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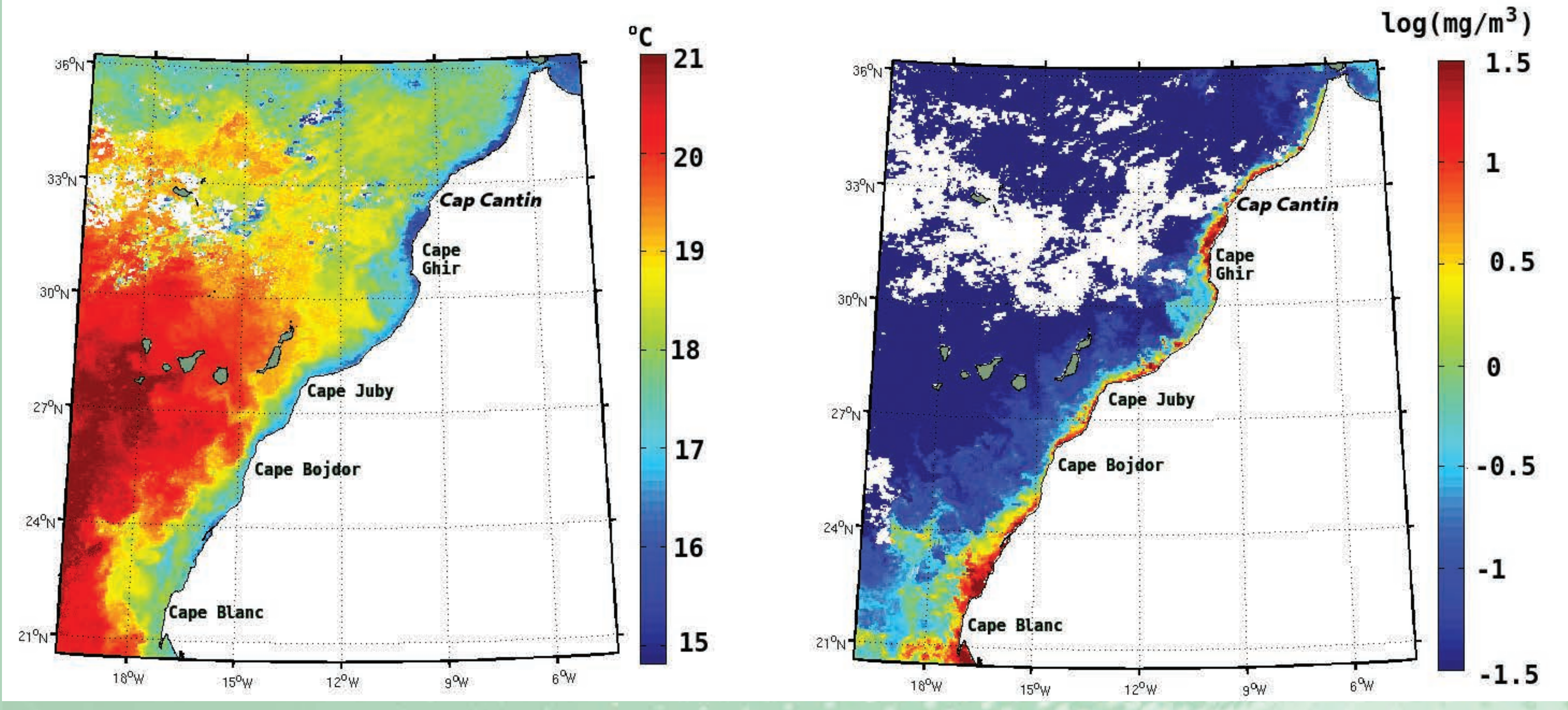

The Marine Environment of the Moroccan Atlantic Coast

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Cover Photo: 8-Day Sea Surface Temperature & Chlorophyl-a concentration, January 2007
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Frontiers in Science and Engineering, an International Journal edited by The Hassan II Academy of Science and Technology and part of the new Hassan II Academy Press, uses author-supplied PDFs for all online and print publications. The objective of this journal is to provide an exchange platform of high-quality research papers in science and engineering. Instead of a broad spectrum, it is organized in a transparent and straightforward interactive manner so that readers can focus on their direct interests.

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- Technical correctness and outputs,
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FORWORD

The four major Eastern Boundary Upwelling Systems (EBUS), namely the Canary and Benguela systems in the Atlantic Ocean; Peru-Chile and California systems in the Pacific Ocean, share similar characteristics and cover less than 1% of the global ocean surface. Nevertheless, they contribute to about 8% of the global marine primary production and more than 20% of the worldwide fish catches.
The Northwest African upwelling area is one of the significant coastal upwelling regions in the world. As in other major upwelling areas, strong equatorward marine winds are dominant in determining the strength and duration of upwelling events. However, the subsurface waters ascending to the surface under the influence of the winds have physical and chemical properties that are distinct from the usual surface waters. The upwelled waters are, for instance, colder and richer in nutrients than the surface waters. Nutrient-rich water, supplied to the sunlit surface layer by wind-driven upwelling, stimulates the growth of phytoplankton that ultimately fuel diverse and productive marine ecosystems. The upwelling activity along the Moroccan Atlantic coast (21°N-36°N) is of great importance. It is the source of the national fishery resources (mainly pelagic resources). Therefore we dedicate this volume of "Frontiers in Science and Engineering" to describe this phenomenon both for its physical/chemical/biological aspects and its impact on fishery resources.

Accordingly, the different aspects of upwelling activity are discussed in six papers as follows:
- ***Long-term upwelling activity along the Moroccan Atlantic coast***, between Cape Blanc (21°N) and Cape Spartel (36°N), during the period 1967-2019 (53 years). This paper focuses on the physical and the wind-driven process, given a general pattern of this phenomenon's spatial/temporal and seasonal variability along this coast.
- ***The variability of the Cape Boujdour upwelling and its relationship with the Cape Blanc frontal zone (Morocco)*** where physical and chemical (nutrients) processes are studied.
- ***Marine Circulation along the Moroccan Atlantic Coast*** details the hydrodynamic processes, from the surface to the depth of this coast's continental shelf/beach and along the Moroccan Atlantic coast.
- Due to the significant global problem of oceanic pollution and particularly the dispersion of seafloor debris, we describe the ***Marine circulation impact on the solid waste spatial distribution in the Moroccan Atlantic seafloor*** The paper also develops the Relationship of these impacts with the general circulation.
- Because of the importance of phytoplankton and zooplankton in the food chain during the upwelling process, it is necessary to study the ***Structure, diversity and habitat characterization of Copepods from the Cape Ghir upwelling***.
- Finally, the ***Relationship between migratory behavior and environmental features revealed by genetic structure of Sardina pilchardus populations along the Moroccan Atlantic coast*** is explained. Indeed, due to the strong relationship between the pelagic resources that represent more than 80% of the national fishery production and the environmental/oceanographic conditions during the upwelling events, it is necessary to explain this interaction (migration-environment).

The different parts of this volume are an example of the very close cooperation between Researchers from the Hassan II Academy of Science and Technology (Science and Technologies of Environment, Earth and Sea College), the National Institute of Fisheries Research of Casablanca, the Hassan II University of Casablanca, and some French researchers from IRD-Perpignan, the National Institute of Research in Computer Science and Automatic Control Grenoble; and the Centre for Insular Research and Environmental Observatory, in the French Polynesian islands.

Prof. Dr. Driss OUAZAR
FSE Executive Director

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Associate Editor

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Guest Editor

Long-Term Upwelling Activity along the Moroccan Atlantic Coast

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Abstract. The long term activity of the upwelling along the Moroccan Atlantic coast between Cape Blanc (21°N) and Cape Spartel (36°N) is investigated in this work using a monthly Ekman Upwelling Index over the period 1967-2019 (53 years). Three stations that are representative of the upwelling's activity along the Moroccan Atlantic coast from North to South were selected in this study for analysis: ST5 (31°N-10.5°W) between Cape Sim and Cape Ghir, ST7 (29°N-10.5° W) between Cape Ghir and Cape Draa and ST12 (24.5°N-15.5°W) North Dakhla between Cape Boujdor and Cape Barbas. The results show a seasonal variability in the northern area between Cape Juby – Cape Spartel and a permanent activity mostly all the year in the southern area between Cape Juby - Cape Blanc. Strongest activities of upwelling were observed during summer seasons in the northern area, in particular over the period 1998-2003, and its activity slightly exceeded the average over the periods 1972-1977, 1980-1984, 2004-2008. The weakest upwelling activities in this region were observed in the fall-winter seasons, particularly during the periods 1967-1970, 1995-1998 and 2000-2005. In the southern area, the upwelling variations showed strong upwelling activity in summer over the periods 1967-1980 and 2009-2019, with annual and interannual variability between these two periods. This activity was slightly above average in summer over the 1981-2007 period, except for the years 1982-1983, 1988-1989, 1995-1997 and 2004-2007 where a relative downward trend was observed. Lower upwelling activities were observed in this area over the 2003-2010 period in fall /winter seasons.

Key words: Morocco, Atlantic Coast, Ekman Upwelling Index, Seasonal & Long Term Activity.

1. Introduction

The upwelling is an upward motion of sea water sea water from intermediate depths (typically 50–200 m) toward the ocean surface. It is an oceanographic phenomenon resulting from the friction of the wind on the ocean surface. Upwelled water masses are colder and richer in nutrients than the surface waters they replace. Upwellings therefore correspond to areas of very productive marine ecosystems and high fish resources (SYLLA DIOP et al. 2019). There are four major coastal upwelling systems (called « EBUSs» for Eastern Boundary Upwelling Systems) in the global ocean, that are the Canary, Benguela, Humboldt and California systems. These areas cover less than 1% of the global ocean surface, but they contribute to about 8% of the global marine primary production (CARR & KEARNS 2003; GOMEZ-LETONA et al. 2017) and more than 20% of the global fish catches (PAULY & CHRISTENSEN 1995). The Canary Upwelling Ecosystem is a typical Eastern Boundary Upwelling System whose coastal dynamics are directly linked to the atmospheric wind forcing and highly influenced by stratification, shelf/slope topographic shapes, and coastline irregularities (ESTRADE et al. 2008; MARCHESIELLO & ESTRADE 2010; ROY 1989, 1998; DEMARCQ & FAURE 2000). The wind regime driven by the seasonal migration of the intertropical convergence zone and of the Azores high-pressure cell (WOOSTER et al. 1976; MASON et al. 2011) is responsible for quasi-permanent Ekman pumping and coastal upwelling along the southern Canary upwelling system during winter and spring (NDOYE et al. 2017). The northwest African upwelling area is a part of the Canary upwelling ecosystem. Like other major upwelling areas in the world, the vigorous equatorward trade winds play a dominant role in determining the strength and duration of upwelling events. The subsurface waters ascending to the surface under the

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influence of the winds have physical and chemical properties that are distinct from the usual surface waters. The upwelled waters are, for instance, colder and richer in nutrients than the surface waters (NYKJAER & VAN CAMP 1994). Coastal upwelling is an upwelling of deep water on the continental shelf that compensates for the drift of surface waters out to sea (Ekman's drift), under the combined actions of a favorable wind and the rotation of the Earth. It characterizes a large part of the eastern borders of the oceans in tropical and subtropical latitudes where the regularity of the trade winds gives the phenomenon of upwelling variability in space and time and a permanent or seasonal character (WOOSTER et al. 1976). According to JACOX et al. (2018), wind-driven coastal upwelling is a key driver of physical, biogeochemical, and ecological variability near the land-sea interface, particularly in EBUS, which are characterized by seasonal equatorward wind forcing. Nutrient-rich water, supplied to the sunlit surface layer by wind-driven upwelling, stimulates the growth of phytoplankton that ultimately fuel diverse and productive marine ecosystems. In addition to this bottom-up forcing through the base of the food web, upwelling can influence higher trophic levels directly through exposure to physical and chemical signatures of the deeper ocean (e.g., lower temperature, oxygen concentration, and pH) (JACOX et al. 2018). Impacts of upwelling variability can be felt on timescales ranging from single events(days) to decades and longer, and they propagate to commercial and recreational activities that derive considerable socioeconomic benefits from EBUS (BOGRAD et al. 2016). The Moroccan Atlantic coast (Fig. 1) which is the subject of this study is under the influence in its northern area to very active seasonal upwelling in summer between Cape Juby and Cape Spartel and almost permanent in its southern area between Cape Juby and Cape Blanc, very active in spring/summer and autumn (ATILLAH et al. 2005; BESSA et al. 2017, 2020; BENAZZOUZ et al. 2013, 2014, 2015; EL AOUNI et al., 2019 a & b, 2020; HILMI et al. 2020; LARISSI et al. 2013; MAKAOUI et al. 2005, 2012; ORBI et al. 1998; TAMIM et al. 2018). The cold waters, coming up along the Moroccan Atlantic coast are generally rich in nutrients (MAKAOUI et al. 2005, 2012; ORBI et al. 1998) are essential for maintaining the organic production (ABDELOUAHAB et al. 2020; BERRAHO et al. 2005; IKRAM et al. 2017).

2. Material and methods

2.1. Study area and objective of the work

We focused in this paper on three stations for analysis that are representative of the upwelling's activity along the Moroccan Atlantic coast from north to south (Fig. 1): ST5 (31°N-10.5°W) between Cape Sim and Cape Ghir, ST7 (29°N-10.5° W) between Cape Ghir and Cape Draa and ST12 (24.5°N-15.5°W) north Dakhla between Cape Boujdour and Cape Barbas. The seasonal, annual to interannual variability of the upwelling's activity over the period 1967-2019 at these three selected stations are presented and discussed in the next sections.

The objective of this work is to assess the long-term upwelling activity of the Moroccan Atlantic coast over the period 1967-2019 (53 years), based on a monthly Ekman Upwelling Index commonly called "Bakun Upwelling Index" (BAKUN 1973, 19975; EKMAN, 1905; SCHWING et al. 1996) at 15 stations (ST1 - ST15) along the Moroccan Atlantic coast (Fig. 1 and Table 1).

Table 1: Ekman Upwelling Stations (ST1 to ST15) and their geographical coordinates along the Moroccan Atlantic coast. The bolded stations in * (ST5, ST7 and ST12) are selected for analysis in this work.

Ekman upwelling stations	Latitude (°North)	Longitude (°West)
ST1	35 N	-6.5 W
ST2	34.5 N	-7 W
ST3	33 N	-8.5 W
ST4	32.5 N	-9 W
ST5*	**31 N**	**-10 .5 W**
ST6	30.5 N	-10.5 W
ST7*	**29 N**	**-10.5 W**
ST8	28.5 N	-11 W
ST9	27 N	-13 W
ST10	26.5 N	-14 W
ST11	25 N	-15 W
ST12*	**24.5 N**	**-15 W**
ST13	23 N	-16.5 W
ST14	22.5 N	-17 W
ST15	21 N	-17.5 W

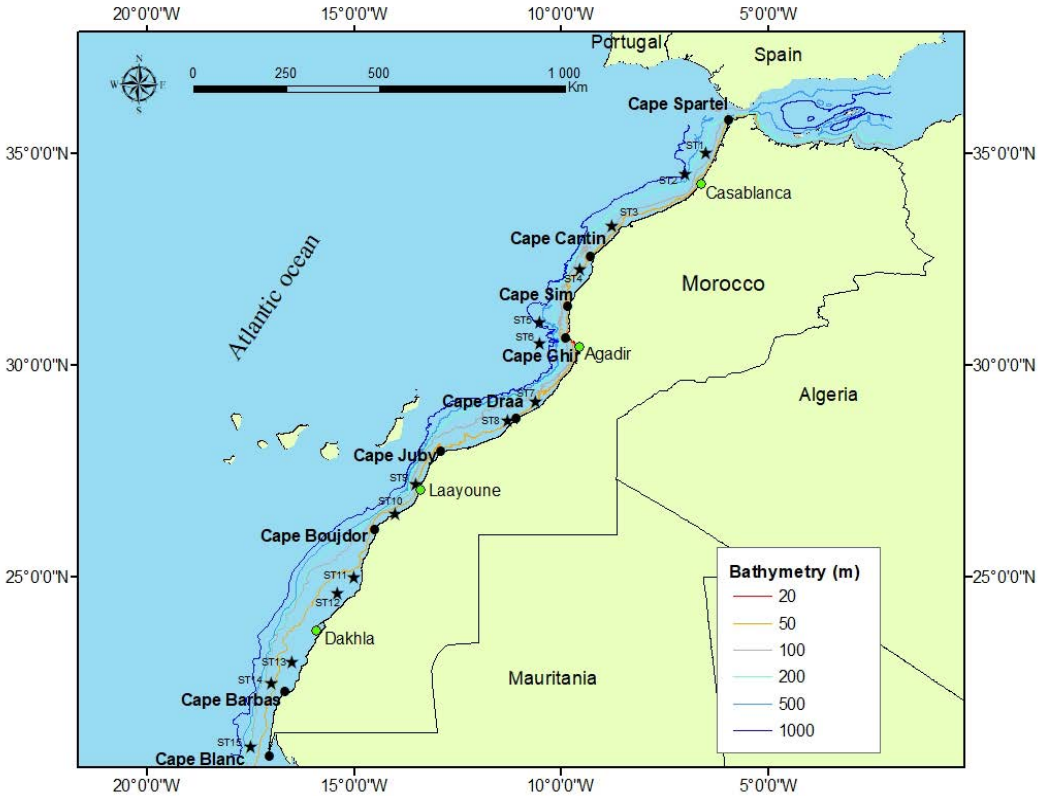


Figure 1: Location of the "Ekman Upwelling Stations" (★) along the Moroccan Atlantic coast. Their geographical coordinates are included in Table 1.

2.2. Ekman Upwelling Index

Given the importance of coastal upwelling as a driver of dynamics in EBUs, the usefulness of quantifying its variability in space and time has been recognized for several decades (NYKJÆR, & VAN CAMP). However, the spatial-temporal variability of vertical oceanic intensities and their weak signal compared to horizontal speeds do not allow direct monitoring of upwelling. To meet the needs of historical and continuous estimates of the intensity of coastal upwelling. BAKUN (1973, 1975) and SCHWING et al. (1996) developed the coastal upwelling index, based on the theory of EKMAN (1905), on coastal upwelling for estimates the Ekman Transport as an indicator of coastal upwelling. This coastal upwelling index is estimated from the following equations, assuming homogeneity across the water column, uniform wind and steady state conditions (BAKUN 1973, 1975; SCHWING et al. 1996):

$$\vec{\tau} = \rho_a C_d |\vec{v}| \vec{v} \quad (1)$$

$$\vec{M} = \frac{1}{f} \vec{\tau} \times \vec{k} \quad (2)$$

where:

- $\vec{k}$ is the unit vector directed vertically upward;
- $\vec{\tau}$ is the wind stress vector (N.m^{-2});
- ρ_a is the air density (kg.m^{-3});
- C_d is an empirical drag coefficient: a Cd of 0.0013 is used to calculate upwelling from the six-hourly surface pressure fields; the Cd is increased to 0.0026 when the monthly-mean pressure data is used (SCHWING et al. 1996).
- $\vec{V}$ is the estimated wind vector near the sea surface with magnitude $\vec{v}$ (m.s^{-1}).
- $\vec{M}$ is the Ekman transports;

According to (SCHWING et al. 1996), Ekman transports are resolved into components parallel and normal to the local coastline orientation. The magnitude of the offshore component is considered to be an index of the amount of water upwelled from the base of the Ekman layer.

Positive values are, in general, the result of equatorward wind stress. Negative values imply downwelling, the onshore advection of surface waters accompanied by a downward displacement of water. The sign of the offshore component of the Ekman transport, $Mx = \tau_y/f$, where x is normal and y parallel to the local coastline orientation, is then reversed to reflect that negative (offshore) Ekman transport leads to positive ("upwelling") vertical transport, and positive (onshore) Ekman transport leads to negative ("downwelling") vertical transport (SCHWING et al. 1996). The upwelling indices are expressed in units of cubic meters per second per 100 meters of coastline ($m^3.s^{-1}.100m^{-1}$), which is equivalent to metric tons/s/100 m coastline. These values are an index of large-scale coastal upwelling, a mean value representative of mass transport averaged spatially over approximately 200 nautical miles. Small-scale upwelling and downwelling events unresolved by the upwelling indices time and space scales may occur during the averaging period for a particular location (SCHWING et al. 1996). The monthly Ekman Upwelling Index data, used in this work, come from the NOAA (National Oceanic and Atmospheric Administration - Fisheries) (www.pfeg.noaa.gov) and cover the period 1967-2019.

2.3. Wavelet analysis

According to GRINSTED et al. (2004), geophysical time series are often generated by complex systems of which we know little. Predictable behavior in such systems, such as trends and periodicities, is therefore of great interest. Most traditional mathematical methods that examine periodicities in the frequency domain, such as Fourier analysis, have implicitly assumed that the underlying processes are stationary in time. However, wavelet transforms expand time series into time frequency space and can therefore find localized intermittent periodicities. There are two classes of wavelet transforms: the Continuous Wavelet Transform (CWT) and its discrete counterpart (DWT). The DWT is a compact representation of the data and is particularly useful for noise reduction and data compression whereas the CWT is better for feature extraction purposes (GRINSTED et al. 2004). As we are interested in extracting low s/n ratio signals in time series, we focus in this work only on CWT, where CWT is a common tool for analyzing localized intermittent oscillations in a time series. More details about CWT are described in GRINSTED et al. (2004).

3. Results and discussion

3.1. Ekman Upwelling Index

Based on this methodology and to meet the objectives of this work, figure 2 presents a Hövmuller plot of the coastal upwelling index computed for the 15 stations stated above, over the period 1967-2019 (53 years) (Fig. 1 and Table 1). Their latitudes are represented on Y axis and their period on X axis (Fig. 2). The monthly Ekman Upwelling index varies from -200 $m^3.s^{-1}.100\ m^{-1}$ to around 950 $m^3.s^{-1}.100\ m^{-1}$. The upwelling maximum ("upwelling favorable") is centered at around 28°N-29°N and during all the year south of 28°N (Fig. 2). Minima occur north of latitude (34°N) in the winter with negative ("downwelling favorable"). These results are in agreement with others studies about the upwelling seasonality along the Moroccan Atlantic coast (ATILLAH et al. 2005; BESSA et al. 2017, 2020; BENAZZOUZ et al. 2013, 2014, 2015; EL AOUNI et al. 2019 a & b, 2020; HILMI et al. 2020; LARISSI et al. 2013; MAKAOUI et al. 2005, 2012; ORBI et al. 1998; TAMIM et al. 2018). Between Cape Juby (28°N) and Larache (34°N), the upwelling's activity is seasonal and very active in summer and, between Cap Juby (28°N) and Cap Blanc (21°N), the upwelling's activity is around all the year and very strong in summer seasons. Based on these criteria, we focuses our analysis in this work on three stations: ST5 (31°N-10.5°W) between Cape Sim and Cape Ghir and ST7 (29°N-10.5° W) between Cape Ghir and Cape Draa in summer and at ST12 (24.5°N-15.5°W) North Dakhla, between Cape Boujdour and Cape Barbas (Fig. 3).

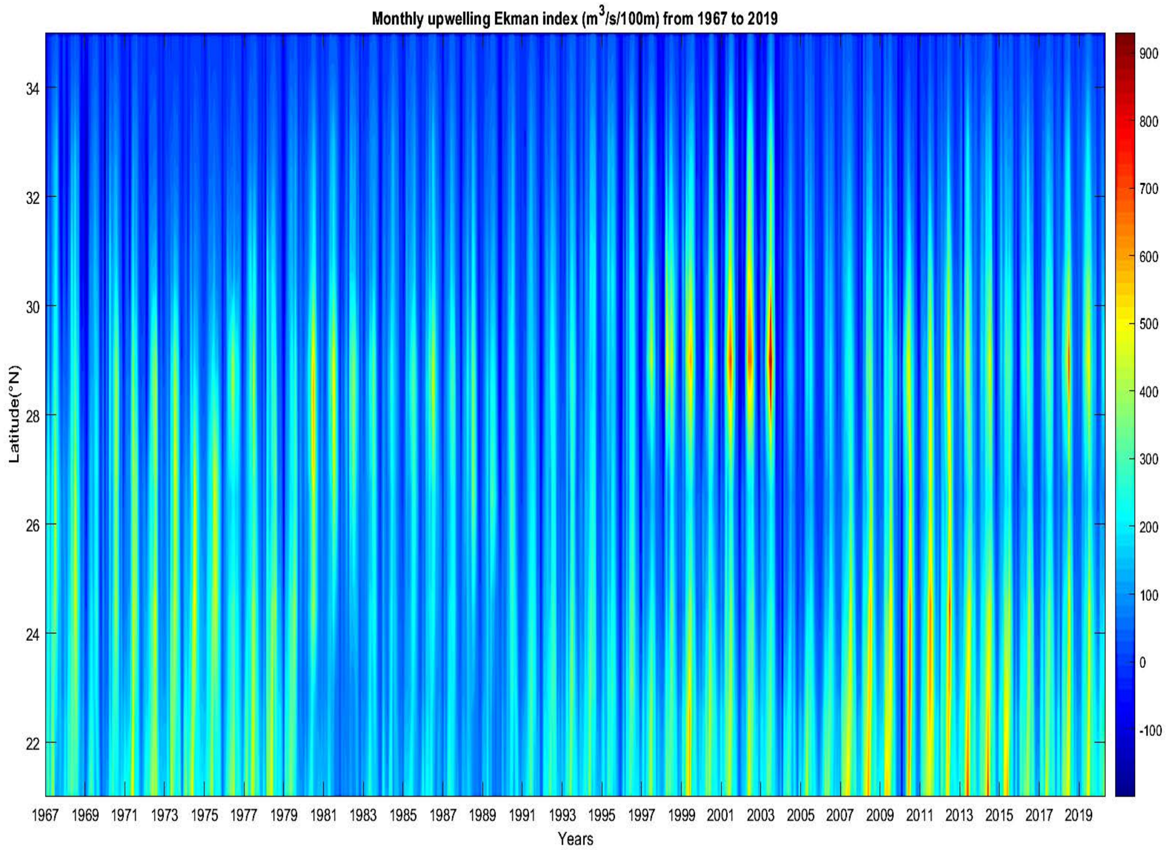


Figure 2: Hövmuller plot of the monthly Ekman Upwelling Index at the 15 stations along the Moroccan Atlantic coast from 1967-2019. The 15 stations refer to Figure 1 and Table1.

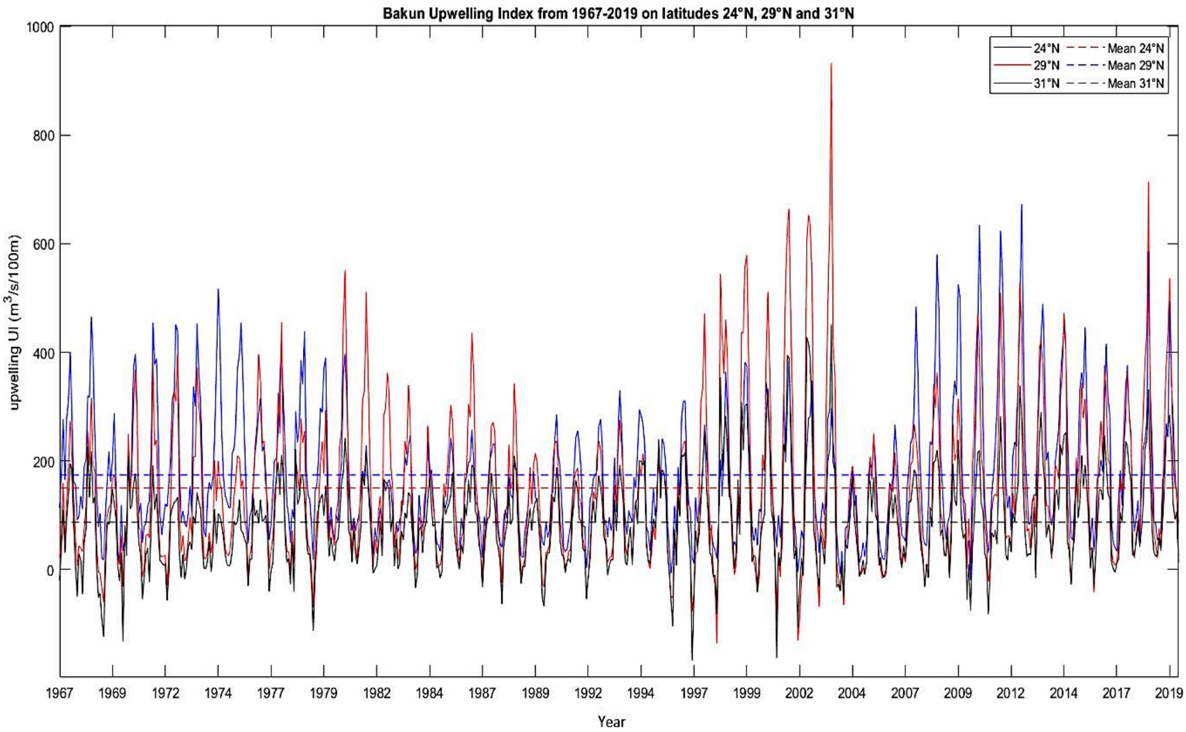


Figure 3: Ekman Upwelling Index (EUI) at the 3 selected stations over the period 1967-2019: ST5 (white color), ST7 (red color), and ST12 (blue color). The mean value (EUI), calculated over this period, is represented by dashed lines at each station.

3.2. Annual/Interannual upwelling's variability

Figure 3 shows the annual and interannual changes of the upwelling's activity over the period 1967-2019 (53 years) at the three selected stations mentioned above. The average of the Ekman Upwelling Index (EUI), estimated over this study period, is also represented in this figure. The average index is around 87.2 (± 88.2) m3.s-1.100 m-1 for ST5 and 174 .2 (± 118.6) m3.s- 1.100 m-1 for ST12 for example. This mode of representation is allowed to provide additional indication on the years where the upwelling's activity is "above" the average activity or "below" its average (Fig. 3). Following these criteria, we observed:

- a similar trend for the three selected stations which follow a general trend during summer seasons where the maximum peaks activities are observed and
- an annual/decadal and interannual upwelling's variability over the period 1967-2019.

On the basis of these results (Fig. 3), a strongest activity is shown for station 12 (ST12) located in the southern part of the Atlantic coast than the other stations (ST5 and ST7) located in the northern part of this coast. Station 12 presents a strong upwelling's activity in summer (maximum Ekman Index) over the periods 1967-1980 and 2009-2019, with annual variable fluctuations between these two periods, for example, for the years 1969, 1976 for the first period and between 2013 and 2017 for the secund period (Fig. 3). Over the period 1981-2007, the upwelling's activity during the summer seasons is slightly above the "average", except for the years 1982-1983, 1988-1989, 1995-1997 and 2004-2007 where a relative downward trend is observed. At this station, the strongest "minima" are observed over the period 2003-2010 in the autumn/ winter seasons (Fig. 3). Concerning ST5, the strongest upwelling activities are observed in the summer seasons as shown in figure 3a. They slightly exceed the average over the periods 1972-1977, 1980-1984, 2004-2008 and a very strong activity was observed in summer between 1998-2003 (Fig. 3). The strongest "minima" were observed in the fall / winter seasons, reporting low activity in these seasons over the periods 1967-1970 and 1995-1998 and 2000-2005 (Fig. 3). The annual upwelling variability between the two stations is explained by the strong seasonal dynamic of the upwelling's activity along the Moroccan Atlantic coast where the north Atlantic area of Morocco is subject to climatic and oceanographic characteristics which are different from the southern part. Based on wavelet analysis (GRINSTED et al. 2004), the figure 4 shows the Continuous Wavelet Transform (CWT) at the three selected stations (ST5, ST7 and ST12). A strong signal (in yellow color) shows a strong signal between 6 and 12 months which reveals a strong seasonal and annual periodicity of the upwelling's activity along the Moroccan Atlantic coast (Fig. 4).

3.2. Seasonal upwelling 's variability

Figure 5 shows the monthly/seasonal Ekman Upwelling Index at stations 5 and 12 for example, averaged over the period 1967-2019. At station 5 (Fig. 5-a), the index shows some negative values which represents a "downwelling" or absence of upwelling's activity in December (-10.7 $m^3.s^{-1}.100m^{-1}$). Upwelling's activity is relatively weak in winter and begins to increase gradually in spring to reach its maximum activity during summer seasons. It begins gradually to decrease in the fall seasons. The maximum peak of upwelling's activity is observed in July (207 $m^3.s^{-1}.100m^{-1}$) (Fig. 5-a). Figure 5b shows this index at ST12, averaged over the period 1967-2019. Similarly to figure 5a, this monthly index shows positive values observed throughout all the year, indicating a permanent upwelling 's activity throughout the year (Fig. 5b). This activity begins to increase gradually in winter (between 57 and 135 $m^3.s^{-1}.100m^{-1}$), reaches its maximum peak in summer during July (359 $m^3.s^{-1}.100m^{-1}$). It gradually decreases in autumn (between 70 and 200 $m^3.s^{-1}.100m^{-1}$) (Fig. 5-b).

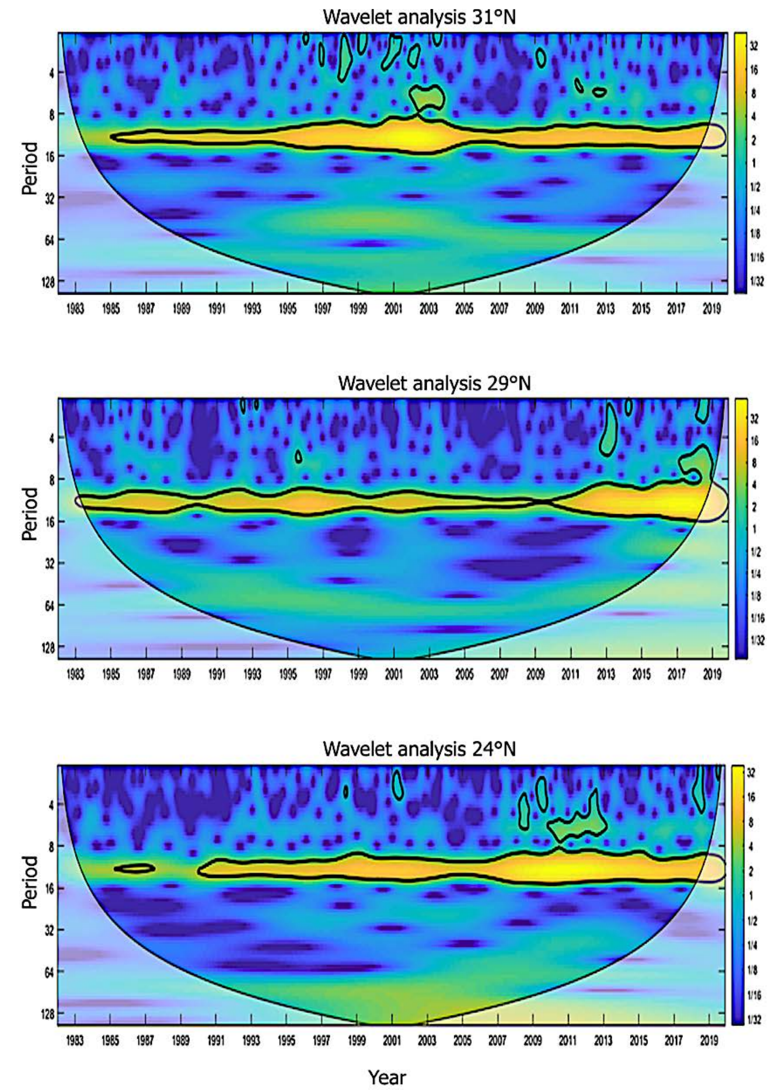
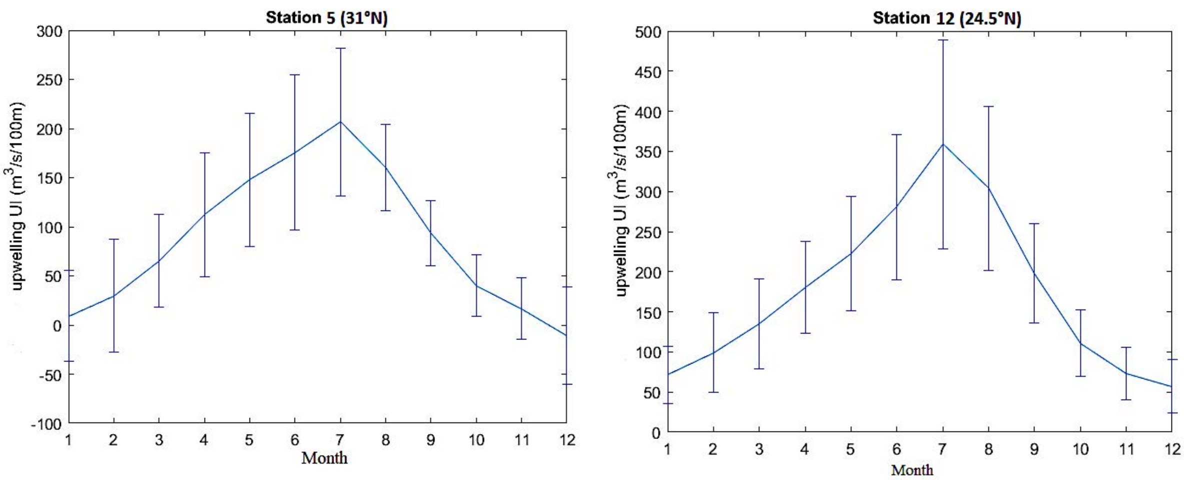


Figure 4: Continuous Wavelet Transform (CWT) of Ekman Upwelling Index at stations 5, 7 and 12. The thick black contour designates the 5% significance level against red noise and the cone of influence (COI) where edge effects might distort the picture is shown as a lighter shade.



a **b**

Figure 5: Monthly variability of Ekman Upwelling Index with its standard deviation (m^3/s/100m) under the period 1967-2019 for **a**) ST5 (31°N-10,5°W) and **b**) ST12 (24,5°N-15,5°W) along the Moroccan Atlantic coast.

Although this study is focused on a long time series of an upwelling index and despite the availability of data from several national and / or international platforms, several studies also focus on data resolution as well as data observation periods [38]. In a context of climate change where the trend of the upwelling's activity in upwelling areas (EBUS) is strongly discussed toward « high » or « low » trend (BARTON et al. 2013; BAKUN 1990; BAKUN et al. 1995), actual work research is oriented towards IPCC climate model projections (RCP 2.0 to RCP 8.5). It is currently the subject of a wide debate among the scientific community and of advanced research (CROPPER et al. 2014; HOEGH-GULDBERG et al. 2014 a & b; MCGREGOR et al. 2007; NARAYAN et al., 2010; WANG et al. 2015) and many other studies on the upwelling areas of the CCLME (GOMEZ-GEISTERA et al. 2008; GOMEZ-LETONA et al. 2017; RUBEN et al. 2021; SANTOS et al. 2012; SOUZA et al. 2017 a and b) and other EBUEs around the world. Given the importance of upwelling activity on the wealth and productivity of the marine environment, this work complements previous studies in the region, most of which are based on the development of a coastal upwelling index, based on the sea surface temperature (or "SST") obtained from satellite observations.

4. Conclusion

In addition to the previous studies established in the Canary current area (CCLME), the long term activity of the upwelling was investigated along the Moroccan Atlantic coast between Cape Blanc (21°N) and Cape Spartel (36°N) under the period 1967-2019 (53 years), using a monthly Ekman Upwelling Index. Three stations are selected here in this work for analysis: ST5 (31°N-10.5°W) between Cape Sim and Cape Ghir, ST7 (29°N-10.5° W) between Cape Ghir and Cape Draa and ST12 (24.5°N-15.5°W) North Dakhla between Cape Boujdor and Cape Barbas. These three stations are representative of the upwelling's activities along the Moroccan Atlantic coast. Therefore, the results show a seasonal variability in the northern area between Cape Juby – Cape Spartel and a permanent activity mostly all the year in the southern area between Cape Juby - Cape Blanc. A strongest activities of upwelling were observed during summer seasons in the northern area, in particular over the period 1998-2003 and its activity slightly exceeded the average over the periods 1972-1977, 1980-1984, 2004-2008. On the other hand, the e weakest upwelling activities in this region were observed in the fall-winter seasons, particularly during the periods 1967-1970, 1995-1998 and 2000-2005. In the southern area, the upwelling activity showed strong upwelling activity in summer over the periods 1967-1980 and 2009-2019, with annual and interannual variability between these two periods. This activity was slightly above average in summer over the 1981-2007 period, except for the years 1982-1983, 1988-1989, 1995-1997 and 2004-2007 where a relative downward trend was observed. Lower upwelling activities were observed in this area over the 2003-2010 period in fall /winter seasons. especially over the 1967-1970 periods, 1995-1998 and 2000-2005. Given the high variability of the upwelling activity in space and time with strong impacts on the productivity of the marine environment and on fisheries, monitoring of upwelling activity by different platforms is required. Further progress are needed to better understand the periods of low / high upwelling activities and the interactions between the climate and the marine environment.

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The variability of the Cape Boujdour upwelling and its relationship with the Cape Blanc frontal zone (Morocco)

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Abstract. The Cape Boujdour and Cape Blanc upwelling areas are a favorable environment for the spawning of multiples pelagic fish species, due to their particular hydrological features, which provide a high productivity to this region. The study area is subdivided into three successful regions with a different hydrological characteristic. The first area (Boujdour – Dakhla) is known for the coastal upwelling of deep water in northern part of the Moroccan Atlantic Ocean. The second area in the middle (Dakhla-Cape Barbas) presents a vertical stratification. The filamentous drift of the waters and the resurgences toward offshore favor photosynthesis far from the coast and promotes high productivity. The presence of front between different water masses characterizes the third area between Cape Barbas and Cape Blanc in southern part of the Moroccan Atlantic coast. An advection variability distinguishes this part from north to south of the upwelled North Atlantic Central Water in Cape Boujdour and from south to north of the South Atlantic Central waters rich in nutrients, deficient in oxygen and high Chlorophyll concentration. This situation leads to a biological richness by the apparition of Thermohaline circulation front at the Cape Blanc area, which depends on the Inter Tropical Convergence Zone temporal and spatial variability.

Keywords: Upwelling, Moroccan Atlantic coast, inter tropical convergence zone, mixed layer depth, frontal zone.

1. Introduction

Small pelagic fish such show strong recruitment variability often associated with environmental changes influencing population dynamics along the northwest African coast. The Moroccan Atlantic coast (36 °N—21 °N), located in the central canary current system, is one of the four world's major coastal upwelling systems with year-round activity (ARISTEGUI et al. 2008; BENAZZOUZ et al. 2014; MAKAOUI 2008). In winter and summer, the evolution of superficial isotherms and phosphates along the coast show four patches that are cold and nutrient-rich: zone 1, between Cape Cantin–Cape Ghir, zone 2, between Cape Draa-Cape Juby, zone 3, between Cape Boujdour –Dakhla, and zone 4, between Cape Blanc-Cape Barbas (MAKAOUI et al. 2005). In fact, the Moroccan coastal upwelling is detected at the surface by cold waters near the coast in response to the intensification of Northeasterly wind and Ekman transport along the continental shelf. The upwelling process promotes high primary productivity of the ecosystem by dispersing nutrients and organisms over the surface layer, favoring the blooming of phytoplankton concentration and the decrease in sea surface temperatures in onshore direction (LARISSI et al. 2013).

The study area between Cape Boujdour and Cape Blanc is subdivided into three sub areas of different hydrological characteristics (MAKAOUI 2008): The area SZ1 (Boujdour-Dakhla) is known by a coastal upwelling of deep water. The active center is localized at the level of the 25°30'N transect and significant turbulence. The SZ2 Dakhla to Cintra is characterized by the homogenization of the water column and by a vertical stratification favorable for photosynthesis. The fresh waters far from the coast are manifested and appear to be due to a drift of the waters of resurgence toward off shore favoring the high abundance of zooplankton (SOMOUE et al. 2013; ABDELOUAHAB et al. 2016). The SZ3 Cape Barbas to Cape Blanc is marked by a stratification which is manifested by the presence of different water masses and a advection of the South Atlantic Central Waters (SACW) rich in nutrient and high Chlorophyll concentration (AUGER et al., 2016) from the south to the north characterized by the

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presence of a front Thermohaline circulation at the Cape Blanc area.

MEUNIER et al. (2012) suggested SACW entering the region from the south via the poleward current is relayed around the topographic anticyclone (TAC), and extended further from the coast around offshore eddies (Cyclonic C and Anticyclonic AC) associated with the Cape Verde Frontal Zone (CVFZ) and further north, the upwelling jet carries North Atlantic Central Waters NACW. WALKER & RADOLPH (2015) showed that vertical mixing and phytoplankton biomass are consistent with the critical depth of the variability of the Mixed Layer Depth (MLD). When the MLD is mainly correlated with the upwelling activity (BESSA et al. 2020). Also, the (MLD) influences the exchange of heat and gases between the atmosphere and the ocean and constitutes one of the major factors controlling ocean primary production as it affects the vertical distribution of biological and chemical components in near-surface waters (STRANNE et al. 2018).

This study's objective is to characterize the upwelling phenomenon and its advection of South Atlantic Central Water that interacts on the variability of oceanographic aspects of the littoral zone between Cape Boujdour and Cape Blanc (21°N to 26°N) on the hydrology of the area during the fall.

2. Data and Methodology

The in-situ data were collected at different stations during oceanographic cruises of the Moroccan R/V "Al Amir Moulay Abdellah" and the "Russian R/V Atlantida" for the oceanographic study of pelagic ecosystem fisheries. Additional data were collected on board the Norwegian R/V, Dr Fridjorf Nansen in the fall (fig. 1):

- The CTD profiles (T, S, O_2, Fluorescence) have been done by Seabird 911+;
- Nutrients analysis have been done by an auto Analyzer Skalar AA3 at INRH's oceanographic laboratories;
- Others physical data was collected from mooring Meteorological (wind speed and direction) and oceanographic INRH buoy (METOCEAN), in the Dakhla offshore (23°57'N - 16°12'W). This buoy is equipped by multi-parameters sensors (T, S, O_2, Fluorescence, Turbidity) and ADCP profiler collecting "in situ" data from October to December 2016;
- Satellite images: marine circulation, sea surface temperature (SST), sea surface salinity (SSS), mixt layer depth and wind circulation are also collected from:

https://resources.marine.copernicus.eu/.

In this work, we also used data from Mercator Global Operational Ocean Analysis and Forecasting System at a resolution of 1/12 degree. The system provides global ocean data in 3D updated daily. In addition, we used monthly average data from 2007 to 2017 of temperature, salinity, currents and depth of the mixed layer over Northwest Africa. The model is corrected with the assimilation of the data with the satellite data and the in-situ profile as previously described. In this work we used wind data since 2007 to 2016 from the marine Copernicus climatology refers to time series of monthly averaged wind variables calculated over the global oceans. It is estimated from daily global wind fields calculated from retrievals derived from ASCAT scatter-meters onboard METOP-A and METOP-B satellites with a spatial resolution of 0.25° in longitude and latitude. A detailed description of the Quality, Accuracy, Calibration, and Product Defects information can be found on the official CMEMS website, along with validation reports and quality documentation (www.marine.copernicus.eu)

The SST upwelling index at each latitudinal point from 22 ° N to 26 ° N is defined as the difference in SST between the SST-coast and the SST-ocean (REYNOLDS et al. 2007). Where SST-coast is the SST of the grid closest to the coast and SST-ocean is the maximum SST of the grid box along the same latitude, to the west. Therefore, an increase in the upwelling index is equivalent to a decrease in the intensity of upwelling (REYNOLDS et al. 2007).

3. Results and discussion

The surface temperature distributions show that the upwelling is active permanently in Dakhla and Cape Blanc regions, with a sea surface temperature less than 18.5°C (Fig. 2). This situation is mainly due to the relaxation of the trade winds during this period of the year, as observed by BESSA (2020). The most significant calm period is the autumn, when wind speed was low (about 5 m/s). The resurgences occur mainly in the south of Dakhla and are marked by the colder and less salty waters, between Cape Barbas (22 °N) and Cape Blanc (21 °N). Low salinity concentration (35.7 PSU) characterizes the Cape Blanc region, compared with the northern areas (Fig. 3).

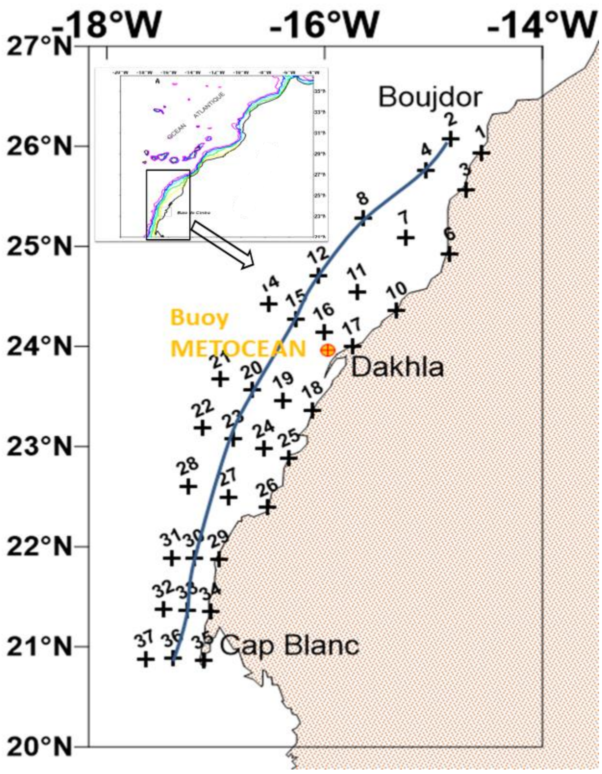

Figure 1: Sampling network stations and Longitudinal transect in the study area between Cape Boujdour et Cape Blanc (Morocco)

This structure is rich in phosphates but has had a significant anomaly in dissolved oxygen concentration since 2010, especially in the sub-column between 10m and the seafloor, where the temperature is below 18° C. These oxygen concentrations have value lower than 4ml / l appearing along the continental shelf and can reach 24°N northward (Fig. 4). MAKAOUI et al. (2017) found that water deficient in dissolved oxygen supplies the area exceptionally depending on the intensity of the North Equatorial Countercurrent present mainly in summer and on the activity of resurgences south of Dakhla in autumn. These factors depend on the effect of climate change which is momentarily manifesting itself in the coastal areas of the southern Atlantic of Morocco. STRAMMA et al. (2008) suggest that Oxygen-Minimum Zones is expanding in the Tropical Oceans and the weak upwelling activities in this area have were also observed in the fall / winter, especially on periods 1967-1970; 1995-1998 and 2000-2005 (HILMI et al. 2020).

In Cape Boujdour (26°N), from the coast to longitude 18°W, the variability of MLD with SSTmin again, we notice that there is a clear correlation between the two parameters, when the temperature is low, the MLD become shallower and as the sea surface temperature increases, the MLD become deeper, especially in fall seasons (Fig. 5). In Cape Blanc, the variability of MLD with the SSTmin seems to be the same as in Cape Boujdour. Indeed, the increase in SST in autumn is slower than in north part (Boujdour) and the MLD doesn’t exceed 50m, while the SST can reach more than 26°C (2010, 2012) (Fig. 5). Thus, during the autumn season, the upwelling is more active in the southern area around Cape Blanc.
The upwelling index shows an evident activity of this process between 25°N and 26°N, except in the fall season when we observe a south activity in Dakhla (24°N). The upwelling activity directly affect the sea surface temperature showing the minimum SST variability. We notice that the source of the upwelling (Cape Boujdour) knows a minimum of temperature all the year (16 to 18°C) except fall season (>21°C). In contrast, we notice the SST seasonality in the region ‘s south, which varies between 24°C in late spring and summer and 16°C in late fall and winter seasons (Fig. 6).

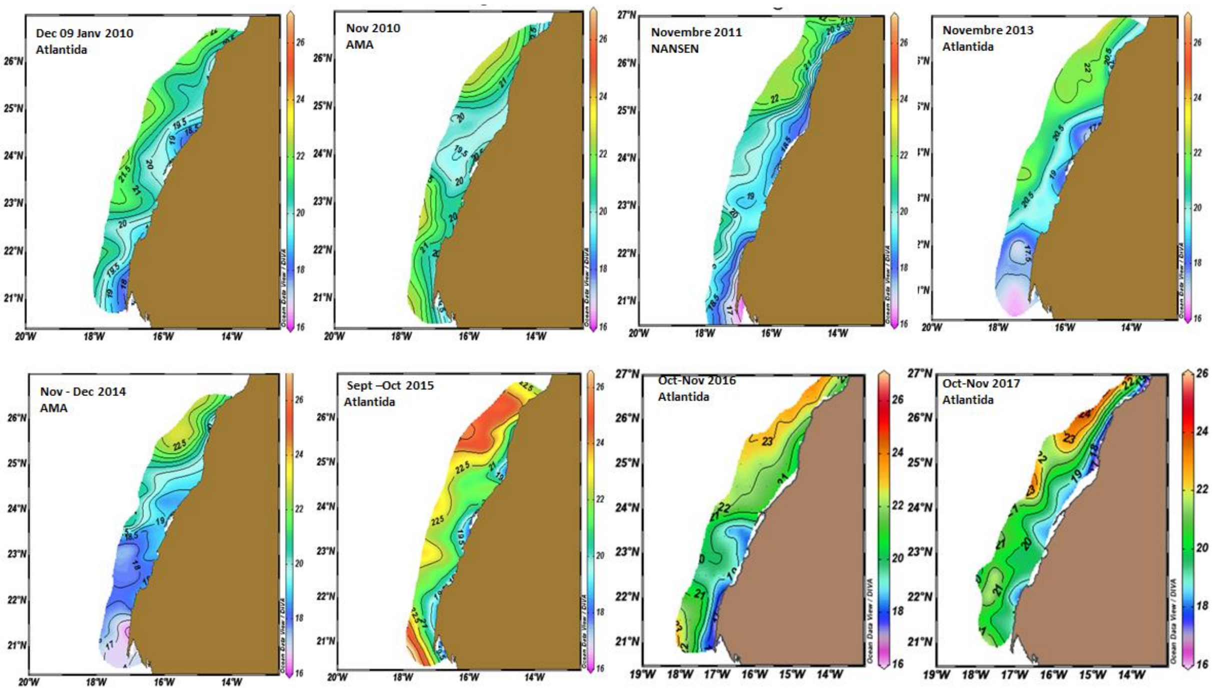

Figure 2: Distribution of the SST (°C) (From 2010 to 2017) during fall season

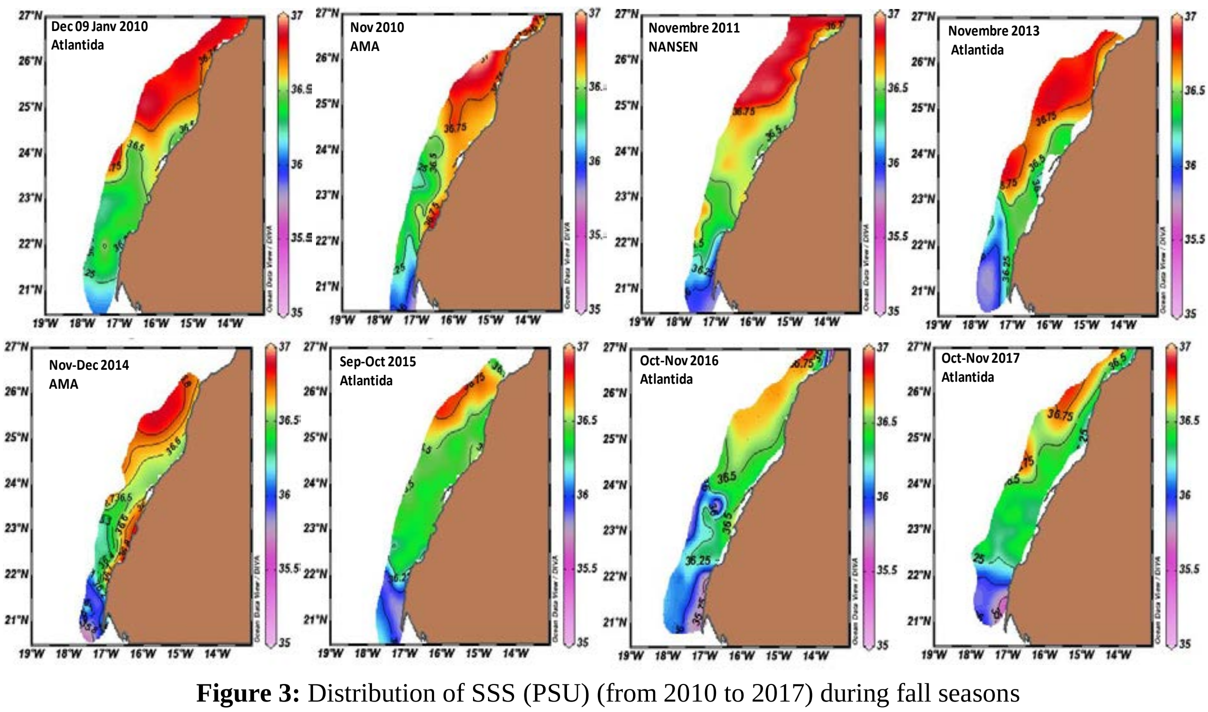

Figure 3: Distribution of SSS (PSU) (from 2010 to 2017) during fall seasons

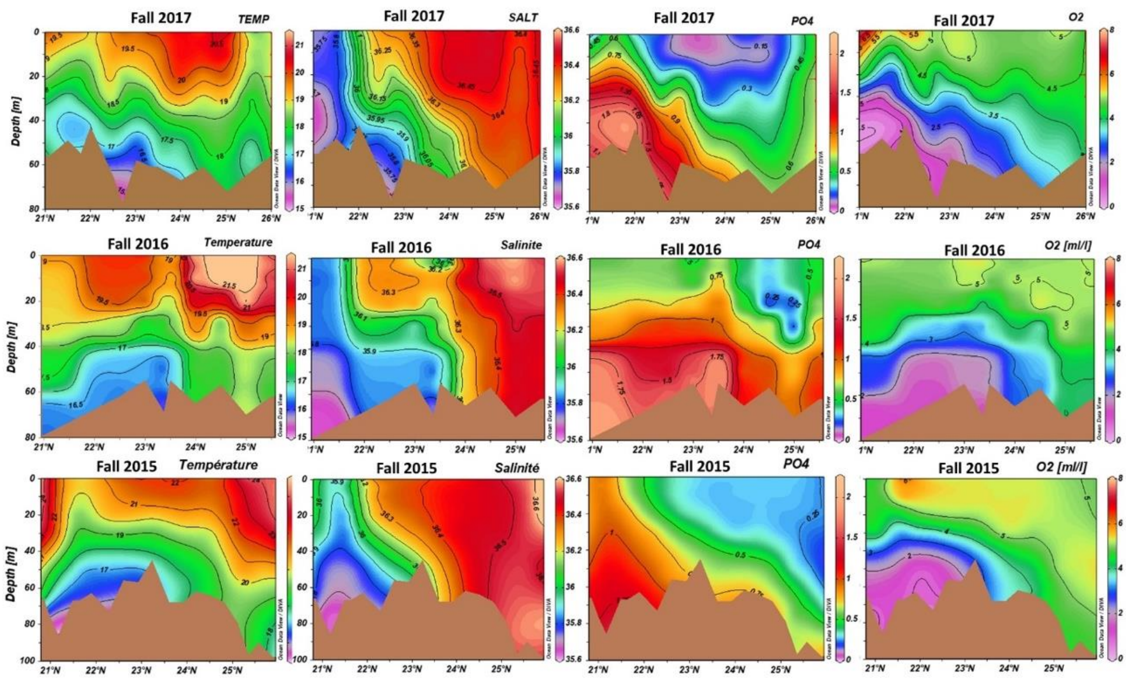

Figure 4: Distribution of temperature (TEMP), salinity (SALT), phosphate (PO4) and oxygene (O2) along the longitudinal transects from south 21°N to the north 26°N between 2015 and 2017

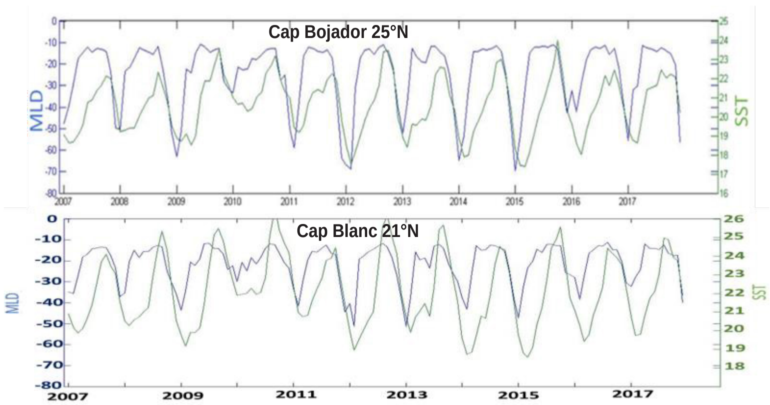

Figure 5: The average of the ocean mixed layer depth (m) in bleu, and minimum sea surface temperature (green) in Cape Boujdour (25°N) and Cape Blanc (21°N) between 2007and 2017

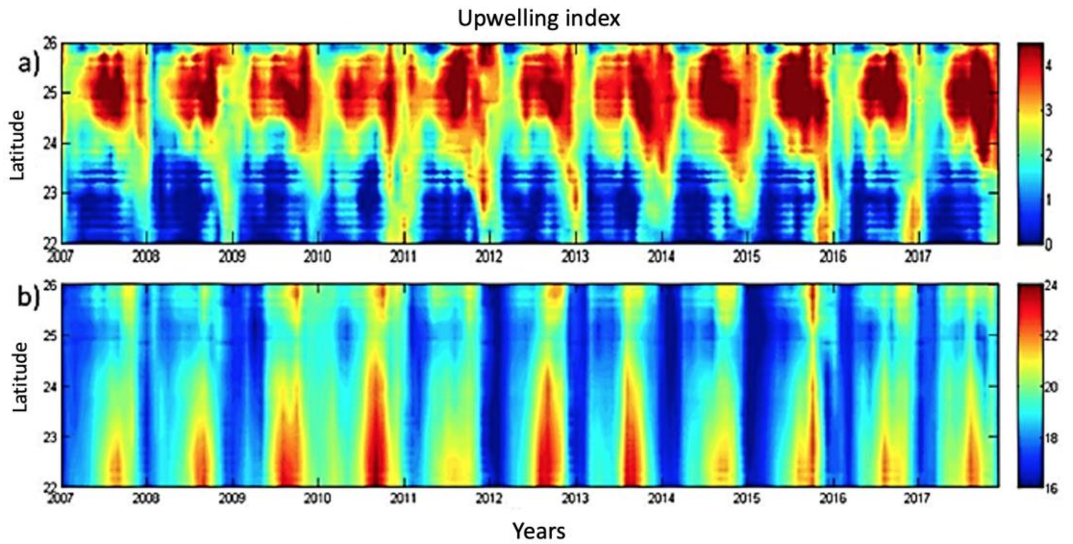

Figure 6: Hovmöller diagrams for a) upwelling index from 2007 to 2017, b) minimum of sea surface temperature in (°C) from 2007 to 2017 along the Moroccan Atlantic coast.

The "in-situ" data measured by the oceanographic buoy in the region of Dakhla (Fig. 7) show a warm ocean temperature at the end of October. The increase of wind intensity on November caused upwelling which caused a cold water about 18.5 °C, with a decreasing of salinity and a chlorophyll richness of 0.1 to 0.13 µg/l, as well as an increase of the current speed about 35cm/s (Fig. 7). AUGER et al. (2016) suggest the effect of wind is amplified off Cape Boujdour and dampened off Cape Blanc and north of Cape Blanc, the phytoplankton supply from northward advection becomes as important as the net local phytoplankton growth, with the latter only dominating off Cape Boujdour . The phytoplankton biomass is also maintained by high levels of regenerated production exceeding new production by more than twofold off Cape Blanc in particular. BODE and SANTIAGO (2018) found that Cape Blanc area is a food sources for plankton and affected by the northwest African upwelling and by the high salinity of the Canary Current which favored high productivity in surface waters related to high inputs of nutrients.

The variability of the current offshore Dakhla confirms that the circulation of the water masses originating from the upwelling of Cape Boujdour is mainly going toward the South West which increased in November 2016 at the three levels (V1, V2, and V3) with the intensity of wind (Figs. 7 and 8).

The Inter Tropical Convergence Zone (ITCZ) position, structure, and migration influence ocean–atmosphere with land–atmosphere interactions on a local scale, the circulation of the tropical oceans on a basin scale, and a number of features of the Earth's climate on a global scale (WALISER & JIANG 2015). As the ocean heats up more slowly than land, the ITCZ tends to move further north and south over land areas than that over water. In July and August, the ITCZ lies well to the North of about 10°N, Asia and Central America before moving south into South America, central Africa and Australia by January and February. The Seasonal variability of the wind average in the area show that the position of the (ITCZ) is located in its maximum northward migration during end of summer and fall seasons between 5 and 10°N when the wind is in the weakest intensity in fall (Fig. 9 a-b). In the other hand, the ITCZ derives southward of 5°N in spring and winter seasons when the wind intensity is maximum. This situation makes the Moroccan Atlantic coast affected by low activity of upwelling with still persists south of Dakhla and deepest mixed Layer Depth during fall season.

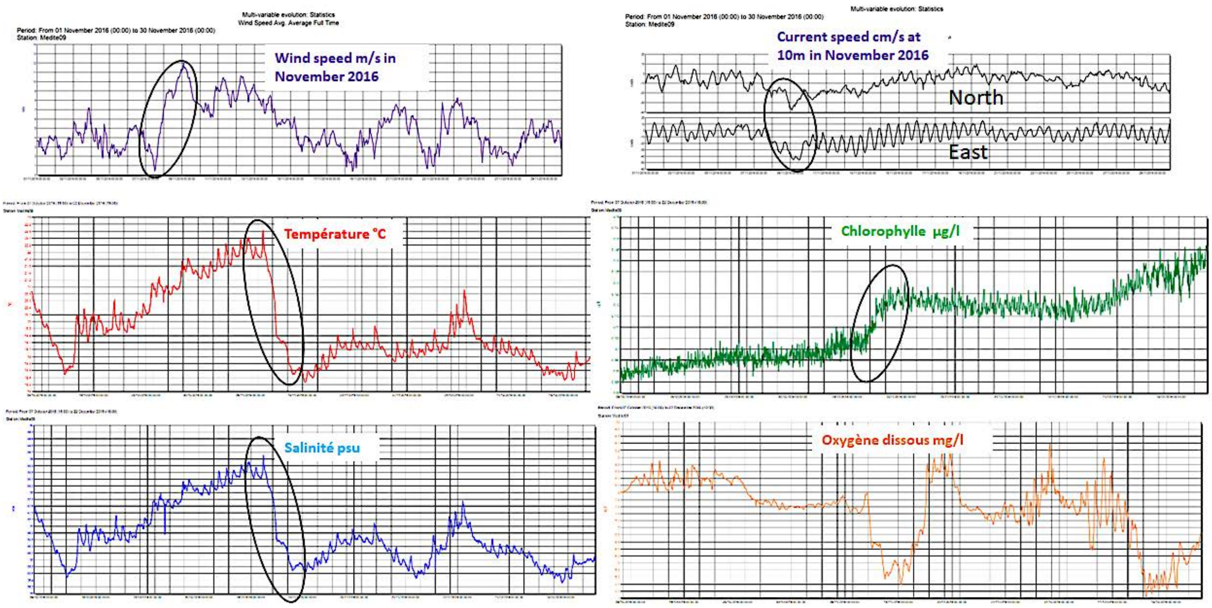

Figure 7: Meteorological and "in situ" parameters collected offshore Dakhla (24°N) at INRH METOCEAN buoy during autumn 2016.

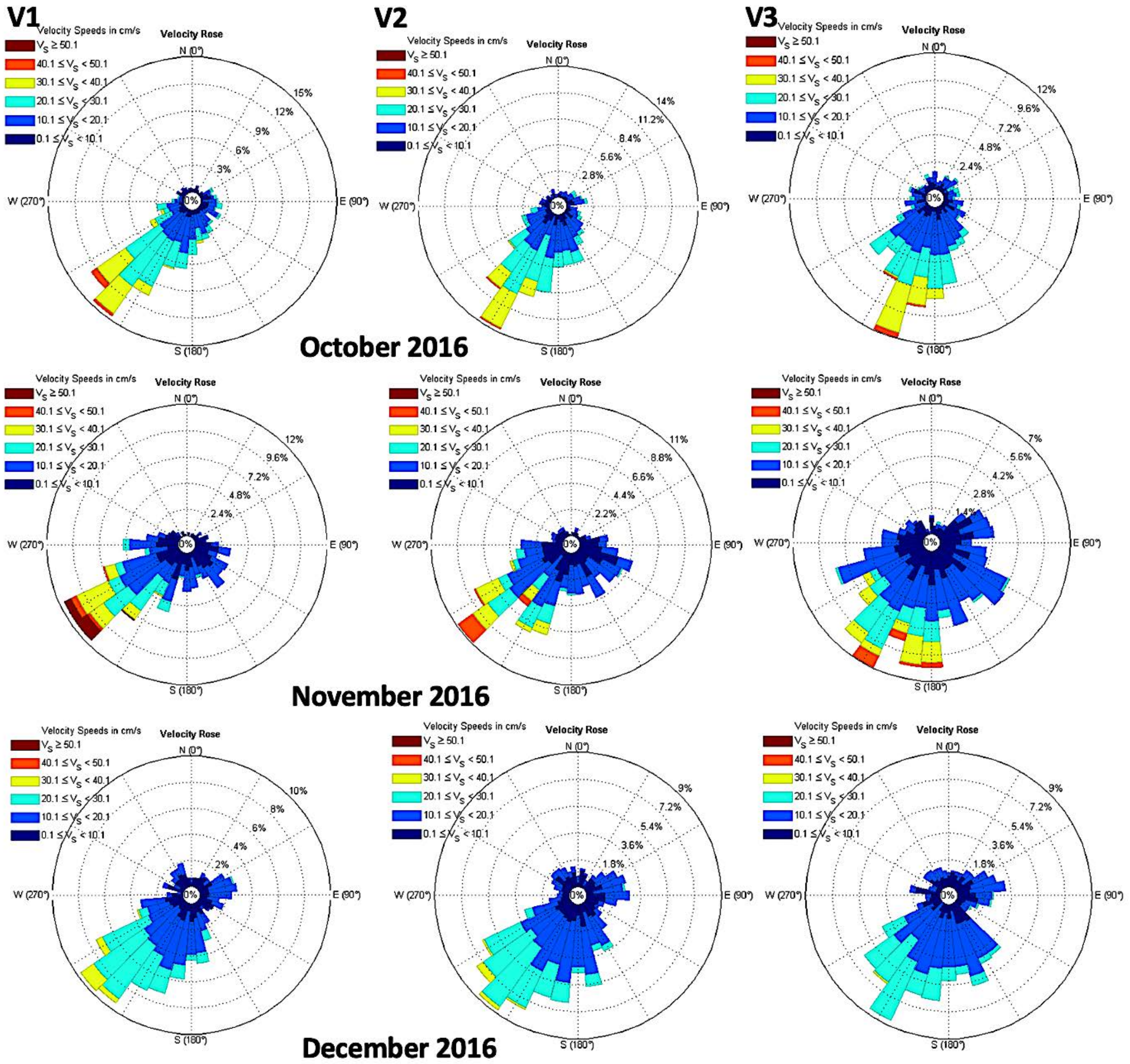

Figure 8: Monthly current intensity and direction collected offshore Dakhla at INRH METOCEAN buoy at depths 10m (V1), 20m (V2) and 30m (V3) during autumn 2016.

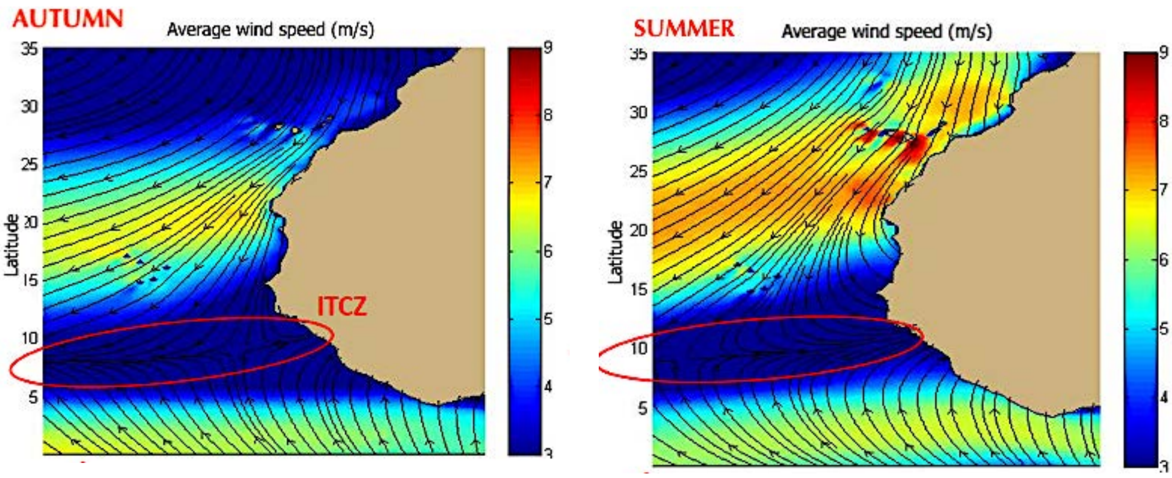

Figure 9-a: Seasonal variability of the wind in relation to the location of ITCZ (Autumn and Summer)

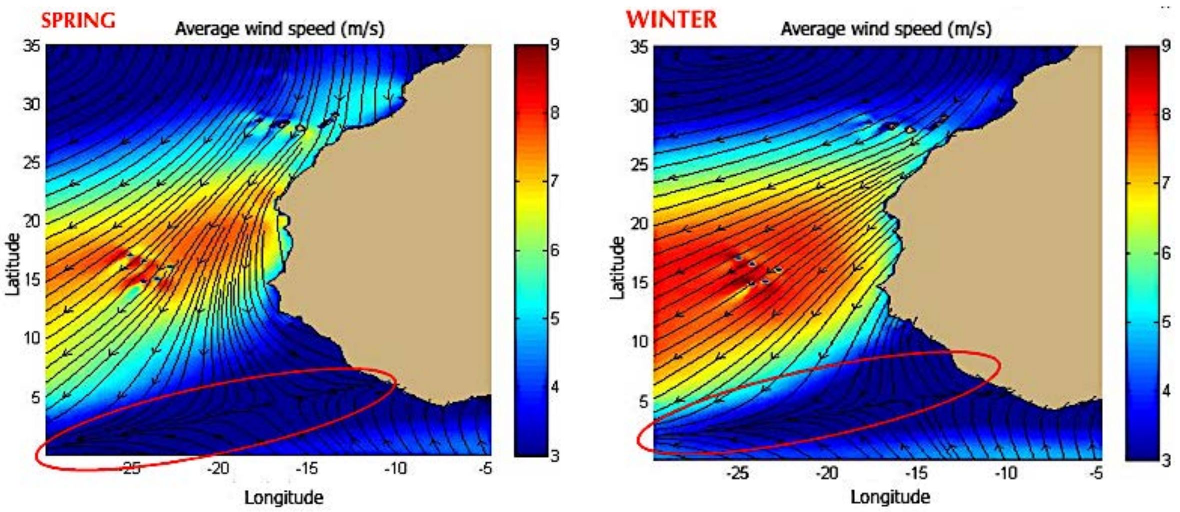

Figure 9-b: Seasonal variability of the wind in relation to the location of ITCZ (Spring and Winter)

The influence of SACW in fall, characterized by high nutrient concentrations and low dissolved oxygen amount can reach the area of Cape blanc (Frontal zone) in its maximum during late summer and Autumn seasons.

4. Conclusion

The upwelling activity is permanent in the south Atlantic of Morocco with the active center in Cape Boujdour, except in autumn, when it drifted south of Dakhla. This active upwelling center's spatial and temporal variability depends closely on the Tropical Convergence Zone (ITCZ) seasonal variability. During fall season, when the ITCZ is north of 5°N and the wind is weak in the area, the upwelling of Cape Boujdour is soft and appears more active south of Dakhla. As a result, the water supplies, deficient in dissolved oxygen and charged in nutrient (SACW), can occur exceptionally from one year to another. These supplies, related to the intensity of the North Equatorial Countercurrent, depend on the northward of ITCZ behavior and the activity of the resurgences south of Dakhla in the fall season. In addition, this water circulation depends on the climate change impact. CHEMKE et al. (2020) suggest that the SST pattern in the North Atlantic, caused by anthropogenic greenhouse gases emissions, is linked to ocean circulation changes in many regions of the Northern Hemisphere.

Acknowledgements

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Marine circulation along the Moroccan Atlantic Coast

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Abstract. As part of the Canary Current Ecosystem, numerical models from Marine Copernicus are used to study the seasonality of marine circulation along the Moroccan Atlantic coast from 2007 to 2017. Therefore, we explore the marine circulation in three areas according to the wind seasonality along the coast. The first area, 33°N-35°N, is specified all the year by a low wind speed. The second area, 28°N-33°N, is characterized by a seasonal wind with the maximum speed in summer seasons, and it becomes weaker in autumn seasons. Finally, the third area, 21°N-27°N, is marked all the seasons by high winds intensity. Due to the Moroccan Atlantic coast topography, the average intensity of marine circulation on the surface is characterized by different trends according to the seasons. Part of the seawater, creating filaments, is exported to the open sea, especially in summer. Marine circulation affects the upwelling process under the effect of seasonal wind patterns. These filaments are identified near the coast and are particularly strong when the upwelling is active. They occur mainly in summer and carry cold, nutrient-rich water offshore. In addition, counter-currents appear at different depths, depending on the topography of the region. They move northward, especially near the coast in spring and fall.

Key words: Moroccan Atlantic coast, decadal marine circulation, costal upwelling, filament, ocean mixed layer depth.

1. Introduction

The surface and upper thermocline waters, developed from the sea at the highest latitudes of the Atlantic, constitute the Canary Current System (CCS). This current boundary is the northwest African middle current system. It is characterized by the coastal upwelling, filaments, eddies, and supports important fisheries (JOHNSON et al., 2000; VALDÉS & DÉNIZ-GONZALEZ 2015; ARÍSTEGUI 1994). The CCS is one of the four main upwelling regions worldwide, which is composed of the Canary Current, the Azores Current (which joins it along the continental shelf between Madeira and the Canary Islands, ZHOU et al. 2000) and the Portugal Current, located off the west Iberian coast (MATTHIAS et al. 1994). This current is large (1000 km) and slow (10-30 cm/s) and flows year-round toward the equator (WOOSTER et al. 1976; BATTEN 2000); its surface waters are cold because it causes upwelling from the coast (Mittelstaedt, 1991). On average, the current depth is about 500 m (WOOSTER et al. 1976), and its speed is 10-15 cm/s (Zhou et al., 2000). Between the open ocean and the coastal upwelling, the Canary Islands' connectivity in the CCS is enhanced, whose presence off the northwest coast of Africa disrupts atmospheric and oceanic flows (BROCHIER, 2011).

The Moroccan Atlantic coast corresponds to a cyclonic region, crossed by several zones of seasonal change (ROSELL-FIESCHI, 2015), whose sea surface is characterized by high temperatures and salinities, high dissolved oxygen content, and low nutrient concentrations (PASTOR et al. 2013). Coastal upwelling activity, as described by (MAKAOUI et al. 2005; BENAZZOUZ et al. 2014; BESSA et al. 2017), is known at the Moroccan Atlantic coast, where several works have been carried out, targeting the lagoons and bays of the Moroccan Atlantic coast (HILMI et al. 2017; MAKAOUI et al. 2017). Coastal upwelling is more pronounced in trade wind areas, but it can occur anywhere, and anytime the winds cause an offshore movement of water. The winds, which reach their maximum in summer, are modulated by the seasonal migration of the Azores' high-pressure cell (MITTELSTAEDT, 1991), making the Canary Current insensitive to the upstream variability of the Azores Current (MASON, 2009).

2. Data and method

This paper aims to study the seasonality of the Canary Current patterns with the coastal upwelling system. We use indirect methods to identify its activity (coastal upwelling) based on its causes or effects. In practice, the physical characteristic of temperature is most often used to identify and study upwelling regions. Thus, we

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propose to examine wind forcing, ocean circulation, temperature, salinity, sea surface chlorophyll-a, and seasonality of the mixed layer depth (MLD) along the Moroccan Atlantic coast from the surface to a depth of 645 m.

The global analysis and forecast product CMEMS from the Copernicus marine database was used in this paper (MADEC 2008), which provides aggregated analyses updated weekly with 10-day forecasts (updated daily). It includes 3D data on temperature, salinity, and currents from top to bottom, 2D sea surface level, bottom temperature, and ocean mixed layer depth. This product is global and defined on a standard 1/12 degree grid (about 8km) and 50 standard levels.

2.2. Data

The high-resolution global analysis and forecasting system PSY4V3R1 adopts version 3.1 of NEMO Ocean model (Madec G. a., 2008). The physical configuration is based on the tri-polar grid type (Madec G. a., 1996). The bathymetry used in the system is a combination of interpolation of ETOPO1 (AMANTE & EAKINS 2009) and GEBCO8 databases (BECKER 2008). The Mercator ocean monitoring and prediction system is based on combination of two types of data: remote sensing observations and in situ data. The ocean model associates both sources of data to offer the finest production.

In this work, we used data from the Mercator Global, Operational Ocean Analysis and Forecasting System at a resolution of 1/12 degree. The system provides global ocean data in 3D updated daily. We used average data from 2007 to 2017 of temperature, salinity, ocean currents and mixed layer depth over Northwest Africa. The model is corrected with the assimilation of the data with the satellite data and the in-situ profile as previously described. The wind data from 2012 to 2016 come from the global ocean surface IFREMER CERSAT surface wind climatology include wind components (southern and zonal). Wind stress is estimated from ASCAT data. The analyzes are estimated as seasonal data averaged over the global ocean with a spatial resolution of 0.25 x 0.25 degrees in latitude and longitude. For chlorophyll data from 2002 to 2016, we used the seasonal mean of the global ocean, the surface chlorophyll of the ESA Ocean Color CCI ($mg.m^{-3}$, with a resolution of 4x4 km) using the recommended chlorophyll algorithm OC-CCI available in CMEMS format, with L4 season composites.

The Ocean Color technique exploits the electromagnetic radiation emerging from the sea surface in different wavelengths. The spectral variability of this signal defines the color of the ocean, which is affected by the presence of phytoplankton. By comparing reflectance at different wavelengths and calibrating the result against in situ measurements, an estimate of the chlorophyll content can be derived. The sea surface temperature (SST) data comes from the ARMOR3D Level 4 Global product. The satellite has a regular grid resolution of 1/4 degree. The product is obtained by combining satellite and in-situ observations (temperature and salinity profiles) by statistical methods.

The SST index of upwelling at each latitudinal point from 21 °N to 35 °N is defined as the difference in SST between the SST coast and the SST ocean (REYNOLDS et al. 2007). Where SST-coast is the SST of the grid closest to the coast and SST-ocean is the SST of the grid box along the same latitude, which is 5° to the west. Therefore, an increase (decrease) in the upwelling index is equivalent to a decrease (increase) in the intensity of upwelling. A detailed description of the Quality, Accuracy, Calibration, and Product Defects information can be found on the official CMEMS website, in addition of the validation reports and quality documentation (www.marine.copernicus.eu).

3. Results and discussion

3.1. Atmospheric forcing

MASON et al. (2011) presented a long-term climatological solution from the Regional Oceanic Modeling System (ROMS) variability associated with the Azores and Canary Current systems, and the northwest African coastal upwelling, and they found that the role of nearshore wind stress curl variability as a generating mechanism for the anomalies is confirmed through a sensitivity experiment forced by low-resolution winds. The mean flow along the Moroccan Atlantic coast is equatorward. However, there is observational evidence for periodic (typically autumn) poleward flows in the upper levels (MACHÍN et al. 2009; 2010).

The wind regime in northwest Africa is mainly affected by pressure differences at sea level between the upper Azores and the Icelandic depression, which causes the mean wind direction to be from the northeast all year with changes in intensity (AMANTE et al. 2009). In the Canary

Archipelago, the trade winds reached maximum monthly mean values of 8.7 m/s in August. On the other hand, the winter regime is determined by the mean winds from the northeast, with the minimum monthly mean values corresponding to January (2.7 m/s) (MASON et al. 2011). Thus, the region is influenced by the northeast wind all the year with different intensities. The wind trend reaches the maximum speed of about 9 m/s covering approximately all the areas in summer, and in autumn, the wind is weak. Therefore, we can distinguish three regions from the wind trend: the first region from (33°N to 35°N), specified by a low wind speed of about (3 to 4 m/s) all the year. The second region from (28° to 33°N), characterized by a seasonal wind with the maximum wind in summer of about 7.5 m/s, shows weak winds in the autumn season about 3.5m/s. The third region from (21° to 27°N) is marked by a high wind intensity (7 to 9 m/s) all seasons, except in autumn, where the wind intensity becomes weaker (Fig.1).

3.2. Water masses circulation

Seawater velocity reaches its maximum in summer, especially near the coast, about 0.3 m/s. in the autumn period, we observed a weak seawater velocity compared to other seasons; moreover, the wind affected the surface seawater velocity speed and direction (Fig. 2). The coastal upwelling along the Moroccan coast is very clear in the temperature and salinity plots (Figs. 3 and 4). This is because an equatorward surface current develops along the coast in response to the northward movement of winds. This current lead to the formation of filament, which carries cold upwelled water offshore, especially in the summer season where the wind speed is maximum.

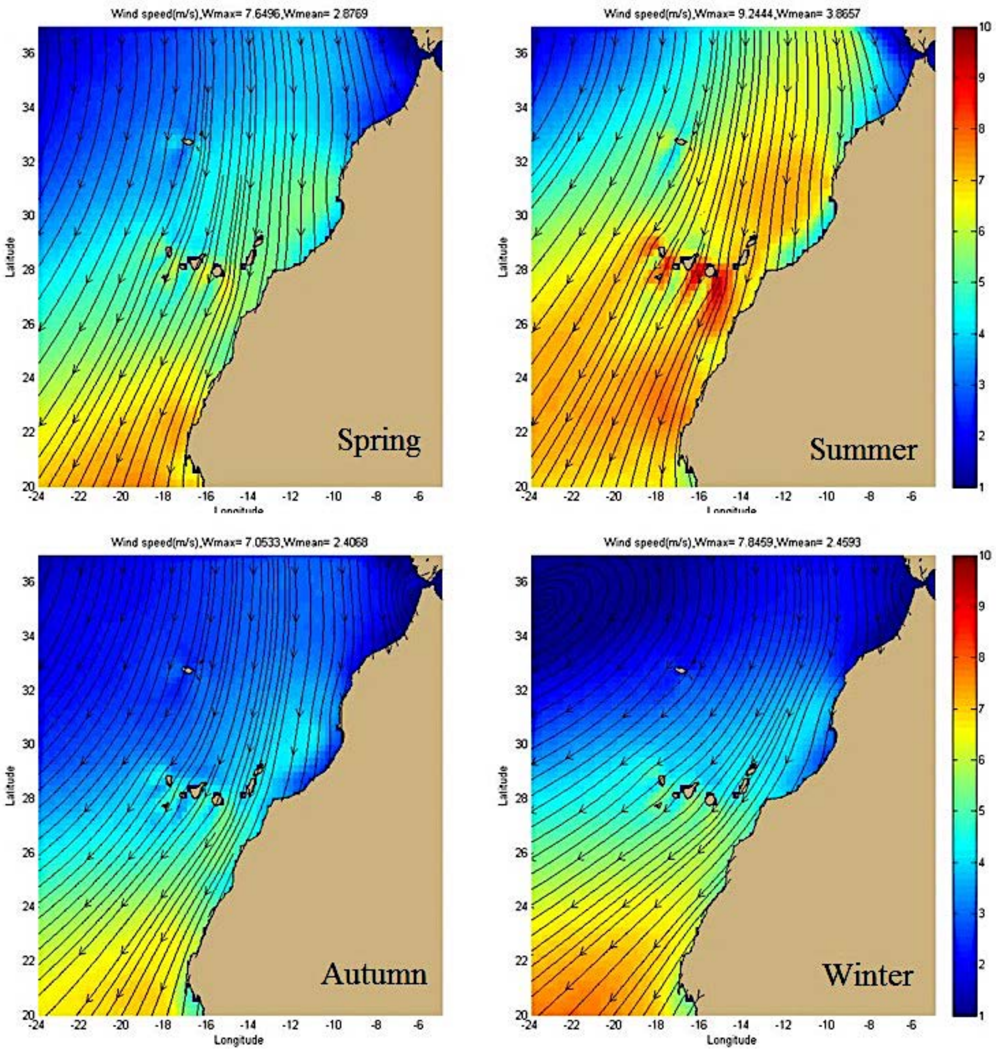

Figure 1: Average seasonal mean wind speed and direction from 2012 to 2016, (Global Ocean Wind L4 Reprocessed Monthly Mean Observations)

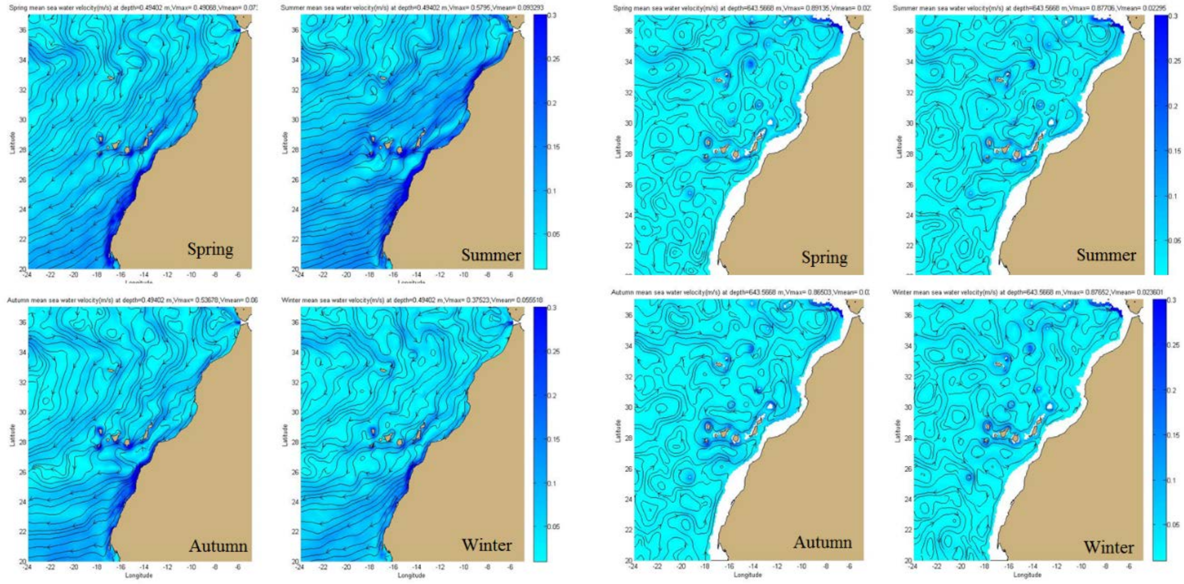

Figure 2: Average seasonal seawater velocity (m/s) 2007 to 2017 in surface left, and in 645m depth right (https://resources.marine.copernicus.eu).

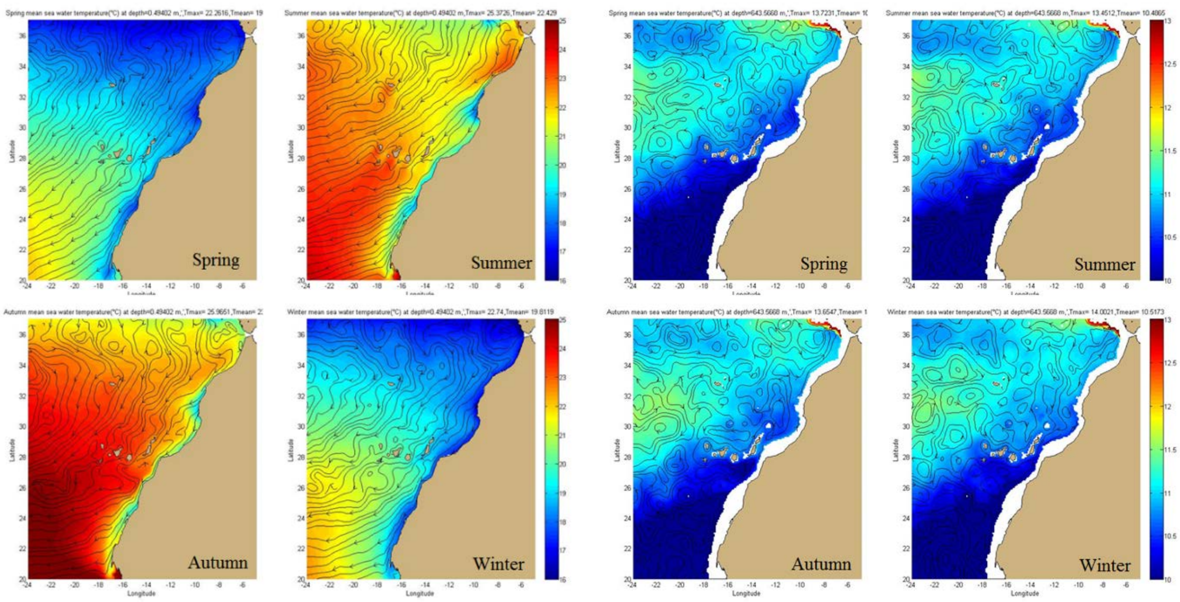

Figure 3: Average seasonal temperature (°C) 2007 to 2017 in surface left, and in 645m depth right (https://resources.marine.copernicus.eu).

On the contrary, the deep Canary Current flow is northern, and it is a common feature of all eastern boundaries current (BARTON 2001). We remarked that in deep water, the seawater velocity is weak, close to 0.1 m/s, and it is higher about 0.3 m/s near the strait of Gibraltar, where the Atlantic Ocean meets the Mediterranean Sea. Along the African coast, we have an undercurrent noted and observed in the South of the region by MITTELSTAEDT (1991). In addition, we observed a cyclonic eddy in all the seasons at a depth of 645m. At the same depth, the temperature is generally cold, and it became warm from the South (10 °C) to the north (13°C). Similarly, the salinity is lower than the surface (35 PSU in the South and 36.5 PSU in the north). Thus, this undercurrent is typically fresher and higher nutrient, and as it travels, northward it tends to separate irregularly from the cost in several places to form eddies.

Regarding the North Atlantic Central Waters (NACW), the masses between the surface and about 650 m depth have been differentiated, by several authors, as a subtropical and subpolar origin. These water masses have a salinity of over 35.66 PSU in this region (PÉREZ et al. 2001). We noticed two water masses from the salinity distributions at 645m depth: the first is more saline and occupies the area of latitude 21°N in the Canary Islands; the second is less salty, covering the Canary Islands archipelago region at latitude 35°N (Fig. 4).

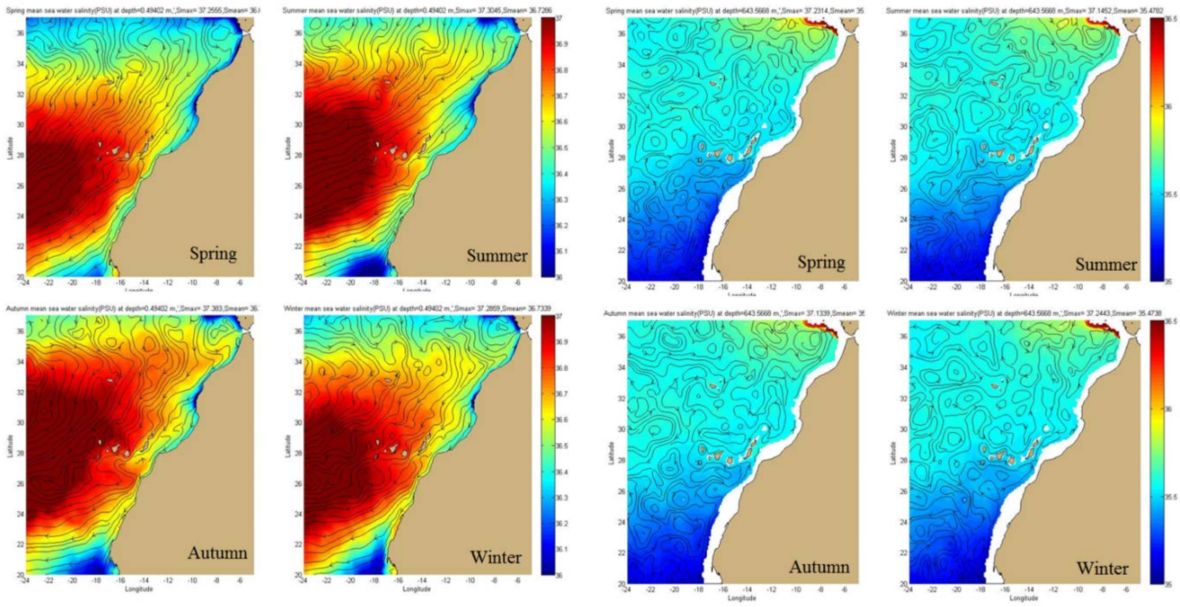

Figure 4: Average seasonal salinity PSU from 2007 to 2017 in surface left, and in 645m depth right (https://resources.marine.copernicus.eu).

3.3. Zonal circulation

To investigate the seawater velocity, according to the wind seasonality, we studied three regions along the Moroccan Atlantic Coast:

- The first area, from latitudes 33°N to 35°N, is specified by a low wind speed (3 to 4 m/s) all the year except in summer when the wind becomes intense (6 m/s), especially in the south's latitudes where the depth reaches 222m. Thus, the trend of seawater velocity changes direction: it becomes weaker and moves from south to north near the coast; offshore, we observe circular appearance movements of seawater. In autumn and winter, seawater flows towards the Strait of Gibraltar with low velocity, and we observed the same structure in the entire water column (Fig. 5).
- The second region, from latitudes 28° to 33°N, is characterized by a seasonal wind with the maximum velocity in summer (7.5m/s) and the weak velocity in autumn (3.5m/s). In the southern area, at a depth of 22m, we observed different direction trends of seawater velocity, especially at latitude 31°N, where the southern water meets the northern water, engendering the latter to move offshore. Finally, at 55m depth, we observed that the coastal seawater moves northward and the offshore water moves southward. The spring season showed different trends compared to the summer and autumn seasons. At 30m depth, the seawater moves to the south and north at 650m near the coast. Offshore, circular movements of seawater are observed in the entire water column (Fig. 6). In addition, we detect a filament in the Cape Ghir region near latitude

31.5°N. This phenomenon is extreme in summer when the upwelling is at its maximum. The structure is visible in seawater velocity field at a depth of 20m, and it transports nutrient-rich cold water offshore out further than 13°W (Fig. 6).

- The third region, between latitudes 21°N to 27°N, is characterized by a high wind velocity (7 to 9 m/s), except in Autumn. The wind intensity becomes weaker between the latitudes 24.5°N to 28°N. This region presents a complex wind circulation because the current is affected by the Canary Islands in the northern part. The Canary Current meets with the equatorial current that moves from the south to the north in the South.

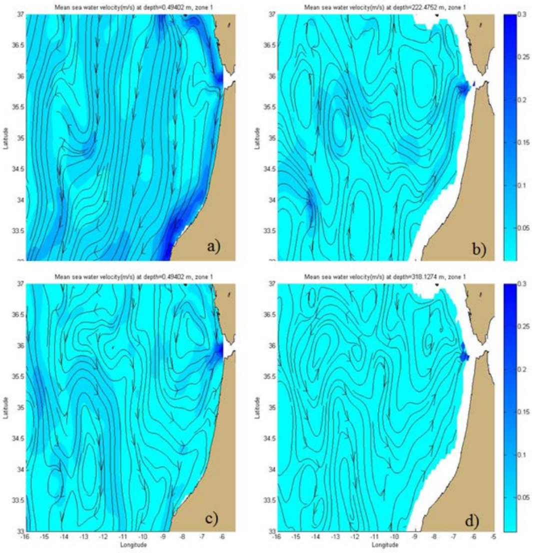

Figure 5: Average seawater velocity (m/s) in summer season at a) surface, b) 222m depth and in winter season at c) surface, d) 318m depth.

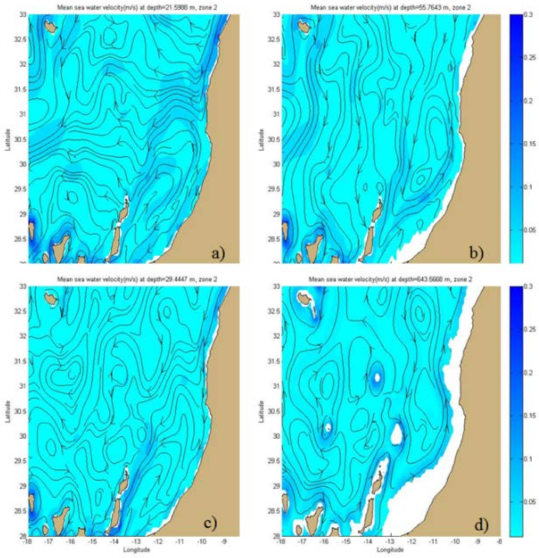

Figure 6: Average seawater velocity (m/s) in summer season at a), 22m depth, b) 55m depth, and in spring season at c) 30mdepth, d) 643m depth.

In summer, the surface seawater velocity is maximum, and it moves from the north to the south, affected by the wind speed and direction. In the same season, at a depth of 22m, we remarked that the water current has a circular movement in the north with a high-speed close to the Canary island. In the Dakhla, the oceanic current is southward with less seawater velocity. In addition, we noticed near the Cap Blanc, where the Canary Current meets with the Equatorial current, the water masses move offshore, generating the filament. At 222m depth, the current has the same circular movements, showing an opposite ocean circulation with the surface current, moving to the north. In the southern area, the equatorial current is comparable to the 22m depth current. In spring, near the coast, the current moves from the north to the south at 22m depth and shows a uniform direction. At 222m depth, we observed the current movements in contrast to the surface direction; the equatorial current moves forward to the north. In autumn, the current has the same trends as in the summer season, particularly at a depth of 22m, but the countercurrent appeared at a depth of 110m, and it moves northward, especially near the coast. In the winter season, the ocean circulation is weaker, and it moves from the north to the south in the entire water column. We remarked that the equatorial current was restricted in this period of the year (Fig. 7) (see close "Appendix A" for more details).

3.4. Coastal upwelling and filaments

Following the latitudes, North-western Africa is known for the upwelling activity with deference trend (MAKAOUI et al. 2005; BENAZZOUZ et al. 2014b). (Fig. 8), shows the coastal upwelling index from 2007 to 2017.

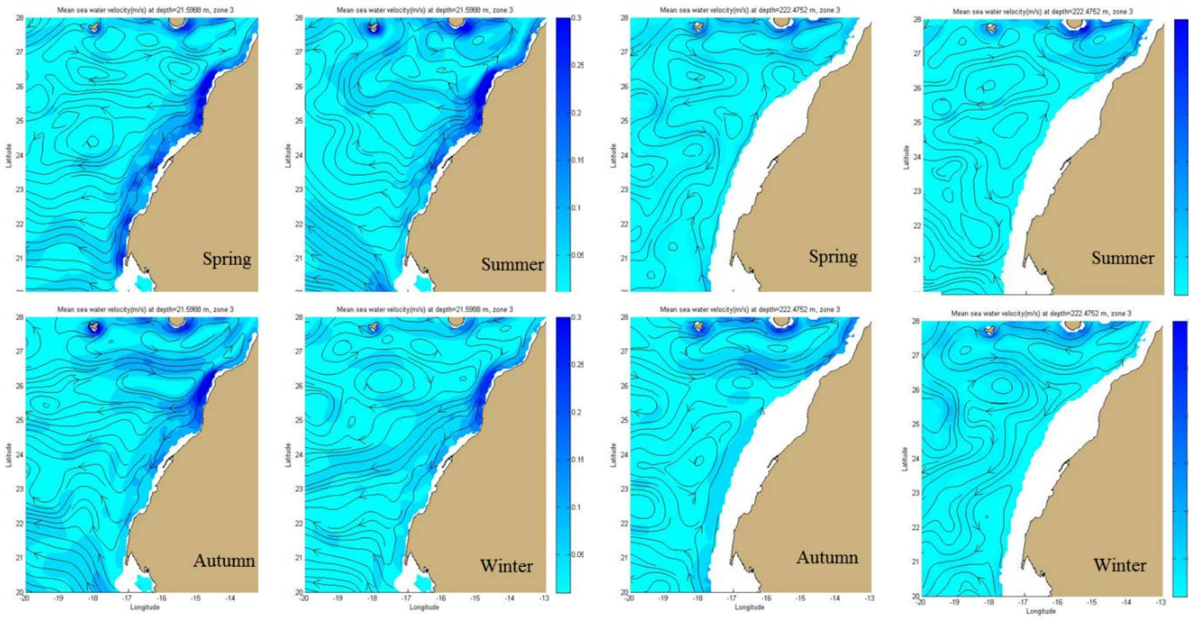

Figure 7: Average seawater velocity (m/s) (left) in 22m depth, and (right) in 222m depth.

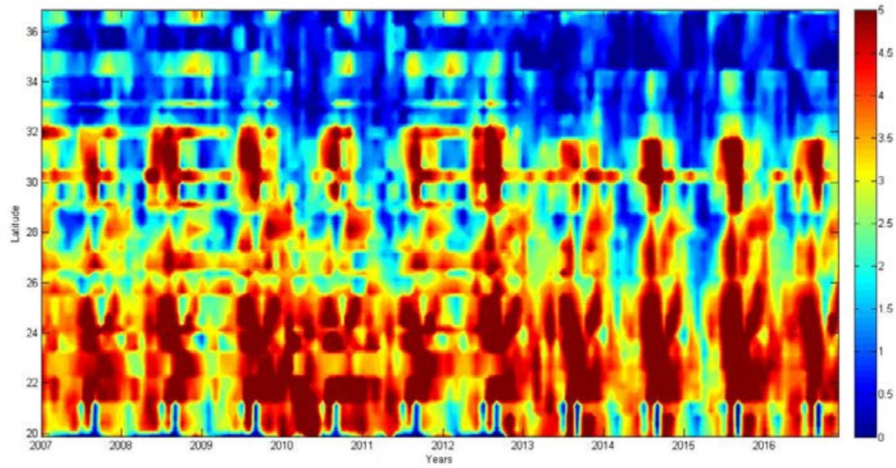

Figure 8: Coastal upwelling index from 2007 to 2017

The upwelling index reveals three different regions:

- From latitudes 33°N to 35°N the upwelling is weak in this region the downwelling is favorable.
- From latitudes 28°N to 33°N, including the Cap Ghir, we observed a seasonal upwelling active in the summer season, and it's weaker in winter. From 2013, the upwelling was shifted south from 32°N to 31°30N.
- From latitudes 21°N to 27°N, we observed a low upwelling activity with strong upwelling in the southern area in the winter of 2009 and 2015. The coastal upwelling activity is maintained by the presence of northeasterly winds all year long. From Cape Blanc (21°N) to the latitude 26°N, the winds are upwelling favorable all year.

In addition, from latitudes 29°N to 32°N, including the Cape Ghir, the coast topography causes a reducing activity of the upwelling. Thus, this region is characterized by a seasonal active upwelling in summer and weaker in winter. Finally, from latitudes 33°N to 35°N, the upwelling in the Larache region, near latitude 35°N, is weak.

Coastal filaments are relatively near the surface and flow offshore from the coast. The filament flows offshore with rather large velocities (0.25 to 0.50 m/s). The filaments are always associated with favorable upwelling conditions because they contain relatively cold water of subsurface origin (PELEGRI et al. 2004). A major physical characteristics description of the observed filaments in the Cap Ghir region was provided by MAKAOUI et al. (2005). Therefore, the filament is active in summer, and it is noticeable, especially at 20m depth, where several branches of seawater flow from the coast to the offshore.

Moreover, the filaments are visible between latitudes from latitudes 25°N to 26°N, and from Cape Blanc to latitude 23°N, especially in spring. This giant filament is typically flowing near 500 km off Cape Blanc (PELEGRI et al. 2004). All of the above features indicate the relationship between filaments and coastal upwelling because the filament is seasonal in areas where upwelling is seasonal and the filament is permanent when upwelling is permanent.

3.5. Seasonal chlorophyll-a in surface

In upwelling regions, additional mechanisms may promote the persistence of biogeochemical transformations. For this reason, coastal oceans bring large amounts of nutrients into the coastal zone and provide pathways for carbon export (PELEGRI et al. 2004). In addition, specific planktonic community structures can be adapted to the changing physical environment and intermittent nutrient supply in the upwelling regime (PELEGRI et al. 2004). Thus, chlorophyll peaks in summer (over 3 mg/m3) and is even higher in autumn. However, chlorophyll-a is low in winter (Fig. 9).

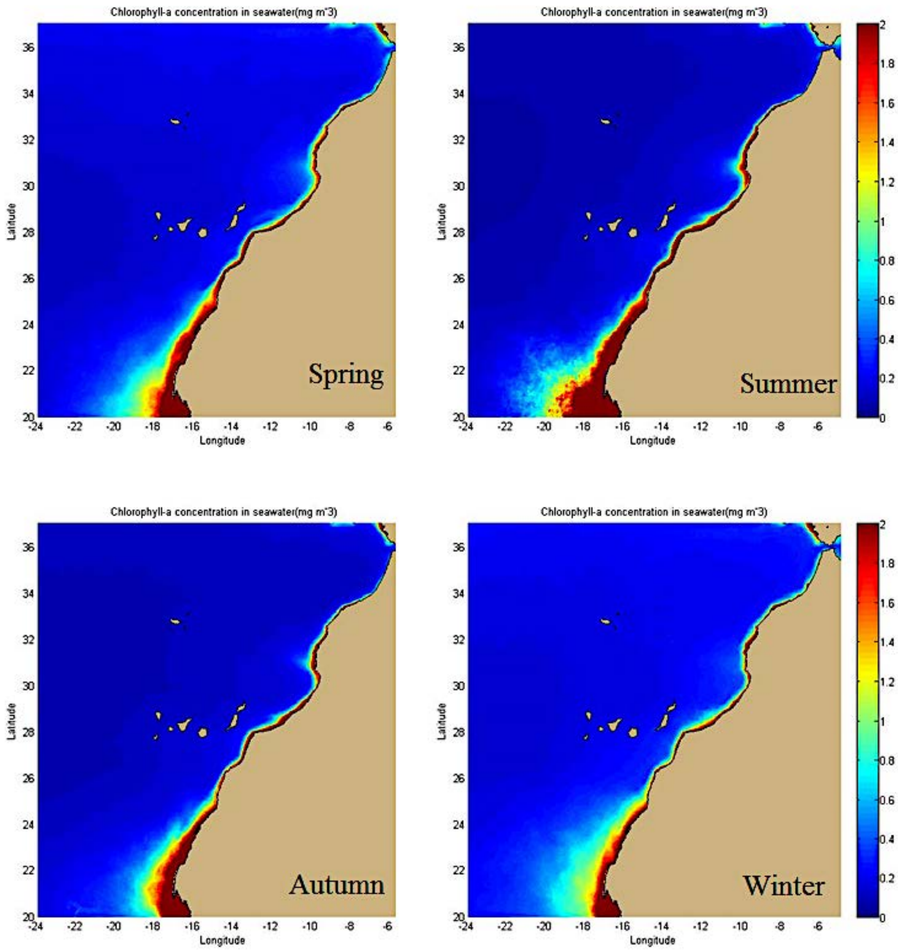

Figure 9: Average seasonal CHL-a concentration (mg.m^{-3}) 2000 to 2016

3.6. Ocean mixed layer depth (MLD)

The MLD interest various oceanic studies, including air-sea exchange processes, upper ocean productivity, and climate variability (Kara, Rochford & Hurlburt, 2000). Many physical features cause upper ocean layer mixings, such as surface wind stress, convective cooling, breaking waves, current shear, upwelling, and high turbulent dissipation. The depth of this mixed layer is determined by the vertical variations of the water property. As a result, the MLD is deeper if the composite layer has almost a certain depth, identical density, and temperature. The MLD can vary by tens of meters daily and 100 m in an annual cycle (LARGE et al. 1994). The Mercator model uses the most widely employed method in the literature, namely threshold methods. The latter uses a threshold value of temperature or density to define the MLD relative to the surface (LUKAS & LINDSTROM 1991; BOYER MONTÉGUT et al. 2004). The results show a mixed layer shallow in the surface in the summer season (20m), reaching its maximum in the winter. However, in spring and autumn, the MLD shallows in surface closer to the cost, and it is gone deeper offshore (Fig. 10). Thus, the mixed layer is deep and cold in winter, following the ocean heat loss and deep convection. In summer, ocean surface heating causes the surface waters, characterized by a shallow warm layer, which increases their thickness throughout summer due to the intense winds. In autumn, the ocean starts losing heat, and the surface temperature decreases while the surface layer thickness continues to increase.

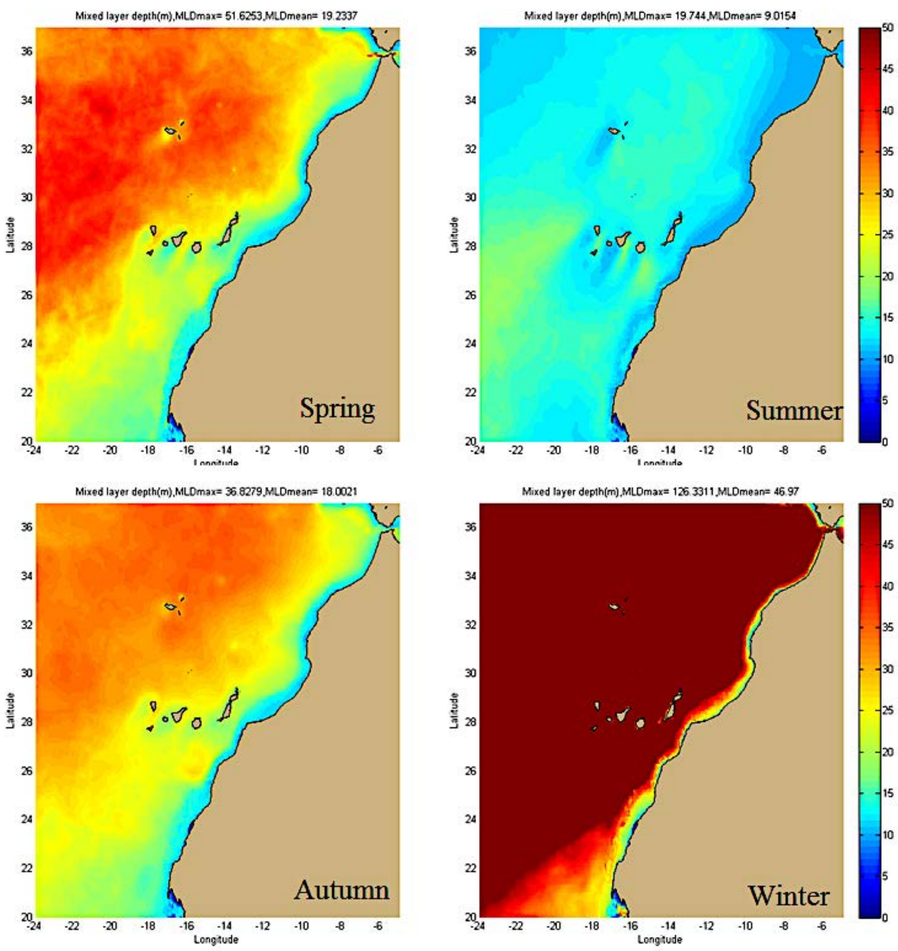

Figure 10: Average seasonal ocean mixed layer depth (m) from 2007 to 2017

4. Conclusion

The numerical model for marine circulation improves year after year as the computer develops and allows more detailed calculations on finer grids. The Mercator model show realistically the Canary Current flows from near-surface to deep water. The marine circulation of the Canary Current is linked to the coastal upwelling system of northwest Africa. This feature is present all year long but intensifies in summer, during the maximum of upwelling activity. Coastal filaments are the largest and easiest to identify during summer. These filaments export water and coastal characteristics into the adjacent upwelling transition zone, but a significant fraction likely recirculate towards the coast (PELEGRI et al. 2004). The ocean MLD has a substantial seasonal variation with a deep MLD in winter and a shallow MLD in summer, while the spring and fall seasons act as transitional periods. The countercurrent appeared at a depth of 110m, and it moved northward, especially near the coast. The undercurrent moved northward and was characterized by a low seawater velocity speed, cold temperature, and less salinity than surface seawater. The seawater circulation in northwest Africa is affected by the wind trend, which varies seasonally. The wind trends directly affected the coastal upwelling and continental currents throughout the region. Therefore, detailed and continuously in situ data are essential to understand the marine circulation along the Moroccan Atlantic coast.

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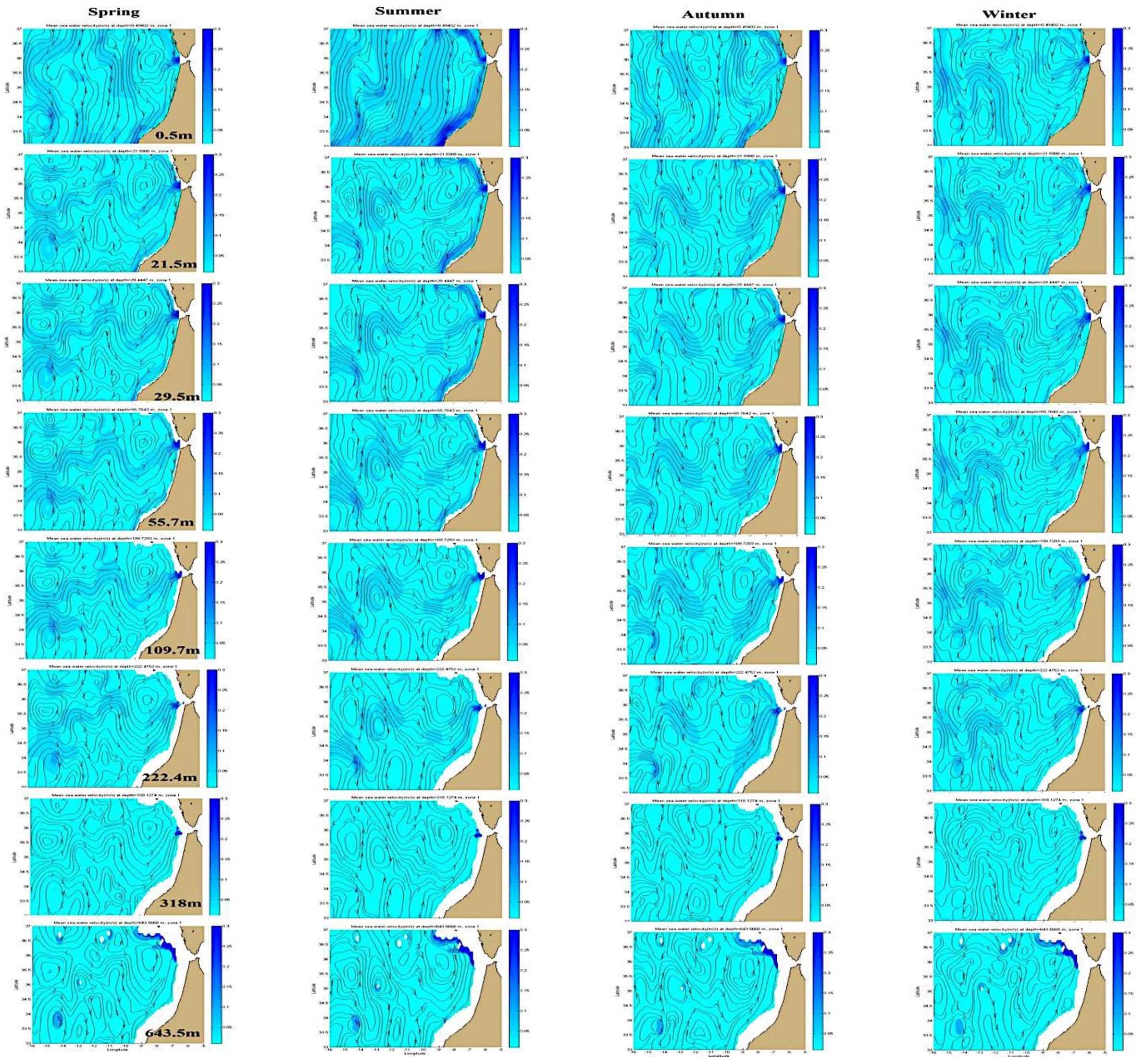
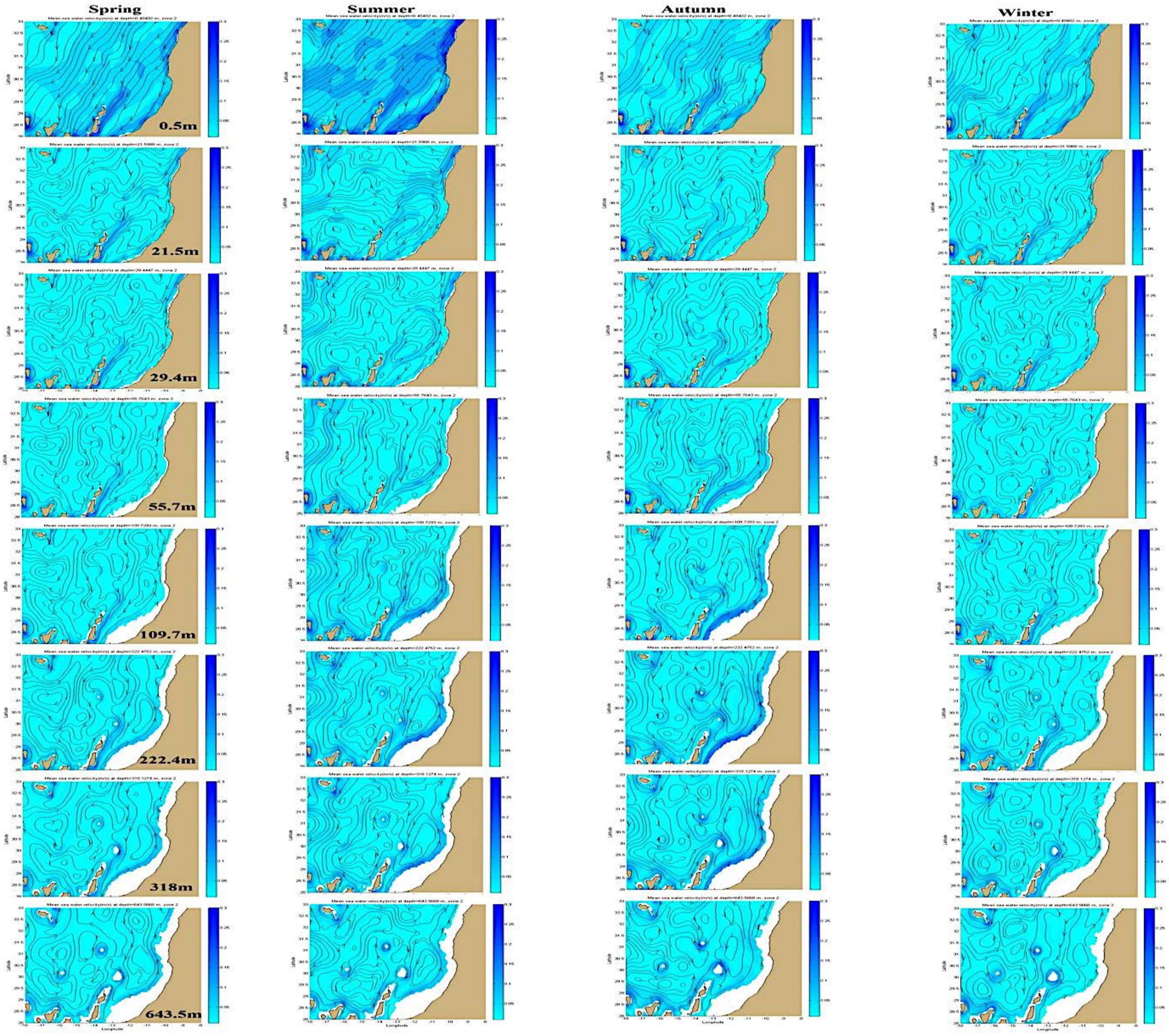
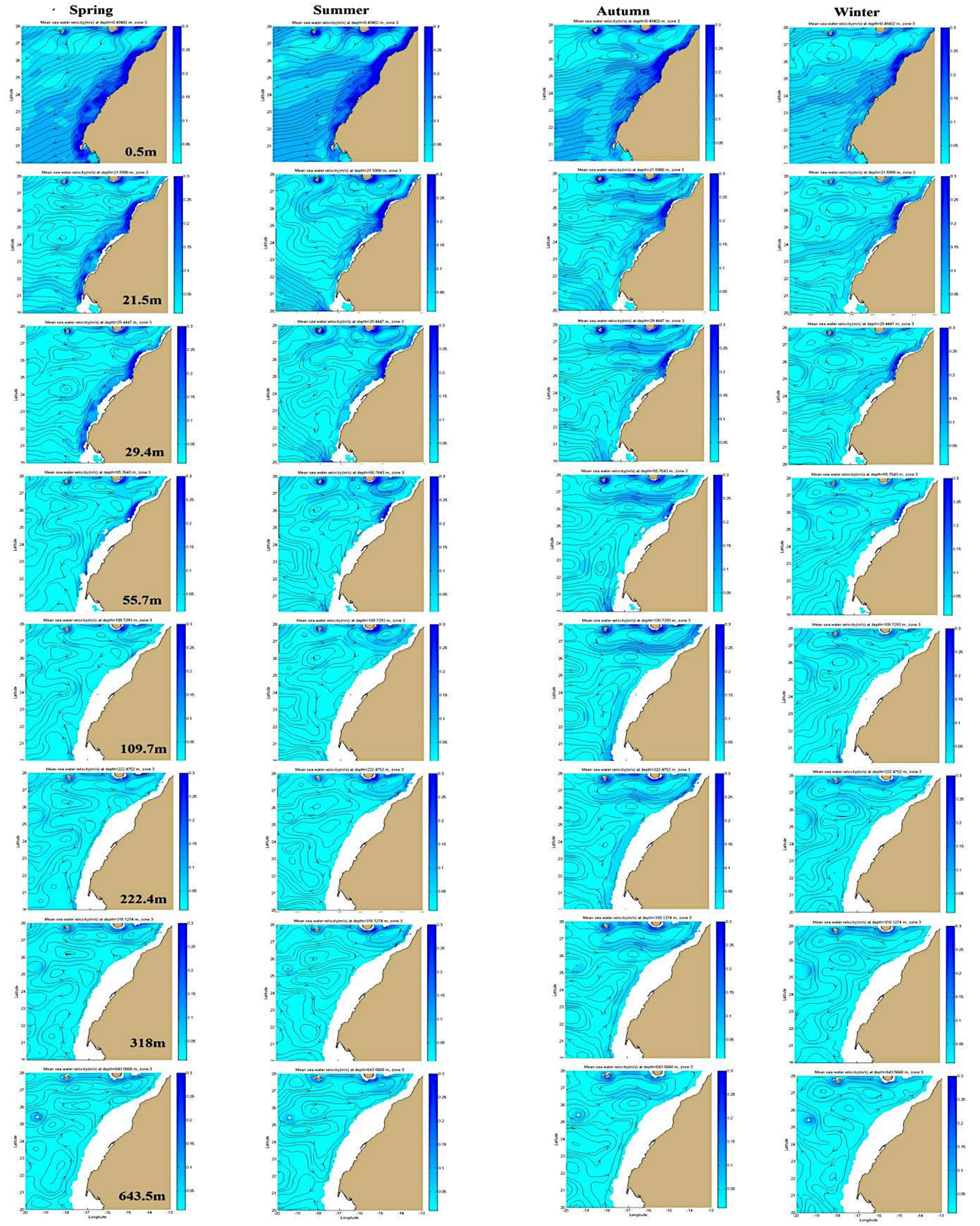


Appendix 1: Average seawater velocity in area (33°N to 37°N) from 2007 to 2017.



Appendix 2: Average seawater velocity in area (28°N to 33°N) from 2007 to 2017.



Appendix 3: Average seawater velocity in area (20°N to 28°N) from 2007 to 2017.

Marine circulation impact on the solid waste spatial distribution in the Moroccan Atlantic seafloor

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Abstract. This study analyses the impact of oceanic circulation on the spatial distribution of seafloor marine debris, in particular plastics, and the identification of high spot areas, which could be the subject of a management plan development for the preservation of marine habitats and fishery resources. The marine debris data analyzed by the GIS tool come from four trawl surveys carried out, between Cape Spartel and Cape Blanc, by the scientific research vessel of the National Institute of Fisheries Research (INRH-Morocco), during the period 2011-2018. Concerning the oceanic circulation, we used the monthly data of sea surface velocity provided from the GLORYS12V1 product of the CMEMS global ocean eddy-resolving, with 1/12° horizontal resolution. By weight, 86.5% was composed of artificial Polymers (fishing nets and plastic), Metal, and Glass. Fishing activity was the source of 94% of these polymers macro-debris. Fishing nets, metal, and Glass are concentrated in small areas, respectively 23%, 21%, and 0.6% of trawling area. At the same time, plastic covers 92% of the prospected surface with an intense concentration in the southern part characterized by a maximum of ocean circulation that can move plastic with low density from their source areas for kilometers before degrading and sinking in the seafloor.

Key words: marine debris, seafloor, oceanic circulation, GIS, Moroccan Atlantic Ocean

1. Introduction

Solid marine wastes correspond to all the objects or materials that are, voluntarily or not, directly or indirectly, thrown or abandoned in the sea and on the coastline. They are of various origins and sizes (plastic bags and bottles, metal cans, fishing gear, clothing fabrics, etc.). Approximately 70 to 80% of marine debris comes from land and is transported by rivers, drains, sewers, or winds (UNEP, 2009; GALGANI et al. 2013; SANTIAGO et al. 2017). The remains come from sea activities, such as fishing and shipping. According to the US National Oceanic and Atmospheric Administration (NOAA), manufactured products are not fully biodegradable. Studies and forecasts predict that they will take decades, if not hundreds of years, to degrade. Some products such as glass never degrade, while plastics do degrade, but never completely. Instead, they break down into micro-parts (microplastics) that sink into the sediment or are ingested by fish, that mistake them for their prey.

With 3500km of coastline, including 3000km in th*e Atlantic, Morocco has a significantly heterogeneous continental shelf; narrow in the center, less than 12 NM, and vast in the North and south, with more than 20 NM (COLLIGNON, 1965; RHINANE et al. 2011). This maritime space promotes important fisheries and significant naval transport activities.

Located in the Canary Current, one of the most fish-rich regions globally, the Large Marine Ecosystem creates an intense and diversified fishing activity in Morocco. For the last ten years (2008-2018), official statistics indicate an annual average of 24,000 active national vessels and 50 foreign ships operating under fishing agreements (DPM, 2019). In addition, due to its geographical position close to Europe, Moroccan maritime transport concentrates around 98% of its trade (DMM, 2013). The ports of Casablanca, Jorf Lasfar, and Mohammedia, on the Atlantic coast, account for 78% of the goods flow moved by sea. In addition, passengers and agricultural products transport trucks is another ferry-related activity in

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the Gibraltar strait, encouraged by the proximity of the Iberian Peninsula (14 km).

On the landside, the big cities with the essential socio-economic activities (fishing and commercial ports, industries, tourism, etc.) cover almost the entire Moroccan coast. Moreover, the latter has the most important hydrographic network since the largest Moroccan rivers flow into the Atlantic. This general pattern may contribute to the pollution of the marine environment by solid wastes (OCEAN CRUSADERS, 2020) that are generally found on the beaches, on the ocean surface, between two waters, or in the deep sea. The estimate of the distribution of marine litter, given by the United Nations Environment Program (UNEP) in 2005, shows that 15% float on the sea surface, 15% remain in the water column, and 70% rest on the seafloor (UNEP, 2005). However, this solid seafloor debris is the least studied due to its inaccessibility and high sampling costs.

Various studies on seafloor waste (plastic, metal, fabric, fishing gear, etc.) describe and estimate the density of each category in weight or items per unit area (SANTIAGO et al. 2017; GALGANI et al. 2000; PHAM et al. 2014). Among the different types of litter, plastics constitute the bulk of marine litter worldwide, with a rate of 60 to 80% of total marine debris (SANTIAGO et al. 2017; ANDRADY, 2011). In Morocco, spatial mapping distribution of seafloor marine debris has shown that plastic takes up more than 80% with a density varying from a few dozens to over a thousand tones per km² (LOULAD et al. 2017; HOUSSA et al. 2017). Other studies on solid waste from the Moroccan Atlantic seafloor have shown that plastic represents more than 80% (LOULAD et al. 2017; RHINANE et al. 2019). This plastic can generate several potential impacts on the marine environment and organisms (COLE et al. 2013; WRIGHT et al. 2013; MAAGHLOUD et al. 2020). Concerning the hydrodynamic process of the Moroccan Atlantic coast, this study analyses the impact of oceanic circulation on the spatial distribution of seafloor marine debris, in particular plastics, and the identification of high spot areas, which could include a developing management plan for the protection of marine habitats.

2. Materials and Methods

2.1. Study area

The Moroccan Atlantic coast is part of the Canary Current Large Marine Ecosystem (CCLME) which extends from the Iberian Peninsula (43°N) to the south of Senegal (8°N); CCLME is one of the world's four major Ecosystems (BARTON et al. 1998) (Fig. 1). Surface waters and upper thermoclines form this ecosystem and develop from the sea surface at the highest latitudes (HILMI et al. 2012; BENAZZOUZ et al. 2015; MAKAOUI et al. 2015). Moroccan Atlantic Ocean is characterized by an almost regular sea coast marked by a succession of large concave and convex parts (COLLIGNON, 1965). The hydrographic network is very dense in the Northern regions (i.e., Sebou, Oum Rabiaa), in the Centre (i.e., Souss, Draa), and becomes very weak (or absent) in the south Moroccan Atlantic. Many estuaries, bays, and lagoons characterize the Atlantic coast; some are RAMSAR sites (i.e., Tahadart, Moulay Bousselham, Sidi Moussa, Oualidia, Khnifiss, Dakhla) and sensitive protected areas, such as the Souss-Massa National Park. The Canary Current, wide (1000 km) and slow (10-30 cm/s), flows all year round towards the equator (Wooster & Baku 1976; Batten et al. 2000). The surface waters of this current are cold and because, as they move southward, they transport water up the coast (MITTELSTAEDT 1991). The seasonality of the Canary Current has been described using a geostrophic calculation that indicates that this current is weak and variable in winter and spring; it reaches its maximum speed during the summer season (STRAMMA & SIEDLER 1988).

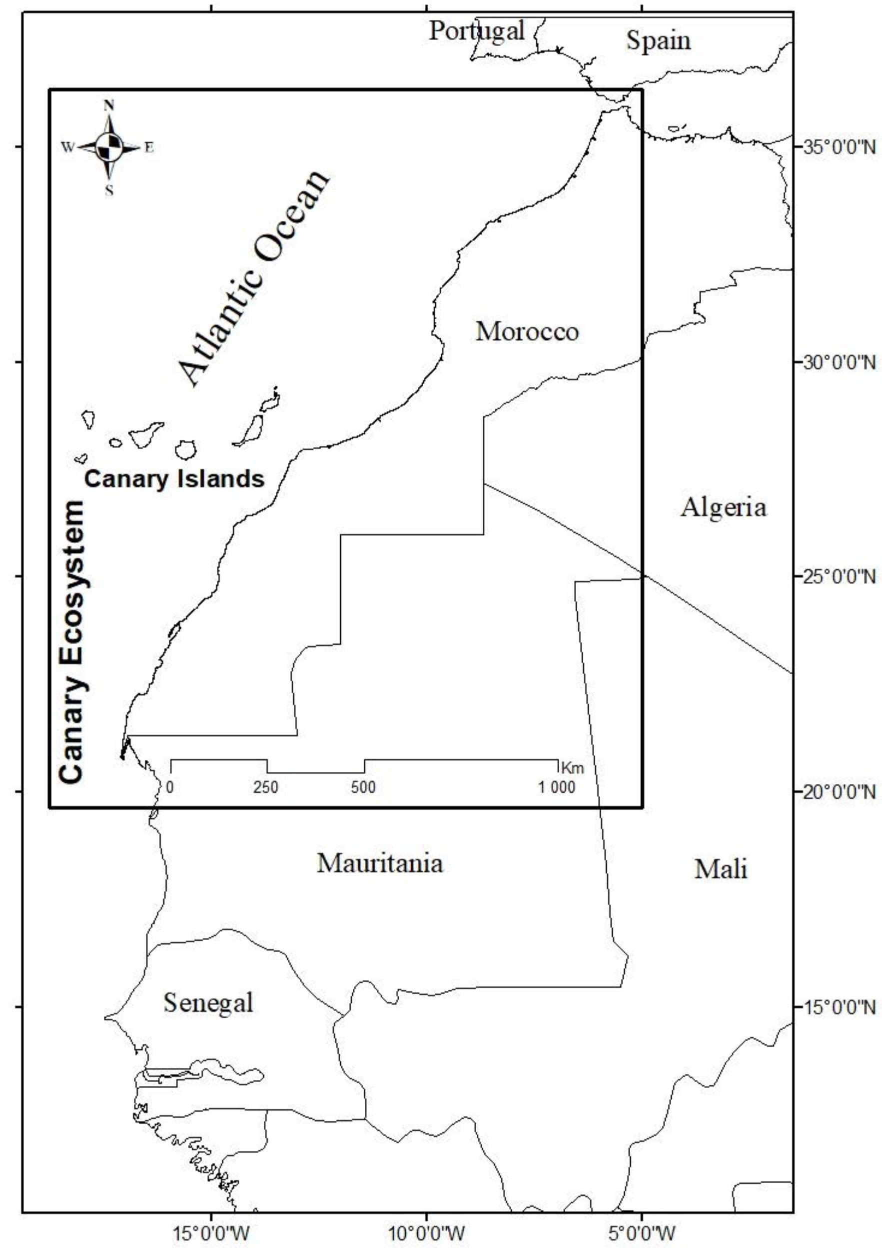

Figure 1: Localization of the Moroccan Atlantic coast (study area).

2.2. Database

2.2.1 Marine debris

This study's seafloor marine debris database comes from four trawling surveys carried out between 2011 and 2018 in the Moroccan Atlantic coast by the Moroccan R/V "Charif Al Idrissi" of the Institut National de Recherche Halieutique (INRH). In addition, two marine surveys (2011 and 2014) were carried out in the south Atlantic of Morocco, between latitudes 21°N and 26°N as part of the cephalopod's monitoring program.

The other two marine surveys (2015 and 2018) were carried out in Morocco's north, and center Atlantic, between latitudes 29°N and 35°N as part of the monitoring's for shrimps and hake programs. No data covers the area between latitudes 26°N and 29°N because it is generally a rocky area and is difficult for trawling. The spatial coverage and the number of explored stations to collect solid debris are presented in figure 2 and table 1. The collected data concerns:

- The geographical position,
- The time of trawling,
- The depth,
- The seafloor nature,
- The total quantity and nature of each type of marine debris.

Onboard the vessel, we separated the trawl contents from the marine species at each sampling station. As a result, a wide variety of anthropogenic debris was found, including plastic shoes, bottles, soda cans, glass bottles, plastic bags, fishing gear, etc. (Fig. 3). According to the Keller et al. methodology (LOULAD et al. 2017; STRAMMA & SIEDLER 1988), these debris were separated and classified. The four most important classes of marine debris will be analyzed and discussed in this study, and it concerns plastic, textile, metal, and glass.

2.2.2 Sea surface velocity

The monthly data of sea surface velocity was provided from the GLORYS12V1 product of the CMEMS global ocean eddy-resolving, with 1/12° horizontal resolution. It is largely on the current real-time global forecasting CMEMS system. The model component is the NEMO platform-driven at the surface by ECMWF ERA-Interim reanalysis. Observations are assimilated by means of a reduced-order Kalman filter. Satellite sea surface vertical is jointly assimilated. The output files are displayed on a standard regular grid at 1/12°.

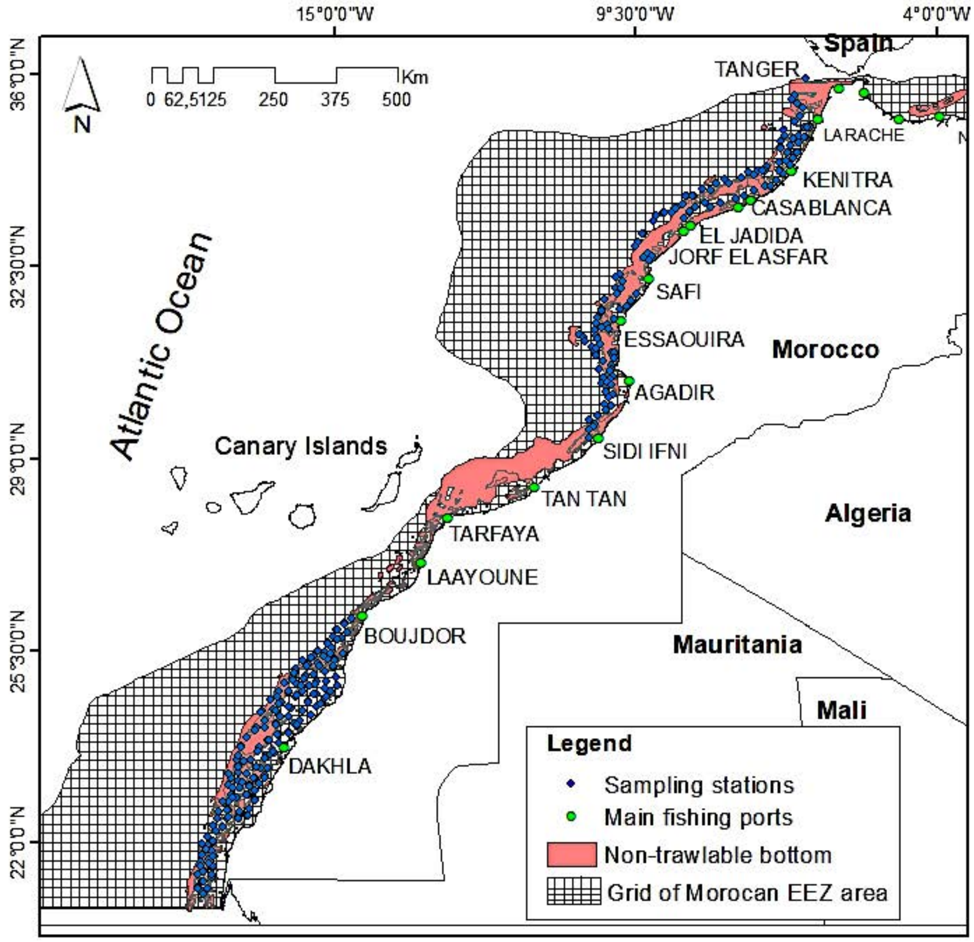

Figure 2: Map of sampling network

Table 1: Explored stations between 2011-2018 along the Moroccan Atlantic coast

Surveys	Surveys date	Number of explored stations	Spatial coverage	Depth (m)
2011	June 2011	94	22°N-26°N	20-300
2014	October 2014	100	22°N-26°N	20-300
2015	Mars 2015	117	35°N-29°N	20-800
2018	July 2018	31	35°N-30°N	20-800

Figure 3: Examples of marine debris items collected during the trawling surveys

2.3. Methodological approach

To analyze the seafloor marine debris data, we proceeded as follows:

- We calculate the density in kg/km² for each debris item.
- We used the ArcGIS software (version 10.5) to map the average density by the square of 10 MN², the average density, and define the spatial distribution of hot spot areas.
- We analyze the impact of oceanic circulations on the formation of these areas of hot spots.

3. Results

To analyze the spatial distribution of seafloor marine debris, we explored a total of 342 trawls carried out during four marine surveys. Two of these surveys were carried out, in 2015 and 2018 in the North and Central Atlantic of Morocco (29°N-35°N); the other two surveys were carried out, in 2011 and 2014 in the South Atlantic of Morocco (26°N-22°N). The sorting process of the content of each trawl hit (fish and solid waste) showed that the marine debris was caught by 50% of trawls. Therefore 50% of the prospected area contains solid waste, including 56% in the South Atlantic of Morocco and 44% in the North and Central Atlantic of Morocco. During the study period, the mean density in the global Atlantic prospected area was about 368 (±1111) kg/km². Thus, the mean density per survey varies between 54 (±93) kg/km² and 653.62 (±1449.63) kg/km² (Fig. 4, table 2). The benthic debris collected is of different types; the most abundant are: plastics in various forms (bags, bottles, jars, shoes, etc.), fishing nets (textiles), iron, and glass. The comparison between the density of these categories shows that, in terms of density, the most important part of seafloor debris is made of the fishing net (43%) and plastic (37%), composed essentially of pots used to catch octopus (78%). Metallic material, containing protecting trawl funds, some cans of soda, and a small percentage of metallic pots, represents 4.32% of the total density of marine debris. Glass occupies the last position with 0.37% of the overall density of marine debris collected by the bottom trawl.

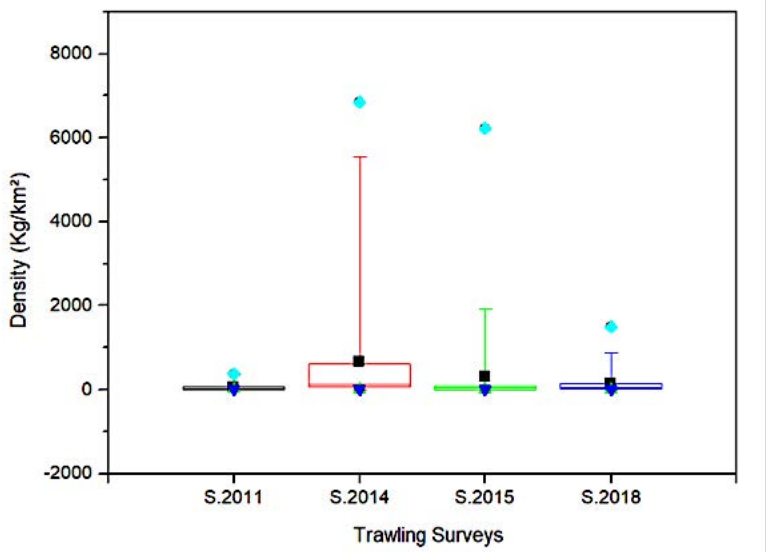

Figure 4: Distribution of marine debris density (kg/km²) estimated during surveys

Table 2: Statistics of marine debris density (kg/km²) by surveys

Surveys	Mean	Maximum	Minimum	Standard deviation
S.2011	54.10	368.38	4.98	93.11
S.2014	653.62	6851.19	0.37	1449.63
S.2015	302.47	6222.70	0.93	1020.08
S.2018	133.85	1493.45	1.87	281.35

Spatial distribution analysis of the marine debris average density, per 10 MN pixel (Fig. 5), shows that the high concentrations (> 100 kg/km²) occupy the coastal areas of North and Central Atlantic Morocco; particularly the areas near the ports of Larache, Kénitra, Casablanca, Jorf Lasfar and Essaouira.

In the South Atlantic, these hot spot areas are located between Boujdour and Dakhla. Two high-density pixels were found further South between latitudes 21° and 22° N. The mapping of the spatial distribution of each of the studied categories of benthic debris shows the following: seafloor marine debris from fishing nets (texture category) is mainly concentrated in the south Atlantic of Morocco, between Boujdour and Dakhla, with isolated surface units, around the 22° N line and in the north Atlantic of Morocco, near the Kénitra port and between Jorf Lasfar and Safi. The total area occupied is of the order of 290 MN², i.e., 23% of the total area prospected during the four trawling surveys (Fig. 6). Plastic debris is present in high concentrations throughout all the Moroccan Atlantic surveyed area. It covers an area of 1160MN², i.e., 92% of the prospected area, where the octopus fishing pots alone occupy 600MN², representing 52% of this surface covered by plastic (Fig. 7). These pots are caught mainly in the area near Dakhla (Fig. 8). Metal (Fig. 9) and glass (Fig. 10) are distributed in a few isolated surface units near Agadir in the North and around Boujdour in the South. They cover 270 and 80 MN²,

Mapping the occurrence of catching benthic debris in the same area, from one survey to another, highlights the most polluted regions of solid seafloor waste (hot spot area). These areas are located North of Larache, between Kenitra and Casablanca, in front of El Jadida and Jorf Lasfar, between Essaouira and Agadir, and between Boujdour and Dakhla (Fig. 11). These hot spot areas are composed mainly of plastic, followed by fishing nets, and finally metal and glass (Fig. 12).

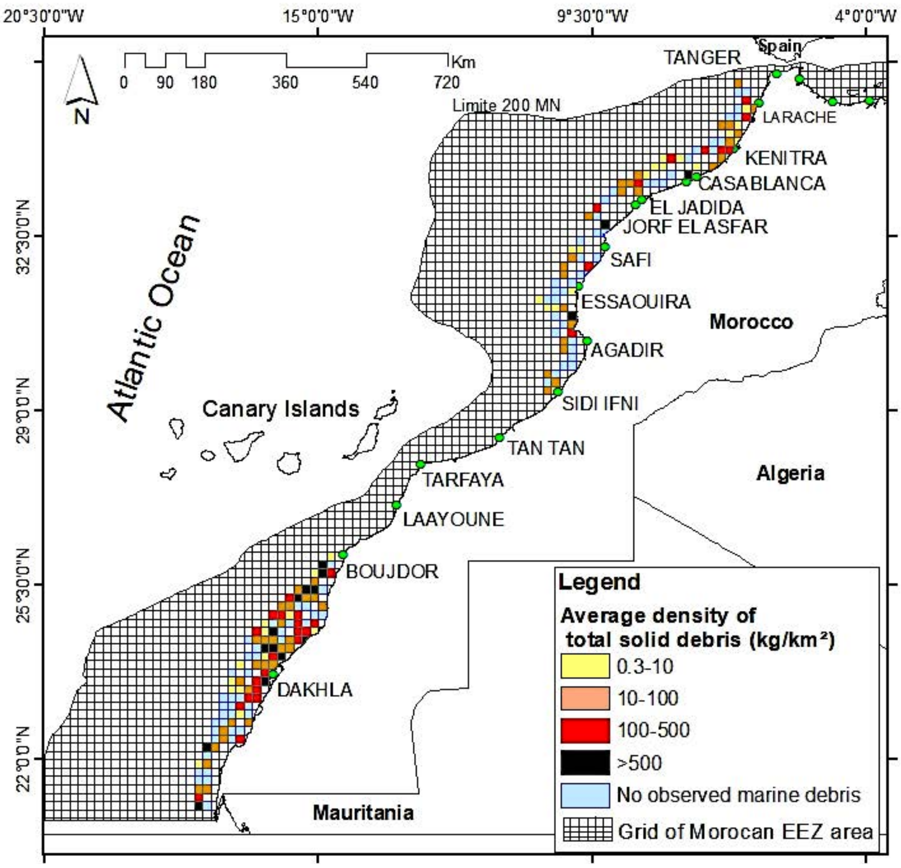

Figure 5: Map of spatial distribution of marine debris in the Moroccan Atlantic coast

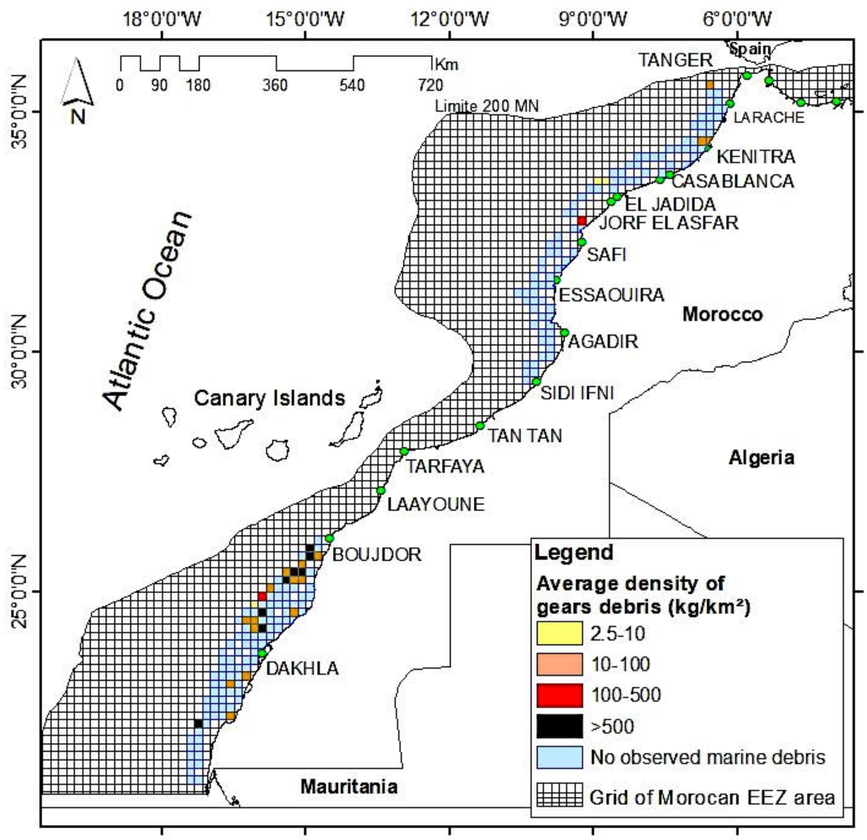

Figure 6: Map of spatial distribution of fishing net debris in the Moroccan Atlantic cost

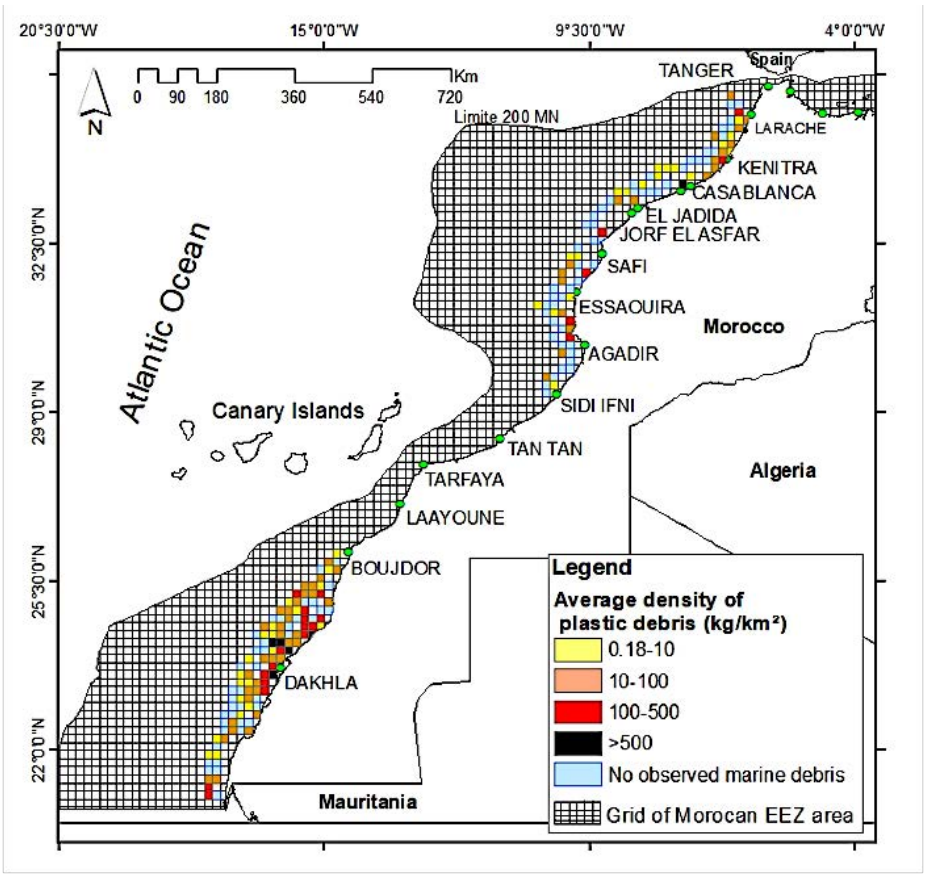

Figure 7: Map of spatial distribution of plastic in the Moroccan Atlantic coast

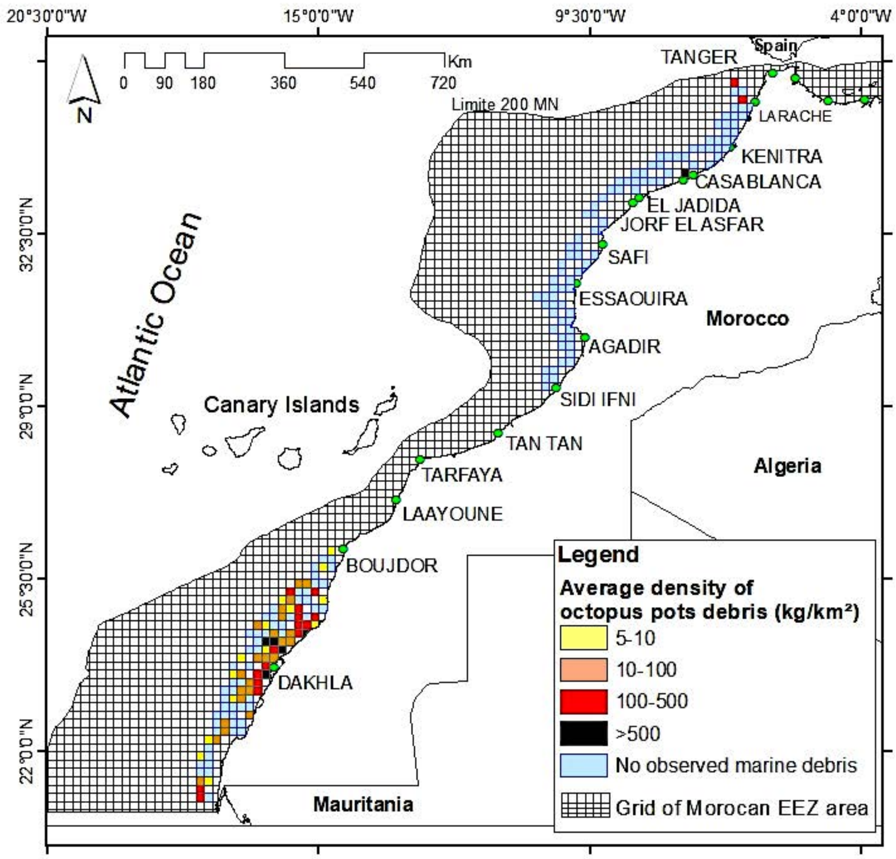

Figure 8: Map of spatial distribution of Octopus pots in the Moroccan Atlantic coast

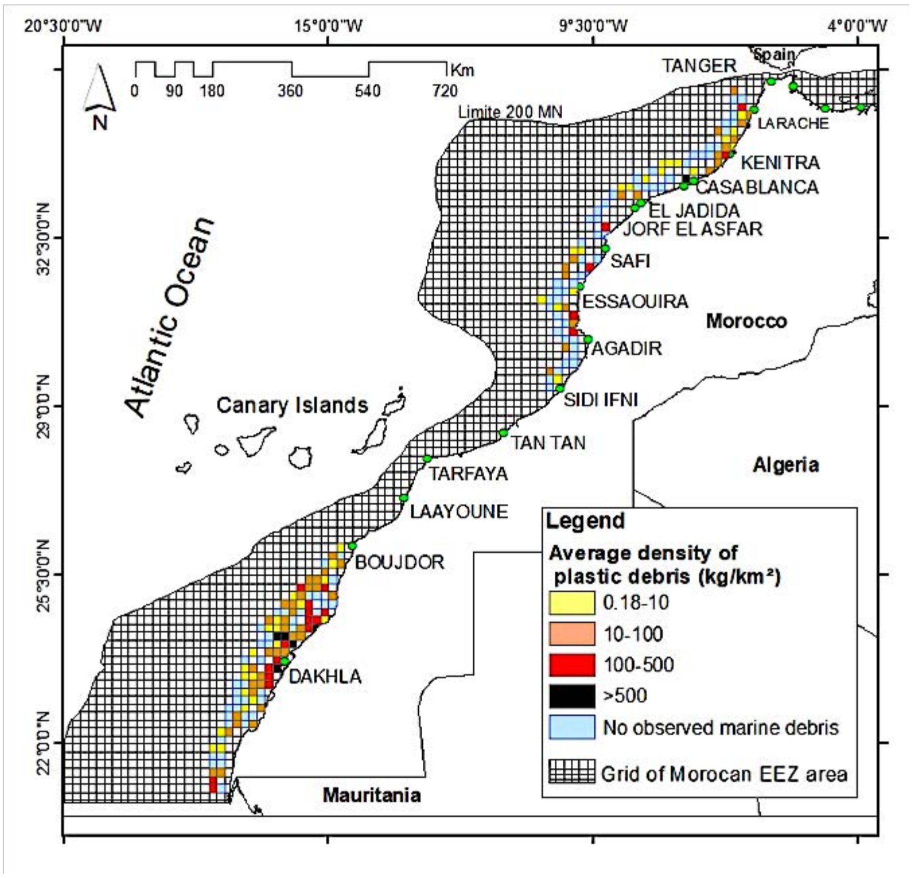

Figure 9: Map of spatial distribution of metal in the Moroccan Atlantic coast

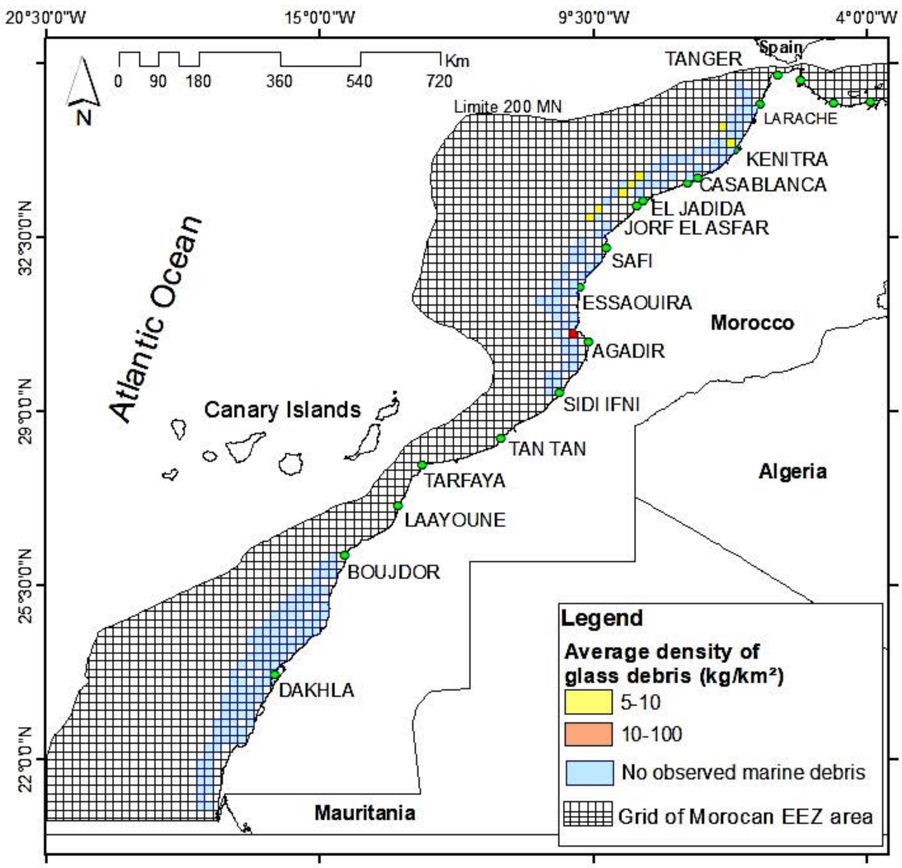

Figure 10: Map of spatial distribution of glass in the Moroccan Atlantic cost

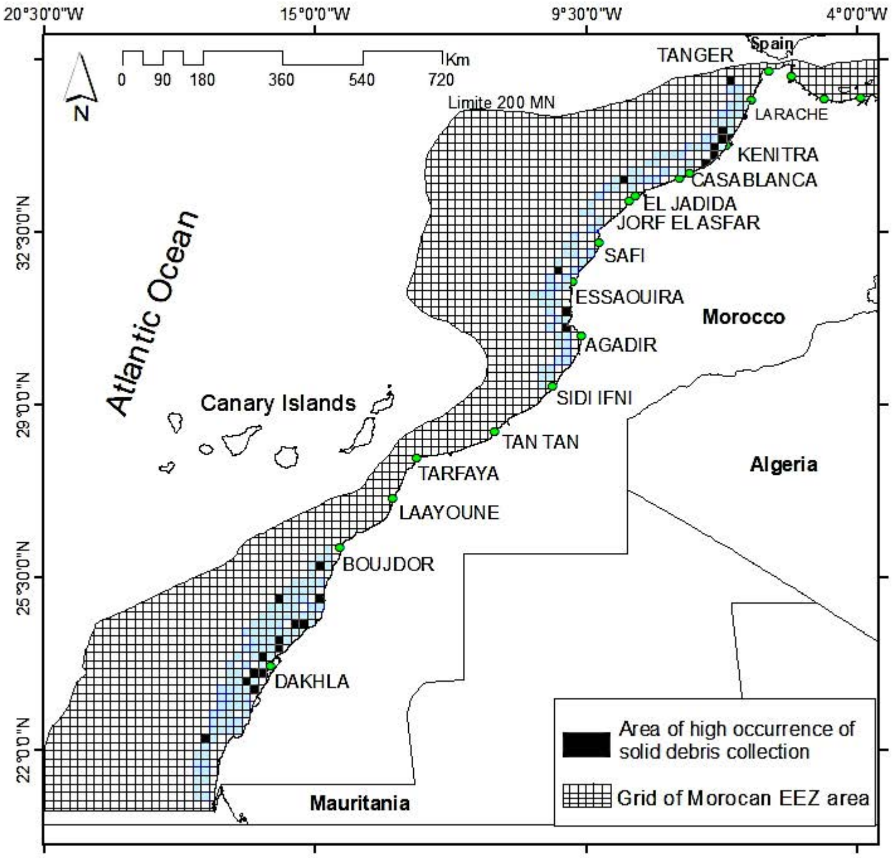

Figure 11: Area of high occurrence of solid debris presence in the Moroccan Atlantic coast

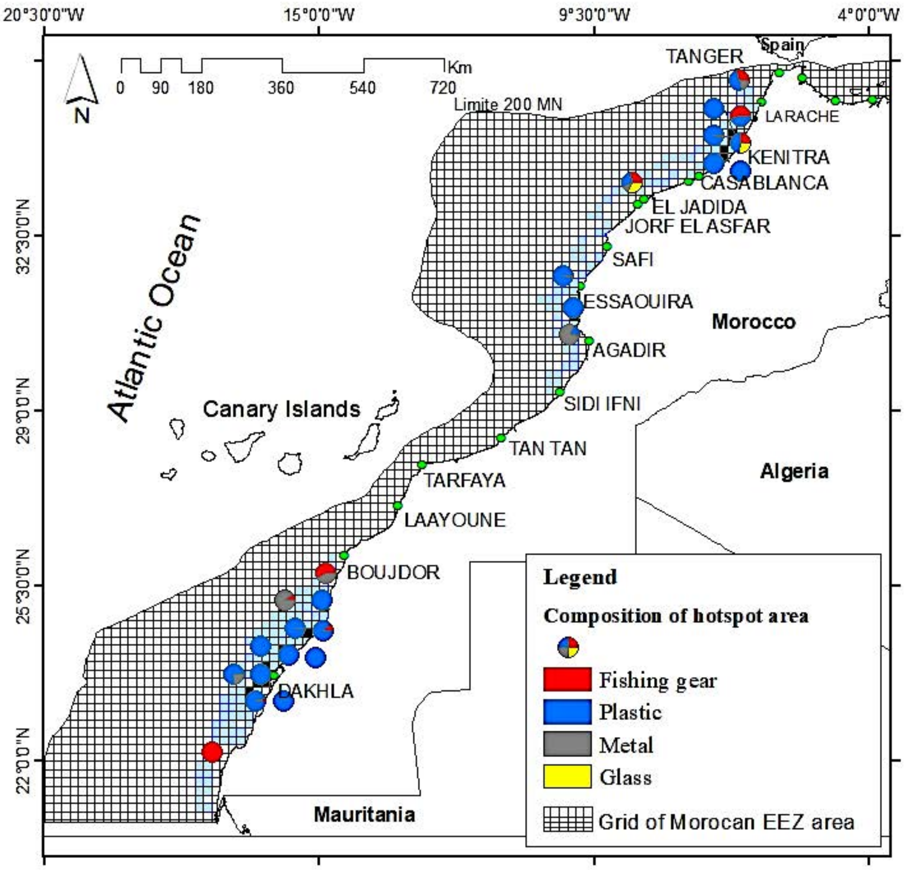

Figure 12: Localization of the hot spot areas in the Moroccan Atlantic coast

Figure 13 shows the monthly sea surface velocity during the sampling months regarding the oceanic circulation along the Moroccan Atlantic coast. The seasonality of the Canary Current is shown with the maximum velocity speed, which is observed in the summer season. At the same time, in spring and autumn, we remarked a weaker ocean circulation in both studied regions, with a south-southwest direction. Filaments are observed in the summer season, especially in Cape Ghir and Cape Boujdour, exporting water and its matter from the coast to the offshore.

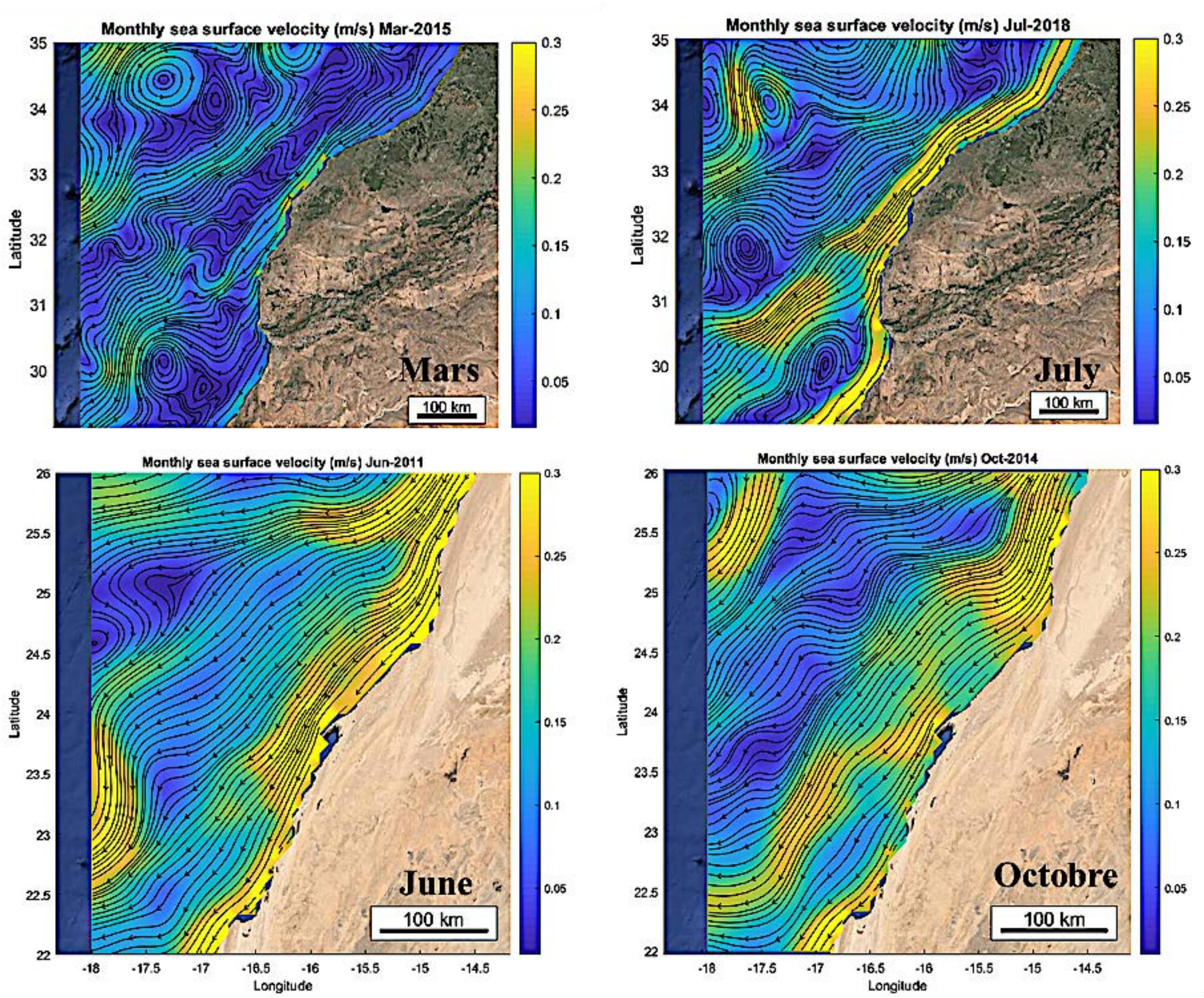

Figure 13: Spatial distribution of monthly sea surface velocity during the month's surveys

4. Discussion

We conducted Bottom trawl surveys to map the spatial distribution of seafloor marine debris in the Moroccan Atlantic offshore area. The highest proportions (86.5%) of marine litter by weight were Artificial Polymers (fishing nets and plastic), Metal, and Glass. This tendency is similar to those observed in other studies carried out in neighboring areas, the Portuguese coast, or in the Alboran Sea (RIVERA et al. 2017; NEVES et al. 2015; GALGANI et al. 2010).

The comparison of the densities by weight of these categories of solid debris shows that the fishing nets have the highest average value (850 kg / km²), followed at far lower levels, by plastic (114 kg/km²), metal (74.5 kg/km²) and at last glass (26 kg/km²). The plastic category includes the pots used to catch octopus; the artificial polymers are therefore composed of 94% of fishing gears in terms of weight. We also reported the dominance of fishing gear in seafloor marine debris by different studies carried out along Portugal and Spanish coasts (RIVERA et al. 2017; NEVES et al.

2015; VIEIRA et al. 2014). These fishing gears, non-degradable or poorly degradable (OSPAR 2009), are accidentally lost or deliberately discarded into the sea due to the important fishing activity along the Atlantic coast.

The portion of metal in the total density of marine debris is 4.5%. This value is close to that found by NEVES et al. (2015) in the Portuguese coasts (6%), lower than that found in the Spanish coasts by RIVERA et al. (2017) (10.5%). The glass has a rate of less than 1%, ten times less than the rate recorded in the Portuguese and Spanish coasts (around 10%). In terms of spatial distribution, fishing nets are concentrated in small areas, 23% of the trawled area. These denser fishing nets generally remain in the source area, where they will continue to capture and kill marine organisms, thus constituting ghost fishing.

On the other hand, the plastic is distributed over 92% of the prospected surface through the Moroccan Atlantic coast, with an intense concentration in the southern part. Indeed, plastics are of low density and can be moved from their source areas for kilometers before degrading and sinking under the effect of active ocean circulation, especially in the summer season, where we observe a maximum of ocean circulation moving to the south. Thus, this anthropogenic marine solid waste problem coupled with the physical phenomenon of ocean circulation has a significant impact on the pollution of vast marine environment areas.

5. Conclusion

Trawl surveys are a fundamental contribution to the data collection on seafloor waste. We successfully mapped the spatial distribution of debris on the seafloor along the Moroccan Atlantic shelf and highlighted the impact of oceanic circulation on the increase of plastic polluted surfaces. Their processing has allowed underscoring the marine circulation impact on the rise of plastic contaminated surfaces. The most important part of this collected marine litter is lost or abandoned fishing gear, followed by metal and glass categories in small proportions. Solid wastes can directly affect organisms such as asphyxiation or ingestion or serve as transport and habitat tools, thus altering the natural composition of communities and threatening biodiversity. These results demonstrate the need, within the framework of the strategy for the sustainable development of marine environments, to raise fishers' awareness of the adoption of better environmental practices that will reduce marine litter and protect marine habitats.

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Structure, diversity and habitat characterization of Copepods from the Cape Ghir upwelling, Morocco

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Abstract. The zooplankton, of the Cape Ghir filament area in Morocco (31°N), was sampled during five oceanographic cruises conducted between 2008 and 2009. Physical and chemical parameters were measured. In total, 11 stations were sampled on two radial perpendiculars: one latitudinal (31°N) with 7 stations coast-large and the other longitudinal (10°09' W) with 5 stations North-South. The intersection between the two radial corresponds to station 4. Copepods constitute the largest fraction of zooplankton community and represented by 86 species. The temporal variability in the copepod community structure showed that the dominant species listed may change their dominance during the study period. Their composition could be analyzed for changes in community structure associated with oceanographic variation with statistical analysis. The relation between the distribution of copepods species and the environment parameters, shows that some species (*Paracalanus parvus*, *Oncaea venusta*, *Acartia clausi*, *Oithona nana* and *Euterpina acutifrons*) are mainly correlated with chlorophyll 'a' and nutrients. However, other species (Oithona plumifera, Oithona similis and Clausocalanus arcuicornis) are correlated with temperature and salinity. Eight copepods species “*Acartia clausi, Calanus helgolandicus, Neocalanus gracilis, Oithona nana, Oithona similis, Oithona plumifera, Oncaea venusta and Paracalanus parvus*” are characterized by their high frequency and their dominance in all periods and were analyzed specially with their relation to the hydrological parameters to determinate their Environmental Preference Habitat. The global quotients were calculated in relationship with each of the hydrological and productive parameters; considered as the most influencing on the distribution of these species. Moreover, the temperature and the chlorophyll 'a' seem to be the most important factors in the determination of the copepod’s habitats in Cape Ghir area.

Key words: zooplankton, Copepods, environmental preference habitat, Cape Ghir, Morocco.

1. Introduction

The high productive coastal upwelling sustains a strong fishery production based on pelagic and demersal fish. The first aspect of heterogeneity is the delivery of nutrient-rich water to the surface, in direct relation to the local strength of the upwelling intensity, due to the role of physical forcing in upwelling systems (PELEGRÍ & BENAZZOUZ 2015). Secondary production of zooplankton must be high, providing large amounts of energy, which will be transferred to fish populations. The upwelling systems and filament create a dispersive environment which strongly influences the mechanisms of structure and diversity in the marine ecosystem (CHIAHOU 1997 ; SOMOUE et al. 2005).

The Canary Current Upwelling System is the most productive eastern boundary upwelling ecosystems after the Humboldt system, because of its permanent or seasonal coastal upwelling, enhanced by a high average solar radiation. The seasonality of the Net Primary Production of the phytoplanktonic compartment (including algae and photosynthetic bacteria) is well described from satellite-based spatial data, which display

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strong seasonal patterns for the phytoplankton component (DEMARCQ & SOMOUE 2015) as well as the zooplankton component (BERRAHO et al. 2015). Also, they estimated that the Cape Ghir filament exports 2 to 3 times more primary production than the other filaments in the same region. Hence, the Cape Ghir filament would export about 63% of the total annual primary production (GARCIA-MUNOZ et al. 2005).

The Cape Ghir area is characterized by a semi-permanent upwelling filament particularly strong in summer. The intensity of this filament is certainly linked to the presence of coastal alongshore winds. It is present even during periods when there are no winds that favor upwelling. However, this filament has a much greater inertia than the coastal upwelling system itself (PELIGRI et al. 2004a; PELIGRI et al. 2004b). HAGEN et al. (1996) have suggested that this filament develops from the interaction of the alongshore flow with bottom topography. The satellite images show that the filament, sometimes, may uplift cold, chlorophyll-rich water offshore the coastal zone of Morocco. It exports upwelled water and particles to the open ocean, even in the absence of upwelling-favorable conditions.

The analysis of measurements the temperature, salinity and chlorophyll concentration in a study conducted by BERRAHO et al. (2012) showed a spatial-temporal variability in the direction of the drift of the upwelling waters towards the open sea, which brings these waters alternately north or south of the 31st parallel north. This variability, observed in situ, is confirmed by the analysis of satellite images relating to both SST and the color of seawater (BERRAHO et al. 2012). This being indicative that their origin is based on large-scale forcing such as the inflow from the Canary Current (PELIGRI et al. 2004a; GARCIA-MUNOZ et al. 2005; MAKAOUI et al. 2012). ÁLVAREZ-SALGADO et al. (2007) estimated that filaments export 2.5 to 4.5 times more carbon offshore than the Ekman transport.

2. Materiel and methods

The Cape Ghir region is located on the Atlantic coast of Morocco (30°37'49’N, 9°53'20’W), about 40 km north of the Agadir city. The changes of concavity in the coastline makes this region easy to be spotted (Fig. 1). The Cape Ghir can be considered as the extension of the High Atlas range, which culminates at 4167 m above sea level (Jbel Toubkal Mountain). The mountain range acts as barrier that separates regions with different weather: the south, under the influence of Sahara Desert and the north, with a Mediterranean climate.

The aim of this work is to analyze the spatial variation of the distribution of zooplankton in the Cape Ghir area between 2008 (December) and 2009 (February, April, June and October), to identify the dominant copepod species and to determine the relationship between these species and the environmental parameters as well as the hydrological parameters. Samples of water and biological material from the Cap Ghir filament (Fig. 1) were taken on board of the INRH oceanographic vessel "Al Amir Moulay Abdallah". The campaigns were carried out every two months for a period of one year covering five periods (December 2008, February, April, June and October 2009). A total of 11 stations were sampled on two perpendicular radials (Figure 1): one southern (31°N) with seven coast-wide stations and the other longitudinal (10°09' W) with five north-south trending stations. The intersection between the two radials corresponds to station 4 (samples were taken twice in this station: once in each radial). At each station, the surface temperature was measured directly using a CTD SeaBird multisensor. The chlorophyll "a" content was measured by fluorimetry (HOLMS-HANSEN et al. 1965) on water samples taken at different levels along the water column, by rosette bottles. At the same time, the collection of zooplankton was carried out using the Bongo net (a large model of 60 cm in diameter and 147 mm mesh void). The net is equipped with a flowmeter at its opening to measure the volume of filtered water. The contents of the collector are collected and stored in 5% neutralizing formalin.

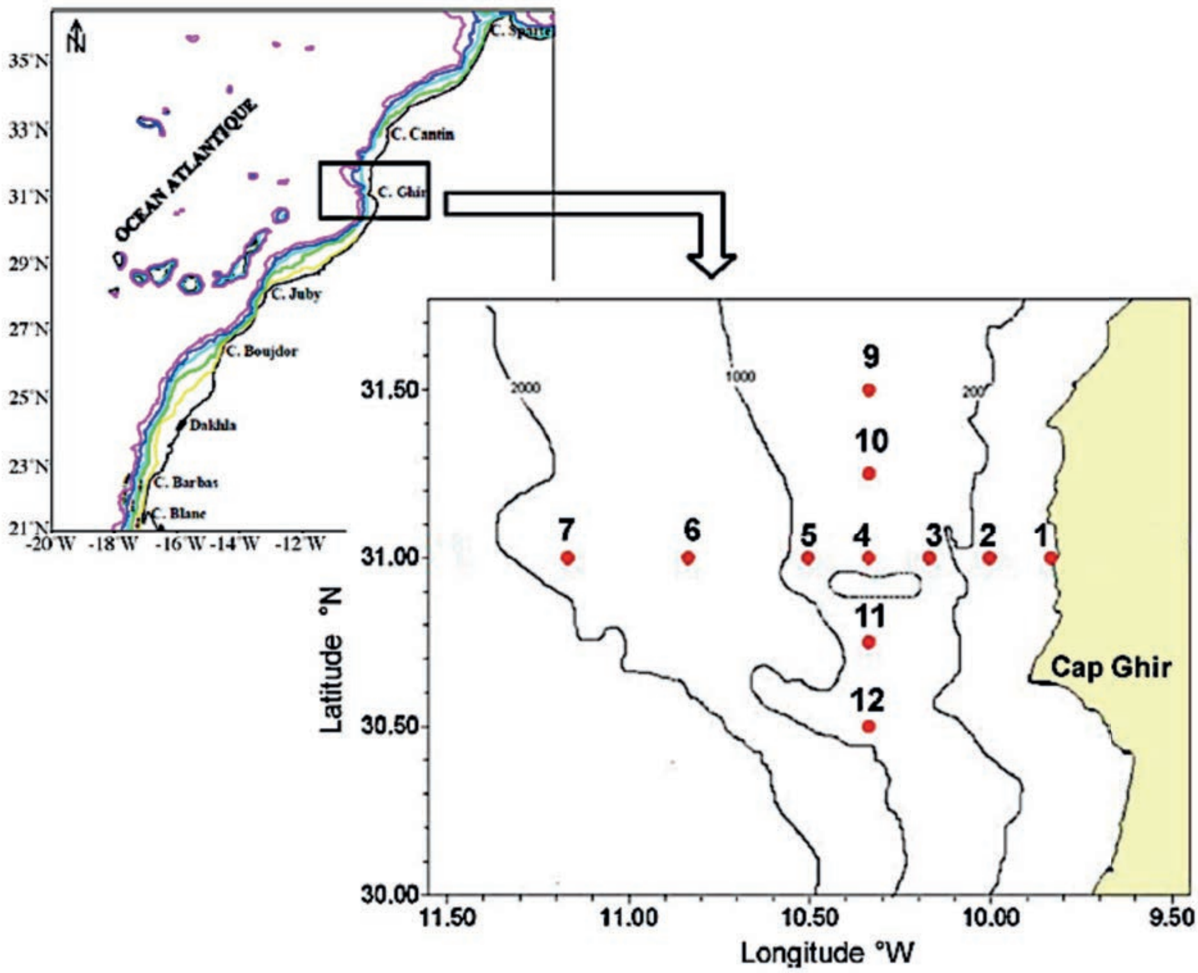

Figure 1: Localization and sampling survey of the studied region at Cape Ghir

3. Data analysis

The processing of the zooplankton samples consists, first, of a quantitative estimate by measuring the wet biomass of the zooplankton per unit of volume (mg.m^3) and a qualitative evaluation based on the identification and counting of the different groups. For this purpose, a fraction of each sample is obtained using the "Motoda" box (MOTODA 1959) and the identification and counting are carried out under a binocular magnifying glass (stereomicroscope). Determination of copepod species was performed using appropriate keys (ROSE 1933; TREGOUBOFF & ROSE 1957; TANAKA 1957). Further work on gender or family revisions was needed during identification (CRISAFI & MAZZA, 1966; FROST & FLEMINGER 1968; BRADFORD et al. 1983).

3.1 Relative Abundance

Relative abundance was used to determine the percent composition of zooplankton groups relative to the total number of organisms in the area.

$$RelativeAbundance(\%) = \frac{n}{\sum N} X100 \quad (1)$$

Where:
n is the Number of individual spp,
N is the Total Number of species population.

3.2 Density

Densities were expressed as individuals per cubic meter (ind. m^{-3}). They were calculated as follows:

$$D = \frac{(n*1000)}{V} \quad (2)$$

Where:
D is the density (expressed in individuals per liter),
n is the number of individuals found per volume of water and,
V is the filtered water volume (m^3).

3.3 Ecological parameters

The description of zooplankton community structure was based on the calculation of various ecological indices such as:

- Specific richness (S) which is the number of encountered species.

- The Shannon-Weaver diversity index H' (SHANNON & WEAVER 1949) was used to characterize species diversity in a community, it establishes the link between the number of species and the number of individuals in the same ecosystem or community, and it is measured using the following formula:

$$H' = -\Sigma [(ni / N) \times \log2 (ni / N)] \quad (3)$$

Where:
ni is the abundance of species I and,
N is the total abundance of all species.

- The Pielou regularity index J (PIELOU 1966) which makes it possible to measure the equitability (or equidistribution) of the species in relation to an equal theoretical distribution for all species according to the following formula:

$$J = H' / \log2 S \quad (4)$$

Where:
R is the Pielou Regularity Index (PIELOU 1966);
H: Shannon-Weaner Diversity Index;
S: Number of species.

To elucidate the relationships between biological assemblages of species and their environment, the multivariate method (Canonical Correspondence Analysis, CCA) (TER BRAAK 1986), was used. This method is designed to extract synthetic environmental gradients from ecological data-sets.

4. Results and discussions

4.1 Upwelling system in Cape Ghir

The Cape Ghir is characterized by a coastal upwelling taking place all year round, and intensifies specially during summer (WOOSTER et al 1976; NYKJAER & VAN CAMP 1994). HAGEN et al. (1996) proposed that the Cape Ghir Plateau (CGP) was responsible for the formation of mesoscale filaments. The hydrographic conditions during the cruises 2008-2009, reflect a period of upwelling processes. The vertical profile of the physical parameters along the 31°N transect indicates an activity of resurgences from April and intensifies during June. It still persists in October 2009 (MAKAOUI et al. 2012). These resurgences are marked by a difference of temperature and salinity gradients between the coast and offshore which can exceed respectively 4°C and 0.3 PSU. The advection of the oligotrophic waters from the offshore towards the coast-line was clearly observed (MAKAOUI et al. 2012). The filament extension is present throughout the year, with a maximum intensity accentuated in summer (June) (SALAH et al. 2012). The water masses derive towards the south while following a very coastal pathway and appears in the south of the 31°N transact by cooler and less salty waters during the period of weak activity of resurgences (December, February, April); whereas during October and June when the upwelling is very active in this zone. The impact of resurgences appears more in the north. The cold upwelled water brings nutrients from deep waters to the surface, necessary for primary and secondary production. In this region, the activity of the upwelling is followed by an important richness in chlorophyll. The maximum biological production occurs between April and October, coinciding with intensified process of upwelling (MAKAOUI et al. 2012; SALAH et al. 2012).

4.2. Copepod density and composition

Several authors acknowledged the dominance of the copepod group over other groups of zooplankton in this area (HAGEN et al. 1996; BOUCHER 1987; FURNESTIN & BELFQHIH 1976; SALAH et al. 2012; SALAH et al. 2013; SALAH 2013). This has been confirmed in the study area, since the Copepods was the dominant group among zooplankton community and presented a peak of abundance in June, with a 662684 ind.m^{-3}. However, a minimum that did not exceed 400 ind.m^{-3} was noted in December. The seasonal evolution of the other zooplankton groups follows the same situation (Fig. 2). The Cape Ghir area is characterized by the existence of upwelling phenomenon (WOOSTER et al 1976; NYKJAER & VAN CAMP 1994) with a reduced intensity in the winter and intense in the summer (NEUER et al. 2001; GARCIA-MUNOZ et al. 2005; MAKAOUI et al. 2012). This corroborated with the seasonality of the upwelling.

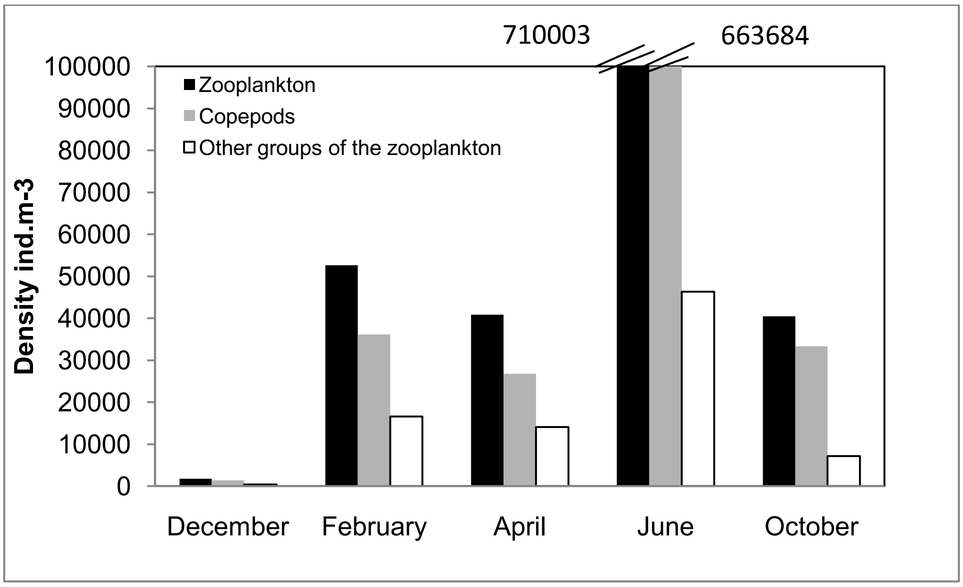

Figure 2: Spatiotemporal fluctuation of copepods densities (individuals. m^{-3})

The Copepods of this region presented a high richness, represented by 86 species in 26 families during all the periods of the survey (Table 1). This zooplankton group was dominated by *Acartia clausi, Calanus helgolandicus, Neocalanus gracilis, Oithona nana, Oithona similis, Oithona plumifera, Oncaea venusta* and *Paracalanus parvus* (Table 2). Some others species dominate seasonally like *Acartia danae, Aetideus armatus, Calanoides carinatus, Calocalanus pavo,* *Centropages chierchiae, Clausocalanus arcuicornis, Clausocalanus jobei, Corycaeus clausi, Corycaeus typicus, Euterpina acutifrans, Lucicutia flavicornis, Mecynocera clausi, Nanocalanus minor, Oithona linearis, Oncaea mediterranea, Paraeucheta hebes, Pleuromamma gracilis, and Temora stylifera*.

Table 1: Copepods composition collected in the waters off the Cape Ghir filament during five periods between 2008 and 2009 (SALAH et al. 2012).

Acartia (Acartia) danae (GIESBRECHT 1889)	*Microsetella rosea* (DANA 1848)
Acartia (Acartiura) clausi (GIESBRECHT 1889)	*Nannocalanus minor* (Claus 1863)
Acartia (Acartiura) longiremis (LILLJEBORG, 1853)	*Neocalanus gracilis* (DANA, 1849)
	Oculosetella gracilis (DANA, 1852)
Aegisthus spinulosus (Farran 1905)	*Oithona brevicornis* Giesbrecht 1891
Aetideus armatus (BOECK, 1872)	*Oithona linearis* (GIESBRECHt 1891)
Aetideus giesbrechti (CLEVE 1904)	*Oithona nana* (GIESBRECHT 1892)
Bradyidius armatus (GIESBRECHT 1897)	*Oithona parvula* (FARRAN 1908)
Calanoides carinatus (KRØYER 1848)	*Oithona plumifera* (BAIRD 1843)
Calanus helgolandicus (CLAUS 1863)	*Oithona setigera* (DANA 1849)
Calocalanus contractus (FARRAN 1926)	*Oithona similis* (CLAUS 1866)
Calocalanus pavo (DANA 1849)	*Oithona sp.*
Calocalanus sp.	*Oncaea media* (GIESBRECHT 1891)
Candacia armata (BOECK 1872)	*Oncaea mediterranea* (CLAUS 1863)
Candacia longimana (CLAUS 1863)	*Oncaea sp.*
Centropages bradyi (WHEELER 1901)	*Oncaea venusta* (PHILIPPI 1843)
Centropages chierchiae (GIESBRECHT 1889)	*Paracalanus denudatus* (SEWELL 1929)
Centropages typicus (KRÖYER 1849)	*Paracalanus nanus* (SARS 1907)
Centropages violaceus (CLAUS 1863)	*Paracalanus parvus* (CLAUS 1863)
Clausocalanus arcuicornis (DANA 1849)	*Paracalanus sp*.
Clausocalanus jobei (FROST & FLEMINGER 1968)	*Paraeuchaeta hebes* (GIESBRECHT 1888)
Clausocalanus paululus (FARRAN 1926)	*Paraeuchaeta sp.*
Clausocalanus pergens (FARRAN 1926)	*Phaenna spinifera* (CLAUS 1863)
Clytemnestra gracilis (CLAUS 1891)	*Pleuromamma abdominalis* (LUBBOCK 1856)
Copilia mediterranea (CLAUS 1863)	*Pleuromamma gracilis* (CLAUS 1863)
Corycaeus (Agetus) flaccus (GIESBRECHT 1891)	*Pleuromamma robusta* (F. DAHL 1893)
Corycaeus (Agetus) typicus(KRØYER 1849)	*Pontella sp.*
Corycaeus (Corycaeus) clausi (F. DAHL 1894)	*Pseudhaloptilus eurygnathus* (SARS 1920)
Corycaeus (Onychocorycaeus) giesbrechti F. (DAHL1894)	*Pseudocalanus elongatus* (BOECK 1865)
	Rhincalanus cornutus (DANA 1849)
Corycaeus sp.	*Rhincalanus nasutus* (GIESBRECHT 1888)
Ctenocalanus vanus (GIESBRECHT 1888)	*Sapphirina iris* (DANA 1849)
Euchaeta pubera (SARS 1907)	*Sapphirina nigromaculata* (CLAUS 1863)
Euchirella curticauda (GIESBRECHT 1888)	*Sapphirina opalina* (DANA 1849)
Euchirella rostrata (CLAUS1866)	*Sapphirina sp*.
Euterpina acutifrons (DANA 1848)	*Scolecithrix bradyi* (GIESBRECHT 1888)
Gaetanus tenuispinus (SARS 1900)	*Scolecithrix danae* (LUBBOCK 1856)
Labidocera wollastoni (LUBBOCK 1857)	*Subeucalanus crassus* (GIESBRECHT 1888)
Lucicutia flavicornis (CLAUS 1863)	*Subeucalanus monachus* (GIESBRECHT 1888)
Lucicutia maxima (STEUER 1904)	*Temora longicornis* (MÜLLER 1792)
Lucicutia tenuicauda (SARS 1907)	*Temora stylifera* (DANA 1849)
Macrosetella gracilis (DANA 1848)	*Triconia conifera* (GIESBRECHT 1891)
Mecynocera clausi (THOMPSON 1888)	*Triconia minuta* (GIESBRECHT 1892)
Microsetella norvegica (BOECK 1864)	*Xanthocalanus obtusus* (FARRAN 1905)

Table 2: Dominance of copepods species communities (2008-2009).

	December	February	April	June	October	Habitat (Vives, 1982)
*Acartia clausi***	2.445	0.962	4.109	4.695	0.570	n-O
Acartia danae	0.005	0.012	0.029	0.000	0.001	n-O
Aetideus armatus	0.106	0.007	0.020	0.000	0.000	O
Calanoides carinatus	0.036	0.001	0.007	0.002	0.002	N-O
*Calanus helgolandicus***	0.846	0.025	0.461	0.023	0.078	N-O
Calocalanus pavo	0.001	0.205	0.105	0.001	0.023	n-O
Centropages chierchiae	0.186	0.003	0.118	0.029	0.426	N-O
Clausocalanus arcuicornis	0.476	0.465	0.014	0.004	0.012	N-O
Clausocalanus jobei	0.027	0.112	0.010	0.006	0.001	?
Clausocalanus ssp	0.322	-	0.002	0.000	-	
Corycaeus clausi	0.011	0.060	0.060	0.000	0.002	n-O
Corycaeus sp	0.065	0.646	0.000	-	-	
Corycaeus typicus	-	0.001	0.020	0.001	0.072	n-O
Euterpina acutifrans	0.011	0.031	0.683	0.969	0.157	N-o
Lucicutia flavicornis	0.064	0.071	0.001	0.000	0.004	n-O
Mecynocera clausi	0.001	-	0.003	0.000	0.075	n-O
Nanocalanus minor	0.471	-	0.059	0.001	-	N-O
*Neocalanus gracilis***	0.241	0.319	0.237	0.075	0.687	N-O
*Oithona similis***	0.119	0.866	0.840	0.021	0.330	N-o
Oithona linearis	0.033	0.006	0.005	0.000	0.000	N-o
*Oithona nana***	0.035	0.647	0.895	2.534	3.289	N-o
*Oithona plumifera***	0.172	0.762	0.745	0.026	0.108	N-O
*Oncaea venusta***	0.472	3.269	0.587	1.724	3.636	n-O
Onceae mediterranea	0.001	0.038	0.002	-	-	n-O
*Paracalanus parvus***	0.248	0.860	0.133	0.595	0.935	N-o
Paracalanus sp.	0.022	0.013	-	-	-	
Paraeucheta hebes	0.046	0.001	0.000	0.000	0.004	?
Pleuromamma gracilis	0.181	0.139	0.000	0.000	-	n-O
Temora stylifera	0.245	0.009	0.588	0.007	0.313	N-o

** Dominant species on the five periods.
A threshold value of Y≥0.02 (CHEN et al. 1994; XU & LI 2005; GUO & HUANG 2011) was applied to determine dominant species.
Habitat: (N-o) neritic, (N-O) neritic-oceanic, (n-O) Ocean-neritic, and (O) oceanic.

For each dominating species, the information on the habitat was analyzed by the work of synthesis achieved by (VIVES 1982) (Table 2). The species are divided equitably into neritic, neritic-oceanic, and Ocean-neritic depending on the habitat where they were most found.

The deep-water species such as *Calanus helgolandicus* (FLEMINGER & HULSEMAN 1973), *Calanoides carinatus* (Smith 2000) and *Ctenocalanus vanus* (SWELL 1948; VERVOOT 1963) have been identified mainly in April and June. Thus, supporting the results of ocean parameters, and reflecting the resurgence of deeper colder water to shallower depths. The results comparison concerning the copepods distribution along the west African coast is summarized in the following table (CORRAL 1970; BELFQUIH 1980; NYKJAER & VAN CAMP 1994; CHIAHOU & RAMDANI 1997; YOUSSARA et al. 2000) (Table 3). The seasonal variations (quantitative and qualitative) for abundant species indicate special preferences to some environmental parameters. This ecological succession was characterized by the appearance of cold-water species (*Calanoides carinatus, Ctenocalanus vanus*), the diversification of phytophagous species (*Neocalanus gracilis, Oithona nana, Oithona similis*, *Oithona plumifera, Paracalanus parvus, Calanus helgolandicus*) and omnivores (*Oncaea venusta, Acartia clausi*). These copepods seem particularly suited to consume the increased primary production that survives and proliferates from the upwelling. This indication is important specified by (RAZOULS 1988) and (JOUFFRE 1989). The variations of the biological and physical parameters can explain the distribution of the zooplankton, with a dominant contribution of the hydrological factors (DALY & SMITH 1993; TILSTONE et al. 2000).

Table 3: Copepods composition along the Moroccan Atlantic coast.

Zone	Longitude	dominant species	References
Cap Ghir	31°N	*Acartia clausi* *Oncaea venusta*	SALAH et al. 2012
Cape Blanc to Cape Boujdor	21° 0’N-26°30’N	*Acartia clausi* *Calanus helgolandicus* *Centropages typicus* *Paracalanus parvus*	SOMOUE et al. 2005
Cape Ghir	30° 36’ 1’’ N	*Acartia clausi* *Paracalanus parvus*	YOUSSARA et al. 2004
El Jadida	33°2'N	*Acartia clausi* *Calanus helgolandicus* *Paracalanus parvus*	CHIAHOU & RAMDANI 1997
Moroccan Atlantic coast	10°N-33°N	*Acartia clausi* *Centropages chierchiae* *Centropages typicus* *Clausocalanus arcuicornis* *Clausocalanus furcatus* *Euterpina acutifrons* *Oithona nana* *Oithona similis* *Paracalanus parvus*	BELFEQUIH 1980
Canary Island Region	28°5'N-29°5'N	*Clausocalanus arcuicornis* *Oithona plumifera* *Temora stylifera*	CORRAL 1970

4.3. Diversity and structure

The high richness is recorded in June and in October on the offshore of the studied area, and the seasons where the upwelling was intense in this region (Fig. 3). It is explained by the cold water rises rich cold deep-waters species and therefore, mainly related to the increase in the zooplankton biomass and the copepods density saved during these two periods. In the open ocean of Cape Ghir, the diversity and regularity are higher and structured. The hydrological conditions are exposed to less variation. For comparison with other upwelling ecosystems, In the California coastal upwelling areas, the specific diversity is low and the species dominance is high and linked to increased biomass.

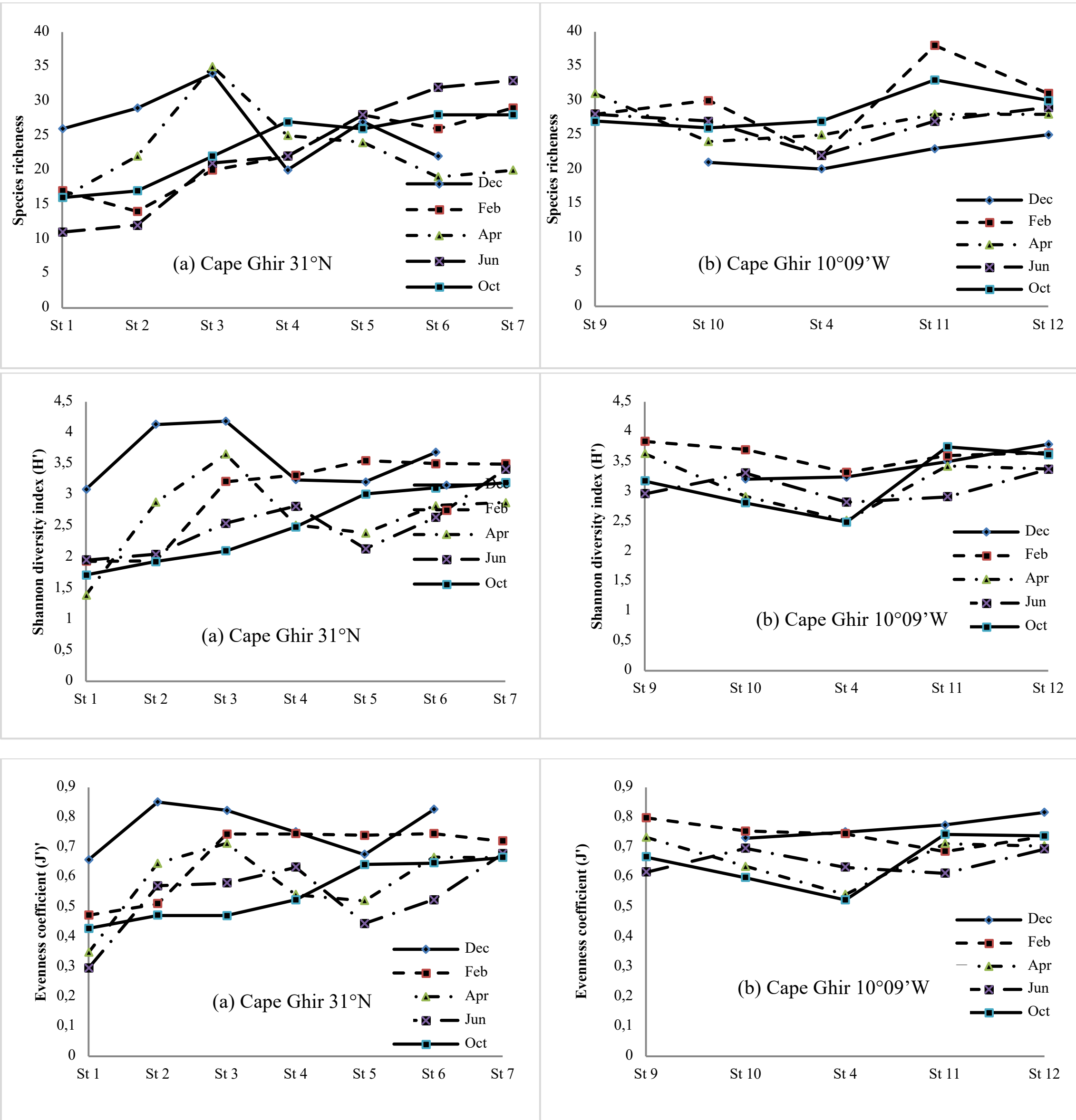

Figure 3: Variations in species richness, the Shannon diversity index (H') (equation 3), and evenness coefficient (J') (equation 4).

LONGHURST 1967 showed that in the California Current, the number of species per plankton is highest in areas of mixing of different ecosystems by vertical superposition of water masses of different origin. In the Benguela Current frontal zone, a similar situation was observed by (BINET 1970) which is also dominated by coastal upwelling. In the Alboran Sea and particularly in the area of the forehead Almeria-Oran, (SEGUIN et al. 1994) have shown that the copepod community structure is linked to the physical and trophic environment of the area. This is in agreement with the results obtained in the Cape Ghir filament during the summer season when the upwelling is intense. In the Moroccan Atlantic waters, (BOUCHER 1987) and (SOMOUE 2004) have emphasized that the specific diversity is higher in the waters of the offshore compared to the coastal waters. Thus, closer to the coast, where the influence of the upwelling is stronger, the hydrological conditions are less stable and, in these conditions, the community suffers more constraints and, thus, it is less structured. The copepod structure is related to the hydrological environment.

4.4. Copepods relations species with environmental parameters

The analysis of some species distribution (*Paracalanus parvus, Oncaea venusta, Acartia clausi, Oithona nana and Euterpina acutifrons*) shows some correlations with the chlorophyll 'a' and nutrients. However, the distribution of others species (*Oithona plumifera, Oithona similis* and *Clausocalanus arcuicornis*) are correlated with the increase of temperature and salinity. In fact, nitrogen and phosphorous nutrients (NO_2, NO_3, NH_4 and PO_4) are used by the phytoplankton which is a source of nutriment for the majority of the zooplankton species. These substances constitute the factors determining in the explanation of the distribution and the abundance of these copepod species (Fig. 4).

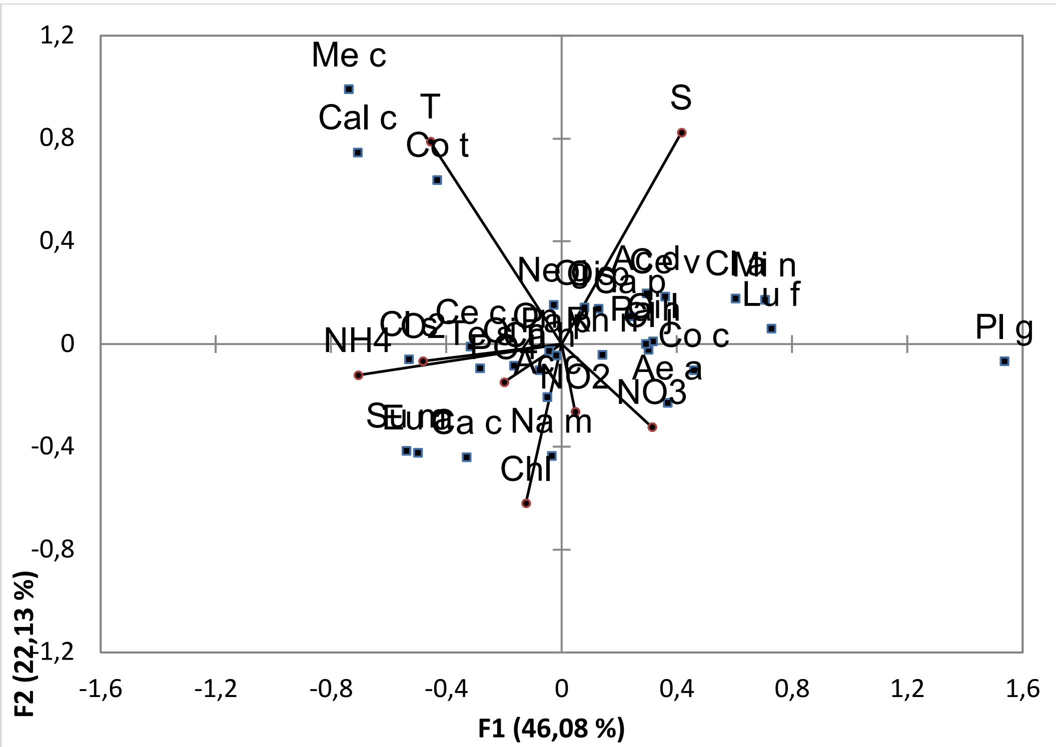

Figure 4: The Canonical Correspondence Analysis (CCA) performed on the copepod species in relation to the hydrological parameters.

4.5. Analysis of global quotient relative to the environmental parameters

The Environmental Preference Habitat (EPH) of the dominant copepod species (*Acartia clausi, Calanus helgolandicus, Neocalanus gracilis, Oithona nana, Oithona similis, Oithona plumifera, Oncaea venusta and Paracalanus parvus*) was determinate. For this, the global quotients were calculated in relationship with each of the hydrological and productive parameters (LLUCH-BELDA et al. 1991; VAN DER LINGEN et al. 2001). Those parameters considered the most influencing on the distribution of these species (Table 4). The parameters taken into consideration are the temperature, the chlorophyll 'a' and the nutrient salts: nitrogen (NO_2, NO_3 and NH_4). Generally, a ratio (quotient) >1 indicates a positive selection of the habitat by the species considered. The quotient analysis, allowed illustrating the effect of the environmental parameters. The neritic copepods *Acartia clausi* seems adapted to the low concentrations of chlorophyll 'a'. It seems to be not opportunist and omnivore (COTENNEC et al. 2001; ANNABI-TRABELSI et al. 2005), because of its incapacity to feed on the phytoplankton below a certain concentration (THOR 2000). It's capable of adapting to any type of nutriments (MAUCHLINE 1998).

Table 4: Environmental Preference Habitat of dominant copepods relative to hydrological and productive parameters.

	Environmental Preference Habitat		
	Temperature	Chlorophyll 'a'	Nutrient salts nitrogen
Acartia clausi	17-17.5	0.25-0.3	1-1.5
Calanus helgolandicus	16-17.5 19-19.5 20-20.5	0.3-0.35	0.5-1 1-1.5
Neocaalanus gracilis	17-17.5 19-19.5	0.1-0.15 0.25-0.3 0.35-0.4	0.5-1 1-1.5
Oithona nana	17-17.5	0.25-0.3	1-1.5
Oithona similis	16.5-17 19-19.5	0.1-0.15 0.3-0.4	0.5-1
Oithona plumifera	16.5-17.5 19-19.5	0.1-0.15 0.3-0.4	0-0.5
Oncaea venusta	16.5-17.5	0.25-0.3	1-1.5
Paracalanus parvus	16.5-17.5	0.25-0.3	1-1.5

Calanus helgolandicus, essentially herbivore (MAUCHLINE 1998), presents a period of intrusion in April and June essentially near to the coast coinciding with the strongest chlorophyll concentrations. This species seems to find the favorable trophic conditions for development in a high concentration of chlorophyll 'a', consequently to nutrients and independent to the temperature values of water. For *Paracalanus parvus*, species typically herbivorous (RAYMONT 1967) presents a maximal frequency in April, June and in October. The *P. parvus* density depends on the variations of temperature and chlorophyll 'a'. In fact, the range of preferable temperature and chlorophyll 'a' is low. The species *Oithona similis*, frequent and dominant in the all the year, is indifferent regarding the variation of the chlorophyll and temperature. This latter is an herbivorous species even more selective to the phytoplankton groups (CASTELLANI et al. 2008; NISHIBE et al. 2010). However, *Oithona nana* presented a period of intrusion throughout the year. This coincides with the average concentrations of chlorophyll 'a'. The ability of this species tolerates the variations in the chlorophyll and temperature would be linked to its low respiratory rate and its omnivorous diet (LAMPITT et al., 1982), the phytoplankton which is the main source of food (KRSINIC et al. 2007). Similarly, *Oithona plumifera* and *Neocalanus gracilis*, herbivorous species, were adapted to the large levels in chlorophyll 'a' and temperatures. As for *Oncaea venusta*, it is present during all years and pronounced indifferently to the type of season. It is an omnivorous species (Turner, 1986), detritivore (YAMAGUCHI et al. 2002), feeding also of large zooplankton, such as the chaetognaths and *appendicularians* (GO & TERAZAKI 1998). Each species is subject to a factor. The herbivorous species (*Paracalanus parvus, Calanus helgolandicus*) are associated with the chlorophyll 'a'. The omnivorous species show a correlation with chlorophyll 'a', and reflecting the interrelations between these two links of the alimentary chain.

5. Conclusion

The cold waters and upwelling filaments assure an export of nutrients and primary production to the open sea, and constitute the basic sequence for phytoplankton development, consumed by most zooplankton. In structure terms, copepods are predominantly coastal species, and best adapted to the environmental and trophic conditions variability. Moreover, some species are more specifically related to hydrodynamics movements, such as *Calanus helgolandicus,* transported by the Canary Current, or *Calanoides carinatus* and *Ctenocalanus vanus*, that characterize the upwelling zones. The influence of Cape Ghir upwelling has an impact on zooplankton composition and variability, as well as for abundance and temporal distribution. These trophic fluctuations seem to be determined by the hydrological fluctuations caused by the upwelling and exercised on the ecosystem.

These results join those established for zooplankton (MACKAS et al. 1991) and for phytoplankton (JONES et al. 1991; STRUB et al. 1991). The enrichment of waters in nutrients promotes the phytoplankton production, necessary for herbivores copepods. However, other copepods remain strictly related to the physical factors such as the temperature or particularly associated to hydrological formations (KOVALEV et al. 2003; FERNANDEZ DE PUELLES et al. 2003; DEVREKER et al. 2005; SOUISSI et al. 2008). The temperature and chlorophyll 'a' seem to be the important factors for the determination of preferential habitats of dominant copepods. The temperature is an important factor for the growth of copepods populations acting and on the rate of their reproduction and their proliferation (LAMPITT et al. 1982; TURNER 1986; KRSINIC et al. 2007; NISHIBE et al. 2010).

The phytoplankton is a source of nutriment for the zooplankton phytophagous, and influences the temporal distribution of the zooplankton (STRUB et al. 1991; VIEVIRA et al. 2003; DEVREKER et al. 2005). Nevertheless, all environmental parameters were interdependent in the marine ecosystem. The nitrogen, for example, is an essential element involved in the increase of phytoplankton in the marine ecosystems. Its deficiency contributes to a decrease of these micro-algae (VITOUSEK & HOWARTH 1991; LIVINGSTON 2001). The quality of the nutrient pool available to the zooplankton influences the copepods species structure. Similarly, the factors intra-interspecific and the migration may appear as elements that are involved in the disposition of plankton. On conclusion, the physical conditions and trophic link are closely nested in the ecosystem.

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Relationship between migratory behavior and environmental features revealed by genetic structure of *Sardina pilchardus* populations along the Moroccan Atlantic coast

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Abstract. We used genetic markers, namely allozymes, to study the genetic structure (stock unit) and the sardine stocks movement along the Moroccan Atlantic coast and its relationship regarding the environmental features, especially upwelling. In this study, we have combined previous results obtained by analyzing eight samples collected during the spawning season (winter 2004) (chlaida et al.2008) and new data obtained by analyzing eight samples gathered during the feeding season (summer 2006). Therefore, we compiled 765 individuals from an earlier study and the 2006 summer sampling and compared seasons' results. In winter, a substantial heterogeneity (Fst =0.205) is described, with a significant genetic break in the Agadir Bay (latitude 30° 48' N) that cuts the coastal sardine populations in the Moroccan Atlantic into two stocks (north and south). In summer, the genetic structure showing two groups is maintained (Fst= 0.135). Still, the genetic break separating the two stocks arises southward, near Tarfaya (latitude 28°08'10" N), suggesting a spreading out towards the south of the northern stocks. This result seems to be related to the sardine movement along the Moroccan Atlantic coast regarding reproduction needs in winter and for trophic reasons in summer. The species' observed genetic break and seasonal activity along the Moroccan coast are expected to result from the Cape Ghir Hydrological barrier, impermeable in winter and semi-permeable in summer. This barrier comprises currents, gyres, and different mesoscale structures related to upwelling dominating in this zone.

Keywords*:* *Sardina pilchardus*, migratory behavior, genetic structure, upwelling, Moroccan Atlantic coast.

1. Introduction

Small pelagic population size and abundance fluctuate significantly from year to year, mainly due to strong variability of recruitment, overfishing (PARRISH et al. 1989; GAGGIOTTI et al. 1999; SCHWARTZLOSE et al. 1999; CENDRERO et al. 2002). However, the real challenge is the management of small pelagic fisheries due to climatic and hydrological variations, as well as variation in seasonal migrations of species (LLUCH-BELDA et al. 1989; CURY 1994; GUISANDE et al. 2001; FAO 2004). Therefore, the assessment of intra-specific diversity and determining the geographical extent of sustainable populations or groups of sub-populations linked by gene flow is vital for managing marine resources to ensure lasting exploitation (ILES & SINCLAIR 1982; GRANT et al. 1999). For example, the European sardine (*Sardina pilchardus* Walbaum 1792) is a clupeoid found in the Atlantic, from the Celtic Sea and the North Sea to south Mauritania, together with populations in the Mediterranean and the Black Sea. On the other hand, populations of Madeira, the Azores, and the Canary Islands are at the western limit of the distribution (PARRISH et al.1989). Occasionally, populations may be found as far south as Senegal during episodes of low water temperature (CORTEN et al. 1996; BINET et al. 1998).

Sardines are the most abundant and commercially important fish species on the Moroccan shelf, with annual purse seine catches exceeding 650,000

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tons. These total catches represent about 70% in the 2000s (FAO 2008). However, the stocks and populations dynamics of this species remain not well-known. Former studies conducted on sardine population's identification in (CHLAIDA et al. 2005; LAURENT et al. 2007; ATARHOUCH et al. 2007; CHLAIDA et al. 2008)] and its ichthyologic aspect FURNESTIN & FURNESTIN 1970; BELVÈZE 1984; ETTAHIRI et al. 2003; BERRAHO 2007) brought important information regarding the reproduction and the genetic structure of sardine stocks. Nevertheless, the stock definition requires knowledge of the fish's life history, migrations, mortality, and strategic adaptation to deal with the environmental fluctuations to which the species is permanently exposed (AGENBAG et al. 2003). Moreover, this knowledge can help understand this pelagic fish's behavior with relatively high migratory capacities. Indeed, this species is characterized by a high gene flow that is accelerated by a strong dispersion. In addition, the adequate size of this population opposes genetic drift (WAPLES 1989; GONZLES & ZARDOYA 2007). Homogenizing forces linked to the hydrodynamic environment characterize this flow. This is notably the case of the northwestern African coasts with the Canary Current and the upwelling phenomenon (LE FLOCH 1974; BELVÈZE &ERZINI 1983) For this reason, each piece of the information constitutes a new element in the understanding of sardine stocks.

Based on biological certainties, these informations allow sardine stocks delimitation that characterizes its migratory flow (direction and amplitude) and adapts management plans for Moroccan sardine fisheries. We used enzyme polymorphism (allozymes) to compare opposite seasons (winter and summer) and to understand the sardine movement along the Moroccan Atlantic coast by investigating the relationship between genetic results and migratory behavior with the upwelling conditions (CHLAIDA et al. 2008; and new data). This is due to the availability and diversity of information using genetic markers, the definition of geographical limits and stock evolution (RICO et al. 1997; EXADACTYLOS et al. 1998 ; GUARNIERO et al. 2002), as well as life history monitoring (BORSA et al. 1997; GRANT & BOWEN 1998; GILLES et al. 2000) and the study of the migration and the estimation of the fish dispersal rate (SOTKA & PAUMBI 2006; PLANES & RAMOS 2004), we used enzyme polymorphism (allozymes) to compare opposite seasons : winter (CHLAIDA et al. 2008) and summer (new data) and understand the movement of the sardine along the Moroccan Atlantic coast by investigating the relationship between genetic results and migratory behavior in relation to the upwelling conditions.

2. Material and methods

2.1 Sampling

To compare the genetic structure observed during the 2004 spawning season (CHLAIDA et al. 2008) to that of the feeding season, another batch of 8 samples of sardines, with 50 individuals per sample, were collected along the Moroccan Atlantic coast on board the R/V "Al Amir Moulay Abdallah" in July 2006 (Fig. 1). Fishes were dissected to isolate the liver and a piece of muscle. Each piece of tissue was manually grounded in 1 ml of pure water on a bench of ice to limit any degradation of the enzymatic activity. Homogenates were sub-divided in 4 Eppendorf and then stored at -30°C.

2.2 Allozymes electrophoresis.

For 2006 Sampling, we only surveyed polymorphic loci described in earlier studies (CHLAIDA et al., 2005; Laurent et al., 2006; CHLAIDA et al., 2008), SOD* [EC.1.15.1.1] and PGM* [EC 2.7.5.1] (SHAKLEE et al. 1990) for locus nomenclature). Alleles were separated on horizontal starch gel electrophoresis following the technique of Pasteur et al. (1987) and using TG (pH=9) buffer. Alleles and genotypes were scored according to SHALKLEE et al. (1990) with the most common allele in the first sample being designated as 100. The other variants were subsequently according to SHALKLEE et al. (1990), we scored Alleles and genotypes, with the most common allele in the first sample designated 100. The other variants were subsequently numbered according to their electrophoretic mobilities relative to the most common allele.

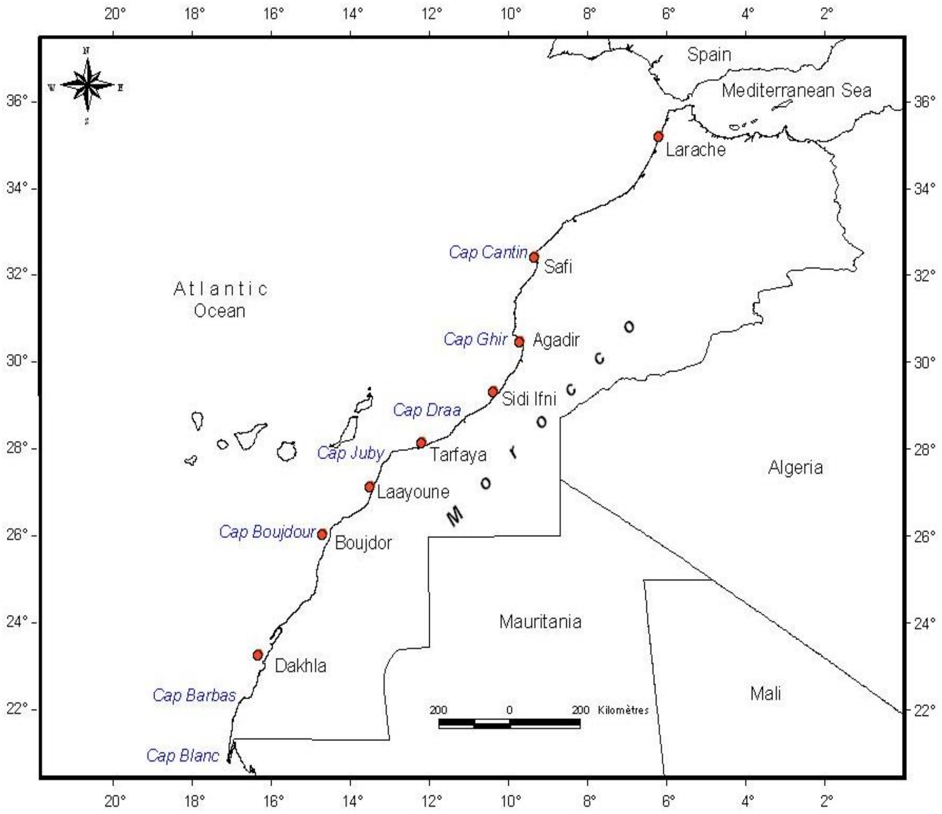

Figure 1: Map of the Moroccan Atlantic coast showing the location (red spots) of sardine sampling site.

2.3 Genetic data analysis

Allele and genotype frequencies were obtained by counting phenotypes directly from the gels and analyzed with the GENETIX 4.05 package (BELKHIR et al. 1996-2004) (http://www.univ-montp2.fr/genome-pop/genetix.htm). Departure from the Hardy-Weinberg proportions was assessed with the fixation index (FIS) and statistically tested using the Markov chain method implemented in Genepop 3.4 (RAYMOND & ROUSSET 1995). We adjust the level Significance for statistical tests according to the standard Bonferroni procedure (RICE 1989). In addition, we used Wright's standardized variance in allele frequencies (F_{ST}) to perform Genetic divergence among pairs of samples (WRIGHT 1969). Following the method of Weir and Cockerham (1984), calculate this index (F_{ST}) using the all-samples algorithm. Therefore, we adjusted the level significance according to the sequential Bonferroni procedure (RICE 1989). Finally, we tested the genetic structure using the hierarchical analysis of molecular variance (AMOVA) implemented in ARLEQUIN v. 2.000 000 (SCHNEIDER et al. 2000; EXCOFFIER et al. 1992).

The AMOVA provided estimates of the portion of the observed total variance accounted for within and among groups of samples. The objective was to test for the best grouping by maximizing the variance among groups while minimizing the variance within groups. Statistical significance was determined using a permutation of genotypes among groups (> 1000 permutations).

3. Results and discussion

Statistical analyses showed that overall samples analysis was in Hardy-Weinberg equilibrium (FIS = -0.0306, p<0.732). Furthermore, the Observed heterozygosity (Ho) in Laâyoune 2006 and Safi 2004 is respectively ranged from 0.071 to 0.310; while the expected heterozygosity (He) is ranged among similar values, from 0.067 (in Laâyoune 2006) to 0.276 (in Safi 2004), (Table 1). Thus, all samples were in Hardy-Weinberg equilibrium after standard Bonferroni correction of the threshold value.

The overall genetic differentiation was highly significant with F_{ST} = 0.135 (p<0.000). This differentiation is the result of the variation of a single locus, enzymatic system SOD (Super Oxyde Dismutase). A comparison of SOD* allele frequencies (Table 1) shows a structured spatial variation of allele frequency with a north-south gradient as well as and a temporal variation (i.e., see allele frequencies in Tarfaya in 2004 compared as in 2006). The test of genetic differentiation test for all pairs of samples illustrates allele frequencies differences (Table 2). In both seasons, the F_{ST} estimates obtained for the southern samples (Dakhla, Laâyoune, Boujdour) are indeed not significant with F_{ST} estimates of 0 - 0.02 (all p-values non-significant after Bonferroni corrections). Consequently, these populations can be considered to be homogenous. Also, the northern samples (Agadir, Safi, and Larache) belong to a second homogeneous group irrespective of the season (F_{ST} estimates obtained among these samples of 0 – 0.106, all p-values non-significant after Bonferroni correction) (Table 2). Among the two seasons, we noticed differences in the transition zone between northern and southern groups identified earlier. Indeed, the Tarfaya sample appeared genetically homogeneous to the southern group in winter (F_{ST} of 0.00). At the same time, in summer it made a homogenous entity with the northern group, being then significantly different from the southern group (F_{ST} of 0.142-158, p<0.001, Table 2). Likewise, Sidi Ifni appeared homogeneous to the northern stock in summer while it was significantly differentiated from it in winter (though F_{ST} estimates < 0.10). The global F_{ST} estimate reaches 0.205 (p<0.000) (result of CHLAIDA et al. 2008) in winter and 0.135 (p<0.000) in summer (2006 data), suggesting summertime movement and/or a mixture of the two stocks. We evaluated the best groupings by testing the significance of two different segregations with an AMOVA (Table 3).

The results of the AMOVA showed that grouping the samples in 2 groups (North and South) with the Sidi Ifni sample of 2004 in the northern group explained 20.12 % of the total variance (p<0.000), with 1.65 % (p<0.000) of the total variance being explained within groups. However, when the Sidi Ifni sample of 2004 (winter) is included in the southern group, the results are nearly identical, explaining 19, 65 % (p<0.000) of the total variance (1.72% (p<0.000) being explained within groups). This result confirms the intermediate position of the Sidi Ifni sample from 2004 (CHLAIDA et al. 2008) suggesting that this sample may be composed of a mix of the two stocks.

The electrophoresis allozyme survey, during winter and summer, reveals the existence of two large sardine populations segregated along the Moroccan coast. The first one was located on the southern coast of Morocco and included the samples from Laâyoune, Boujdour, and Dakhla; the second northern population consisted of Agadir, Safi, and Larache samples (See sample location on Fig. 1). Although SOD* loci mainly drove the analyses, this genetic structure was stable during the two winter seasons, 2003 and 2004 (CHLAIDA et al. 2005; 2008) and 2006 data of summer season. These two large homogeneous populations are set apart by more than 200 km transition zone located between Cape Juby (latitude ~28°N) and the Agadir-bay (latitude 30°38’N) (Fig. 1). Considering the switch in allele frequencies, in summer and winter periods, the Tarfaya samples and the distinctiveness of the Sidi Ifni sample (northern and southern stocks), our results suggest that this zone is successively occupied in winter by sardine of the southern stock and in summer by those of northern stock. Thus, the limit of the two stocks is placed between Laâyoune and Tarfaya in summer (possibly at Cape Juby) and around Sidi Ifni in winter. (see Figure 2 for seasonal distribution).

Table 1: Allele frequencies and gene diversity for each sample of S. pilchardus. N = sample size (N), Ho = observed heterozygosity, He = expected heterozygosity, Fis = Wrights' fixation index.

Locus/Population

SOD	**Lar.04**	**Saf.04**	**Aga.04**	**S.Ifni.04**	**Tarf.04**	**Lay.04**	**Boj.04**	**Dakh.04**	**Lar.06**	**Safi.06**	**Aga.06**	**S.Ifni.06**	**Tarf.06**	**Lay.06**	**Boj.06**	**Dakh.06**
(N)	**49**	**50**	**43**	**50**	**50**	**50**	**50**	**30**	**46**	**50**	**50**	**49**	**50**	**49**	**50**	**49**
80	0.459	0.440	0.337	0.230	0.080	0.090	0.040	0.067	0.565	0.370	0.310	0.316	0.300	0.061	0.050	0.051
100	0.541	0.560	0.663	0.770	0.920	0.910	0.960	0.933	0.435	0.630	0.690	0.684	0.700	0.939	0.950	0.949

PGM

(N)	**50**	**50**	**50**	**50**	**50**	**50**	**50**	**30**	**50**	**50**	**50**	**49**	**50**	**50**	**50**	**50**
100	0.990	0.970	0.990	0.950	0.960	0.970	0.950	0.967	0.990	0.990	0.960	0.980	0.970	0.990	0.970	0.910
150	0.010	0.030	0.010	0.050	0.040	0.030	0.050	0.033	0.010	0.010	0.040	0.020	0.030	0.010	0.030	0.090
Ho	0.245	0.310	0.254	0.240	0.120	0.120	0.090	0.100	0.249	0.300	0.270	0.194	0.270	0.071	0.080	0.101
He	0.258	0.276	0.233	0.225	0.112	0.111	0.086	0.094	0.256	0.243	0.252	0.236	0.239	0.067	0.077	0.130
Fis	0.063	-0.115	-0.077	-0.059	-0.061	-0.071	-0.038	-0.042	0.036	-0.225	-0.060	0.189	-0.119	-0.047	-0.034	0.238

Table 2: F_{ST} pairwise estimates among all sites with emboldened values representing statistically significant differences after Bonferroni correction

	Safi.04	Aga.04	S.Ifni.04	Tarf.04	Lay.04	Boj.04	Dakh.04	Lar.06	Safi.06	Aga.06	S.Ifni.06	Tarf.06	Lay.06	Boj.06	Dakh.06
Lar.04	-0.008	0.019	**0.092**	**0.274**	**0.263**	**0.334**	**0.273**	0.010	0.006	0.034	0.029	0.040	**0.320**	**0.328**	**0.300**
safi.04		0.011	**0.073**	**0.244**	**0.234**	**0.301**	**0.242**	0.020	0.002	0.022	0.019	0.028	**0.288**	**0.295**	**0.268**
Aga.04			**0.018**	**0.159**	**0.147**	**0.220**	**0.163**	0.086	-0.007	-0.007	-0.011	-0.006	**0.200**	**0.210**	**0.191**
S.Ifni.04				**0.054**	**0.047**	**0.096**	**0.059**	0.184	0.035	0.004	0.007	0.002	**0.084**	**0.090**	**0.077**
Tarf.04					-0.009	-0.001	-0.012	**0.390**	**0.186**	**0.119**	**0.130**	**0.113**	-0.003	-0.004	0.003
Lay.04						0.005	-0.010	**0.380**	**0.175**	**0.109**	**0.119**	**0.104**	-0.003	-0.001	0.010
Boj.04							-0.007	**0.449**	**0.245**	**0.170**	**0.185**	**0.166**	0.004	-0.007	-0.003
Dakh.04								**0.386**	**0.189**	**0.122**	**0.133**	**0.118**	-0.009	-0.011	-0.001
Lar.06									0.062	0.106	0.102	0.117	**0.439**	**0.445**	**0.409**
Safi.06										0.000	-0.004	0.003	**0.228**	**0.237**	**0.216**
Aga.06											-0.010	-0.009	**0.155**	**0.163**	**0.144**
S.Ifni.06												-0.010	**0.167**	**0.176**	**0.160**
f.06													**0.149**	**0.158**	**0.142**
Lay.06														-0.006	0.021
Boj.06															0.006

Table 3: AMOVA results comparing two groups of *Sardina pilchardus*. (A) Group 1 = samples from Larache 2004, Larache 2006, Safi 2004, Safi 2006, Sidi Ifni 2004, Agadir 2004, Agadir 2006, Sidi Ifni 2006, Tarfaya 2006; Group 2 = samples from Tarfaya 2004, Laayoune 2004, Laayoune 2006, Boujdour 2004, Boujdour 2006, Dakhla 2004, Dakhla 2006. (B) same grouping except that Sidi Ifni 2004 is moved to Group 2.

Source of variation		d. f.	Variance components	%
A	Among groups	1	33.93	20.12***
	Among samples within groups	14	7.3	1.65***
	Within samples	1544	263.37	78.23***
B	Among groups	1	33.76	19.65***
	Among samples within groups	14	7.46	1.72***
	Within samples	1544	263.37	78.23***

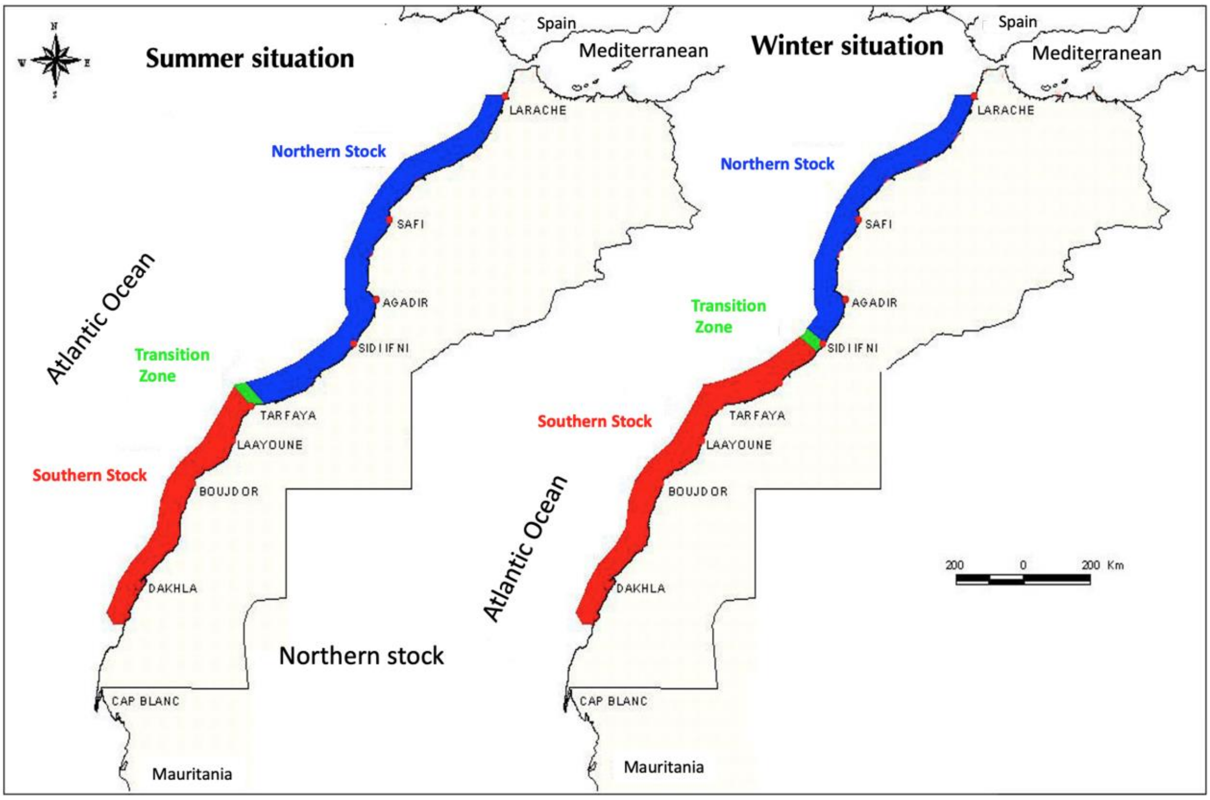

Figure 2: Summary Map showing seasonal distribution of sardine stocks along the Moroccan Atlantic coast

Several authors have already described massive sardine movements along the Moroccan Atlantic coast (FURNESTIN & FURNESTIN 1970; JOHANNESON et al. 1975; FAO 1978; LAMBOUF 1977; BELVÈZE & ERZINI, 1983; BELVÈZE, 1972, 1984). The small pelagic fish can undertake large migrations seasonally. Therefore, our results confirm that sardines undergo seasonal drifts along the Atlantic coast. These movements depend on the developmental stage, nutrient availability, reproduction, and thermal conditions of the study area (OLIVAR et al. 2001; RIVEIRO et al. 2000).

The global hypothesis suggests that the sardine coming from the south migrate northwards during the summer season. This idea is supported by significant sardine catches conducted by fishing vessels operating between Safi and Sidi Ifni. Encouraged by wide sardine availability, fishing activity indeed increases during the summer season (BELVÈZE, 1984; FAO 1985; KIFANI. 1991). Authors of the abovementioned studies stated that the sardines migrate back to the south for reproduction purposes during winter. Other works reported that sardines from the south concentrate in Dakhla during this spawning season (DOMANOVSKI & BARKOVA 1976). However, neither the direction nor the amplitude of this migratory flow has been verified using molecular techniques or tagging experiments. Near the Moroccan Atlantic Coast, in the North-Eastern Atlantic, and within the framework of SARDYN Project (2002-2005), only one trial of sardine tagging has been undertaken. The results of this campaign were promising regarding the survival in captivity of the marked individuals. Still, the experiment was not concluding about fish movement, primarily because of the meager percentage of recaptured (SARDYN report).

Regarding the direction of this migration, our results confirm that Moroccan sardines undergo seasonal migrations, except that these are not consistent with what has been admitted. The genetic analyses have revealed that in winter, the southern population scatters from the Cape Blanc (19°03'N) to the south of Sidi Ifni (29°12' N) (CHLAIDA et al. 2005; ATTARHOUCH et al. 2007; CHLAIDA et al. 2008; and summer samples included in this study), While in the summer, its northern limit arose south to the winter season limit, between Laâyoune and Tarfaya (28°08'10"N). Consequently, our results suggest a sardine migration towards the south in summer, contrary to previously stated.

The winter season corresponds to the main spawning period since 90% of the analyzed sardines were spawning (unpublished personal data). Furthermore, the eggs and larvae study carried out between 1996-2006 (ETTAHIR et al. 2003; BERRAHO et al. 2007). confirms our results. The latter indicates that during winter, the south stock undergoes an extension northward to spread out towards the Sidi Ifni zone during spawning reasons. In contrast, the northern stock concentrates north of Sidi Ifni, yielding the niche available for the southern stock. This winter migration pattern would correspond to a need from genitors to spawn in propitious zones for early survival stages (BAKUN, 1989; 1996). Indeed, several spawning grounds have been identified along the Moroccan coast, between Cape Ghir (30°37'N) - Cape Cantin (~32°30'N), between Cape Juby - Cape Draa (~28°N -29° N), and between Cape Boujdour and Cape Barbas in the south (~26°-22°N) (see Fig. 1 for caps location). These areas have favorable hydrological and/or geomorphological characteristics (wide and shallow continental shelf) in favor of better water retention, as well as nutrients for adult species (BKAUN, 1996; ETTAHIRI, 1996).

In summer, the reverse phenomenon would occur. The southern stock will be concentrated between Dakhla and Cape Juby (its northern limit), leaving the Sidi Ifni - Tarfaya zone to the sardines of the north stock, which spreads out southwards to the south of Tarfaya. This result contradicts some previous acoustic observations in this area, indicating that, in summer, sardines coming from the south form the fisheries located between Safi and Agadir, particularly from the zone between Sid Ifni and Laâyoune (LAMBOUF, 1977; FAO, 1985). The southward drift of the northern stock is likely driven by trophic purpose since spawning is weak during this period (ETTAHIRI et al. 2003; BERRAHO et al. 2007). This expansion would then occur after the spawning period and recruitment of new individuals (June-July). Indeed, during summer, the upwelling activity increases along the Atlantic Moroccan coast, ensuring a significant abundance of nutrients and subsequent primary production (BELVÈZE 1984; MAKAOUI et al. 2005). Concerning the area of Dakhla, the upwelling activity is permanent with intensification in summer, guaranteeing enough nutrients for each member of the population. Therefore, individuals of the southern stock would not have to move northward in search of food.

4. Conclusion

Through this study, we have clearly shown that *Sardina pilchardus* is a small pelagic resource that is known to be a highly fluctuating marine species. This high variability is mainly attributed to their strong dependence on the marine environment and their adaptive strategies to ensure their survival in a changing environment. We have also shown that, in addition to the spatial delimitation of stocks, genetic markers can also provide important information concerning fish migrations. For *Sardina pilchardus*, in the Moroccan Atlantic coast, the results of this genetic analysis disagree with previous assumptions related to seasonal migrations, namely those proposed by FURNESTIN & FURNESTIN (1970) and BELVÈZE & ERZINI (1983). The patterns of sardine movements drawn from the present investigation suggest that during winter, sardines carry out a migration following a south-north direction, likely linked with a reproduction purpose. During summer, they undertake a trophic north-south migration. These movements are conditioned by the hydro-climatic factors which vary according to the season (JOHNSON & STEVENS, 2000; BARTON et al., 2004; PELEGRI et al. 2005), and to the zone (BAKUN et al. 2015; XIU et al. 2018; FAO 2018). Future research should focus on a more acceptable spatio-temporal scale analysis to provide further details concerning seasonal sardine migrations that depend on the environmental conditions that change over time and space along the Moroccan Atlantic coast.

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