll-a in the senegalese exclusive economic zone showed that from November the concentration of Chl-a was very high until May, which corresponded to the cold season. The highest values of Chl-a concentration at the coast were noted from January to May with an average of 4.99 Ug/l in April. From June onwards, the concentration of chlorophyll-a decreased progressively over the whole area until October, corresponding to the warm season. In the month of, the lowest concentration of chlorophyll-a over the whole area were noted in July and August with an average of 0.68 Ug/l.

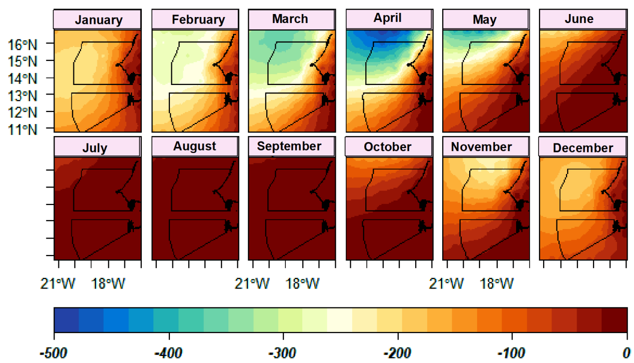

Figure 2. Monthly and latitudinal evolution of turbulence index (TI, m^3/s^3) in the EEZ of Senegal from 2003 to 2017. The TI was represented by a color scale.

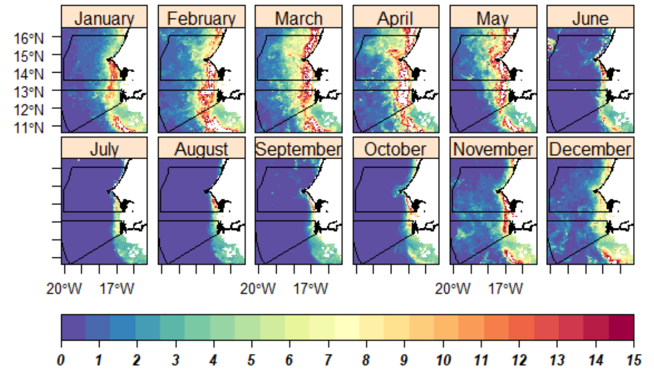

Figure 3. *Monthly and latitudinal evolution of chlorophyll-a concentration (Chl-a, mg.m^{-3}) in the EEZ of Senegal from 2003 to 2017. The Chl-a was represented by a color scale.*

3.1.2. Seasonal Variability of the Sea Surface Temperature

The distribution of the sea surface temperature showed that low temperatures (below 25°C) were obtained from January to May with minimum values in February and March (about 22°C) all along the coast (Figure 3). From June onwards, the temperature increased with average values of 26°C in June and 28°C in September and October, corresponding to the hot season. In December, the temperature dropped to 25.7°C corresponding to the beginning of the cold season until May. The sea surface temperature was very low on the coast especially during the cold season and increases gradually towards the open sea.

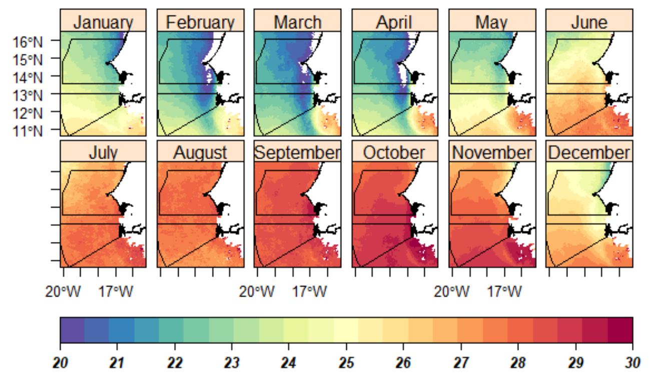

Figure 4. *Monthly and latitudinal evolution of sea surface temperature (SST, °C) in the EEZ of Senegal from 2003 to 2017. The SST was represented by a color scale.*

3.1.3. Seasonal Variability of the Turbulence Index

The spatial distribution of turbulence in the Senegalese EEZ showed that from June to October there was strong turbulence in the water throughout the economic zone, especially in July, August and September. From November, a decrease in the turbulence of the water column was observed until May. Low turbulence was observed in April at about -300 m^3/S^3. The turbulence of the water had started to decrease especially on the large coast until May (Figure 4).

3.1.4. Seasonal Variability of the Coastal Upwelling Index

The intensity of the upwelling was very important in the North especially between latitudes 16°N and 15.25°N. This intensity decreased progressively towards the South. The spatial distribution of the coastal upwelling index in the Senegal EEZ showed strong upwelling intensities from October to June. The highest values were observed from February to May with a peak in April. On the other hand, the weakest intensities were noted from June to October with minimum values in August and September. The months of November, December and January had intermediate upwelling intensities (Figure 5).

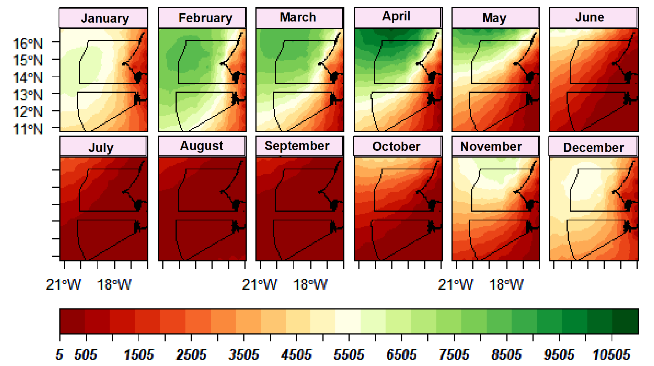

Figure 5. *Monthly and latitudinal variation of coastal upwelling index in the EEZ of Senegal from 2003 to 2017. The CUI was represented by a color scale.*

3.1.5. Chlorophyll-a and Sea Surface Temperature

The average monthly variation of the chlorophyll-a concentration, with which was associated the sea surface temperature, showed that these two parameters evolved in opposite directions. During the cold season (November-May) the sea surface temperature was low and the Chl-a concentration was very high. In the warm season (June-October) the temperature was very high and the Chl-a concentration very low. In the exclusive economic zone of Senegal, high chlorophyll-a concentrations corresponded to low sea surface temperature values and vice versa. The correlation coefficients (R^2) of these two parameters as a function of month were quite strong (greater than 0.5). This showed that chlorophyll-a and sea surface temperature are seasonal in the Senegalese exclusive economic zone (Figure 6).

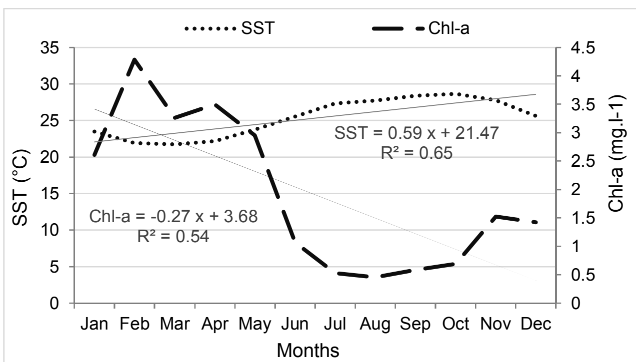

Figure 6. *Monthly evolution of sea surface temperature (SST, °C) and chlorophyll-a concentration (Chl-a, mg.m^{-3}) in the EEZ of Senegal from 2003 to 2017.*

3.2. Monthly Variation of Small Pelagic Catches and Environmental Variables

High quantities of landings of the four pelagic species were observed during the cold season with a high concentration of chlorophyll-a. During the warm season the quantity of landings was very low, especially for mackerel and horse mackerel, with a quantity of less than 1000 tons.

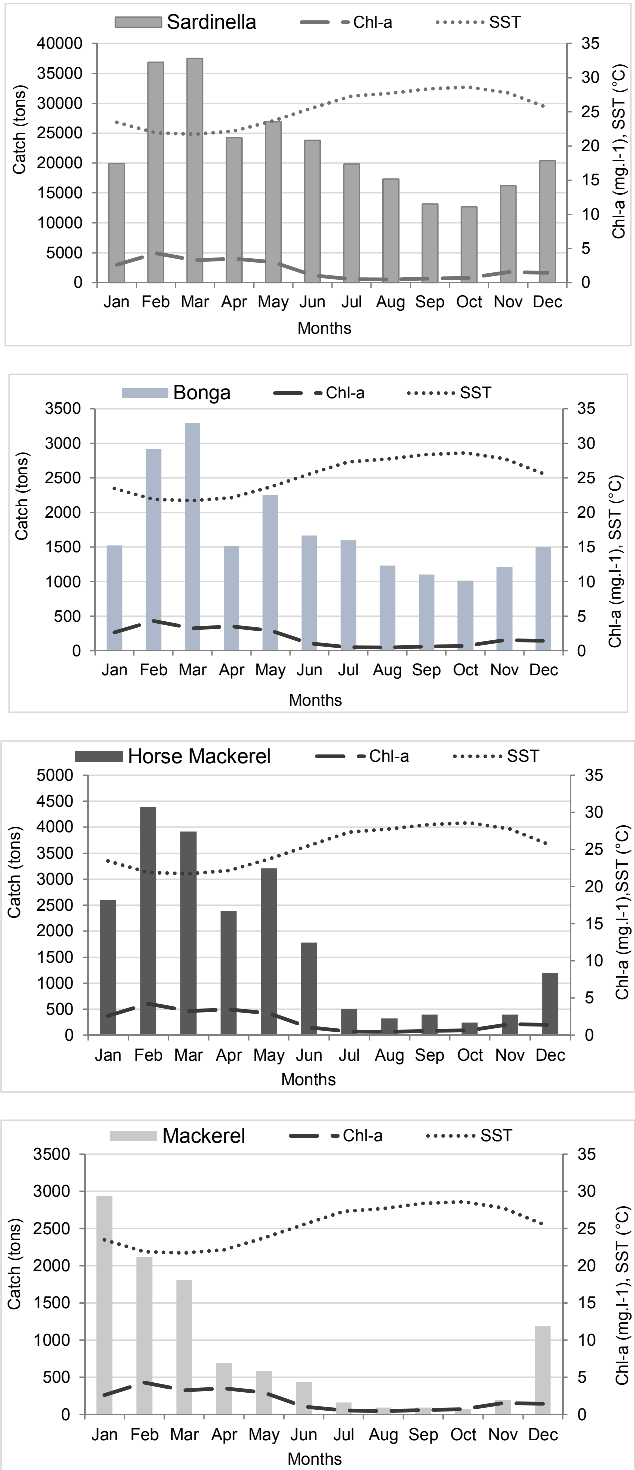

Figure 7. *Monthly distribution of small pelagic fish catch with sea surface temperature (SST, °C) and chlorophyll-a concentration (Chl-a, mg.m-3) in the EEZ of Senegal from 2003 to 2017.*

The average monthly variations of the chlorophyll-a concentration and surface temperature, which were associated with the catches of pelagic species in the exclusive economic zone of Senegal over the period 2003 to 2017, showed a large variation between the landings and the satellite variables. They showed a more or less close relationship between periods of high chlorophyll-a concentration, periods of low sea surface temperature and significant peaks in landings of pelagic resources. Indeed, the months of January, February, March and April recorded high chlorophyll-a concentrations with a significant peak in February and March. During this same period, a decrease in the surface temperature of the ocean below 25°C was noted with a significant amount of pelagic species landed. From May onwards, the concentration of chlorophyll decreased until September, characterized by an increase in the sea surface temperature above 25°C and a decrease in the amount of landings of pelagic resources. In November, the concentration started to increase with the decrease in temperature and the increase in landings of coastal pelagic species (Figure 7).

4. Discussion

The results of the spatio-temporal variations of this study showed that there are two seasons in the Senegalese exclusive economic zone, a cold season from November to May and a warm season from June to October. During the cold season, the lowest temperatures were observed on the coast and they gradually increased towards the open sea. The concentration of chlorophyll-a during this period was very high at the coast and decreased towards the open sea. The coastal upwelling index was very high during this period, especially in the northern part of the exclusive economic zone of Senegal. During the warm season, sea surface temperatures were very high, especially in August, September and October, when values exceed 26°C. During this period the concentration of chlorophyll-a was very low over the whole area and the coastal upwelling index progressively decreased. Strong spatial and seasonal variability of environmental parameters (sea surface temperature, chlorophyll-a concentration, upwelling and turbulence indices) were observed. The southern part of the zone was characterized by warmer waters and richer in chlorophyll-a than the northern part. Seasonal variations were also very marked. The temperature could vary from 16-18°C in February-March (cold season) to 30°C in July-October (hot season). Strong latitudinal temperature gradients existed in the region with a more significant and narrower temperature change between 20°22′N. These latitudinal temperature variations depended primarily on heat exchange with the atmosphere, but also on the intensity of the upwelling itself [11].

The upwelling phenomenon played an important role on the variation of other parameters in the exclusive economic zone of Senegal. The Senegalese coastal upwelling is the southern part of the Canary Islands system. It is seasonal, as it is subject to the southern movement of the trade winds [12]. The Senegalese upwelling lasts from November to May and could be subdivided into two sub-seasons: a cold season of advective type with weak upwelling from November to January characterized by weak and irregular winds (installation of the trade winds) and a cold season with strong upwelling from February to April characterized by strong winds (established trade winds). The wind became the main driver of horizontal and vertical circulation of the shelf waters. This study has been done by several authors: Schemaida et al. [13-18]. However, this general view was complicated by many subtleties. From November to January, the upwelling is due to the Northeast wind and is slightly more intense on the north coast.

In February, the north-west orientation of the trade winds was favorable for the whole area, where the upwelling became more intense. During this period, the winds intensified and those parallel to the coast are the main drivers of the upwelling. Chlorophyll-a increased while sea surface temperature decreased considerably at the coast [19]. The upwelling season extended until June on the north coast and May on the South coast and its intensity was maximum between February and April [20]. The upwelling phenomenon was the main factor of enrichment along the Senegalese coast [21]. The strong variations in chlorophyll-a concentration and sea surface temperature were due to these upwelling events on the Senegalese coast favoring a high availability of coastal pelagic species during the cold season. During this period, peaks of high chlorophyll-a concentration coincided with low sea surface temperature values. This suggested that sea surface temperature and chlorophyll-a concentration evolved in opposite directions [18].

The results of the temporal variations showed that there was a significant relationship between the landings of coastal pelagic species and the biophysical parameters of the ocean (Chl-a, SST, CUI and TI) in the Senegalese exclusive economic zone. These parameters played a major role in explaining the monthly variability in landings of coastal pelagic species. During the cold season, a strong intensification of the upwelling was observed. During this period the upwelling would enrich the neritic zone of the ocean and the nutrient salts would have an immediate influence on the biological production, the phytoplankton. Indeed, the nutrients transported to the surface by this phenomenon contributed to the development of phytoplankton, whose chlorophyll-a concentration measured the abundance, and an important decrease of the sea surface temperature, hence the important productivity of the environment. This high concentration of chlorophyll and the decrease in temperature provided an important element for direct knowledge of pelagic species. During the warm season, the presence of warm waters was linked to the decrease in the intensity of upwelling in the area but also a decrease in nutrients and an increase in sea surface temperature. This led to a decrease in biological production. The high concentration of chlorophyll-a observed during the warm seasons at the Senegalese coast indicated that terrigenous inputs contributed to the enrichment of the coastal zone. The enriching inputs were from runoff that washed out the cleared land surrounding the coastal areas [22].

The abundance of coastal pelagic species was more controlled by biological productivity, thermal gradient and upwelling intensity. The high presence of these pelagic species observed from November to May was due to suitable environmental conditions (high biological productivity, lower sea surface temperature, high upwelling intensity and low water column turbulence) in the Senegalese coast. The low presence of these species from July to October was due to unfavorable environmental conditions where the species migrated to other more favorable areas. Pelagic species play a very important role and constitute the intermediate level in the marine environment. The fluctuations in abundance of pelagic fish stocks reflected important changes in the structure and functioning of marine ecosystems. However, the control of the trophic chain is realized by the intermediate link (pelagic species). Thus, this intermediate link will play a central role in the structure and dynamics of the ecosystem, both through top-down control (top predator control over lower trophic links), over the plankton they feed on, and through bottom-up control over the many marine predators that consume them [11]. These pelagic species thus occupied an important weight in the country's diet and economy and played strategic environmental, social and economic functions. They participated in the conservation of marine biodiversity [23] and were a source of food for the populations in general and the most disadvantaged communities in particular.

5. Conclusion

The results of the monthly mean space-time variation showed that there are two seasons in the exclusive economic zone of Senegal, a cold season from November to May and a warm season from June to October. During the cold season, sea surface temperatures were low. High upwelling intensity and high chlorophyll-a concentration were also noted. In the warm season sea surface temperatures were high while upwelling intensity and chlorophyll-a concentration were low. The results of the temporal variation showed that the environmental parameters had a very important role on the monthly variability of landings of coastal pelagic species in the Senegalese exclusive economic zone. During the cold season, the stock of coastal pelagic species was very important in contrast to the warm season where the stocks progressively decreased.

These results provided new knowledge on the biophysical parameters of the ocean in the Senegalese exclusive economic zone and their relationship with the landings of coastal pelagic fish. They should allow the preparation of operational maps for the identification of potential fishing areas, thus helping the fishermen to work more efficiently and to save fuel. This is certainly not to encourage overfishing, but rather to provide practical means to ensure sustainable management and more efficient fishing. Areas of high upwelling intensity correspond to areas that regularly record high chlorophyll-a concentrations and low ocean surface temperature values and correspond to areas that are constantly populated by pelagic resources.

References

[1] Diankha O, Demarcq H, Fall M, Thiao D, Thiaw M, Sow BA, Gaye AT, Brehmer P. Ecosystem Approach to the management of fisheries and the marine environment in West African waters conference. Aquatic Living Resources. 2017; 30 (27): 1-8.

[2] Lazar N, Ndiaye V, Thiaw M. Climate change impacts on small pelagic stocks and food security of North West Africa, 2014; ICAWA, WP1_S2_1_26.

[3] Bakun A. Patterns in the ocean: ocean processes and marine population dynamics. California Sea Grant College System, National Oceanic and Atmospheric Administration, in cooperation with Centro de Investigaciones Biológicas del Noroeste, 1996, 323.

[4] Cury PM, Roy C. Upwelling et pêche des espèces pélagiques côtières de Côte d'Ivoire: une approche globale. Oceanologica acta. 1987; (3): 347-357.

[5] Fréon P. L'introduction d'une variable climatique dans les modèles globaux de production. 1991; 395-424.

[6] Fréon P, Mendoza J. The sardine (Sardinella aurita), its environment and exploitation in Eastern Venezuela. IRD Éditions. Institut de Recherche pour le Développement. Collection Colloques et séminaires. Paris, 2003, 549.

[7] Demarcq H. Influence des variations de l'upwelling sur la répartition des poissons pélagiques au Sénégal 1991, 65.

[8] Ekman VW. On the influence of the earth's rotation on ocean currents. Arkiv för Matematik, Astronomi och Fysik. 1905; 11 (2): 1-51.

[9] Kassi AJB. Caractérisation et suivi des zones d'Upwelling pour la détermination des zones de rétention des espèces pélagiques dans le Golfe de Guinée à L'aide de la Télédétection et du Système d'Information Géographique: Cas de la Côte d'Ivoire. Ph. D. Thesis, Université Felix Houphouët-Boigny, Abidjan, Côte d'Ivoire, 2012.

[10] Bakun A, Parrish HP. Turbulence, transport, and pelagic fish in the California and Peru current systems. CalCOFI Rep. 1982; XXIII: 99-112.

[11] Jeyid MAA. Relations environnement et évolution spatio-temporelle des petits poissons pélagiques dans le système d'upwelling de la zone NW Africaine. Océan, Atmosphère. Université du Littoral Côte d'Opale, 2016.

[12] Nykjær L, Van Camp L. Seasonal and interannual variability of coastal upwelling along Northwest Africa and Portugal from 1981-1991. Journal of Geophysical Research. 1994; 99 (7): 14197-14207.

[13] Schemaida R, Nehring D, Schulz S. Ozeanologische untersuchungen zum Produktions potential der nordwestafrikanischen wasserauftriebsregion 1970-1973. Geodätische und Geophysikalische veroffentlichungen. 1975; 4 (6), 85.

[14] Teisson C. Le phénomène d'upwelling le long des côtes du Sénégal: caractéristiques physiques et modélisation. Dakar: CRODT, 1983, 74.

[15] Rébert J. Hydrologie et dynamique des eaux du plateau continental sénégalais. Documents Scientifiques du Centre de Recherche Océanographique de Dakar- Thiaroye, 1983; 67, 14.

[16] Roy C. Fluctuations des vents et variabilité de l'upwelling devant les côtes du Sénégal. Oceanologica Acta. 1989; 12 (4): 361-369.

[17] Demarcq H, Faure V. Coastal upwelling and associated retention indices derived from satellite SST. Application to Octopus vulgaris recruitment. Oceanologica acta. 2000; 23: 391-408.

[18] Dème-Gningue I, Roy C, Touré D. Variabilité spatio-temporelle de la température, des nitrates et de la chlorophylle devant les côtes du Sénégal. Documents Scientifiques du Centre de Recherche Océanographique de Dakar- Thiaroye, 1990; 122 (5-6), 21.

[19] Dème-Gningue I, Touré D. Variabilité interannuelle et saisonnière de l'environnement sur le plateau continental sénégalais. In: Barry-Gérard M, Diouf T, Fonteneau A. (ed.). L'évaluation des ressources exploitables par la pêche artisanale sénégalaise: documents scientifiques présentés lors du symposium. Paris: ORSTOM, 1994; 11-24.

[20] Ndoye S. Fonctionnement dynamique du centre d'upwelling sud-sénégalais: Approche par la modélisation réaliste et l'analyse d'observations satellite de température de la mer. Ph. D. Thesis, Université Pierre et Marie Curie, 2016; 185.

[21] Binet D. Dynamique du plancton dans les eaux côtières ouest-africaines: écosystèmes équilibrés et déséquilibrés. In: Pêcheries ouest-africaines, Variabilité, Instabilité et Changement (Cury P, Roy C. eds). Paris: ORSTOM, 1991; 117-136.

[22] Djagoua EV, Affian K, Larouche P, Bachir SM. Variabilité saisonnière et interannuelle de la chlorophylle en surface de la mer sur le plateau continental de la Côte d'Ivoire à l'aide des images de seawifs, de 1997 à 2004. Télédétection. 2016; 6 (2): 143-151.

[23] Mbengue BA. Evaluation de l'efficacité bioécologique des aires marines protégées (AMP): le cas de l'AMP de Joal-Fadiouth. Mémoire de fin d'études, Université polytechnique de Bobo Dioulasso, Burkina Faso, 2016, 40.