

Research Article.

Phytoplankton functional types abundance in Bejaia Gulf and El Kala waters (Mediterranean Sea) using eleven years of remotely sensed data (2010-2020)

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ABSTRACT

Remote sensing and empirical models have facilitated and enabled a broad spatio-temporal survey of biological parameters, contributing to the preservation and conservation of marine ecosystems. In this study, we used 11 years (2010-2020) of MODIS Chlorophyll-*a* (Chl*a*) data to examine the spatio-temporal variability of phytoplankton groups in Bejaia Gulf and El Kala surface waters (the southwestern Mediterranean Sea). We evaluated five Chl*a* algorithms dedicated to the MODIS sensor, as well as the regional phytoplankton model based on the abundance approach. The annual and monthly variability of Phytoplankton biomass in terms of Size Classes (PSCs) and Functional Types (PFTs) were examined. The annual climatology revealed significant differences in PFTs and PSCs abundances between the two study regions. The micro-phytoplankton, which is primarily represented by diatoms in Bejaia Gulf, dominated the coastal edge, whereas the nano-phytoplankton, which is mainly represented by haptophytes, dominated El kala coast. However, according to the monthly climatology, haptophytes predominated, followed by prokaryotes in both study areas. The variability of PFTs is strongly influenced by precipitation in Bejaia Gulf and by SST in El-Kala waters.

KEYWORDS

Phytoplankton
groups;
Algorithms;
Algerian Basin;
Phytoplankton
monitoring;
Chlorophyll-*a*;
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1 INTRODUCTION

Phytoplankton is the set of microscopic algae formed by a single cell. They have a large diversity in terms of color and shape, and a wide range of sizes (Molo and Noury, 2013). It assumes an integral function in aquatic ecosystems, thus controlling the processes implicated in biogeochemical cycles, notably that of CO₂ (Falkowski *et al.*, 1998; IOCCG, 2014).

The notion of phytoplankton functional groups was created to make the study of phytoplankton easier, due to the difficulty of interpreting variations for each species separately. The grouping of species based on their ecological role, similarities in morphological or physiological features, as well as responses to abiotic factor variations, improved the monitoring in space and time using models specifically designed to plot and predict the biogeochemical distribution of phytoplankton (Anderson, 2005; Gregg *et al.*, 2003; Iglesias-Rodriguez *et al.*, 2002; Le Quere *et al.*, 2005; Litchman *et al.*, 2007). The major phytoplankton groups have been grouped into four functional types (Blondel, 2003; Falkowski *et al.*, 2003; Litchman *et al.*, 2007; IOCCG, 2014) which are: Nitrogen fixers or diazotrophs (as Blue-green algae), Calcifier (as Prymnesiophyceae), Silicifier (as Diatoms), and Dimethyl Sulfoniopropionate Producers DMSP (as Dinophyceae, Chrysophyceae, Pelagophyceae, Prasinophyceae, Haptophyceae) (IOCCG, 2014).

Phytoplankton study in Algerian sea waters is very interesting, given the specificity brought by the fertile of Atlantic current, which runs along the coast of Algerian Basin from West to East (Bernard, 1948; Millot, 1999). Although the main line of hydrological phenomena associated with the exchange of Atlantic and Mediterranean waters through the Gibraltar Strait, has been

known for a long time. Algerian waters influenced by Atlantic enrichment, as well as the phytoplankton that colonizes them, are listed in few studies. The main investigations carried out are those of: (Bernard, 1948; Tellai, 1964; Pincemin, 1966; Lalami-Taleb, 1971, 1983; Illoul, 1991, 2008; Benmeradi, 1993; Fiala, 1994; Videau *et al.*, 1994; Boudjenah, 2019; Abdallah *et al.*, 2024a).

Through satellite imagery, the importance of phytoplankton was revealed by Boufeniza *et al.* (2020) at Algiers Bay and by Abdallah *et al.* (2024b) in the eastern Algerian waters. Nevertheless, our study represents the first investigation on the Phytoplankton Size Classes (PSCs) and Phytoplankton Functional Types (PFTs) in the eastern Algerian Basin by involving *in situ* measurements and remotely sensed data. Phytoplankton sensing via satellite imagery represents significant progress in oceanic optics. A variety of models (ecological, biological, and physical) has been established to investigate the PSCs and PFTs fractions using diverse approaches (Alvain *et al.*, 2005, 2008; Ciotti and Bricaud, 2006; Uitz *et al.*, 2006; Hirata *et al.*, 2008, 2011; Aiken *et al.*, 2009; Bracher *et al.*, 2009; Kostadinov *et al.*, 2009; Brewin *et al.*, 2010; Mouw and Yoder, 2010; Roy *et al.*, 2013; Ben Mustapha *et al.*, 2014; IOCCG, 2014; Di Cicco *et al.*, 2017).

In this study, we used 11 years (2010-2020) of MODIS ocean color data to investigate phytoplankton composition and fluctuation in Bejaia Gulf and El Kala. The choice of the study areas is based on the loads of effluent discharged through the wadis, which differ between the two regions. First, we compared the *in situ* Chla measured in our study areas to that estimated using MODIS sensor algorithms (OC3M, OC4M,

OC5M, OC6M, Medoc3). Following that, the best performing Chla algorithm was used to evaluate the model of Di Cicco *et al.* (2017), which is based on the abundance approach, and was then applied to MODIS Chla data time series from January 2010 to December 2020. Afterwards, we mapped Chla, PFTs and PSCs distributions and analyzed their annual and monthly climatologies in each study area. Finally, the fluctuation of PFTs and PSCs in response to Sea Surface Temperature (SST) and precipitation was also investigated.

2 METHODOLOGY

2.1 Study area

This study was conducted in the eastern Algerian waters (south-western Mediterranean Sea). Considering two study areas: Bejaia Gulf, which is delimited from 5° 02' to 5° 36' East and from

36° 39' to 36° 47' North. On Bejaia's coast are located Bejaia city and a relatively important industrial area. However, the harbor of Bejaia is one of the leading exporters of crude oil (Bakalem, 1999). The main wadis opening at sea are: Soummam Wadi, where various discharges are spilled out, Djemaâ Wadi; Agrioun Wadi where industrial wastewater is discharged (Mouni *et al.*, 2009; Grimes, 2010; Merah, 2020). The second study area is El Kala waters, situated at the extreme eastern Algerian coast (from 8° 13' to 8° 35' East and from 36° 54' to 37° 1' North), stretches from Cape Rosa to Cape Segleb. The only wadi that flows into the El Kala coastal area is Messida. El Kala coast is connected to El-Mellah lagoon, which is allied by the marine waters but also by the fresh waters of three wadis: R'kibet, El Mellah and Belaroug (Arrignon, 1963; Guelorget *et al.*, 1989) (Fig. 1).

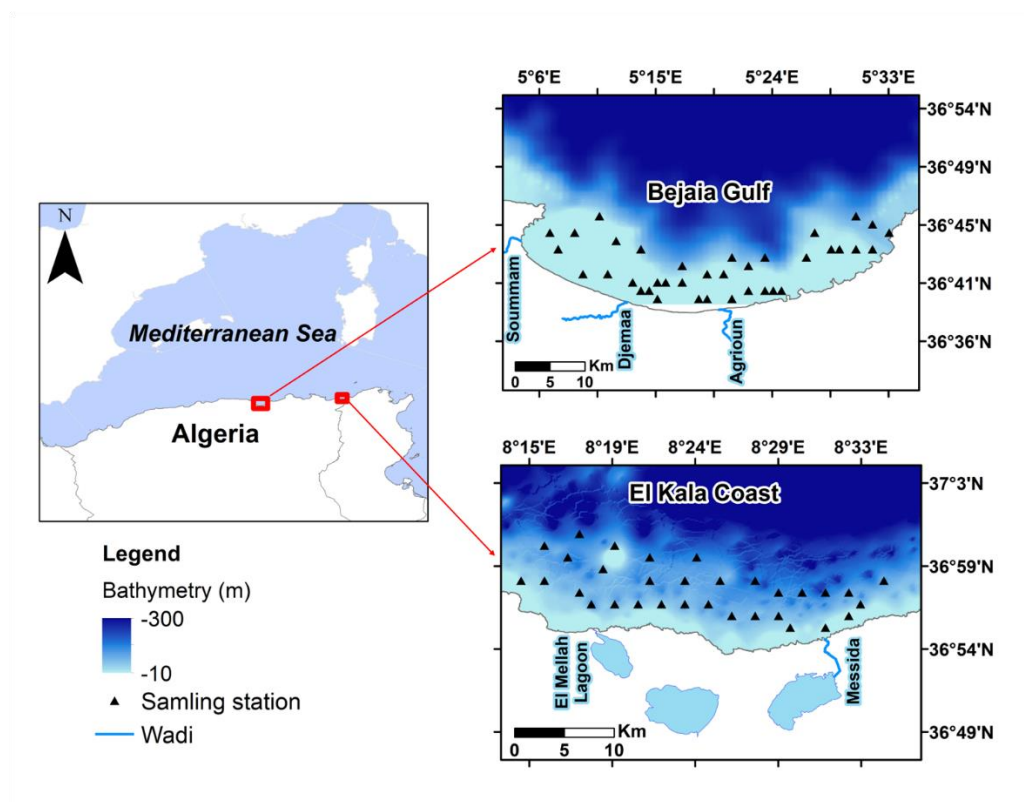


Figure 1. Study areas and location of sampling stations (the bathymetry data have been acquired from website GEBCO (The General bathymetric Chart of the Oceans) (<https://download.gebco.net/>).

2.2 *In situ* measurement

As part of this study, 37 stations at Bejaia Gulf and 32 at El Kala in coastal and offshore waters were sampled (Fig. 1) on March 21st, 2013, using a 5L Niskin bottle. All samples were collected from the surface layer (depth of less than 3 m). Our choice is supported by the considerations of D'ortenzio and prior (2012) on the optical features of the Mediterranean Sea, as well as a regular procedure for evaluating and validating Chla satellite measurements (Kahru *et al.*, 2014). Sampling was carried out within $\pm$ 2h of MODIS passage, with the aim of reducing effects due to marine environment's dynamic and abiotic conditions variation over time (Butt and Nazeer, 2015; Mouw *et al.*, 2015).

After sampling, 1.5 L of sea water from each station was filtered using glass fiber filters, type GF/F (Whatman) of 25 mm diameter and 0.7 μ m porosity. The examination of pigments was done in the laboratory. The concentration of Chlorophyll-*a* (Chla) was assessed using spectrophotometry after its extraction into 90% acetone. Thus, according to Lorenzen's method, which identifies it as a very valuable technique in wide scale marine ecological operations (Lorenzen, 1966).

Temperature and salinity *in situ* measurements were obtained for each station using a multiparameter HANNA (HI 9829). The measures were performed by introducing the sensor into the Niskin bottle after each sample.

2.3 Remote sensing data

Ocean color data for the same sampling date, March 21st, 2013, were provided by the Moderate Resolution Imagery Spectroradiometer (MODIS sensor) for the evaluation and validation of Chla

algorithms. The satellite produces daily images of the study areas with a spatial resolution of one kilometer. The NASA's Ocean Color website (<https://oceancolor.gsfc.nasa.gov/>) has been used to download all level 2 (L2) images that partially or completely cover our study areas for the period from January 2010 to December 2020. Reflectance values in MODIS-AQUA spectral bands (412, 443, 488, 531, 547, 555, 645, 667, and 678 nm) are included in each image. The scene sections, including the pixel closest to the sampling stations were extracted (distance < 1km between the pixel and the point sampling). Inadequate catches due to clouds were eliminated.

The sea surface temperature daily data (2010-2020) were also provide using the same sensor (MODIS-Aqua) from the NASA website (<https://oceancolor.gsfc.nasa.gov/>), all Level 2 images covering our study areas were acquired. On the other hand, the monthly and annual cumulated precipitation data (2010-2020) for the entire study areas have been acquired from the NASA website (<https://giovanni.gsfc.nasa.gov/>). Sentinel Application Platform (SNAP) version 7.0 was used to process the images and apply the algorithms.

2.3.1 Algorithms

Chlorophyll-*a* estimation algorithms: Here we focus on the algorithms proposed by O'Reilly *et al.* (1998), which are polynomial algorithms that relate the reflectance ratio involving several wavebands between blue and green for each version OC3M, OC4M, OC5M, OC6M. The Medoc 3 developed for Mediterranean open ocean waters by Santoleri *et al.* (2008) was also tested, it follows the OC3M formulation but with modified

coefficients. Chla concentration is calculated from polynomial equation of four order. All algorithms follow the same formula (Eq. 1) with distinct coefficients. The coefficients were derived from O'Reilly *et al.* (2019).

$$\log_{10}(\text{Chla}) = a_0 + a_1X + a_2X^2 + a_3X^3 + a_4X^4 \quad (\text{Eq. 1})$$

where a_0, a_1, a_2, a_3, a_4 are the polynomial fit coefficients and X is:

$$X = \log_{10}(\text{Rrs}_{\text{bleu}}/\text{Rrs}_{\text{green}}) \quad (\text{Eq. 2})$$

The evaluation of these algorithms allowed for the selection of the one that best fits measured data, which will then be considered subsequently in the assessment of Di Cicco *et al.* (2017) model.

Phytoplankton estimation algorithms: The regional model of Di Cicco *et al.* (2017) follows the abundance approach, selecting the Chla as an indicator of the trophic quality of the marine environment. They used *in situ* phytoplankton pigment composition data measured by high performance liquid chromatography, to estimate the fractional contribution of the different groups to the Chla in the Mediterranean waters. This subsequently allowed the establishment and fitting of nine empirical equations in order to estimate the PSCs (micro, nano, and pico-phytoplankton) and PFTs (diatoms, dinophytes, cryptophytes, green algae and prochlorophytes, haptophytes, and prokaryotes) fractions, from the Chla obtained from the satellite measurements.

2.3.2 Statistics

For the measured data, the statistics calculated are minimum, maximum, and mean. Regression, p -value, and the coefficient of determination (R^2) were performed using the R software (version 4.0.2). Other indicators were used to evaluate the performance of algorithms, including root mean

square error (RMSE, Eq. 3), root mean square difference (RMSD, Eq. 4), mean bias error (MBE, Eq. 5), and (BIAS, Eq. 6).

$$\text{RMSE} = \sqrt{\frac{1}{N} \sum_{i=1}^N (\text{Model}_i - \text{insitu}_i)^2} \quad (\text{Eq. 3})$$

$$\text{RMSD} = \sqrt{\frac{1}{N} \sum_{i=1}^N (\log_{10} \text{Model}_i - \log_{10} \text{insitu}_i)^2} \quad (\text{Eq. 4})$$

$$\text{MBE} = \frac{1}{N} \sum_{i=1}^N (\text{Model}_i - \text{insitu}_i)^2 \quad (\text{Eq. 5})$$

$$\text{MBE} = \frac{1}{N} \sum_{i=1}^N (\log_{10} \text{Model}_i - \log_{10} \text{insitu}_i)^2 \quad (\text{Eq. 6})$$

3 RESULTS AND DISCUSSION

The average Chla content measured at the surface water was 0.297 and 0.339 mg m⁻³ with a minimum of 0.192 and 0.126 mg m⁻³ and a maximum of 0.972 and 0.7 mg m⁻³ in Bejaia Gulf and El Kala waters, respectively. The highest values of Chla are found along the coastal edge, located near Soummam Wadi and that of Agrioun for Bejaia Gulf, and near Messida Wadi and Cap Rosa in El Kala. Overall, the concentrations are contingent on the other stations and decrease as one move from the coast to the open sea for both study areas.

The average salinity measured in surface water was 36.12 and 36.76 psu with a minimum of 35.04 and 36.23 psu and a maximum of 36.85 and 36.98 psu for Bejaia Gulf and El Kala waters, respectively. The lowest values of salinity are located near the Agrioun and Djemâa Wadis for Bejaia Gulf, and near Messida Wadi for El Kala, which can be explained by the contributions of fresh water led by the wadis.

The average temperature observed at the surface water was 15.12 and 15.08 °C, with a minimum of 14.61 and 14.84 °C and a maximum of 15.86 and 15.91 °C for Bejaia Gulf and El Kala waters, respectively. The temperature measured is quite

irregular and the maxima are measured near the harbor and Soummam wadi for Bejaia Gulf, and close to Messida wadi for El Kala.

3.1 Evaluation and validation of MODIS-Aqua Chla algorithms

Thirty six and 31 match-ups for Bejaia Gulf and El Kala, respectively, were confronted with the satellite data. For both study areas, all Chla estimation algorithms dedicated to MODIS show good performances with *in situ* data (R^2 from 0.75 to 0.89), except for OC6M, which shows a medium correlation (0.534 for Bejaia Gulf) (Table 1). However, the one that reveals the best performance ($R^2 = 0.818$, BIAS = 0.726) and overestimates the least measured data is the OC5M version (RMSD = 0.729, slope = 7.36) for Bejaia Gulf, and the OC4M version for El Kala ($R^2 = 0.89$, BIAS = 0.642, RMSD = 0.652). Those two algorithms were selected to estimate the daily Chla for each study area, for the period from January 2010 to December 2020, and then implied to estimate phytoplankton fractions

using the algorithms designed to assess phytoplankton abundance.

3.1.1 Evaluation and validation of Di Cicco *et al.* (2017) algorithms

We tested the model of Di Cicco *et al.* (2017), which is a set of empirical equations based on the abundance of PSCs and PFTs. For both study areas, the model shows good performances for most phytoplankton groups considered (Table 2). With a strong coefficient of determination ranging from 0.739 to 0.816 for Bejaia Gulf except for the Dinophytes ($R^2 = 0.663$). Regarding El Kala, the same model performs strongly (R^2 from 0.767 to 0.872) except for the nano component ($R^2 = 0.572$), dinophytes ($R^2 = 0.549$), and haptophytes ($R^2 = 0.566$) it shows medium performances (Table 2). The deviation of the estimated data, from the observed *in situ* data represented by the RMSE, decreases while passing from the model application in Bejaia to El Kala, except for nano class and haptophytes (Table 2).

Table 1. Statistical results of the evaluation of MODIS Chla algorithms

Algorithm	Bejaia Gulf					El Kala waters				
	R^2	BIAS	RMSD	Slope	Intercept	R^2	BIAS	RMSD	Slope	Intercept
OC3M	0.795	0.859	0.865	13.89	-1.724	0.782	0.719	0.731	9.059	-1.057
OC4M	0.805	0.787	0.794	11.97	-1.513	0.890	0.642	0.652	5.587	-0.299
OC5M	0.818	0.726	0.729	7.363	-0.527	0.781	0.590	0.601	3.749	0.101
OC6M	0.609	0.721	0.735	13.37	-2.081	0.756	0.532	0.542	2.652	0.259
MEDOC3	0.788	0.936	0.949	22.95	-3.667	0.867	0.766	0.794	13.174	-1.922

For both study areas, all groups show very low values of the mean bias error (MBE), ranging from -0.178 to 0.171, and that for the evaluation data set (Table 2). The MBE demonstrates that Di Cicco's *et al.* (2017) model slightly overestimates the micro component in both regions (0.159 for Bejaia, and 0.149 for El Kala). For the nano and pico-classes, the model's behavior is reversed,

underestimating the observed values. However, this underestimation remains minor. For the pico-phytoplankton, a convergent MBE is noticed for both study areas, which can be explained by the fact that this algorithm is derived by subtraction (Table 2).

Table 2. Statistical results of the evaluation of Di Cicco *et al.* (2017) phytoplankton algorithms. MBE and RMSE (mg m^{-3})

PSCs/PFTs	Bejaia Gulf			El Kala waters		
	R ²	MBE	RMSE	R ²	MBE	RMSE
Micro-phytoplankton	0.815	0.158	0.162	0.872	0.149	0.161
Nano-phytoplankton	0.745	-0.012	0.031	0.572	-0.018	0.052
Pico-phytoplankton	0.806	-0.145	0.146	0.849	-0.131	0.133
Diatoms	0.814	0.171	0.175	0.869	0.160	0.172
Dinophytes	0.663	-0.013	0.013	0.566	-0.010	0.011
Cryptophytes	0.813	0.068	0.069	0.869	0.063	0.068
Green algae and prochlorophytes	0.809	-0.022	0.023	0.825	0.009	0.009
Prokaryotes	0.753	-0.178	0.179	0.767	-0.150	0.153
Haptophytes	0.739	-0.025	0.059	0.549	-0.072	0.119
Mean	0.773	-2.07E-11	0.0953	0.749	1.23E-17	0.098

The statistical results revealed that Di Cicco *et al.* (2017) model performed very well in our study areas, with a mean coefficient of determination over all PFTs of 0.773 and 0.749 and with a mean RMSE of 0.095 and 0.098 for Bejaia Gulf and El Kala, respectively, while the mean MBE is very low for both study areas (Table 2). The model was applied over an 11-year time series of satellite Chla to calculate phytoplankton fractions in our study areas and to plot the spatio-temporal variation of PSCs and PFTs. Figures 2 and 3 illustrate the annual climatology of PSCs and PFTs (2010-2020), respectively.

3.2 Application of the regional algorithms to daily Chla time series (2010-2020)

3.2.1 Annual climatology

Figure 2 depicts the fractions of Chla represented by each phytoplankton class (PSCs) for each pixel. While in Figure 3, the PFTs fractions were mapped. The percentage maps give fraction values relative to Chla concentration (Fig. 2, A: Bejaia Gulf, B: El Kala waters). The annual climatology of Chla shows that the highest

concentrations are found near the coast and at the level of the wadi's embankments, reaching 0.59 mg m^{-3} for El Kala and 1.04 mg m^{-3} for Bejaia Gulf. These findings are coherent with previous research, which noticed that biomass maxima are generally located near the coasts, especially when they are close to the outlets of large rivers (D'Ortenzio and Ribera d'Alcalà, 2009). Chla's distribution is typically characterized by a decreasing gradient from coastal to offshore waters and from the west to the east, showing an average of 0.37 mg m^{-3} for Bejaia Gulf and 0.26 mg m^{-3} for El Kala waters, supporting the findings of Siokou-Frangou *et al.* (2010) and Estrada and Vaqué (2014).

Bejaia Gulf is represented by a significant average abundance of the micro class, about 43.4%, followed by the nano class, about 41.5%, and lastly the pico-plankton, with 15.1% of Chla. While El Kala is represented principally by the nano class (average abundance = 46.2% of Chla), followed by the pico-phytoplankton at about 34.6% and, at last, the micro-phytoplankton with 19.2% of Chla.

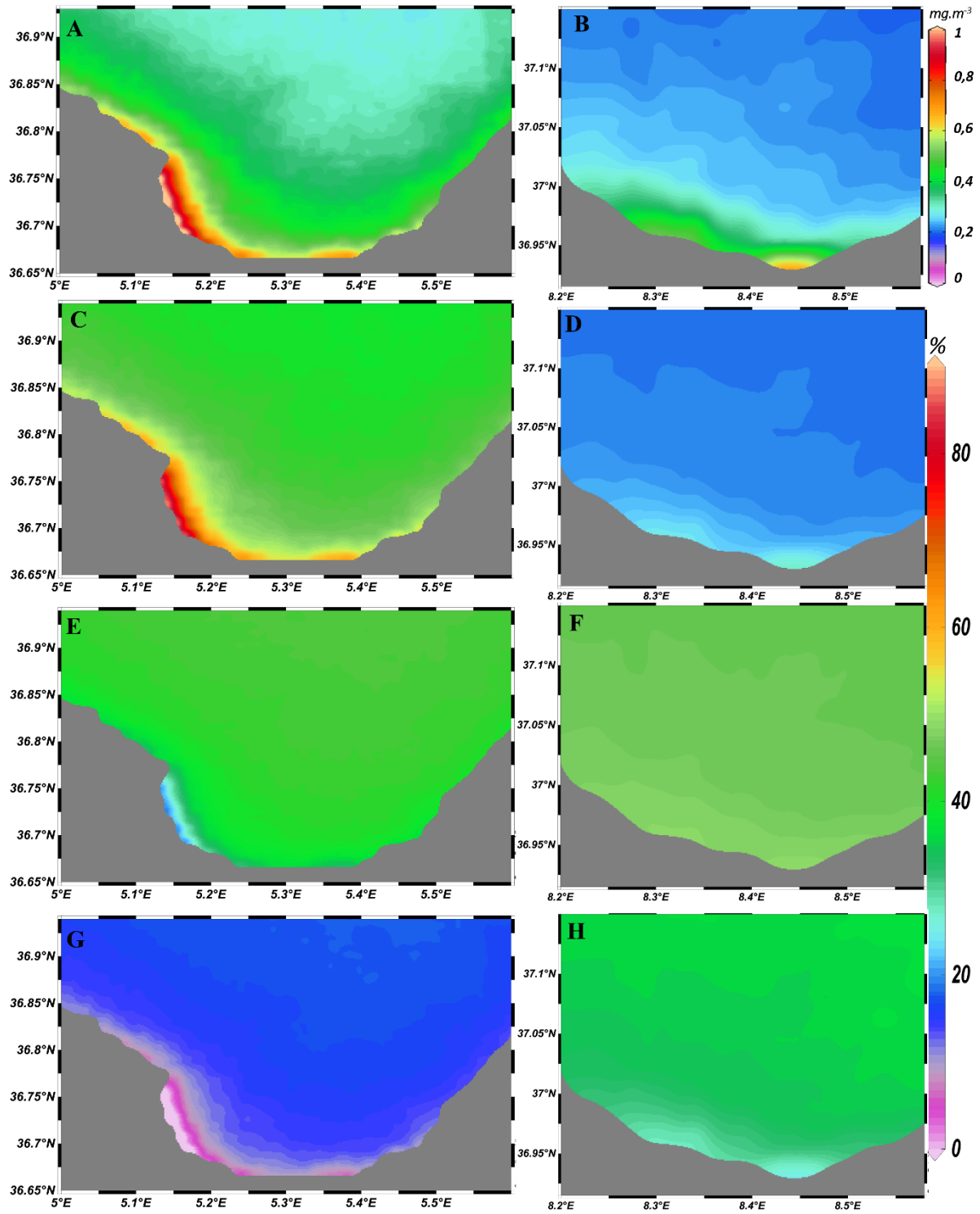


Figure 2. Annual climatology (2010-2020) of the Chla and PSCs (Bejaia Gulf on the left side and El Kala on the right one) for each pixel, fractions are expressed in % with respect to the Chla. PSCs are retrieved applying Di Cicco *et al.* (2017) algorithms on the daily Chla times series OC5M for Bejaia Gulf (A), and OC4M for El Kala (B); (C and D) Micro-phytoplankton; (E and F) Nano-phytoplankton; and (G and H) Pico-phytoplankton.

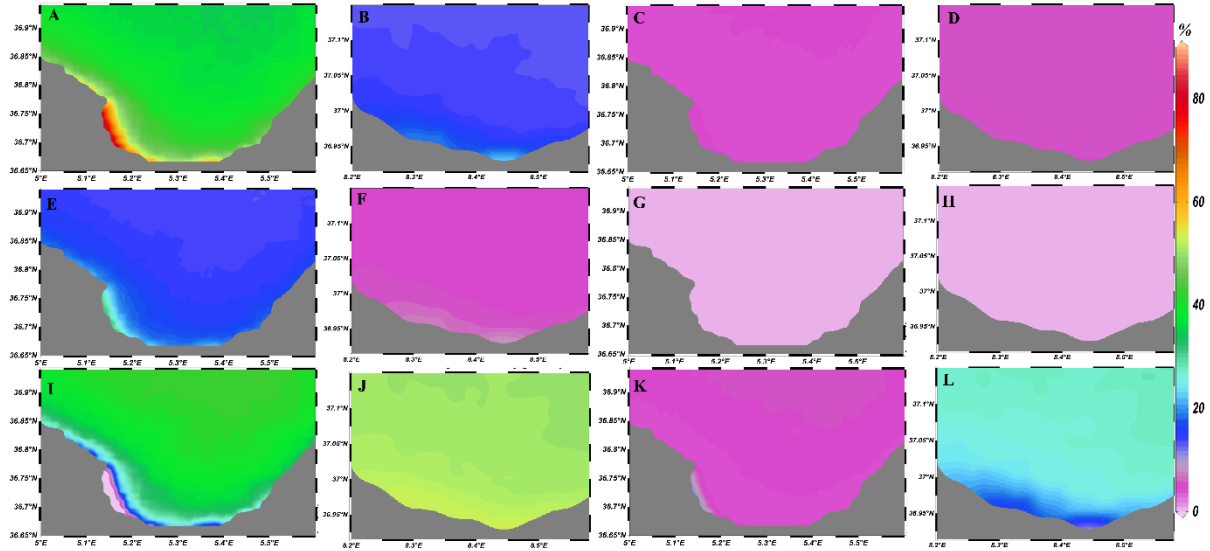


Figure 3. Annual climatology (2010-2020) of the PFTs for each pixel; fractions are expressed in % with respect to the Chla. PFTs are retrieved by applying Di Cicco *et al.* (2017) algorithms on the daily Chla time series (OC5M for Bejaia Gulf and OC4M for El Kala). (A and B) Diatoms, (C and D) Dinophytes, (E and F) Cryptophytes, (G and H) Green algae and Prochlorophytes, (I and J) Haptophytes, and (K and L) Prokaryotes, for Bejaia Gulf and El Kala Coast, respectively

The locations where the Chla climatology indicates the lowest absolute concentrations (Fig. 3, A and B), the pico-phytoplankton fraction attains its highest abundance, and that for both study areas (Fig. 2. G, and H), while in the more productive region of the Basin, the contribution of the pico component in terms of Chla concentration corresponds to a relatively small percentage of Chla, which fits the reasoning of Chisholm (1992), and supports the considerations of Li (2002), where the pico-phytoplankton contribution declines as Chla concentration increases. Regarding Bejaia Gulf, the pico-phytoplankton contribution remains less important than the other two classes, even when it reaches its maximums, representing at least half of the contribution of the other two classes. While in El Kala waters, it contributes nearly twice as much as micro-phytoplankton.

Conversely, for both study areas, in regions where the Chla concentration reaches higher values, the micro component reaches its maximum, the contribution percentage of the micro component increases following the gradient of Chla which decreases from the coastal to the offshore waters (Fig. 2. C and D). The highest values for the micro-phytoplankton class are observed along the coastal edge of both study areas, as well as near the harbor and the outlets of the wadis, mainly the Soummam and Agrioun wadis for Bejaia Gulf, which provide a high level of pollution due to the urban and industrial discharges they carry (Mouni *et al.*, 2009; Merah, 2020). And near El Mellah Lagoon, which carries out hydrodynamic exchanges with the littoral and tends to fertilize El Kala coast with nutrients (Retima, 1998). Thus, explaining the important contribution of nutrients favoring the development of micro-phytoplankton in

comparison with the other two classes. The nano-phytoplankton abundances are relatively high and homogeneous, ranging from 44 to 48% of Chla, and from 19 to 44% of Chla for El Kala waters and Bejaia Gulf, respectively (Fig. 2. E and F).

For the PFTs, the abundance of each class in regard to Chla concentration (Fig. 3), reflects the gradient of this pigment (Fig. 2. A and B), as was the case for the size classes, showing for diatoms (Fig. 3. A and B), and cryptophytes (Figs. 3E and F) higher abundances along the coast, whereas their lowest abundances are observed offshore for both study areas. The haptophytes are represented inversely with high values at the offshore, although abundance remains high and varies slightly until it reaches a minimum on the west side of Bejaia Gulf, but it always remains high on the other side (Fig. 3. I). Regarding El Kala waters, the haptophytes (Fig. 3. J) show high abundance in the entire study area (49 to 52% of Chla). The abundance of dinophytes follows a regular distribution expressed by very low values (Fig. 3. C and D) in both study areas. Prokaryotes are less abundant in Bejaia Gulf (average = 4.5%) compared with El Kala (average = 26.6%) (Fig. 3. K and L).

Annual climatological analysis indicates that diatoms are the major component of micro-phytoplankton in almost all of Bejaia Gulf (average = 39.3%), representing the absolutely dominant group in the coastal waters (Fig. 3. A). This can be justified by their ecological strategy, which is physiologically best adapted to high dynamic conditions and more effective in nutrient absorption. Furthermore, they can absorb nutrients and store them in their large vacuoles, depriving other groups while promoting their own growth (Margalef, 1978;

Falkowski *et al.*, 2003; Litchman *et al.*, 2007; Estrada and Vaqué, 2014). It also agrees with the considerations of Falkowski *et al.* (1998) regarding the availability of silica, which mainly comes from rivers, being aware that this element is fundamental for Diatom's proliferation.

The second most important group in terms of Chla concentration is the Haptophytes (Fig. 4. I), which represent the dominant class within the nano-phytoplankton throughout Bejaia Gulf (average = 37.2%), and in this study, it dominates the offshore waters. Cryptophytes (Fig. 3.E) are dominant in pico-phytoplankton and can be considered the third group in terms of Chla concentration (average = 37.2%), followed by prokaryotes (Fig. 3.K), dinophytes (Fig. 3.C), and finally green algae and prochlorophytes with trace concentrations (Fig. 3.G).

Regarding El Kala, and at the scale of the entire study area, the haptophytes (Fig. 3. J) are the major component of the nano-phytoplankton with an average of 50.4% of Chla, reaching their maxima near the coastal edge (52.97%), and that agrees with Di Cicco *et al.* (2017) observations concerning the dominance of haptophytes along the Algerian-Tunisian coasts, followed by prokaryotes (Fig. 3. L), which represent the dominant group within the pico-phytoplankton (average = 25.6% of Chla). Diatoms (Fig. 3. B) come in third position with 13.6%, followed by dinophytes (Fig. 3. D), cryptophytes (Fig. 3. F), and last, with the lowest average (6.33579 E-10), the green algae and prochlorophytes, represented by trace concentrations (Fig. 3. H).

For PFTs and PSCs annual climatology, the ANOVA test was performed to investigate the difference of PFTs and PCSs abundance between the two regions. The test yields the same p-value

of 0.000 for all groups, which is highly significant (p -value less than 0.001). The average abundance of all size classes and functional groups in Bejaia Gulf is found to be significantly different from that observed in El Kala. Micro-phytoplankton is more abundant in Bejaia Gulf (mean = 43.38) than in El Kala (mean = 19.13), whereas the nano-phytoplankton and pico-phytoplankton are more abundant in El Kala with means of 46.10 and 34.76, respectively. In terms of PFTs, the test shows that diatoms (mean = 39.32) and cryptophytes (mean = 14.88), and the green algae and prochlorophytes with a negligible contribution, are more plentiful in Bejaia Gulf. While haptophytes (mean = 50.36), prokaryotes (mean = 25.82), and dinophytes (mean = 5.63) are more abundant in El Kala. In the Bioregionalization proposed by D'Ortenzio and Ribera d'Alcalà (2009) with seven models, which was expanded to eleven bioprovinces by Mayot *et al.* (2016). The Algerian Basin is labeled as a "No bloom" region. Nonetheless, previous research demonstrated heterogeneity in nutrient and phytoplankton distribution, as well as an unexpectedly high biomass, according to Sournia (1973). Furthermore, the Algerian eastern Basin is highlighted by strong mesoscales and considered as one of the most energetic sections of the entire Mediterranean Sea (Larnicol *et al.*, 1995; Ayoub *et al.*, 1998; Vignudelli, 1997; Millot, 1999). This could explain the heterogeneous distribution of PSCs and PFTs, and the substantial variation within every group's contribution and abundance between the two study regions.

3.2.2 Monthly climatology

Figure 4 depicts the monthly climatology of each size class in Bejaia Gulf and El Kala, averaged over the entire study area. On the scale of the two study regions, the nano-phytoplankton is the

most representative component of the Chla, followed by the pico, and lastly, the micro-phytoplankton with the lowest contribution to the Chla. Our results support the findings of Uitz *et al.* (2012), who indicated that the primary production in the Mediterranean Sea is mainly attributable to the nano-phytoplankton element.

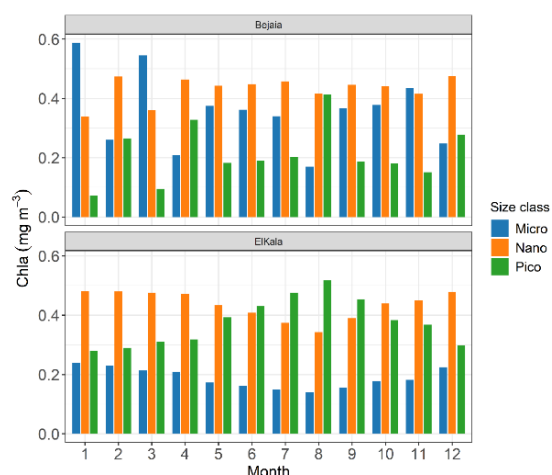


Figure 4. Monthly average climatology (2010-2020) of the PSCs in terms of their contribution to the Chla (mg m^{-3})

The monthly climatology of the PFT's (Fig. 5) confirms the predominance of haptophytes within the nano-phytoplankton in both study areas (average = 0.47 and 0.48 mg m^{-3} of Chla) for Bejaia and El Kala, respectively, followed by prokaryotes (average = 0.23 mg m^{-3} of Chla for Bejaia and 0.29 mg m^{-3} of Chla for El Kala), and diatoms, which represent the main component of micro-phytoplankton (average = 0.15 and 0.12 mg m^{-3} of Chla for Bejaia and El Kala, respectively) (Fig. 5 and 6). The cryptophytes and dinophytes are present all over the year in both study areas, but their contributions to the Chla remain low (Fig. 5A, B). And last come the green algae and prochlorophytes with the weakest average fraction (0.015 for Bejaia Gulf and 5,817E-12 mg m^{-3} for El Kala of Chla) and a contribution almost insignificant (Fig. 5 and 6).

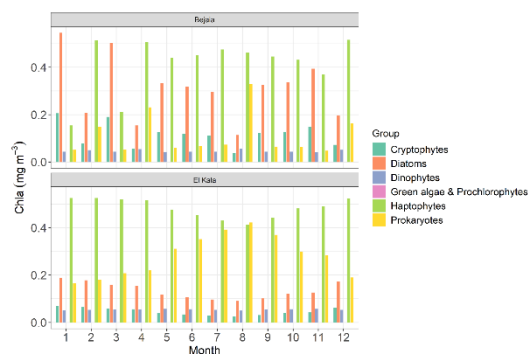


Figure 5. Monthly average climatology (2010-2020) of the PFTs in terms of their contribution to the Chla (mg m^{-3})

In both study areas, productivity begins in November with an average Chla of 0.37 and 0.20 mg m^{-3} in Bejaia Gulf and El Kala, respectively, and ends in April for El Kala and in March for Bejaia Gulf meeting their peaks in December with Chla of 1.23 mg m^{-3} for Bejaia Gulf and in January with Chla of 0.53 mg m^{-3} for El Kala waters, while the lowest Chla is estimated during the summer season for both regions (Fig. 6). Our findings match the seasonal cycle of the Algerian Basin established by Bosc (2002), which is marked by a maximum of biomass in winter, an early autumn onset with a smaller phytoplanktonic bloom, and minimal biomass in summer. Our estimations are also consistent with the Mediterranean seasonality curve, which was plotted based on 10 years of *in situ* measurements by Marty *et al.* (2002) and highlighted by Siokou-Frangou *et al.* (2010) synthesis of phytoplankton studies in the Mediterranean Sea, and largely substantiated by satellite data (Morel and André, 1991; Bosc *et al.*, 2004; D'Ortenzio and Ribera d'Alcalà, 2009; Sammartino *et al.*, 2015; Mayot *et al.*, 2016).

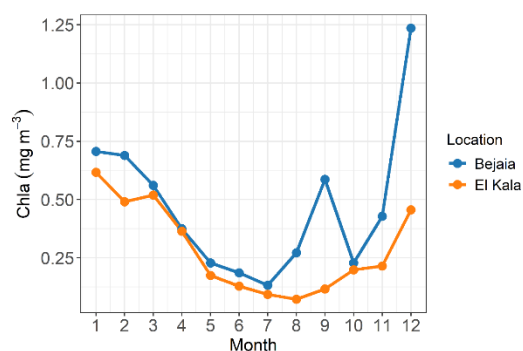


Figure 6. Monthly Climatology of Chla concentration (mg m^{-3}) along the time series (01/2010 to 12/2020)

3.2.3 Variability of PFTs in response to SST and precipitation

The sea surface temperature, which exemplifies the thermal stratification of the ocean, has an average of 21.02 °C and 21.08 °C in Bejaia Gulf and El Kala, respectively, for the period (2010-2020). Rainfall is important in plankton dynamics because it brings a significant amount of nutrients as well as participate to the initiation of spring blooms (Zingone *et al.*, 1995; Jamet *et al.*, 2005). It has an average of 1144 mm in Bejaia Gulf and 1310 mm in El Kala. PFTs and PSCs abundance in our study areas is affected differently by those environmental factors.

The study of the variability of PFTs and PSCs in response to SST and precipitation fluctuations in Bejaia Gulf revealed that the abundance of PSCs and PFTs is strongly influenced by precipitation (p -value = 0.000, R^2 = 37.79 to 53.23%). The effect of SST remains insignificant, as confirmed by the study of each factor separately, where the variation in PFTs and PSCs depends primarily on precipitation. On the scale of the entire gulf, the precipitation varies considerably (796 to 1505 mm). In contrast, the abundances of diatoms and cryptophytes are negatively dependent on rainfall, whereas dinophytes, prokaryotes, and

haptophytes have a positive dependency (Table 3). Because the chemical and physical features of rain are fluctuating wildly, precipitation could be a major driver of change in the ocean. Rainwater's chemical composition has altered substantially because of pollutants accumulating in the atmosphere resulting of increased usage of fossil fuels and agricultural fertilizers. Sulfur, nitrogen, and heavy metals are among the pollutants that end up in the marine environment by precipitation (Rodhe *et al.*, 2002; Galloway *et al.*, 2004, 2008; Doney *et al.*, 2007).

While in El Kala, both SST and precipitation affect PSCs and PFTs abundance (p -value = 0.000,

$R^2 = 52.46$ to 57.03%). Nevertheless, the study of their dependence separately reveals that the SST affects the variability of PSCs and PFTs more than the precipitation (Table 3), supporting the considerations of Hays *et al.* (2005), where temperature variations cause a change in phytoplankton distribution as well as in their composition and abundance. Diatoms, cryptophytes, and haptophytes show a positive relationship with SST, whereas dinophytes and prokaryotes have a negative dependency with SST (Table 3). Our results can't be explained by the ecological preferences of each group since the SST varies slightly (21 to 21.19 °C) in El Kala waters and over the eleven study years.

Table 3. Statistical results of the PFTs and PSCs dependency model in responses to SST and precipitation in Bejaia Gulf and El Kala. (Applied on the annual climatology)

PFTs/PSCs	Bejaia Gulf			El Kala		
	Model formula	p -value	R^2 (%)	Model formula	p -value	R^2 (%)
Micro-phytoplankton	57.102 - 0.011606 Prec	0.000	42.53	-290.8+ 14.69 SST	0.000	43.02
	97.0 - 1.87 SST	0.000	42.95	-240.3+ 12.45 SST	0.000	55.10
	- 0.012017 Prec			- 0.002348 Prec		
Nano-phytoplankton	34.855 + 0.005655 Prec	0.000	41.59	-190.1+ 11.19 SST	0.000	47.07
	15.4 + 0.915 SST	0.000	42.01	-160.8 + 9.89 SST	0.000	54.71
	+ 0.005856 Prec			- 0.001363 Prec		
Pico-phytoplankton	8.044 + 0.005950 Prec	0.000	43.42	580.8 - 25.89 SST	0.000	48.37
	-12.4 + 0.959 SST	0.000	43.85	501.1 - 22.34 SST	0.000	56.86
	+ 0.006161 Prec			+ 0.003711 Prec		
Diatoms	53.184 - 0.011728 Prec	0.000	43.03	-322.7 + 15.94 SST	0.000	42.68
	93.4 - 1.89 SST	0.000	43.45	-267.3 + 13.47 SST	0.000	54.96
	- 0.012143 Prec			- 0.002578 Prec		
Dinophytes	3.91766+ 0.000122 Prec	0.000	37.74	31.94 - 1.247 SST	0.000	38.19
	3.576 + 0.0161 SST	0.000	37.99	27.00 - 1.027 SST	0.000	52.46
	+ 0.000126 Prec			+ 0.000230 Prec		
Cryptophytes	20.119- 0.004428 Prec	0.000	43.24	-140.4 + 6.879 SST	0.000	43.27
	35.29- 0.713 SST	0.000	43.67	-116.8 + 5.828 SST	0.000	55.39
	- 0.004584 Prec			- 0.001098 Prec		
Green algae+ prochlorophytes	0.00- 0.00Prec	0.000	40.8	-0.00+ 0.00 SST	0.000	45.97
	0.00- 0.00 SST	0.000	41.21	-0.00+ 0.00 SST	0.000	54.93
	- 0.00 Prec			- 0.00Prec		
Prokaryotes	2.8701 + 0.001363 Prec	0.000	53.23	752.9 - 34.47 SST	0.000	45.97
	-1.28 + 0.195 SST	0.000	53.64	643.3 - 29.59 SST	0.000	57.03
	+ 0.001406 Prec			+ 0.00510 Prec		
Haptophytes	19.91 + 0.014671 Prec	0.000	39.75	-221.7 + 12.89 SST	0.000	47.17
	-31.0 + 2.39 SST	0.000	40.15	-186.2 + 11.31 SST	0.000	55.69
	+ 0.01520 Prec			- 0.001652 Prec		

SST: Sea surface temperature, Prec.: Precipitation.

4 CONCLUSION

The current study has confirmed that satellite derived data remains the best alternative to fill the lack of *in situ* data due to the inaccessibility of some sites, and even when we can access them, the necessary material means, and laboratory analysis remain prohibitively expensive. Furthermore, unlike *in situ* data, which is limited to a specific location, satellite data enables long-term and expanded spatial monitoring.

In this study, we were interested in providing an overview of the spatial and temporal variability of phytoplankton size classes and functional types using satellite images for the first time in Eastern Algerian waters. The phytoplankton estimation model's assessment reveals that the algorithms developed by Di Cicco *et al.* (2017) perform strongly in both study areas. which can be explained by the fact that this model has been calibrated for the Mediterranean region and validated for all Mediterranean trophic regimes, of which our study areas are a part.

The Chla data, derived from MODIS images, permitted us to conduct a first analysis on the distribution of PSCs and PFTs in the surface water of Bejaia Gulf and El Kala over an 11-year period (2010-2020), which revealed several points of consistency with previous research conducted at the Mediterranean scale, but also differences as well as more information, particularly on the coastal edge.

This study confirmed that the PFTs are strongly influenced by environmental factors such as the sea surface temperature and precipitation. However, their responses vary from one area to another, which can be explained by the morphological distinction of each area. Nevertheless, the interpretation of those

fluctuations remains complicated considering the number of abiotic factors that can co-vary with SST and precipitation.

This study is an initiation. The deficit of validation and calibration research fields in our study areas leads us to other questions: Is it necessary to design a specific model for each Gulf and Bay? which can consider the heterogeneity of each region in terms of geomorphological characteristics, and physical characteristics such as the sea surface temperature, bathymetry, and the mixed layer depth, to better understand the spatiotemporal variations of biological parameters such as Chla and phytoplankton, especially along the coastline. Or is it adequate to opt for calibrations in each area, taking into consideration all photosynthetic pigments?

These questions define our perspectives, in order to improve the model accuracy allowing for a better representation of the satellite data and obtaining information that is even closer to the field reality. Thus, tracking the spatio-temporal variation of these components, as well as monitoring the state of the marine environment in order to mitigate the effects of anthropogenic activities.

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REFERENCES

- Abdallah, K. W., Djabourabi, A., Samar, F., Harid, R., Izeboudjen, H., Djebbari, N., Bachari, N. El., & Houma-Bachari, F. (2024). Evaluation of the physico-chemical and biological quality of the eastern algerian coastal waters (southwestern mediterranean). *Geo-Eco-Marina*, 30, 93-105.
- Abdallah, K. W., Harid, R., Demarcq, H., Samar, F., Djabourabi, A., Izeboudjen, H., Bachari, N. El., & Houma-Bachari, F. (2024). Retrieval of Micro-Phytoplankton Density using Sentinel-3 and MODIS Satellite Sensors on the Eastern Algerian Coast. *Thalassas: An International Journal of Marine Sciences*, 40(1), 285-297.
- Aiken, J., Pradhan, Y., Barlow, R., Lavender, S., Poulton, A., Holligan, P. & Hardman-Mountford, N. (2009). Phytoplankton pigments and functional types in the Atlantic Ocean: A decadal assessment 1995-2005. *Deep-Sea Research Part II: Topical Studies in Oceanography*, 56(15), 899-917. doi: 10.1016/j.dsr2.2008.09.017
- Alvain, S., Moulin, C., Dandonneau, Y. & Bréon, F.M. (2005). Remote sensing of phytoplankton groups in case 1 waters from global SeaWiFS imagery. *Deep-Sea Research Part I: Oceanographic Research Papers*, 52(11), 1989-2004. doi: 10.1016/j.dsr.2005.06.015
- Alvain, S., Moulin, C., Dandonneau, Y., & Loisel, H. (2008). Seasonal distribution and succession of dominant phytoplankton groups in the global ocean: A satellite view. *Global Biogeochemical Cycles*, 22(3), 1-15. doi: 10.1029/2007GB003154
- Anderson, T.R. (2005). Plankton functional type modelling: Running before we can walk? *Journal of Plankton Research*, 27(11), 1073-1081. doi: 10.1093/plankt/fbi076
- Arrignon, J. (1963). Contribution à l' inventaire des marécages, tourbières et autres zones humides d' Algérie. *Annales du centre de recherches et d'expérimentation forestière*, 5, 30-32.
- Ayoub, N., Le Traon, P.Y. & De Mey, P. (1998). A description of the Mediterranean surface variable circulation from combined ERS-1 and TOPEX/POSEIDON altimetric data. *Journal of Marine Systems*, 18, 3-40. doi: 10.1016/S0924-7963(98)80004-3
- Bakalem, A. (1999). Peuplement des sables fins des côtes algériennes : Amphipodes et pollution. *Amphipodes et pollution. Proceedings of a symposium. Marine Pollution, IAEA*, 5 and 9 oct. 1998, Monaco : 315-317.
- Benmeradi, S. (1993). Matière nutritive, production primaire et populations phytoplanctoniques de la retenue collinaire de Cap Jinet. *Magister Thesis. Algiers university, Algeria*, 117 pp.
- Ben Mustapha, Z., Alvain, S., Jamet, C., Loisel, H. & Dessailly, D. (2014). Automatic classification of water-leaving radiance anomalies from global SeaWiFS imagery: Application to the detection of phytoplankton groups in open ocean waters. *Remote Sensing of Environment*, 146, 97-112. doi: 10.1016/j.rse.2013.08.046
- Bernard, F. (1948). Recherches préliminaires sur la fertilité marine au large d' Alger. *International Council for the Exploration for the Sea Journal of Marine Science*, 15(3), 260-267. doi: 10.1093/icesjms/15.3.260
- Blondel, J. (2003). Guilds or functional groups: Does it matter? *Oikos* 100(2), 223-231. doi: 10.1034/j.1600-0706.2003.12152.x
- Bosc, E. (2002). Variations saisonnières et interannuelles de la biomasse phytoplanctonique et de la production primaire en Méditerranée : Evaluation et utilisation des données satellitaires de couleur de l' océan (SeaWiFS, POLDER et OCTS). *Ph.D. Thesis, Toulon et du Var University. France*, 203 pp.
- Bosc, E., Bricaud, A. & Antoine, D. (2004). Seasonal and interannual variability in algal biomass and primary production in the Mediterranean Sea, as derived from 4 years of SeaWiFS observations. *Global Biogeochemical Cycles*, 18(1), 1-17. doi: 10.1029/2003gb002034
- Boudjenah, M., Mokrane, Z. & Soualili, D. (2019). Diversity of Phytoplanktonic populations along the Algerian coastline. *Biodiversity Journal*, 10(2), 81-92. doi: 10.31396/biodiv.jour.2019.10.2.81.92
- Boufeniza, R.L., Alsahli, M.M., Bachari, N.I. & Bachari-Houma, F. (2020). Spatio-temporal quantification and distribution of diatoms and dinoflagellates associated with algal blooms

- and human activities in Algiers Bay (Algeria) using Landsat-8 satellite imagery. *Regional Studies in Marine Science*, 36, 10 pp. doi: 10.1016/j.rsma.2020.101311
- Bracher, A., Vountas, M., Dinter, T., Burrows, J.P., Röttgers, R. & Peeken, I. (2009). Quantitative observation of cyanobacteria and diatoms from space using PhytoDOAS on SCIAMACHY data. *Biogeosciences*, 6(5), 751-764. doi: 10.5194/bg-6-751-2009
- Brewin, R.J.W., Sathyendranath, S., Hirata, T., Lavender, S.J., Barciela, R.M. & Hardman-Mountford, N.J. (2010). A three-component model of phytoplankton size class for the Atlantic Ocean. *Ecological Modelling*, 221(11), 1472-1483. doi: 10.1016/j.ecolmodel.2010.02.014
- Butt, M.J. & Nazeer, M. (2015). Landsat ETM+ Secchi Disc Transparency (SDT) retrievals for Rawal Lake, Pakistan. *Advances in Space Research*, 56(7), 1428-1440. doi: 10.1016/j.asr.2015.06.041
- Chisholm, S. W. (1992) Phytoplankton size. In Falkowski, P.G. and Woodhead, A.D. (Eds.), *Primary Productivity and Biogeochemical Cycles in the Sea*. NY: Plenum Press, New York, pp. 213-237.
- Ciotti, A.M. & Bricaud, A. (2006). Retrievals of a size parameter for phytoplankton and spectral light absorption by colored detrital matter from water-leaving radiances at SeaWiFS channels in a continental shelf region off Brazil. *Limnology and Oceanography: Methods*, 4(7), 237-253. doi: 10.4319/lom.2006.4.237
- D'Ortenzio, F. & Ribera d'Alcalà, M. (2009). On the trophic regimes of the Mediterranean Sea: a satellite analysis. *Biogeosciences*, 6, 139-148. doi: <https://doi.org/10.5194/bg-6-139-2009>.
- D'Ortenzio, F. & Prieur, L. (2012) The upper mixed layer. In Noga Stambler (Eds.) *Life in the Mediterranean Sea: A Look at Habitat Changes*. Nova Science Publishers, Bar-Ilan University, Ramat-Gan, pp. 127-156.
- Di Cicco, A., Sammartino, M., Marullo, S. & Santoleri, R. (2017). Regional empirical algorithms for an improved identification of phytoplankton functional types and size classes in the Mediterranean Sea using satellite data. *Frontiers in Marine Science*, 4(may), 1-18. doi: 10.3389/fmars.2017.00126
- Doney, S. C., Mahowald, N., Lima, I., Feely, R. A., Mackenzie, F. T., Lamarque, J. F., & Rasch, P. J. (2007). Impact of anthropogenic atmospheric nitrogen and sulfur deposition on ocean acidification and the inorganic carbon system. *Proceedings of the National Academy of Sciences of the United States of America*, 104(37), 14580-14585. doi: 10.1073/pnas.0702218104
- Estrada, M., & Vaqué, D. (2014) Microbial components, in Goffredo, S. and Dubinsky, Z. (Eds.) *The Mediterranean Sea, Its History and Present Challenges*, Springer, New York, London, pp. 87-111.
- Falkowski, P.G., Barber, R.T. & Smetacek, V. (1998). Biogeochemical controls and feedbacks on ocean primary production. *Science*, 281(5374), 200-206. doi: 10.1126/science.281.5374.200
- Falkowski, P.G., Laws, E.A., Barber, R.T. & Murray, J.W. (2003). Phytoplankton and their role in primary, new, and export production. In Michael Fasham, J.R. (Eds.), *Ocean Biogeochemistry: A Synthesis of the Joint Global Ocean Flux Study (JGOFS)*, Global change-the IGBP series, Springer-Verlag, Berlin, pp.1619-2435.
- Fiala, M., Sournia, A., Claustre, H., Marty, J.C., Prieur, L. & Vétion, G. (1994). Gradients of phytoplankton abundance, composition, and photosynthetic pigments across the Almeria-Oran front (SW Mediterranean Sea). *Journal of Marine Systems*, 5(3-5), 223-233. doi: 10.1016/0924-7963(94)90048-5
- Galloway, J. N., Dentener, F. J., Capone, D. G., Boyer, E. W., Howarth, R. W., Seitzinger, S. P., Asner, G. P., Cleveland, C. C., Green, P. A., Holland, E. A., Karl, D. M., Michaels, A. F., Porter, J. H., Townsend, A. R., Vorosmarty, C. J., Voro, V., & Vorosmarty, V. (2004). Galloway-et-al-2004-BioGeoCh. In *Biogeochemistry* (Vol. 70, Issue 2). Retrieved from papers://aa15ed4a-8b41-4036-84a6-41087bba0cd6/Paper/p3387
- Galloway, James N., Townsend, A. R., Erisman, J. W., Bekunda, M., Cai, Z., Freney, J. R., Martinelli, L. A., Seitzinger, S. P., & Sutton, M. A. (2008). Transformation of the nitrogen cycle: Recent trends, questions, and potential

- solutions. *Science*, 320(5878), 889-892. doi: 10.1126/science.1136674
- Gregg, W.W., Ginoux, P., Schopf, P.S., & Casey, N.W. (2003). Phytoplankton and iron: Validation of a global three-dimensional ocean biogeochemical model. *Deep-Sea Research Part II: Topical Studies in Oceanography*, 50(22-26), 3143-3169. doi: 10.1016/j.dsr2.2003.07.013
- Grimes, S. (2010). *Peuplements benthiques des substrats meubles de la côte algérienne : taxonomie, structure et statut écologique*. Ph.D. Thesis, Oran University, Algeria. 265 pp.
- Guelorget, O., Frisoni, G.F., Ximenes, M.C. & Perthuisot J.P. (1989). Expression biologique du confinement dans une lagune méditerranéenne : le lac Mellah (Algérie). *Revue d'Hydrobiologie Tropicale*, 22(2), 87-99.
- Hays, G. C., Richardson, A. J., & Robinson, C. (2005). Climate change and marine plankton. *Trends in Ecology and Evolution*, 20(6 SPEC. ISS.), 337-344. doi: 10.1016/j.tree.2005.03.004
- Hirata, T., Aiken, J., Hardman-Mountford, N., Smyth, T.J., & Barlow, R.G. (2008). An absorption model to determine phytoplankton size classes from satellite ocean colour. *Remote Sensing of Environment*, 112(6), 3153-3159. doi: 10.1016/j.rse.2008.03.011
- Hirata, T., Hardman-Mountford, N.J., Brewin, R.J.W., Aiken, J., Barlow, R., Suzuki, K., Isada, T., Howell, E., Hashioka, T., Noguchi-Aita, M., & Yamanaka Y. (2011). Synoptic relationships between surface Chlorophyll-a and diagnostic pigments specific to phytoplankton functional types. *Biogeosciences*, 8(2), 311-327. doi: 10.5194/bg-8-311-2011
- Iglesias-Rodríguez, M.D., Brown, C.W., Doney, S.C., Kleypas, J., Kolber, D., Kolber, Z., Hayes, P.K., & Falkowski PG. (2002). Representing key phytoplankton functional groups in ocean carbon cycle models: Coccolithophorids. *Global Biogeochemical Cycles*, 16(4), 1-20. doi: 10.1029/2001gb001454
- Illoul, H. (1991). *Contribution à l' étude qualitative, quantitative et structurale des populations phytoplanctoniques au large du cap Caxine (Région algéroise)*. Magister Thesis. ISMAL, Algiers, Alegria. 170 pp.
- Illoul, H., Fortuño, J.M., Miguel, L.C., Morales-Blake, A.R., & Séridji, R. (2008). Potentially harmful microalgae in coastal waters of the Algiers area (Southern Mediterranean Sea). *Cryptogamie Algologie*, 29(3), 261-278
- IOCCG. (2014). *Phytoplankton functional types from Space*. In: Sathyendranath, S (Eds.), *Reports and Monographs of the International Ocean Colour Coordinating Group*. N° 15, Dartmouth, NS, Canada, pp. 154.
- Jamet, J. L., Jean, N., Bogé, G., Richard, S., & Jamet, D. (2005). Plankton succession and assemblage structure in two neighbouring littoral ecosystems in the north-west Mediterranean Sea. *Marine and Freshwater Research*, 56(1), 69-83. doi: 10.1071/MF04102
- Kahru, M., Kudela, R.M., Anderson, C.R., Manzano-Sarabia, M., & Mitchell, B.G. (2014). Evaluation of satellite retrievals of ocean chlorophyll-a in the California current. *Remote Sensing*, 6(9), 8524-8540. doi: 10.3390/rs6098524
- Kostadinov, T.S., Siegel, D.A., & Maritorea, S. (2009). Retrieval of the particle size distribution from satellite ocean color observations. *Journal of Geophysical Research: Oceans*, 114(9), 1-22. doi: 10.1029/2009JC005303
- Lalami-Taleb, R. (1971). Facteurs de répartition verticale du phytoplancton au large d' Alger. *Pelagos, Bulletin de l'Institut océanographique*, 3(3), 1-186.
- Lalami-Taleb, R. (1983). *Biologie et structure des populations phytoplanctoniques de l' Adriatique. Comparaisons avec d' autres zones de la Méditerranée et en particulier avec la baie d' Alger*. Ph.D. Thesis Sciences. Université des Sciences et Techniques. Languedoc. 512 pp.
- Larnicol, G., Le Traon, P.Y., Ayoub, N., & De Mey, P. (1995). Mean sea level and surface circulation variability of the Mediterranean Sea from two years of TOPEX/POSEIDON altimetry. *Journal of Geophysical Research*, 100(C12), 163-177. doi: 10.1029/95jc01961
- LE Quéré, C., Harrison, S.P., Prentice, I.C., Buitenhuis, E.T., Aumont, O., Bopp, L., Claustre, k., Cotrim, D.A, Cunha, H., Geider, R., Giraud, X., Klaas, C., Kohfeld, K.E., Legendre, L., Manizza, M., Platt, T., Rivkin, R.B., Sathyendranath, S., Uitz, J., Watson, A.J., &

- Gladrow, D. (2005). Ecosystem dynamics based on plankton functional types for global ocean biogeochemistry models. *Global Change Biology*, 11, 2016-2040. doi: 10.1111/j.1365-2486.2005.01004.x
- Li, W. (2002). Macroecological patterns of phytoplankton in the northwestern North Atlantic Ocean. *Nature*, 419, 154-157.
- Litchman, E., Klausmeier, C.A., Schofield, O.M. & Falkowski, P.G. (2007). The role of functional traits and trade-offs in structuring phytoplankton communities: Scaling from cellular to ecosystem level. *Ecology Letters*, 10(12), 1170-1181. doi: 10.1111/j.1461-0248.2007.01117.x
- Lorenzen, C.J. (1966). Determination of Chlorophyll and Phaeopigments: Spectrophotometric Equations. *Limnology and Oceanography*, 12(2), 343-346. doi: 10.4319/lo.1967.12.2.0343
- Margalef, R. (1978). Life-forms of phytoplankton as survival alternatives in an unstable environment. *Oceanologica Acta* 1(4), 493-509.
- Marty, J.C., Chiavérini, J., Pizay, M.D. & Avril, B. (2002). Seasonal and interannual dynamics of nutrients and phytoplankton pigments in the western Mediterranean Sea at the DYFAMED time-series station (1991-1999). *Deep-Sea Research Part II: Topical Studies in Oceanography*, 49(11), 1965-1985. doi: 10.1016/S0967-0645(02)00022-X
- Mayot, N., D'Ortenzio, F., D'Alcalà, M.R., Lavigne, H. & Claustre, H. (2016). Interannual variability of the Mediterranean trophic regimes from ocean color satellites. *Biogeosciences*, 13(6), 1901-1917. doi: 10.5194/bg-13-1901-2016
- Merah, F. (2020). Etude et modélisation informatique de la qualité des eaux de surface de l'oued Agroun. Ph.D. Thesis. Batna 2 University, Batna, Algeria. 210 pp.
- Millot, C. (1999). Circulation in the Western Mediterranean Sea. *Journal of Marine Systems*, 20(1-4), 423-442. doi: 10.1016/S0924-7963(98)00078-5
- Mollo, P. & Noury, A. (2013). *Le Manuel du plancton*. Charles Léopold Mayer (Eds.), Paris, 198 pp. (accessed on October 19, 2021), <https://books.google.dz/books?id=6rGeBgA> AQBAJ&printsec=frontcover&hl=fr#v=onepage&q&f=false.
- Morel, A. & Andre, J.M. (1991). Pigment distribution and primary production in the western Mediterranean as derived and modeled from coastal zone color scanner observations. *Journal of Geophysical Research*, 96(C7), 685-698. doi: 10.1029/91jc00788
- Mouni, L., Merabet, D., Arkoub, H. & Moussaceb, K. (2009). Etude et caractérisation physico-chimique des eaux de l'oued Soummam (Algérie). *Sécheresse*, 20 (4), 360-6.
- Mouw, C.B. & Yoder, J.A. (2010). Optical determination of phytoplankton size composition from global SeaWiFS imagery. *Journal of Geophysical Research: Oceans*, 115(12), 1-20. doi: 10.1029/2010JC006337
- Mouw, C.B., Greb, S., Aurin, D., DiGiacomo, P.M., Lee, Z., Twardowski, M., Binding, C., Hu, C., Ma, R., Moore, T., Moses, W. & Craig, S.E. (2015). Aquatic color radiometry remote sensing of coastal and inland waters: Challenges and recommendations for future satellite missions. *Remote Sensing of Environment*, 160, 15-30. doi: 10.1016/j.rse.2015.02.001
- O'Reilly, J.E., Maritorena, S., Mitchell, B.G., Siegel, D.A., Carder, K.L., Garver, S.A., Kahru, M. & McClain, C. (1998). Ocean color chlorophyll algorithms for SeaWiFS. *Journal of Geophysical Research: Oceans*, 103(C11), 24937-24953. doi: 10.1029/98JC02160
- O'Reilly, J.E. & Werdell, P.J. (2019). Chlorophyll algorithms for ocean color sensors - OC4, OC5 & OC6. *Remote Sensing of Environment*, 229(April), 32-47. doi: 10.1016/j.rse.2019.04.021
- Pincemin, J.M. (1966). Note préliminaire à l'étude écologique des dinoflagellés de la baie d'Alger et comparaison avec les diatomées. *Pelagos* 2, 5-47.
- Retima, A. (1998). Indice des échanges hydrologiques, chimiques, biochimiques et phytoplanktoniques sur la fertilisation de la lagune El Mellah et du littoral voisin (El Kala, Algérie), selon le régime des marées, dix ans après l'aménagement du chenal de communication. Magister Thesis, Annaba university, Algeria, 87 pp.
- Rodhe, H., Dentener, F. & Schulz, M. (2002). The global distribution of acidifying wet

- deposition. *Environmental Science and Technology*, 36(20), 4382-4388. doi: 10.1021/es020057g
- Roy, S., Sathyendranath, S., Bouman, H., & Platt, T. (2013). The global distribution of phytoplankton size spectrum and size classes from their light-absorption spectra derived from satellite data. *Remote Sensing of Environment*, 139, 185-197. doi: 10.1016/j.rse.2013.08.004
- Sammartino, M., Di Cicco, A., Marullo, S., & Santoleri, R. (2015). Spatio-temporal variability of micro-, nano- and pico-phytoplankton in the Mediterranean Sea from satellite ocean colour data of SeaWiFS. *Ocean Science*, 11(5), 759-778. doi: 10.5194/os-11-759-2015
- Santoleri R, Volpe G, Marullo S, Nardelli BB. 2008 Open Waters Optical Remote Sensing of the Mediterranean Sea. In: Barale, V, and Gade, M. (Eds.), *Remote Sensing of the European Seas*. Springer, Dordrecht, pp. 103-116. https://doi.org/10.1007/978-1-4020-6772-3_8
- Siokou-Frangou, I., Christaki, U., Mazzocchi, M.G., Montresor, M., Ribera D'Alcalá, M., Vaquer, D., & Zingone, A. (2010). Plankton in the open mediterranean Sea: A review. *Biogeosciences*, 7(5), 1543-1586. doi: 10.5194/bg-7-1543-2010
- Sourina, A. (1973). La production primaire planctonique en Méditerranée : Essai de mise à jour, *Bulletin d'Etude Commune en Méditerranée*, Special Issue 5, 1-128.
- Tellai, S. (1964). Répartition géographique et saisonnière du microplancton dans la Baie d'Alger. *Pelagos, Bulletin d'Institut d'Océanographie. Algiers (Fasc. I)*, 1-50.
- Uitz, J., Claustre, H., Morel, A., & Hooker, S.B. (2006). Vertical distribution of phytoplankton communities in open ocean: An assessment based on surface chlorophyll. *Journal of Geophysical Research: Oceans*, 111(8), 23 pp. doi: 10.1029/2005JC003207
- Uitz, J., Stramski, D., Gentili, B., D'Ortenzio, F., & Claustre, H. (2012). Estimates of phytoplankton class-specific and total primary production in the Mediterranean Sea from satellite ocean color observations. *Global Biogeochemical Cycles*, 26, 10 pp. doi: 10.1029/2011GB004055
- Videau, C., Sournia, A., Prieur, L., & Fiala, M. (1994). Phytoplankton and primary production characteristics at selected sites in the geostrophic Almeria-Oran front system (SW Mediterranean Sea). *Journal of Marine Systems*, 5, 235-250. doi: 10.1016/0924-7963(94)90049-3
- Vignudelli, S. (1997). Potential use of ERS-1 and Topex/Poseidon altimeters for resolving oceanographic patterns in the Algerian Basin. *Geophysical Research Letters*, 24 (14), 1787-1790.
- Zingone, A., Casotti, R., D'Alcalá, M. R., Scardi, M., & Marino, D. (1995). "St Martin's summer" : The case of an autumn phytoplankton bloom in the Gulf of Naples (Mediterranean Sea). *Journal of Plankton Research*, 17(3), 575-593. doi: 10.1093/plankt/17.3.575