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On the use of validated ocean models to investigate the evolution of primary productivity in the Levantine Sea

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Abstract: Marine ecosystems are vital natural resources that contribute to the global biogeochemical cycle, food, and energy production. In order to monitor and evaluate variations of different factors for decision making processes, validated ecosystem models were used in this study to analyze the evolution of different variables: temperature and salinity concentrations (from 1987 to 2014) and nitrate, phosphate, dissolved oxygen, chlorophyll concentrations, and phytoplankton biomass (from 1999 to 2014) in four sites (from 0 to 66 m depth) along the Levantine Sea: Lebanon, Turkey, Egypt and in the Open Sea. Principal component analysis and TRIX were then applied. Spatio-temporal analysis and PCA results showed that phytoplankton biomass is temporally affected by temperature and nutrients (in all stations) as well as salinity in some cases, in addition to its decrease with depth. TRIX analysis showed that all stations had higher primary productivity, in the first half of the year (January-May). Intense anthropogenic activities in Turkey and Egypt have altered the ecosystem's stability and affected the phytoplankton biomass.

Key words: primary production, spatiotemporal analysis, limiting factors, PCA, Levantine

Introduction

Oceans are one of the most important natural resources. Their importance lies in their ability to sustain all living organisms and to incorporate a broad range of ecosystem goods and services, including global biogeochemical cycling, food, and energy production, regulation of temperature, as well as providing a source of transport, recreation and job creation (Costanza 1999). Anthropogenic activities and land degradation are negatively affecting marine ecosystems (Darwish et al. 2018; Ghoussein et al. 2018). Continuous monitoring of these ecosystems has become a must to better understand and improve planning and decision-making, especially in regions with scarce data (Douvere and Ehler 2011; Fadel et al. 2014).

The Levantine Basin is located in the easternmost region of the Mediterranean Sea between Cyprus and the Nile Delta marine cone in Egypt (Roberts and Peace 2007), stretching over an area of 83,000 km^2 with depths reaching up to 2000 m. The central Levantine basin, has been found to have extremely low nutrient concentrations and oligotrophic conditions (El Hourany et al. 2017; Tanaka et al. 2007). Anthropogenic pressure (Fakhri et al. 2005), climate change (Slim et al. 2014), land degradation and erosion (Darwish and Fadel 2017) and nutrient runoff are key driving factors for primary productivity. Temperature, salinity and nutrients are said to be amongst the main factors which control phytoplankton biomass in aquatic ecosystems (Abi Saab et al. 2008; Fadel et al. 2015; Fakhri et al. 2005). The most recent research depicting seasonal changes in the abundance and production of phytoplankton in the eastern-most oligotrophic coast of the Levantine Basin was conducted 20 to 30 years ago and was incomplete (Azov 1991). Monitoring the phytoplankton community can be done through classical field visits (Fadel 2014) and remote sensing imagery (Fadel et al. 2016; Pinardi et al. 2018; Sharaf et al. 2019). Biogeochemical modeling has

also been used to perceive the growing complexity with the increase in variables (Fadel et al. 2017; Vinçon-Leite et al. 2017). These models offer a way to synthesize our understanding of the environment, analyze changes in ecosystems, and forecast future changes (Fadel et al. 2019).

The present study aims to use the outputs of validated ocean models to investigate the evolution of primary productivity (phytoplankton biomass) in four sites in the Levantine Sea on a monthly basis as well as along a vertical profile of up to 66 meters depth. The main objectives are to: (i) study the spatiotemporal change of factors with respect to phytoplankton biomass, (ii) identify the limiting factors for the presence of phytoplankton biomass in this region, (iii) use Principal Component Analysis (PCA), to understand the correlation among the variables in the different countries, and (iv) apply the TRIX index to assess trophic conditions in these areas.

Study area

The Mediterranean Sea is a semi-enclosed water basin, covering about 2.5 million km^2 and divided into the western and eastern basins. It is known to have increasing oligotrophy eastward toward the Levantine Basin, with a substantial decrease in phytoplankton biomass (Turley 1999). Although the coastal marine environment has great ecological and economic importance, it is highly sensitive to variations especially due to terrestrial input and open seawaters, which affect physical, chemical, and biological processes (Kurt and Polat 2015). Four stations were taken into consideration in this study (Fig. 1): Egypt (31.813° N; 31.875°E), Lebanon (33.812° N; 35.4375° E), Turkey (36.625° N; 35.812° E) and in the Open Sea (33.625° N; 32.062° E).

Methods

Outputs of two models developed and validated previously for the Mediterranean Sea were used to monitor chlorophyll-a, phytoplankton biomass concentrations, sea water temperature, salinity, nitrogen, phosphate and dissolved oxygen. The Mediterranean Forecasting System - Physical Reanalysis Component (MED REA), which is a hydrodynamic model, was used to determine salinity levels and temperatures. This hydrodynamic model was supplied by the Nucleus for European Modelling of the Ocean (NEMO). It provides water temperatures and salinity vertical profiles, satellite Sea Level Anomaly along track data and horizontal velocity. The data is available for 27 years (1987-2013) with a horizontal resolution of 1/16 degrees. The quality of the MED REA system has been assessed and found to be acceptable with low Root Mean Square Error (RMSE).

The biogeochemical model Océan Parallelisé Transport Model-Biogeochemical flux model (OPATM-BFM) is a three dimensional ecosystem model that resulted from long-term research on the biogeochemical characteristics of the Mediterranean Sea. Istitito Nazionale di Oceanografia e di Geofisica Sperimentale (OGS) in Italy has developed this model within a series of Italian and European projects. Reanalysis of Mediterranean Sea biogeochemistry at 1/16 degrees has been achieved using the OPATM-BFM biogeochemical model data assimilation of surface chlorophyll concentration between 1999 and 2012.

According to Fratianni et al. (Fratianni et al., 2016), an average RMSE of 0.34°C was reported for temperature and 0.1 psu for salinity through the water profile (Fratianni et al. 2016). The quality of the data supplied by OPATM-BFM has been assessed by comparing the results with observational datasets derived by satellite and by experimental research cruises. Teruzzi et al. (2015) found that the relative bias between model and observations did not exceed 30% with the exception of phosphate in the upper layer (Teruzzi et al. 2015). The model bias is 13 to 17% for nitrate, 27 to 39% for phosphate, and -2 to 7% for dissolved oxygen. The model performance in terms of bias for surface chlorophyll (top 200 m) in winter is better than in summer (chlorophyll values usually order 0.005 mg m^{-3}), when the model tends to slightly underestimate the satellite values in summer where chlorophyll bias is usually -0.02 mg/m^3 (Teruzzi et al. 2015).

The factors taken into consideration have data sets between 1999 and 2014 for: the concentration of phytoplankton biomass (PCB) in mol m m^{-3}, mole concentration of dissolved molecular oxygen (DOX) in mmol m^{-3}, mole concentration of nitrate (Nit) and phosphate (Pho) in $mmol.m^{-3}$, concentration of chlorophyll (Chl) in mg m^{-3}. As for salinity (Sal) in psu and temperature (Temp) in degrees celsius (°C),

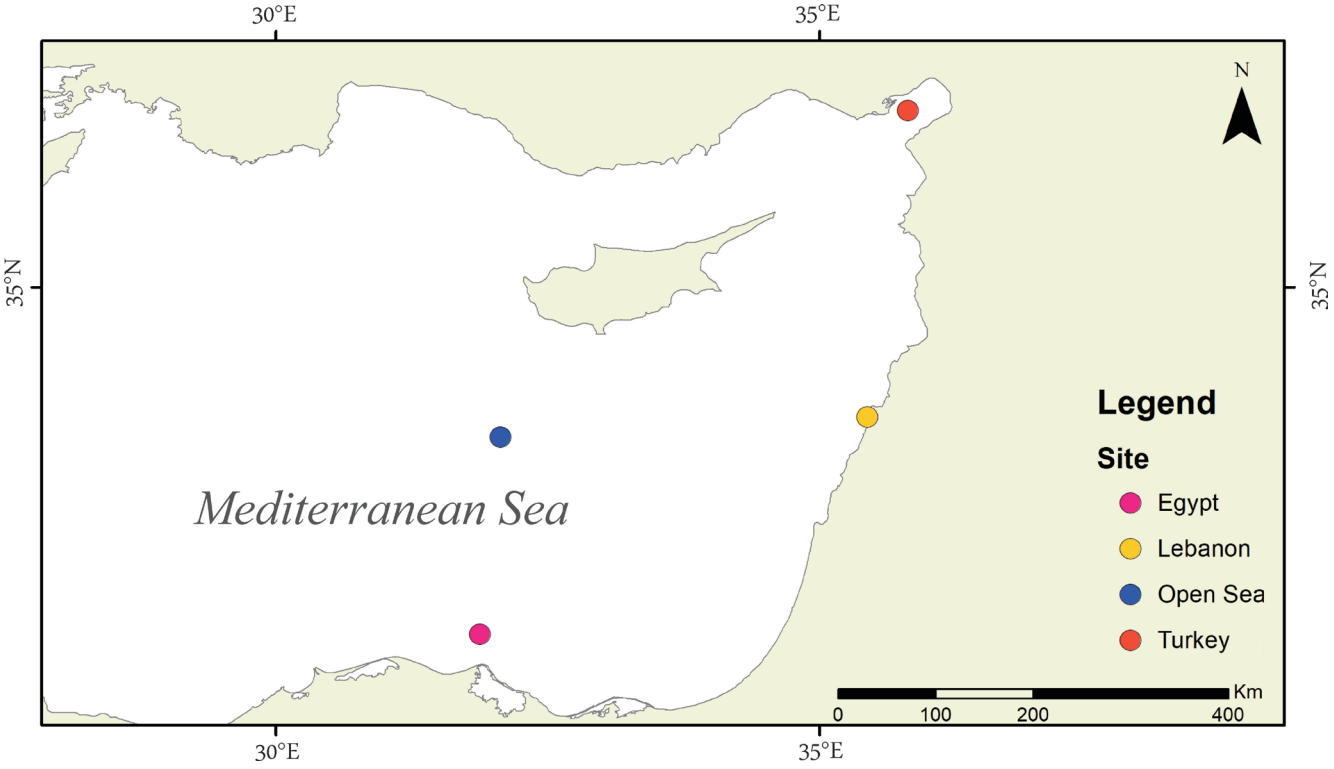

Fig. 1. Map showing location of studied sites

the data available is between 1987 and 2014. The data sets were extracted then standardized along a single range of depths (0-66.45 m).

The factors were then studied on a monthly basis and along different depths. The former was done to check the effect of time/seasonal variation on phytoplankton biomass and on other factors. The latter was studied to understand the effect of depth on phytoplankton biomass and physiochemical factors. Data was later analyzed by Excel Analysis ToolPak and XLSTAT plugins, through first correlating (r) the different factors along depths and seasonal variation in order to arrive at a general interpretation of how the different factors tend to move together or have an effect on one another.

Principal Component Analysis was then done, not only to identify important features of correlation between data, but also to simplify the complexity in high-dimensional data by transforming the data to fewer dimensions. PCA was done based on taking the average of each factor monthly and over depth, and checking the relation of factors in each study area.

The Trophic State Index (TRIX) is used to define the trophic category of the study area. It is calculated by applying the formula proposed by Vollenweider et al. (1998), based on chlorophyll a data, OS, total inorganic P and N. The index (Equation 1) derived from the four chosen variables is:

$$Xc = (k/n)\sum_{1}^{i=n}[(M-L)/(U-L)]_i \quad [1]$$

where: k is the number of degrees, n the number of variables (in our case four), M the measured value of the variable, U the upper limit and L the lower limit of each variable. Numerically TRIX is scaled from 0–10 covering a wide range of trophic conditions and defining 4 trophic categories: < 4 – low trophic level; 4-5 – moderate trophic level; 5-6 – high trophic levels, and > 6 – very high trophic level (Moncheva et al. 2002).

Results

Spatiotemporal analysis

Average temporal variations of the different monitored variables in the four sites are presented in Figure 2. Phytoplankton biomass varied both with time and depth. For Egypt and Turkey, it showed a maximum concentration in February while for Lebanon and the open sea the maximum concentration

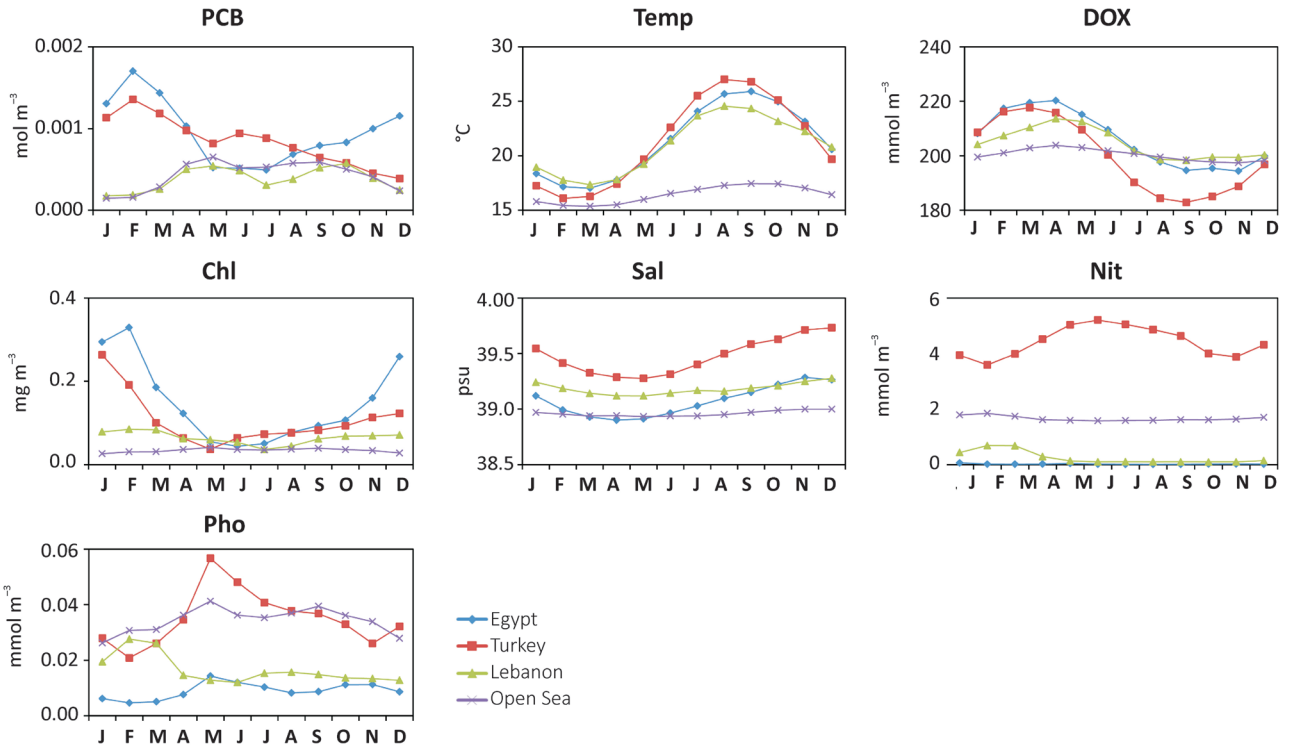

Fig. 2. Temporal variation of different factors off Egypt, Lebanon, Turkey, and in the Open Sea: Phytoplankton Biomass concentration (PCB), Temperature (Temp), Dissolved oxygen concentration (DOX), Chlorophyll mass concentration (Chl), Salinity (Sal), Nitrate concentration (Nit) and Phosphate concentration (Pho)

was in May. It then decreased with time till December in Turkey, January in Lebanon and the Open Sea station and, showed a decrease in July for Egypt, after which it increased again.

Along depth, average phytoplankton biomass concentration varied in all stations from the surface to 66.45 m depth (Fig. 3). In the same range, temperature and salinity decreased in all stations (Fig. 3). Phytoplankton biomass concentrations in Egypt, Turkey, Lebanon and the Open Sea showed strong correlation along depth for r = -0.95, -0.94, -0.55 and 0.96 respectively, indicating that phytoplankton biomass generally decreases with an increase in depth in all locations except the Open Sea. Phytoplankton biomass decrease is noticeable when phosphate concentration increases in Egypt, as well as in Turkey and Lebanon in addition to the increase of nitrate concentration (Fig. 3). In the Open Sea, the case is reversed, where phytoplankton biomass increases with depth, as well as when temperature and salinity decrease, unaffected by other factors (Fig. 3).

Principal component analysis

The results of the PCA on a monthly basis with respect to average phytoplankton biomass, are shown in Figure 4. In Egypt, a positive correlation with chlorophyll, and a negative one with phosphate was found. In Turkey, there was a positive correlation with dissolved oxygen and a negative one with salinity and temperature; in Lebanon, it was seen to have a negative correlation with chlorophyll, phosphate and nitrate; in the Open Sea, it had a positive correlation with chlorophyll and a negative one with nitrate and phosphate (Fig. 4).

The results of the PCA with respect to depth and the correlation between average phytoplankton biomass is as follows: in Egypt there was a positive relation with chlorophyll, and an uncorrelated one with the rest; in Turkey, a positive correlation with temperature and salinity and a negative with dissolved oxygen, nitrate and phosphate was found; in Lebanon, a negative correlation with nitrate and phosphate; in the Open Sea there was a positive correlation with dissolved oxygen and a negative one with salinity and temperature (Fig. 5).

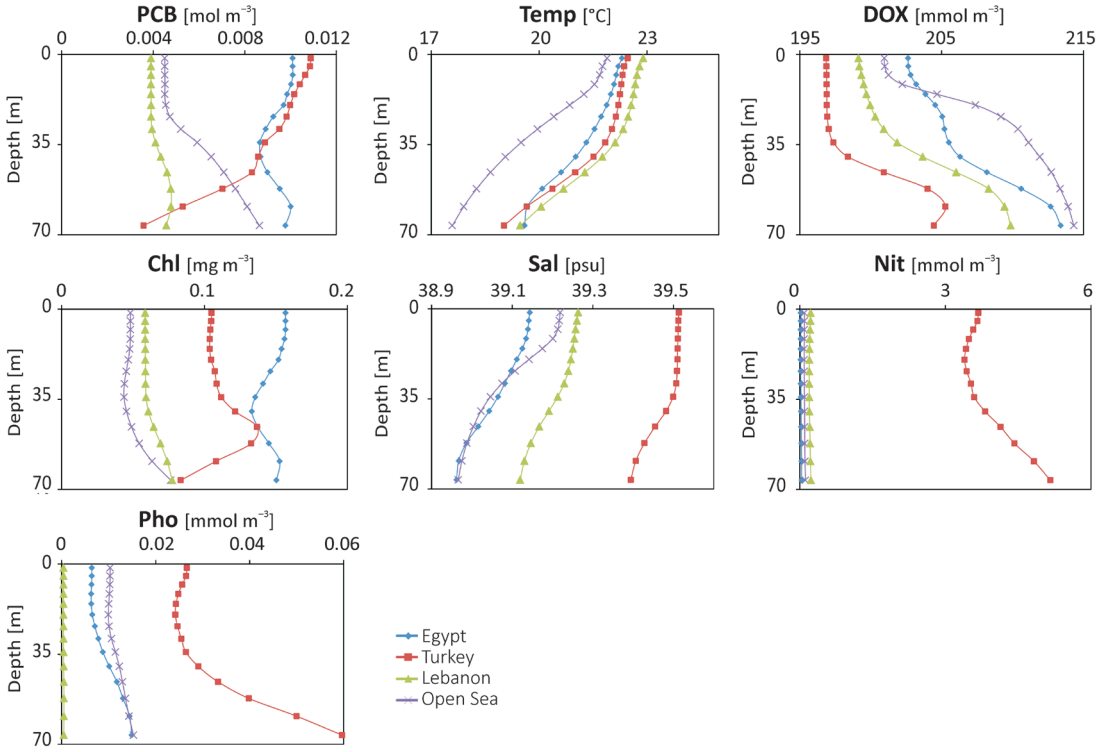

Fig. 3. Spatial variation of different factors off Egypt, Lebanon, Turkey, and in the Open Sea: Phytoplankton Biomass concentration (PCB), Temperature (Temp), Dissolved oxygen concentration (DOX), Chlorophyll mass concentration (Chl), Salinity (Sal), Nitrate concentration (Nit) and Phosphate concentration (Pho)

Trophic state analysis

In defining trophic conditions of the study areas (Fig. 6), it showed that TRIX ranged from 2.3 to 6.8 in Egypt (August and January respectively), 2.9 to 6.7 in Turkey (November and May), 1.4 to 9.2 in Lebanon (July and March), and from 3 to 7.2 in the open sea (October and February).

Discussion

Higher concentrations of phytoplankton biomass were found in Egypt and Turkey than in Lebanon and the Open Sea. The selected site in Egypt is located across the highly polluted city of Damietta. Nitrate is consumed rapidly between winter and spring; while phosphate concentrations remains low, impacting phytoplankton presence such that the presence of phosphate negatively affects the biomass. Another limiting factor for the phytoplankton biomass is temperature, where the maximum increase in phytoplankton population is during the period when both temperature and salinity are low. The PCA showed a negative correlation established with phosphate. As for the trophic conditions of this station, it is considered to have very low trophic levels in the summer but high productivity in the winter. According to El-Sheekh et al. (2010), this is due to the presence of aquaculture and other discharges (El-Hady 2014; Rifai and Shaaban 2007), including industrial, agricultural and urban sewage that cause serious environmental damage (El-Amier et al. 2015). The seasonality in nutrient concentration can also be linked as to the seasonal phytoplankton blooms that occur during winter and the beginning of spring (Azov 1986).

The site in Turkey is located in İskenderun Bay. From our results, across time, temperature and salinity are having an affect on biomass presence, while across depth, the nutrients, phosphate and nitrate limit its presence as they increase with depth (Özman-Say and Balkis 2012). From the PCA, the same could be confirmed. Temperature and both nutrients (phosphate and nitrate) can be the main factors resulting in phytoplankton decline. Due to the limiting values of phosphate in comparison to nitrate, the former can be considered as a limiting factor for growth. As for the trophic conditions of

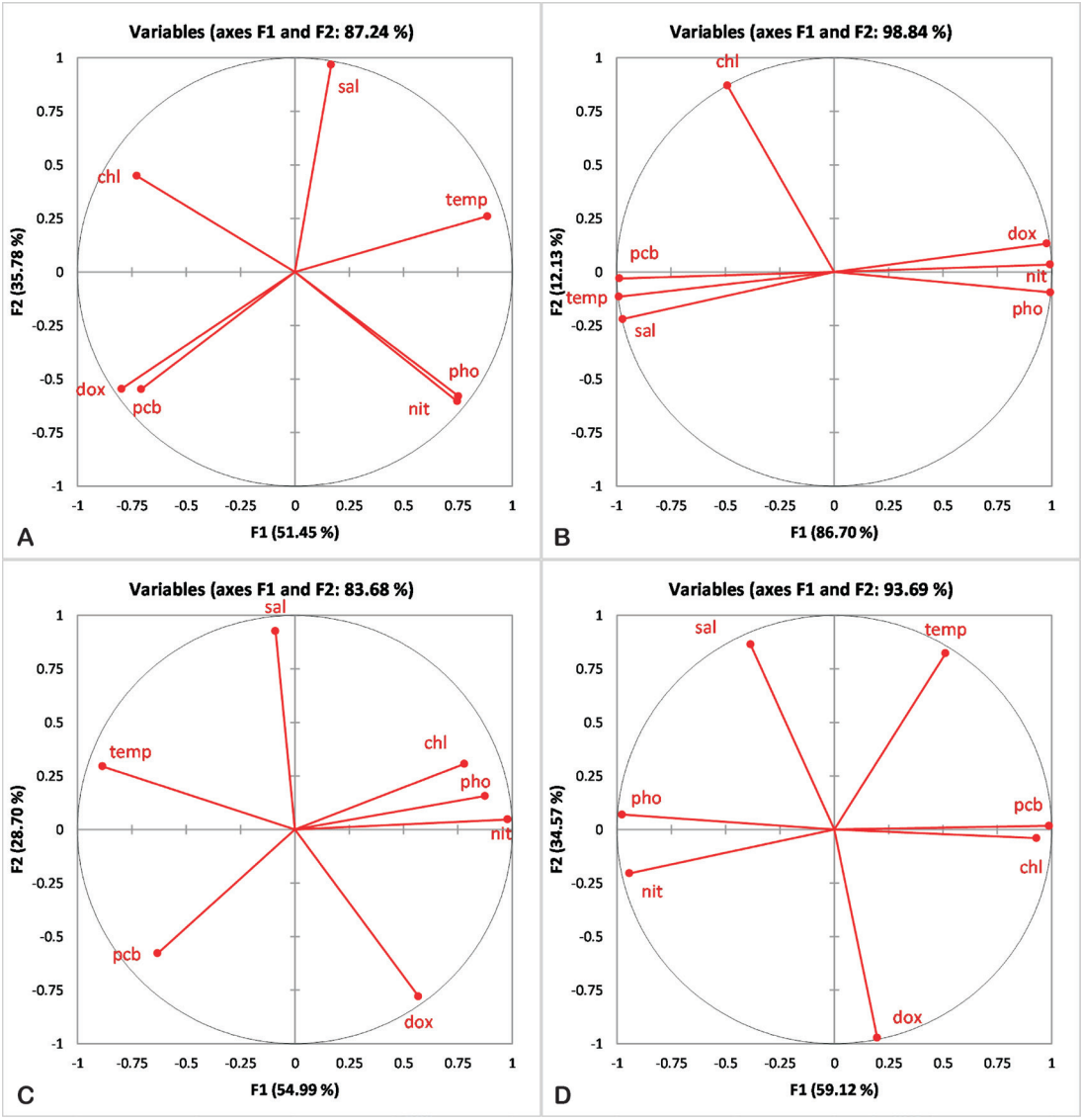

Fig. 4. PCA analysis of the average of factors in (a) Egypt, (b) Turkey, (c) Lebanon and (d) Open Sea as a function of monthly variation

this station, it is considered to have low trophic levels in November, but with high productivity in May. This is because the bay is surrounded by many industrial facilities, and agricultural activities are carried out in the areas adjacent to the bay (Kurt and Polat 2015). Main activities include heavy maritime traffic (Tüfekçi et al. 2013), fisheries (Kurt and Polat 2015), and tourism. Furthermore, these activities increase phytoplankton productivity as a result of the discharge of nutrient-rich freshwater from the Ceyhan River localized on the NE Mediterranean coast of Turkey, into the Levantine basin.

In Lebanon, the station is in the proximity of the Lebanese International Airport. Across time, nitrate and phosphate negatively affect phytoplankton biomass, which was also confirmed by PCA analysis. This is due to the worsening status of the Lebanese coast, as a result of overexploitation and pollution. In the absence of operational wastewater treatment plants, the by-products of urban, agricultural and industrial development are released into coastal waters (Abi Saab et al. 2008). An important constituent of these by-products are nutrients, mainly nitrate and phosphate that with time affect the stability of the phytoplankton community. The high trophic index at the beginning of the year > 6 corresponds to the high nutrient contents (Moncheva et al. 2002).

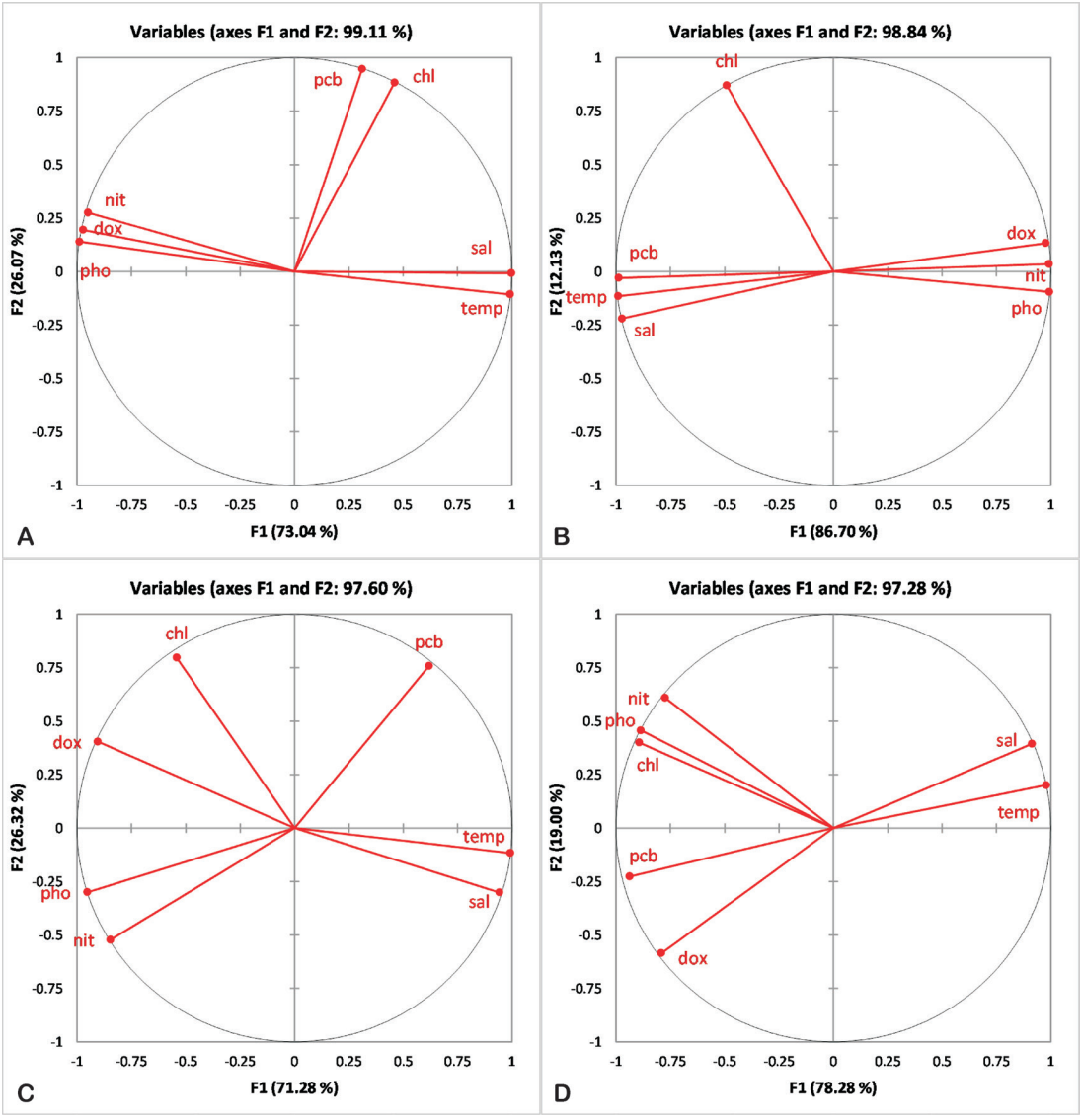

Fig. 5. PCA analysis of the average of factors in (a) Egypt, (b) Turkey, (c) Lebanon and (d) Open Sea as a function of average depth variation

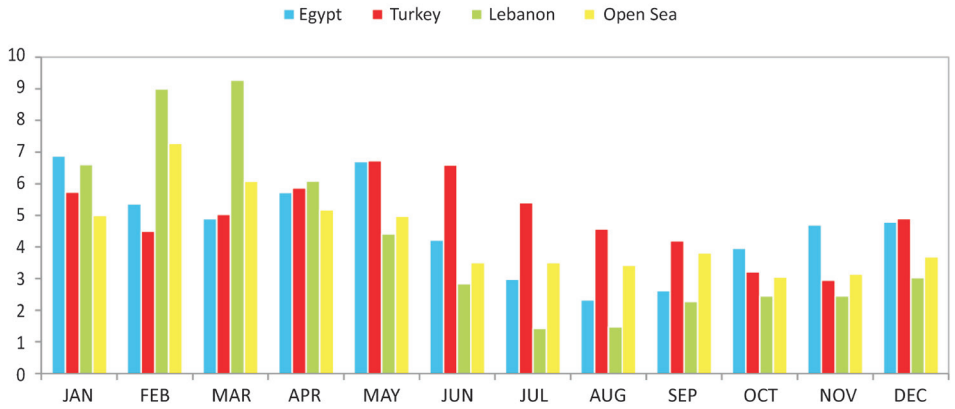

Fig. 6. TRIX analysis of trophic conditions in each station

The Open Sea site is less impacted by direct human input. Over time, phytoplankton biomass correlated negatively with nitrate and phosphate, and positively along depth, while over depth, phytoplankton biomass correlated negatively with temperature and salinity. PCA only showed that salinity and temperature correlate negatively with biomass along depth. The moderate to high trophic levels, with the exception of the summer months, can be attributed to temperature and nutrients (particularly phosphate), which limit phytoplankton biomass in sea water.

Conclusion

In this study we have shown temperature and phosphate increase to be limiting factors for phytoplankton biomass, followed by salinity. Our results have also shown high productivity in all stations in the first half of the year (January-May). Stress caused by humans is expected to increase through the development and exploitation of coastal areas, increasing nutrient input into the Levantine basin, and affecting phytoplankton communities in these areas, thereby affecting the base of the food chain and resulting in a possible shift in the trophic state. This work can be transferred for application to other regions in the Mediterranean Sea where data are scarce.

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