Phytoplankton communities under fluctuating hydrological upwelling conditions off Cape Juby (28°N) in the Canary Current System (Northwest Africa)

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Abstract— Phytoplankton in the Canary Current System coastal upwelling region is considered as an important compartment and play a significant role in the food web. This work studies the effect of hydrological conditions on the distribution and dynamics of phytoplankton communities of Cape Juby (28°N) from 2009 to 2010 at different seasons. A strong correlation was observed between the upwelling intensity fluctuations and the phytoplankton community quantitative variability. Multivariate analysis of the environmental and biological variables enabled highlight an important spatial and temporal variability in the community structure, closely related to sea water temperatures and macro-nutrients rates variations, particularily NH4 and PO4, governed by upwelling seasonnality that characterize cape Juby area.

Index Terms— Canary Current System, phytoplankton community structure; upwelling; hydrological parameters, Cape Juby (28°N).

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1 INTRODUCTION

Mesoscale features such as meanders, filaments and eddies have been suggested to be involved in the horizontal export of coastal waters containing higher nutrients, organic matter, and/or phytoplankton biomass than the adjacent waters in the CTZ (coastal transition zone) [1,2,3,4].

These processes modify the nutrient distribution in the photic or mixed layer and, thereby, influence the distribution and structure of planktonic communities, primary production and ecosystem functioning in the CTZ [5,6] but also affect the productivity of the coastal upwelling system[4] .

Moreover, the dynamics and species composition of phytoplankton communities in relation to hydrological conditions especially in areas of upwelling was studied in aquatic ecology [7] and several studies have described the characteristics and mechanisms of phytoplankton dynamics in the upwelling ecosystems [8 ,9,10,11,12,13,14,15].

At the Cap Juby area, several authors have been interested in the study of upwelling, and exchanges that take place between the African coast and the Canary Islands [16, 17]. [18] examined the transfer of organic material mechanisms through a filament from the African northwest coast to the Canary Islands and which would interact with eddies in front of Cape Juby. [19] were also interested in the variability of the structure of plankton communities in general and carbon flow along the filament Cap Juby, thus qualifying this filament of a complex and variable hydrological system in terms of structure, but also biological properties.

Furthermore, [1] studied the structure of zooplankton communities at Cape Juby under the influence of a filament generated by the upwelling.

However, the effects of upwelling processes and mesoscale activities on planktonic communities have been assessed mostly in terms of organic matter export and Chl-a distribution and no detailed study on the dynamics of the structure and taxonomic composition of phytoplankton, were conducted at Cape Juby, as at Cap Ghir where more work was begun on phytoplankton [20], ichtyoplankton [21], or zooplankton [22].

In these terms, the aim of this study is to evaluate the effects of variations in upwelling conditions, on the phytoplankton communities structure in the coastal transition zone off C. Juby (28°N). This area being described by [23] in terms of upwelling dynamic in 2010, we went therefore in this work, up to february 2009 for a much more extensive study.

2 MATERIAL AND METHODS

2.1 Study site, oceanographic samples

Within the framework of the oceanographic study of the pelagic ecosystem, the INRH institute organized, on board the N/R "Amir Moulay Abdellah (AMA)", seven oceanographic cruises relating to the study of the filament of the Cape Juby between February 2009 and August 2010.

Sampling concerned the Cape Juby zone (28°30N) (Fig.1). During each cruise, Five stations east-west oriented was sampled and five depth levels were considered except in shallowest stations (depth 1 : 0-5m, depth 2 : 25m, depth 3 : 50m, depth 4 : 90m and depth 5 : 150m) (Table 1). Hydrographic data were obtained with a CTD Sea Bird Electronic SBE 9-11 (temperature and salinity). Seawater samples were collected with Niskin Bottles for the analyses of phytoplankton species and macro-nutrients (NH4, NO2, NO3, PO4).

Phytoplankton samples were immediately preserved with a Lugol solution (2% final concentration), according to the Utermöhl method and observed under an inverted microscope (Nikon type). For the taxonomic identification, the following guides were used [24,25,26]. Results were expressed in densities (number of cells per liter (Cell.l-1). The cruises were conducted in two years 2009 and 2010 at different periods to assess the seasonal variability of different parameters.

Moreover, changes in the upwelling index (IUC) were also used to check the impact of upwelling on the dynamics of phytoplankton communities.

2.2 Statistical Analysis

A Canonical Correspondance Analysis "CCA" of the various parameters and phytoplankton species was applied in this study to assess the relationship that links species distribution to environmental parameters. This statistical analysis was performed using XL-STAT.

A threshold of 0.1% for adundance and 6 for occurrence were used to determine the phytoplankton species list used in the multivariate analysis [28, 29,1]

A first CCA concerned phytoplankton species distribution according to hydrological conditions (T°, S, NO3, NO2, NH4, PO4) variations (Fig 7B). And a second one to examine how stations from all the cruises group together based on the cell densities of the top 18 phytoplankton taxa in order to assess linkages between oceanographic features and phytoplankton distribution (Fig7A).

3 RESULTS AND DISCUSSION

3.1 Hydrological parameters

The TS diagrams showed an absence of deep water masses during the winter period (February 2009). We noted the dominance of one homogeneous water mass with a density of about 26.85Kg / m3. In other seasons, cold and less salted deep waters resurgences occur at the coast marking a coast-offshore gradient most pronounced in April and June. In October, we noticed a significant stratification associated to warmer water masses. In 2010, [23] reported that the temperature salinity diagram in 28°N transect shows the appearance of cold and less salted upwelled water, visible on the coastal stations, from June to August. They also shows that the major upwelled water caused a horizontal thermo-halin stratification between the coast and offshore. Whereas during April, the absence of these water masses is very marked by the predominance of one warm and salted water mass, mainly in December of this year (Fig.2). these results are consisted with those of [30] which reported that time series results on winds and SST in the NW African coastal zone indicated that the region between 20 and 33°N is characterized by persistent upwelling, being more intense during summer in the area between 25 and 33°N.

The contributions of nutrients in 2009 are well marked, on the continental shelf, with the upwelling activity in April and June, which is manifested by significant concentrations of surface nutrients including phosphates [PO4]=0,8 μmol/l and ammonium [NH4]=1,4μmol/l In October, despite the low activity of upwelling, we recorded quite significant nutrient rates due to stratification observed during this period, preventing thereby the circulation of nutrient rich water. In February, the absence of upwelling activity has a negative impact on the nutrients rates ([NH4]= 0,12 μmol/l ; [PO4]= 0,15 μmol/l) marked by low levels of macro-nutrients at the continental shelf.

In 2010, the impact of the resurgences activity of deep water in the summer period appears on the nutrients vertical distributions on transect 28°N and brought important concentrations of nitrates, phosphates and ammoniums through of the continental shelf [23].

3.2 Structure of planktonic communities under varying oceanographic conditions

3.2.1 Phytoplankton densities and structure

The highest densities were recorded in February and June 2009, and the lowest at august 2010. Phytoplankton mean abundance was higher at station 3 (3292.10^2 Cell.L-1) during February 2009 and lower at the same station (40.10^2 Cell.L-1) during August 2010. A well marked variation was observed in station 3 during all sampling periods, with a density decrease at this station during October 2009, April, June and August 2010. While a marked peak can be observed during February, April and June 2009 at same station. In fact, at station 3 which can be considered as an intermediate station, remarkable and sudden variations were observed during all the periods. An overall density decrease can be observed in station 5 during all the periods (Fig 5).

The maximum number of species (87) was recorded in stations 4 and 5 during February 2009 while the minimum was noted in station 3 (22) during August 2010 (Fig 6).

Diatoms represented the majority group in all seasons, with a percentage up to 97% in February 2009. Diatoms densities reaches its maximum during February (8657.10^2 Cell.L-1), April (3686.10^2 Cell.L-1) and June (4001.10^2 Cell.L-1) 2009. The lowest densities were recorded in August 2010 (552. 10^2 Cell.L-1) and June 2010. Dinoflagellates, represented in February (230.10^2 Cell.L-1) and April (122.10^2 Cell.L-1), less than 5% of the phytoplankton population, while in June, their contribution to the community rises to 53% with 1145.10^2 Cell.L-1 and 1061.10^2 Cell.L-1 respectively during June 2009 and June 2010.

3.2.2 Upwelling versus Phytoplankton abundance

In order to check the impact of IUC fluctuations on the phytoplankton quantitative variability, only neritic stations (st1, st2 and st3) were selected, the resurgences being mainly significant at these stations. Thus, for each period, the contribution of these three stations in the total phytoplankton densities was calculated according to the formula below, and held to assess the impact of upwelling on phytoplankton biomass.

Phytoplankton abundance = Costal Phytoplankton/Total Phytoplankton

Phytoplankton abundance =∑ Phytoplankton (St1+St2+St3)/∑ Phytoplankton (St1+St2+St3+St4+St5)

A strong correlation ($R^2 = 0.9$) was observed between the CUI and changes in phytoplankton densities, indicating a positive impact of upwelling cold water on phytoplankton proliferation (Fig.3 a,b).

In fact, phytoplankton blooms were more important in upwelling periods, especially in April and June 2009 but more particularly in August 2010 (Fig.3a). We noticed an exceptional peak in phytoplankton densities in October 2009 despite a weak resurgence activity, due to an intense proliferation (bloom) of Skeletonema costatum representing 75% from total phytoplankton, this specie was cited as a neritic cosmopolitan specie [31,32] developing intensely in autumn, with a strong capacity of adaptation to warmer temperatures and a wide range of salinities [33,34].

Important phytoplankton densities are relatively high in winter (February) despite the absence of upwelling, this could also be explained by the fact that in oceanic waters of the Canaries area, the annual plankton production cycle is affected by almost permanent seasonal thermocline that disappears during the winter as a result of decreasing surface water temperatures. Thus, the mixed layer reaches its maximum penetration depth (150-200 m). The seasonal thermocline reappears in April-May, leading to the most common situation of an euphotic zone depleted of nutrients. Therefore, it is only during the short mixing period (winter) following deep convection, that phytoplankton grow rapidly [17].

3.3 CCA Analysis

The CCA analysis revealed the existence of two distinct groups of stations Grp A and Grp B in relation with the temperature factor.

The Group A (Grp A) is inversely correlated to temperature and corresponds to an association of stations (STF, STA1, STA2) sampled in winter and spring, corresponding to low temperatures are noted.

At the opposite of F1 axis, the group B (Grp B) is positively correlated with temperature and includes stations (STJ1, STJ2, STO) sampled in summer and autumn, when temperatures are highest (Fig.4 -A).

Moreover, the study of species distribution in relation to the hydrological parameters using a multivariate analysis CCA, has identified two main groups: Gr1 and Gr2.

The first group includes diatom species and the second corresponds to a dinoflagellates association. Group 1 comprises two sub groups Gr1.1 Gr1.2 (Fig.4-B).

In terms of interaction between phytoplankton species and environment, the analysis allowed to highlight an association between species Gyrodinium fusus, Gyrodinium spiralis Oxytoxum sp, Alexandrium sp, Prorocentrum micans, Neoceratium fusus, Scrippssiella sp and the elevation of the temperature. These taxa are all from Dinoflagellates group. It is in fact known that Dinoflagellates need high temperature water for reproduction unlike diatoms whose growth is negatively influenced by higher temperatures [35]. Associated with this group, we note a diatom of the genus Rhizosolenia (Rhizosolenia sp and Rhizosolenia setigera), known as dominant in summer phytoplankton communities in many parts of the world [36] and whose main proliferation would be in the warmer water (25 to 28 °C) [37].

At the opposite of F1 axis, species group Gr1.1 is inversely correlated to the temperature (Fig 4-B). This group consists on Diatoms taxa : Lauderia annulata, Chaetoceros sp, Skeletonema costatum, Pseudo-nitzschia seriata, Pseudo-nitzschia delicatissima, Cylindrotheca closterium. Diatom species are actually known to proliferate in cold temperatures [37,38]. A correlation was observed between species of this group, and phosphate (PO4), as Skeletonema costatum, which was cited by [39] as being highly correlated with PO4.

Furthermore, a second combination of diatoms (Gr1.2) is located in relation to ammonium (NH4) rather than nitrogen forms NO2 and NO3. [40] reported that phytoplankton communities typically prefer to take up N in the reduced form of NH4 rather than in the oxidized forms NO2 and NO3. More over, [41] reported the inhibitory effect of NH4 on NO3 which severely reduces the rate of NO3 uptake and some studies also found a threshold ammonium concentration of 1 μM, above which NO3 uptake is largely inhibited despite high concentration of ambient NO3.

A negative correlation was observed between the majority of species and water salinity, it has indeed been demonstrated that cell division of phytoplankton is favored by low salinities [39].

Other species are grouped in the center regardless of any physicochemical variable; these species distribution would probably be influenced by other extrinsic parameters like zooplankton grazing.

4 CONCLUSION

This study shows a clear seasonal variability of hydrological upwelling conditions, having a direct impact on phytoplankton distribution. A remarquable correlation ($R^2 = 0.9$) was observed between the CUI and changes in phytoplankton densities. The environmental variables that best explained the changes in the phytoplanktonic communities were a combination of water temperature and nutrients. Thus, our results show clearly a seasonality illustrated primarily by the effect of water temperature and macro-nutrient rates, governed by changes in upwelling, on the distribution of phytoplankton communities. Introducing additionnal predictors such as estimation of grazing rates could be very indicative in phytoplankton communities dynamic.

5 FIGURES AND TABLE

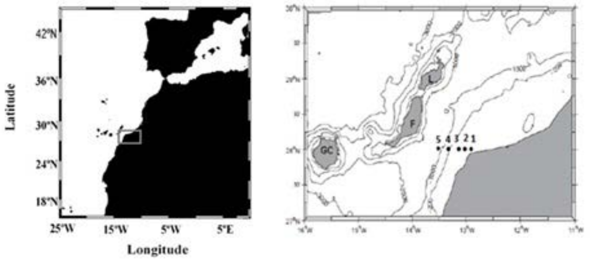

Fig.1. Study area and sampling stations, Cape Juby area

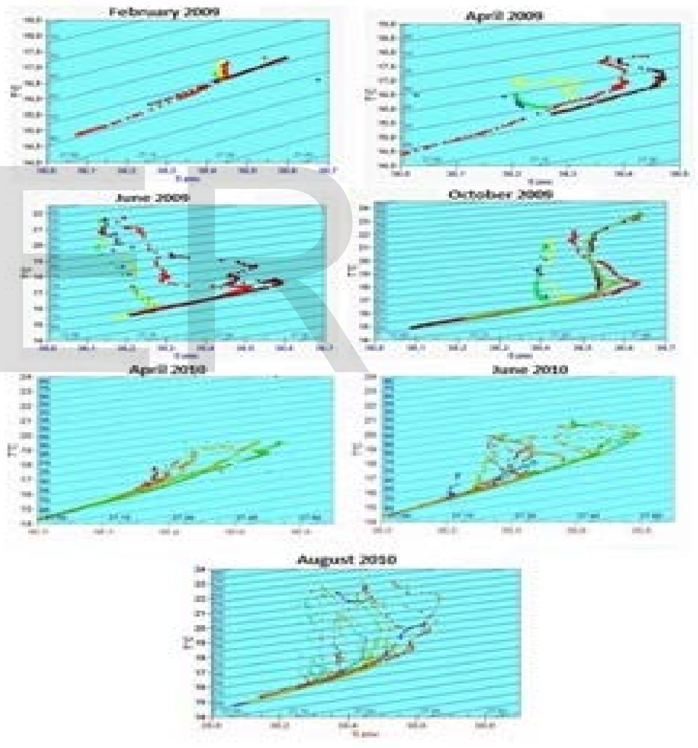

Fig 2. TS DIAGRAMS INDICATING WATER MASSES STRUCTURE

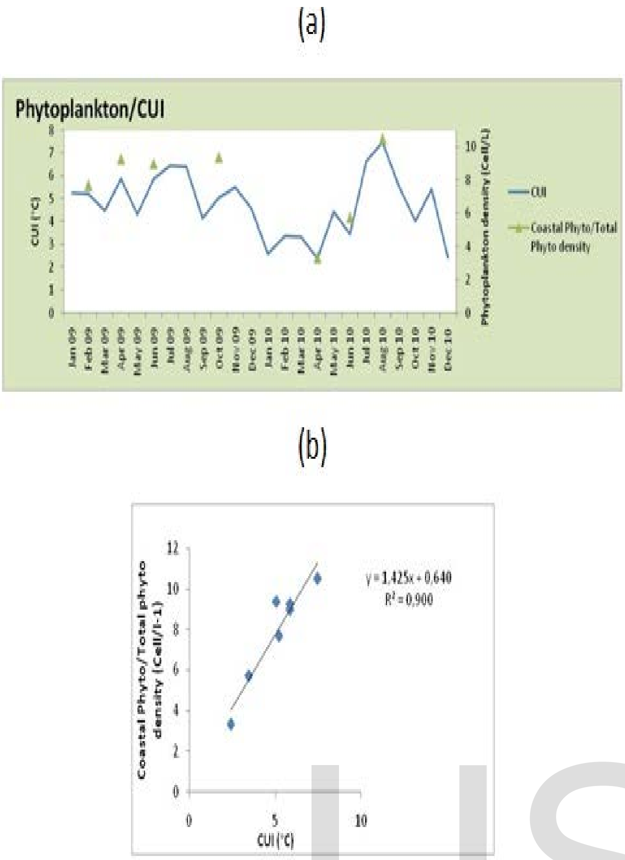

Fig 3. PHYTOPLANKTON DENSITIES VARIATION IN RELATION TO CUI FLUCTUATIONS

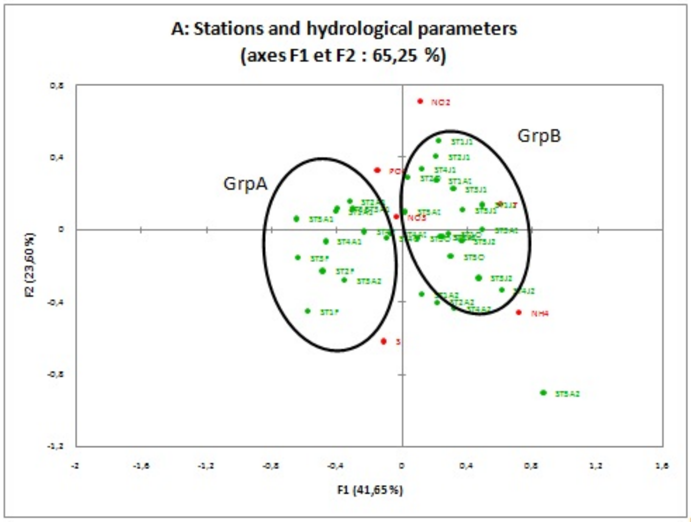

Fig.4. CCA ORDINATION OF STATIONS WITH ENVIRONMENTAL VARIABLES

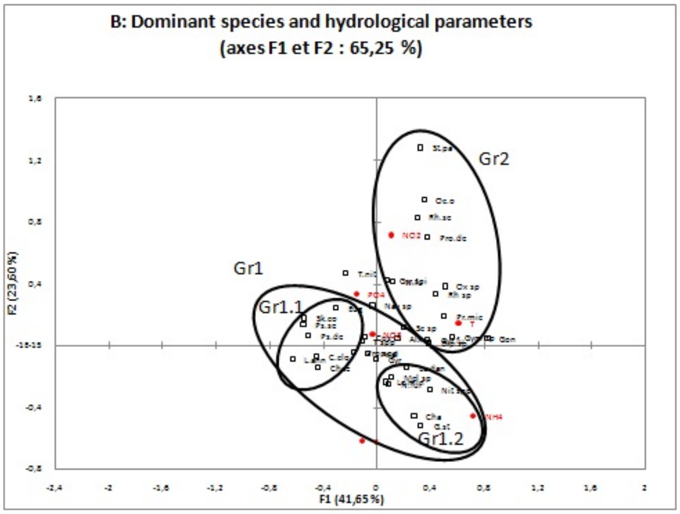

Fig.5. CCA ordination of main phytoplankton species

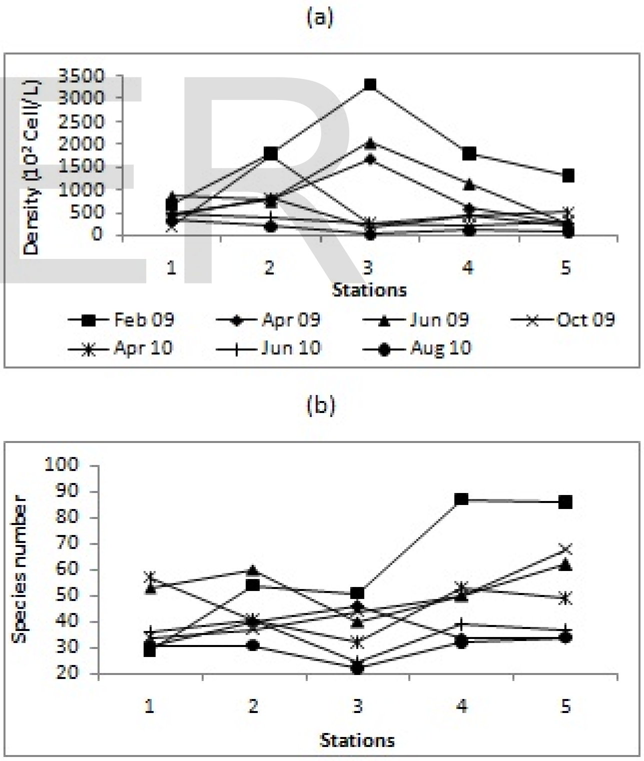

Fig.6. SPATIAL VARIATIONS IN (A) PHYTOPLANKTON DENSITIES AND (B) RICHNESS

TABLE 1

SAMPLING STATIONS (GEOGRAPHIC COORDINATES, MAXIMAL DEPTHS AND DISTANCE FROM COAST); CRUISES CALENDAR (FEBRUARY, APRIL, JUNE, OCTOBER 2009 AND APRIL, JUNE, AUGUST 2010) NEAR CAPE JUBY AREA (28°N, MOROCCO, ATLANTIC)

Stations	Latitude	Longitude	Depth (m)	Distance from coast (Km)
1	28°00,14	12°45,51	28	8
2	27°59,73	12°56,78	40	26,3
3	28°00,20	13°08,85	68	46,6
4	28°00,00	13°20,29	396	64,6
5	28°00,10	13°31,67	1185	83,5

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REFERENCES

[1] S. Salah, A. Errhif, A. Berraho, A. Benazzouz, A. Makaoui, and O. Ettahiri, "Contribution à l'étude de l'influence du filament d'upwelling de Cap Juby (Maroc) sur la distribution des copépodes," *Journal des Sciences Halieutiques et Aquatiques* 6 (2013) 207-220.

[2] X.A. Álvarez-Salgado, J. Arístegui, E.D. Barton and D.A. Hansell, "Contribution of upwelling filaments to offshore carbon export in the subtropical Northeast Atlantic Ocean," *Limnology and Oceanography* 52 (2007) 1287–1292.

[3] P. Bécognée, M. Moyano, C. Almeida, J.M. Rodriguez, E. Fraile-Nuez, A. Hernandez-Guerra and S. Hernandez-Leon, "Mesoscale distribution of clupeoid larvae in an upwelling filament trapped by a quasi-permanent cyclonic eddy off Northwest Africa," *Deep-Sea Research I* 56 (2009) 330–343.

[4] N. Gruber, Z. Lachkar, H. Frenzel, P. Marchesiello, M. Münnich, J. C. McWilliams, T. Nagai and G-K. Plattner. "Eddy-induced reduction of biological production in eastern boundary upwelling systems," *Nature Geoscience* 4 (2011) 787–792.

[5] T.S. Moore, R.J. Matear, J. Marra and L. Clementson, "Phytoplankton variability off the Western Australian Coast: mesoscale eddies and their role in cross-shelf exchange," *Deep-Sea Research II* 54 (2007) 943–960.

[6] P. Relvas, A. Peliz, P.B. Oliveira, J. Da Silva, J. Dubert, E.D. Barton and A.M.P. Santos, "Physical oceanography of the western Iberia ecosystem: latest views and challenges," *Progress in Oceanography 74* (2007) 149–173.

[7] D.R. Khanna, R Bhutiani and K.S. Chandra, "Effect of the Euphotic Depth and Mixing Depth on Phytoplanktonic Growth Mechanism," *Int. J. Environ. Res.*, 3 (2009) 223-228.

[8] B. Casas, M. Varela and A. Bode, "Seasonal succession of phytoplankton species on the coast of A Coruna (Galicia, northwest Spain)," *Bol. Inst. Esp. Oceanogr.* 15 (1999) 413–429.

[9] S.E. Fitzwater, K.S. Johnson, V.A. Elrod, J.P. Ryan, L.J. Coletti, S.J. Tanner, R. Gordon and F.P. Chavez, "Iron, nutrient and phytoplankton biomass relationships in upwelled waters of the California coastal system," *Continental Shelf Research* 23 (2003) 1523–1544.

[10] A.P. Martin, "Phytoplankton patchiness: the role of lateral stirring and mixing," *Progress in Oceanography* 57 (2003) 125–174.

[11] A.M. Lassiter, F.P. Wilkerson, R.C. Dugdale and V.E. Hogue, "Phytoplankton assemblages in the CoOP-WEST coastal upwelling area," *Deep-Sea Research II* 53 (2006) 3063–3077.

[12] L. Herrera, R. Escribano, "Factors structuring the phytoplankton community in the upwelling site off El Loa River in northern Chile," *Journal of Marine Systems* 61 (2006) 13-38.

[13] J. Zhao, M. Ramin, V. Cheng and G.B. Arhonditsis, "Competition patterns among phytoplankton functional groups: How useful are the complex mathematical models?," *Acta ecologica* 33 (2008) 324-344.

[14] N. Guiselin, "Etude de la dynamique des communautés phytoplanctoniques par microscopie et cytométrie en flux, en eaux côtières de la Manche orientale, Thesis, Université du littoral côte d'opale-Equipe Ecologie planctonique, 2009.

[15] J. Sun, Y. Feng, F. Zhou, S. Song, Y. Jiang and C. Ding, "Top-down control of spring surface phytoplankton blooms by microzooplankton in the Central Yellow Sea, China," *Deep Sea Research II* (2013)

[16] Barton, E. D., J. Aristegui, P. Tett, and E. Navarro-Perez, "Variability in the Canary Islands area of filament-eddy exchanges," *Progress in Oceanography* (2004).

[17] J.L. Pelegri, J. Aristegui, L. Cana, M. G-Davila, A. Hernandez Guerra, S. Hernandez-Leon, A. Marrero-Diaz, M.F. Montero, P. Sangra and M. Santana-Casiano, "Coupling between the open ocean and the coastal upwelling region off northwest Africa: water recirculation and offshore pumping of organic matter," *Journal of Marine Systems* 54 (2005) 3– 37.

[18] M. Garcia-Muňoz, J. Aristegui, M.F. Montero and E.D. Barton, Distribution and transport of organic matter along a filament-eddy system in the Canaries-NW Africa coastal transition zone region, *Progress in Oceanography*, 62 (2004) 115-129.

[19] J. Aristegui, E.D. Barton, P. Tett, M. Montero, M. Garcia-Munoz, Basterretxea G., A.S Cussatlegras, A. Ojeda and D. De Armas, "Variability in plankton community structure, metabolism, and vertical carbon fluxes along an upwelling filament. (Cape Juby, NW Africa)" *Progress in Oceanography*, 62 (2004) 95-114.

[20] V. Anabalon, J. Aristegui, C.E. Morales, I. Andrade, M. Benavides, M.A. Correa-Ramirez, M. Espino, O. Ettahiri, S. Hormazabal, A. Makaoui, M.F. Montero and A. Orbi, "The structure of planktonic communities under variable coastal upwelling conditions off Cape Ghir (31°N) in the Canary Current System (NW Africa)," *Progress in Oceanography* 120 (2014) 320-339.

[21] A. Berraho, O. Ettahiri, A. Makaoui, T. Brochier, L. Somoue, S. Salah, K. Hilmi, and A. Orbi, "Distribution des larves de sardine et d'anchois le long du filament de Cap Ghir,," *Journal des Sciences Halieutique et Aquatique*, 6 (2012) 178-193

[22] S. Salah, O. Ettahiri, A. Berraho, A. Benazzouz, K. Elkalay and A. Errhif "Distribution des copépodes en relation avec la dynamique du filament de Cap Ghir, (Côte atlantique du Maroc)," *Comptes Rendus de Biologies*, 335 (2012) 155-167.

[23] A. Makaoui, M. Idrissi, A. Benazzouz, M. Ait Laamel, A. Agouzouk, J. Larissi, and K. Hilmi, "Hydrological variability of the upwelling and the filament in Cape Juby (28°N) Morocco," *International Journal of Advanced Research* 3 (2015) 9-26.

[24] C.R. Tomas, "Identifying marine diatoms and dinoflagellates," *Academic Press, Inc., San Diego*, 1996.

[25] M. Ricard, "Atlas du phytoplancton," Volume 2, *Editions du CNRS*, Paris, 1987.

[26] G. Drebes, M. Elbrachter, "A checklist of planktonic diatoms and dinoflagellates from Helgoland and List (Sylt)," *German Bight. Bot. Mar*. 19 (1976) 75-83.

[27] A. Benazzouz, S. Mordane, A. Orb, M. Chagdali, K. Hilmi, A. Atillah, J.L. Pelegrí and H. Demarcq, "An improved coastal upwelling index from sea surface temperature using satellite-based approach – The case of the Canary Current upwelling system," *Continental Shelf Research* 81 (2014) 38–54.

[28] D. Jouffre, T. Lam-Hoai, B. Millet and M. Amanieu, "Structuration spatiale des peuplements zooplanctoniques et fonctionnement hydrodynamique en milieu lagunaire," *Oceanologica Acta*, 14 (1991) 489-504.

[29] L. Somoue, N. Elkhiati, M. Ramdani, T. Lam Hoi, A. Berraho and T. Do Chi. "Abundance and structure of copepod communities along the Atlantic coast of southern Morocco.," *Acta adriat*ica., 46 (2005) 63-7630.

[30] J. Marcello, A. Hernandez-Guerra, F. Eugenio and A. Fonte, "Seasonal and temporal study of the northwest African Upwelling System," *International Journal of Remote Sensing*, 32 (2011) 1843-1859.

[31] E.E. Cupp, "Marine Planktonic diatoms of the west coast of North America," *Bulletin of the Scripps Institution of Oceanography of the University of California* 5 (1943) 1-238.

[32] R.A. Horner, A taxonomic Guide to Some Common Phytoplankton. Biopress Limited, Dorset Press, Dorchester, UK. 200, (2002) 195.

[33] D. Liu, J. Sun, J. Zou, and J. Zhang, Phytoplankton succession during a red tide of Skeletonema costatum in Jiaozhou Bay of China, Marine Pollution Bulletin, 50 (2005) 91–94.

[34] T. Yan, M.J. Zhou and P.Y. Qian, "Combined effects of temperature, irradiance and salinity on growth of diatom Skeletonema costatum." *Chinese Journal of Oceanology and Limnology*, 20 (2002) 237–243.

[35] C.M. Mutshinda, Z.V. Finkel and A.J. Irwin, "Which Environmental factors control phytoplankton populations? A Bayesian variable selection approach," *Ecological Modelling* 269 (2013) 1–8.

[36] I. Gailhard, "Analyse de la variabilité spatio-temporelle des populations microalgales côtières observées par le «réseau de surveillance du phytoplancton et des Phycotoxines» (REPHY)," Thesis, (2003) 293pp.

[37] J. Reyssac. 1970. "Phytoplancton et production primaire au large de la côte d'Ivoire," *Bulletin de l'Institut Fondamental d'Afrique Noire* 32A 869-981.

[38] D. Sarno, D. Zingone, V. Saggiomo and V. Carrada, "Phytoplankton biomass and species composition in a Mediterranean coastal lagoon," *Hydrobiologia* (1993) 271 27–40.

[39] W.K.W Lii, F.A. McLaughlin, C. Lovejoy and E.C. Carmack, "Smallest Algae Thrive As the Arctic Ocean," *Fisheries Science* (2009) 326-539

[41] J.Twomey Luke, F. Piehler Michael and W. Paerl Hans. "Phytoplankton uptake of ammonium, nitrate and urea in the Neuse River Estuary, NC, USA , " *Hydrobiologia* (2005) 533 123-134.

[40] S. Mochmadkar, M. Gauns , A. Pratihary, B. Thorat, R. Roy, I.K. Pai and S.W.A. Naqvi, "Response of phytoplankton to nutrient enrichment with high growth rates in tropical monsoonal estuary – Zuari estuary, India," *Indian Journal of Geo-Marine Sciences*, 42 (2013) 314-325.