Black Sea Eutrophication Dynamics from Causes to Effects *(Luminița Lazăr, Laura Boicenco, Oana Marin, Oana Culcea, Elena Pantea, Elena Bișinicu, Florin Timofte, Maria-Emanuela Mihailov)*	**“Cercetări Marine“ Issue no. 48** **Pages 100-117**	**2018**

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ABSTRACT

The paper aims to study the natural variability of the Black Sea’s pelagic habitat in the light of the acknowledged causes and effects of the Black Sea eutrophication but also to other essential elements that overlap with the nutrient’s enrichment from the inland and coastal intake of the marine ecosystem, like climate changes and regime shift in species composition. For the analysis, we developed the qualitative static models and translated into semi-quantitative dynamic eutrophication models for spring and summer, 2016, two seasons with good ecological status in terms of eutrophication and statistically different seawater temperature. In an apparent non-eutrophic ecosystem, with mainly criteria fulfilling the good ecological status criteria, we assessed the natural variability from spring to summer 20016, two statistically different seasons. Based on significant correlations between physical (T, S), chemical (O_2, nutrients) and biological parameters (phytoplankton and zooplankton) involved in eutrophication, grouped by season, considering the medium influence for all, and introduced into Mental Modeler software, we obtained two semi-quantitative models for eutrophication which capture our knowledge in a standardized format that can be used for scenario analysis. The models’ findings show different drivers for the two seasons. In spring, salinity is shaping the ecosystem dynamics while in summer the ammonium level is of major importance. The model showed that the ammonium is particularly influencing the eutrophication status in summer due to the nitrogen fixation of the cyanobacteria and its transformation into available nutrients. Thus, the semi-quantitative models open specific pathways for the researches on the Black Sea’s eutrophication and the cumulative effects of different parameters on its status and might represent a tool for decisions based on different scenarios.

Key-Words: Black Sea, eutrophication, fuzzy cognitive maps, mental modeler, phytoplankton, zooplankton, climate change

AIMS AND BACKGROUND

Eutrophication of the Black Sea was an environmental problem that has long appeared before being the subject of a European Directive. Thus, due the increased nutrients input via the major rivers, in 70s-80s there were several adverse events in the northwestern Black Sea - an increase in number and peak abundance of phytoplankton blooms including several red-tide events, modification of the phytoplankton composition in favor of flagellates, decreased oxygen concentration and expansion of hypoxia, reduced transparency of the water column, a decrease in non-gelatinous zooplankton, mass mortality among the entire benthos, demersal and pelagic fish populations (Kideys, 2002; Mee and Topping, 1999; Gomoiu, 1992). Apparently solved by limiting the upstream (Danube basin) for at least one of the nutrients, phosphorus, improving waste water treatment plants and due to loss of industry and agriculture, eutrophication has ceased to show the same effects with same magnitude, leaving room for newer ones that we are researching these days. Thus, in recent years, a slight improvement of the water quality has been observed, but also a system change (Oguz and Velikova, 2010; Daskalov et al., 2016). Thus, the highly productive and eutrophic coastal ecosystem was transformed into a less productive but degraded state during the early 1990s, significantly different from the pristine state, and does not really represent a recovery (Oguz and Velikova, 2010). The major ecosystem regime shift of the early 1990s resulted from a combination of environmentally-induced scarcity of planktivorous fish, persistent overfishing and an invasion by an alien species (Daskalov et al., 2016). All of these findings lead us to the evaluation of eutrophication and the criteria that, by excellence, refer to the well-known effects without considering recent changes to alternative states and much different from the original, pristine state from 60s.

The paper aims to analyze the natural variability of the Black Sea's pelagic habitat in the light of the known causes and effects of the Black Sea eutrophication but also to other essential elements that overlap with the enrichment with nutrients from the inland and coastal intake of the marine ecosystem, like climate changes and regime shift in species composition. For the analysis, we developed qualitative static models and translated into semi-quantitative dynamic eutrophication models for spring and summer, 2016, available for different scenarios as a basis for future researches.

EXPERIMENTAL

We present results from two cruises completed in 2016 (31 March - 3 April and 16 - 19 August) on a network of 19 stations from three transects (Portita, Est Constanta and Mangalia) with bottom depth in the range 0 -100m (Fig.1). We sampled water for chemistry (N=162), chlorophyll *a* (N=121), phytoplankton (N=38) and zooplankton (N=29) analyzes.

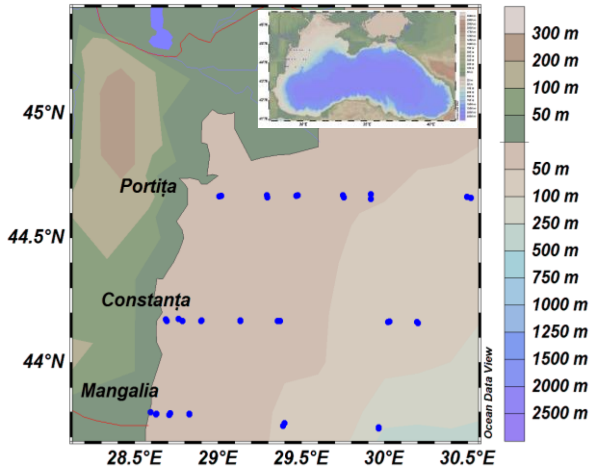

Fig.1. Network stations - Black Sea continental shelf, 2016.

Samples were measured in-situ or analyzed into NIMRD laboratories as follows: physical and chemical parameters – temperature (T), salinity (S), dissolved oxygen (O2 and %); eutrophication indicators – causes - nutrients – phosphate (PO_4^{3-}), silicate (SiO_4^{4-}), nitrate (NO_3^-), nitrite (NO_2^-), ammonium, (NH_4^+), total organic carbon (TOC), total nitrogen (TN), total phosphorus (TP) and effects – chlorophyll *a*, phytoplankton and zooplankton.

Methods. Temperature and salinity were measured with CTD model YSI Cast Away. Dissolved oxygen was measured with Winkler method (SR EN 25813:2000) according to „Methods of Seawater Analysis” (Grasshoff, 1999). Nutrients dissolved in seawater were quantified with spectrophotometric methods, according to „Methods of Seawater Analysis” (Grasshoff, 1999). TOC and TN in water were measured automated with TOC/TN Shimadzu analyzer. Chlorophyll *a* was determined by method based on pigment extraction with acetone 90% (after separation of the glass fiber filter) and measuring absorbance of the sample at three wavelengths (Λ = 630nm; Λ = 645nm and Λ = 663nm). Calculation of chlorophyll *a* concentration is by SCOR-UNESCO tri-chromatic equations. Phytoplankton samples were preserved with 4% formaldehyde seawater buffered solution and processed by the sedimentation method (Morozova-Vodianitkaia, 1948; Utermohl, 1958; Bodeanu, 1987 - 1988). The taxonomic identification of species and counting of cells in a 0.1 ml fraction of each sample was carried out under Olympus inverted microscope, using a 40x objective lens for nanoplankton (less than 15–20µm) and 10x or 20x for larger cells. The cell biovolume was calculated using relevant morphometric measurements of phytoplankton cells and approximation by corresponding geometric shapes after Edler (1979), Hillebrand et al. (1999).

Mesozooplankton sampling and analysis was performed according to “Black Sea Monitoring Guidelines for Mesozooplankton”. Samples were collected with by means of vertical hauls using a Juday net (open mouth diameter 36 cm and 150 µm nylon mesh size). This is a biconical net with non-filtering upper part and filtering lower part. The net is equipped with flowmeter for correction of the total volume of filtered water.

Juday net was hauled vertically with a speed not more than 1 m/s. After each sample has been collected, the net was rinsed, and the samples transferred in plastic jars with a volume of 500 ml. Samples are preserved in 4% buffered formaldehyde solution. Samples are processed to determine the taxonomical composition down to species level.

For the data analysis we used specific software as follows: for statistics – Excel, Graphpad [1] and Statistica [2], for oceanographic data representation - Ocean Data View (Schlitzer, 2016) and for fuzzy cognitive maps, models and scenarios, Mental Modeler [3].

RESULTS AND DISCUSSION

According to the World Meteorological Organization (WMO), in a clear sign of continuing long-term climate change caused by increasing atmospheric concentrations of greenhouse gases, 2015, 2016 and 2017 have been confirmed as the three warmest years on record. 2016 still holds the global record, whilst 2017 was the warmest year without an El Niño, which can boost global annual temperatures [4]. In 2016, seawater's column temperature ranged between 6.62ºC and 25.93ºC (Table 1). We found significant differences between end of March – April (spring) and August (summer) (t-test, $p<0.0001$). Spring was characterized by homogenous values, while for summer the water masses were intensely stratified, thermocline being installed in the layer 20-30m. The mixing layer had an average temperature of 24.4ºC, a difference of about 16 degrees that the ecosystem had to escalate in 4 months and a half, and between the two layers, too. We didn't find any differences between salinities (t-test, $p=0.3187$) (Table 1). The increasing gradient from North to South is observed during the study, highlighting the rivers input influence on the NW Black Sea. The dissolved oxygen content of the water column was significant reduced in summer (t-test, $p<0.0001$), and highly negatively correlated with the temperature ($r = -0.84$) at surface. The lowest dissolved oxygen concentration and saturation were measured at bottom (90m-Mangalia 7) and represent one of the Black Sea's natural feature (Table 1).

Although in summer all concentrations were significantly dropped, nutrients reached normal values both seasons (Table 2). Nutrients levels are influenced by rivers input in spring. Thus, surface's phosphate concentrations were significantly ($p<0.05$) negatively correlated with salinity ($r_{PO4} = -0.68$) (Table 3). We observed higher values on the Northern continental shelf (station Portița 6) which could increase the risk of not achieving Good Ecological Status (GES), expressed as percentile 75th, in the area (Table 2). Alternatively, for summer, the risk becomes more predominant for the coastal area (station Mangalia 1).

Table 1. Temperature, salinity, dissolved oxygen - main statistics - NW Black Sea - 2016.

	N	Min.	Max.	Average	Std. dev.
T, ºC	162	6.62	25.93	13.20	6.62
Spring	81	6.62	9.76	6.79	0.80
Summer	81	7.63	25.93	18.44	7.48
S, PSU	162	14.06	20.51	17.89	1.39
Spring	81	14.06	20.51	17.95	1.33
Summer	81	14.46	20.44	17.83	1.45
Dissolved Oxygen, µM	162	102.70	396.10	300.93	52.27
Spring	81	111.60	396.10	334.72	34.56
Summer	81	102.70	344.80	267.15	44.65
Dissolved Oxygen, %	162	32.10	139.50	102.42	17.61
Spring	81	34.90	121.50	102.70	10.91
Summer	81	32.10	139.50	102.08	22.89

Table 2. Nutrients and organic matter - main statistics - NW Black Sea - 2016.

	N	Min.	Max.	Average	Percentile 75	Std. dev.	GES
PO_4^{3-}, µM	162	0.02	1.09	0.12	0.14	0.14	0.23
Spring	81	0.02	1.09	0.14	0.18	0.16	
Summer	81	0.03	0.62	0.10	0.11	0.10	
TP, µM	162	0.02	1.86	0.44	0.60	0.29	na*
Spring	81	0.02	1.86	0.45	0.60	0.33	
Summer	81	0.12	1.51	0.43	0.59	0.25	
SiO_4^{4-}, µM	161	0.50	37.10	8.14	12.00	7.43	na
Spring	81	2.80	37.10	10.06	13.90	7.41	
Summer	80	0.50	31.90	6.20	10.70	6.99	
NO_3^-, µM	162	0.43	6.42	1.43	1.80	0.84	na
Spring	81	0.43	3.75	1.52	2.08	0.85	
Summer	81	0.50	6.42	1.33	1.54	0.82	
NO_2^-, µM	162	0.04	4.46	0.32	0.38	0.52	na
Spring	81	0.04	2.61	1.52	2.08	0.85	
Summer	81	0.04	4.46	0.22	0.13	0.59	
NH_4^+, µM	162	0.07	18.95	2.70	3.31	2.93	na
Spring	81	0.45	18.95	3.48	5.57	3.67	
Summer	81	0.07	8.05	1.93	2.74	1.60	
DIN, µM**	162	0.90	22.76	4.45	5.06	3.57	10.50
Spring	81	0.45	18.95	3.48	5.57	3.67	
Summer	81	0.90	12.07	3.48	4.42	2.05	
TN, µM	100	26.67	116.43	55.54	68.53	20.59	na
Spring	19	62.14	116.43	83.57	92.14	14.77	
Summer	81	26.67	108.00	48.96	55.86	15.65	
TOC, mg/L	100	3.21	9.69	4.86	5.67	1.15	na
Spring	19	5.20	6.30	5.65	5.96	0.39	
Summer	81	3.21	9.69	4.68	3.89	1.19	

*not available; ** sum of nitrate, nitrite and ammonium

Like phosphate, silicate and inorganic nitrogen (nitrate, ammonium and total) were significantly correlated with salinity in the spring (Table 3). The inorganic nitrogen distribution was dominated by nitrate's in the Danube's mouths neighborhood and ammonium in the continental shelf. Significant negative correlations with salinity indicate in spring increased and slightly more pronounced input for nitrate (r_{NO3} = - 0.65) and ammonium (r_{NH4} = - 0.56). The lack of correlation between nutrients and salinity in August outlined other sources of nutrients for phytoplankton development, too.

Table 3. Correlation coefficients (surface waters) significant (red) $p < 0.05$ (N=30) for abiotic eutrophication indicators and chlorophyll *a*.

		S	Bottom O2	Chlorophyll *a*
		PSU	%	µg/L
PO_4^{3-}	Spring	-0.68	0.07	0.71
[µM]	Summer	-0.32	0.82	0.66
SiO_4^{4-}	Spring	-0.85	0.04	0.92
[µM]	Summer	-0.47	0.80	0.43
NO_2^-	Spring	-0.48	0.08	0.42
[µM]	Summer	-0.42	0.03	0.17
NO_3^-	Spring	-0.65	0.18	0.62
[µM]	Summer	-0.43	0.27	0.45
NH_4^+	Spring	-0.56	0.02	0.63
[µM]	Summer	-0.43	0.32	0.48
DIN*	Spring	-0.64	0.06	0.70
[µM]	Summer	-0.52	0.35	0.53

*sum of nitrate, nitrite and ammonium

The direct effects of inorganic nitrogen on primary production were observed due to significant correlations with chlorophyll *a* content observed in the spring (r_{NO3}=0.62; r_{NH4}=0.63). Chlorophyll *a* concentration does not indicate an increase of eutrophication and the risk of not achieving GES in the Romanian Black Sea. The limiting nature of inorganic phosphorus on phytoplankton blooms expressed by significant correlations with chlorophyll *a* content is found regardless of the season, more pronounced in the spring. The distribution of chlorophyll *a* concentration highlights the risk that GES might not be reached in summer in the southern coastal area (Mangalia 1 station), near the port area and the wastewater treatment plant (Fig. 2).

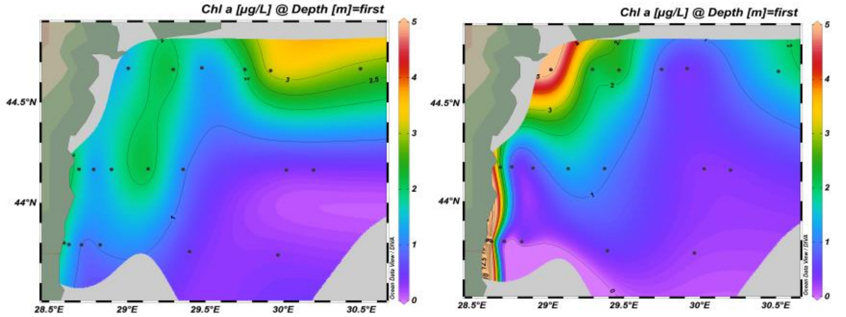

Fig. 2. Chlorophyll *a* distribution in the surface waters - Black Sea, April (left) and August (right), 2016.

The dissolved oxygen saturation at the water-sediment interface decreases significantly (t-test, p = 0.0068) from spring to summer at depths ranging from 5m to 90m with maximum amplitude on the 20m-90m bathymetric strip where the water masses stratification was pronounced (Fig.3). Therefore, one of the indirect effects of nutrient enrichment and eutrophication with impact on benthic habitats can be amplified by the increased heating of water masses and their pronounced stratification.

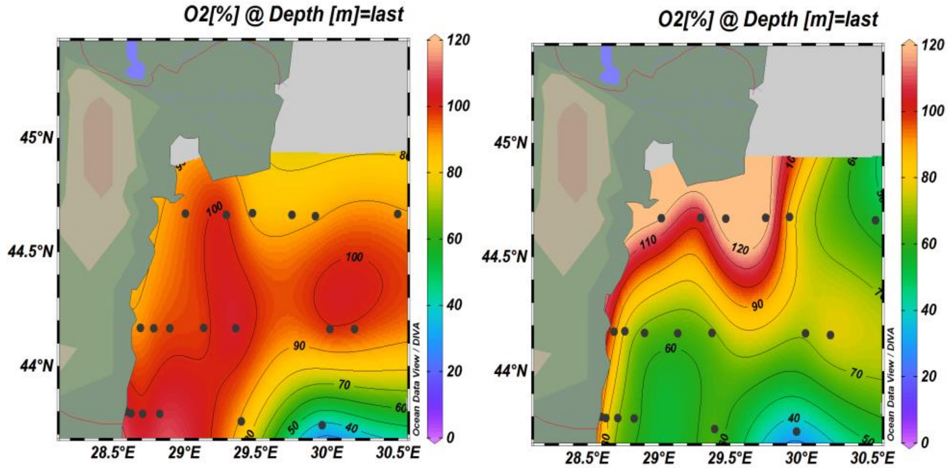

Fig. 3. Bottom oxygen saturation distribution - Black Sea, April (left) and August (right), 2016.

The phytoplankton abundance and biomass varied between 420 - 236·10^3 cells/L and 0.005 - 173.12 mg/m^3 (in April), and between 380 – 886·10^3 cells/L and 0.014 - 616.97 mg/m^3 (in August). None of the species recorded developments of over one million cells per liter. We observe the maximum development and the decrease of biomass in summer due to the change of species and lowering of the cells size. Among the species with higher development, in spring was observed the crysophyte *Dinobryon balticum* (116·10^3 - 236·10^3 - cells/L) in shelf waters. Other groups abundance actually dominated the spring (78%). Excepting the diatom *Thallassiosira subsalina* (155.52 mg/m^3), all the biomasses highest than 100 mg/m^3, were of Dinoflagellates - *Polykrikos schwarzi* recorded the highest biomass of spring, *Neoceratium tripos* (160.70 mg/m^3) and *Protoperidinium grani* (99.54 – 118.50 mg/m^3), which predominated as biomass (81%) (Fig. 4).

In summer, other groups abundance was net (69.9%) and the cyanophytes *Pseudanabaena limnetica* (886000 cells/L), *Planktolyngbya circumcreta* (604000 cells/L), *Phormidium hormoides* (372000 cells/L) *and* cryptophycean *Hillea fusiformis* (316000 cells/L) had the highest development in coastal waters from Northern and central littoral. In term of biomass, strongly predominated (67.81%) the diatom *Pseudosolenia calcar-avis* (150.82 - 616.97 mg/m^3) found in shelf waters (Fig. 5).

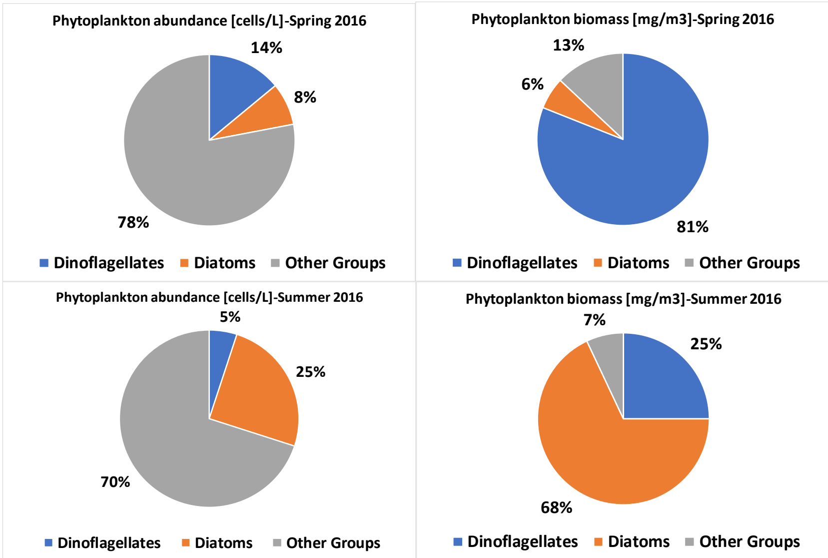

Fig. 4. Phytoplankton abundance and biomass - Black Sea - spring (up) and summer (down), 2016.

Zooplankton's development reached 434-48696 ind./m^3 and 5.0-911.6 mg/m^3. Spring was dominated by copepods and meroplankton abundance and *Noctiluca scintillans*, copepods and meroplankton biomass. In summer, cladocers were obeserved. Overall the fodder zooplankton dominated (Fig 5).

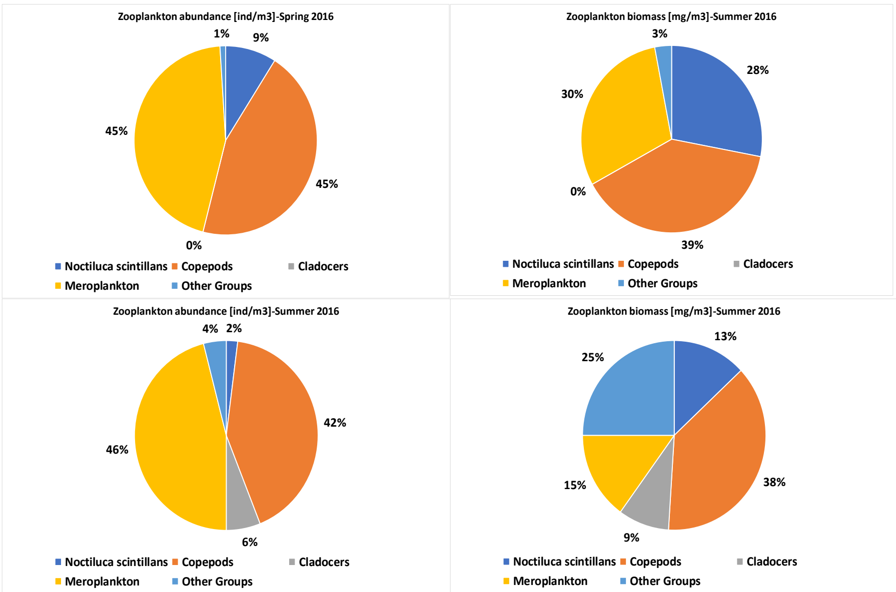

Fig. 5. Zooplankton abundance and biomass - Black Sea - spring (up) and summer (down), 2016.

During summer 2016, the macrophytobentos perennial species were also monitored on the Southern sector of the Romanian shore, from Mangalia to Vama Veche, where the development areas for the brown alga *Cystoseira barbata* and the marine phanerogam *Zostera noltei* are localized. *C. barbata* fields of various dimensions were identified at Mangalia, Jupiter-Saturn, 2 Mai and Vama Veche, with a high average fresh biomass, ranging between 5,000 and 9,000 g/m^2, with a maximum value at Vama Veche. For *Zostera noltei*, the average biomass varied at Mangalia between 600 – 1.800 g/m^2, depending on the sampling depth, with an annual average biomass of 1.320 g/m^2. In 2016, two of the sensitive species, *Cystoseira barbata* and *Zostera noltei* maintained the recovery process along the Romanian shore, and also was identified the red algae *Coccotylus truncatus*, in the Northern part, a species who suffered a severe decline over decades along the Romanian shore.

Consequently, all data showed a low risk of not achieving the good ecological status for eutrophication criteria in 2016. Thus, we consider the ecosystem as less perturbated by the main anthropogenic pressures coming through rivers and coastal sources input, and the natural variability between the two seasons of the Black Sea continental shelf ecosystem could be reviewed. Therefore, in an attempt to increase knowledge and understanding the Black Sea ecosystem and its dynamics under various conditions and to identify and clarify (Gray, 2014) the dynamics of causes and effects of eutrophication, we built the Fuzzy-Logic Cognitive Mapping (FCM), a concept introduced in 2010 (Gray et al., 2013) by drawing it from data showing significant causal relationships (Özesmi, 2004). FCM is a parameterized form of concept mapping where we developed the qualitative static model and translated afterwards into a semi-quantitative dynamic model for eutrophication (spring and summer 2016). FCM represents knowledge by defining three characteristics of a system: the components of the system, the positive or negative relationships between the components, the degree of influence that one component can have on another, defined using qualitative weightings (e.g. high, medium, or low influence) (Table 4). We used all statistically significant correlations (positive – blue line and negative - orange line) and their values between physical (T, S), chemical (O_2, nutrients) and biological parameters (phytoplankton and zooplankton) (system components) involved in eutrophication, grouped for spring and summer, considering the medium influence for all, and introduced into Mental Modeler software (Gray, 2013; Gray, 2014) to obtain two semi-quantitative models for eutrophication. Thus, Mental Modeler helped us to capture our knowledge in a standardized format that can be used for scenario analysis (Fig. 6 and Fig. 7).

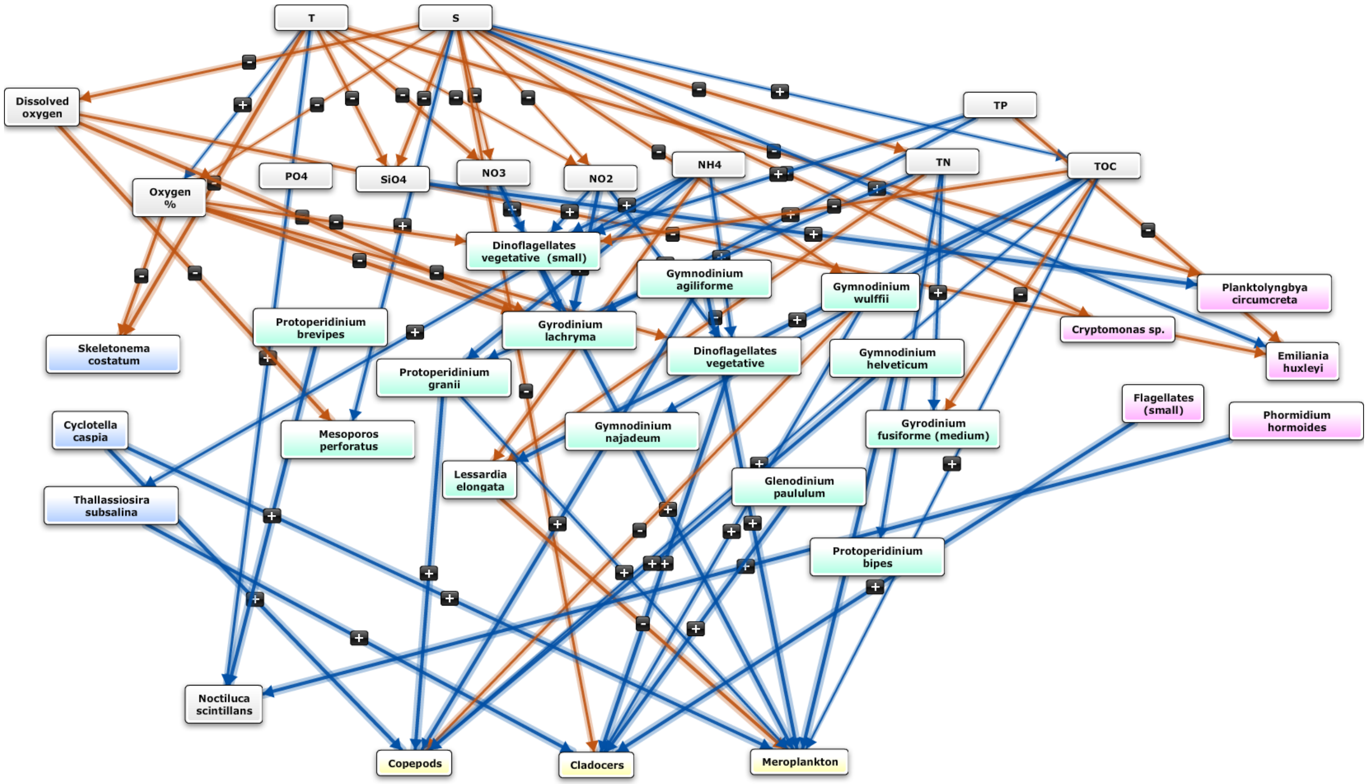

Fig. 6. Semi-quantitative dynamic model for causes and effects of eutrophication - Romanian Black Sea, Spring 2016 - all links are representing statistically significant correlations calculated between components (blue - positive, orange - negative).

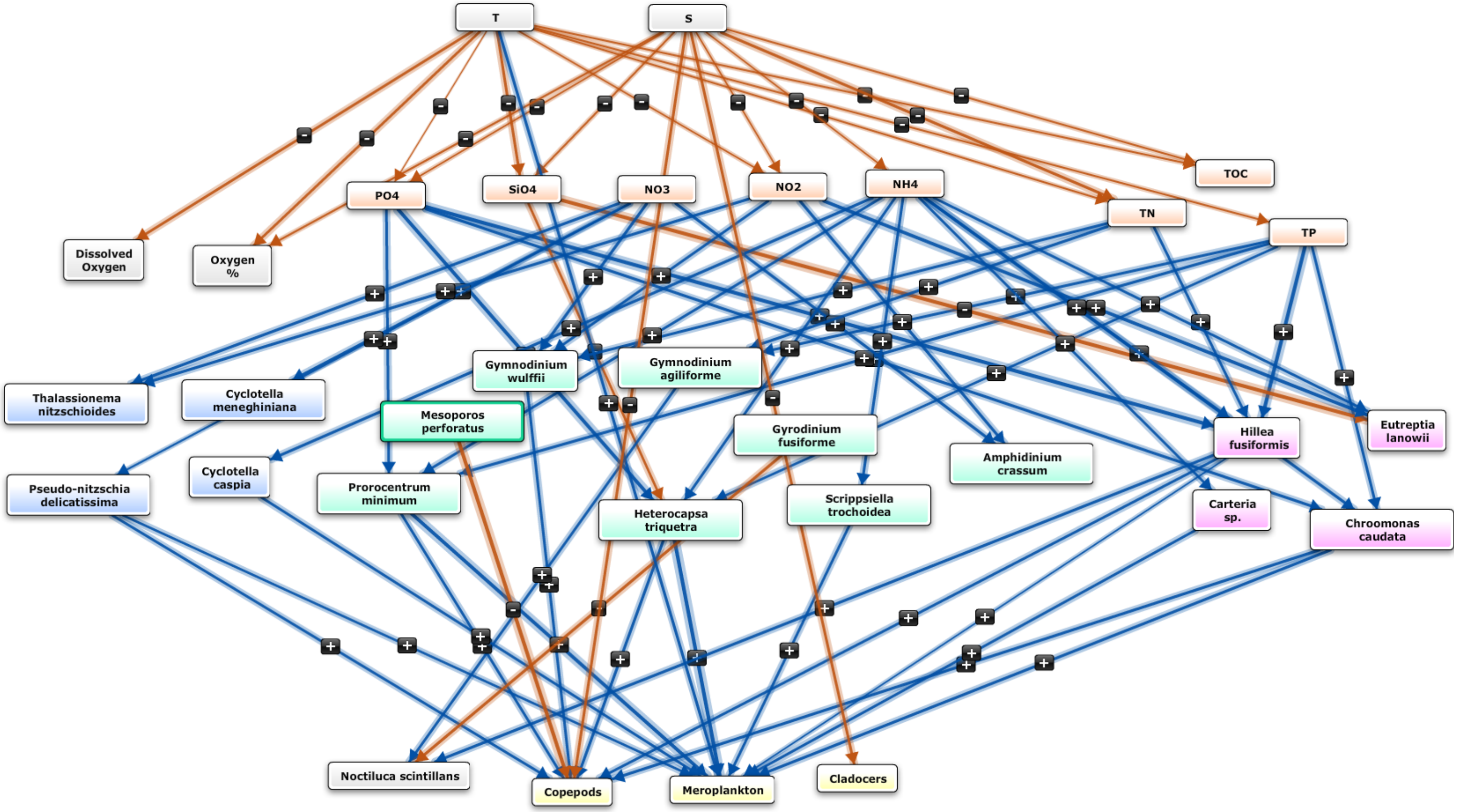

Fig. 7. Semi-quantitative dynamic model for causes and effects of eutrophication - Romanian Black Sea, Summer 2016.

Table 4. Eutrophication semi-quantitative models' main components.

	Spring	Summer
Total Components	38	32
Total Connections	68	67
Drivers - Components in a system that affect other components and are not affected by other parts of the system	11	5
Receivers - Components in a system that are affected by other components and do not affect other parts of the system	13	11
Ordinary – both influenced and influencing components	13	16

We compared the two models using centrality, which finds the most important concepts in a network. Centrality score (C) of individual variables represents the degree of relative importance of a system component to system operation (Gray, 2014). Thus, despite the lack of significant differences between seasons, salinity represents in spring both the main driver (C=6.39) and the most important component. Increased freshwater input from spring brought also nutrients - silicate and nitrogen (nitrate, nitrite and total nitrogen) but also directly involved in *Gymondinium wulfii*, *Cryptomonas* sp. and cladocers progress. Thus, *Cryptomonas* sp. and cladocers had the maximum growth in spring at the minimum salinity (14.06PSU) found on the continental shelf (Portita 5 station-bottom depth 57m), while *G.wulfii* were better developed at greater salinities (17.18PSU) in the central area (Est Constanta 5 station – bottom depth 54m). High salinity also directly influenced *Emiliania huxleyi*, and *Mesoporos perforatus* growth with the maximum abundances at 19.08PSU (station Est Constanta 6, bottom depth 70m). Additionally, *Emiliania huxleyi* benefitted by the low nutrients environment and assimilates organic phosphorus possible through the controlled expression of enzymes active (alkaline phosphatase) in specific metabolic pathways (Dyhrman and Palenik, 2003; Bruhn et al.,2010). This ecological strategy stems from a low nutrient quota and an extremely high phosphate affinity under phosphate-limiting conditions (Riegman et al., 2000; Ruoco et al., 2013). The outcome of the model showed also the temperature influence on *Skeletonema costatum* and *Planktonlyngbya circumcreta* preferring seawater temperature in the range 7.94 – 9.60ºC and usually found together. Due to the decrease in the oxygen saturation linked to *Skeletonema costatum* and increase of silicate level we assume that *Planktonlyngbya circumcreta* took advantage and followed for blooming. The organic matter expressed as total organic carbon (TOC) increased together with salinity for the Southern coastal area (Mangalia). Thus, the organic matter was important for *Lessardia elongata* (a non-native species (Moncheva et al., 2014) and *Gymnodinium najadeum* (heterotroph), both dinoflagellates emerging in spring. From these two species, only *Lessardia elongata* counted for meroplankton development. Through the model we didn't find any links between the most abundant phytoplanktonic mixotrophic species *Dinobryon balticum* and other components. In this case, the influence of allochthonous dissolved organic matter (ADOM) can be strong, fueling the heterotrophic microbial food web. Under such conditions mixotrophic phytoplankton may be enhanced, since they feed, e.g. on heterotrophic bacteria (Paczkowska et al., 2017).

The model identified the phytoplankton species as “drivers” for zooplankton development as follows - *Cyclotella caspia, Gymnodinium agiliforme and Gymnodinium heleveticum* for meroplankton and copepods, *Protoperidinium brevipes* and *Phormidium hormoides* for *Noctiluca scintillans* progress. At this moment, since meroplankton it is the second important component (receiver, C=5.85) of the system development, followed by cladocers (C=4.97) and copepods (C=4.85), we consider essential for knowledge to strengthen researches on this component and to build the model using zooplankton’s taxonomic composition. Additionally, the scenario of salinity decreasing by 20% (3.5 PSU) showed a 40% growing of meroplankton, enhancing though its role in the ecosystem (Fig. 7).

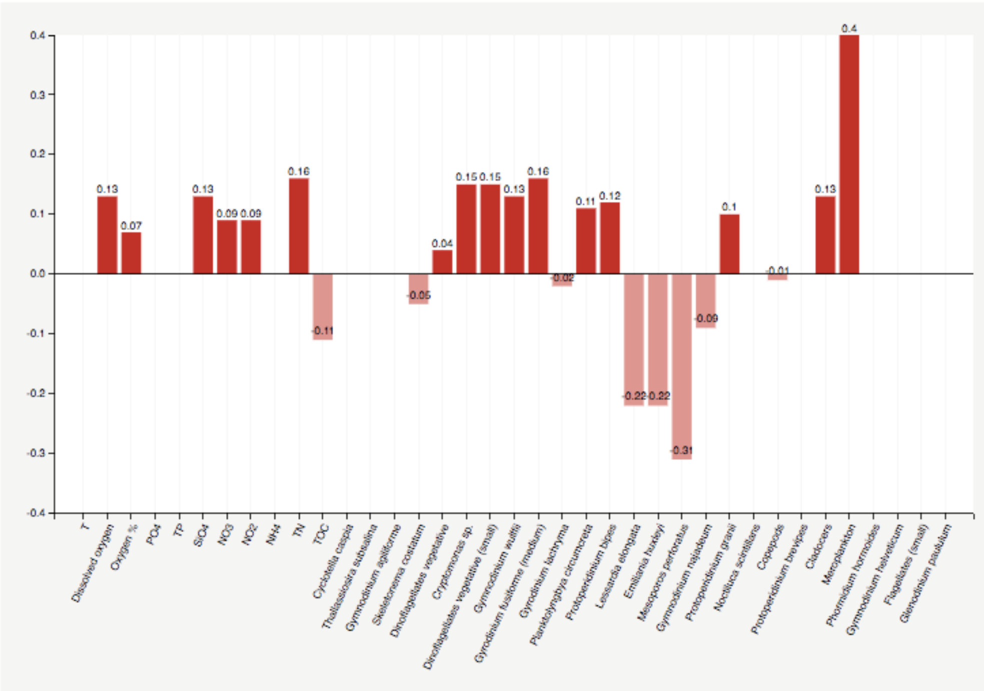

Fig. 8. Scenario of decreasing salinity in spring based on semi-quantitative model (eutrophication spring 2016).

Summer 2016 was characterized by a strong stratified water column, particularly in term of temperature (Fig.9). The salinity gradient was shaped as well from surface to bottom (Fig.10). In summer, with highest values at surface, ammonium was the main component (C=6.14) of the ecosystem dynamics, an ordinary one, followed as in spring by meroplankton (C=6.04). Ammonium was positively correlated with salinity, suggesting that not only the rivers input is impacting the ecosystem in the summer. Thus, the highest concentration (5.02μM) was found in the southern coastal waters (station Mangalia 1). Due to the dominant abundance of cyanophytes *Pseudanabaena limnetica*, *Planktolyngbya circumcreta* and *Phormidium hormoides* the atmospheric molecular nitrogen was converted by prokaryotic algae through fixation. Ammonium contributed then to the development of diatom - *Cyclotella caspia*, dinoflagellates - *Prorocentrum minimum, Heterocapsa triquetra, Scrippsiella trochoidea*, and other groups - *Hillea fusiformis, Carteria* sp., *Chroomonas caudata,* and *Eutreptia lanowii.* From all, *Heterocapsa triquetra* had a major influence (C=5.06), most probably due to its ability to use dissolved organic C during the day and night which allow mixotrophic bloom organisms a competitive advantage over co-occurring phytoplankton that are restricted to photoautotrophic growth, obtaining N and C during the day and in well-lit surface waters (Mulholland et al., 2018). Additionally, *H. triquetra* can successfully compromise between dark nutrient acquisition and the use of the internal nutrient storage for photosynthesis later in the light field (Ojamae et al., 2016). Another model's output was that the cryptophyte *Hillea fusiformis* an important component because of its highcentrality, 5.02. The community structure and ecological function of contemporary marine ecosystems are critically dependent on eukaryotic phytoplankton. Although numerically inferior to cyanobacteria, these organisms are responsible for majority of the flux of organic matter to higher trophic levels and the ocean interior (Falkowski et al., 2004). Thus, *Hillea fusiformis*, unable to perform fixation, incorporate fixed nitrogen by the cyanophytes *Pseudanabaena limnetica*, *Planktolyngbya circumcreta* and *Phormidium hormoides*, either ammonium or nitrate, into organic N compounds by assimilation and though could be one of the transferrers of organic phosphorus and nitrogen to zooplankton - *Noctiluca scintillans*, copepods and meroplankton, according to our model (Fig. 6).

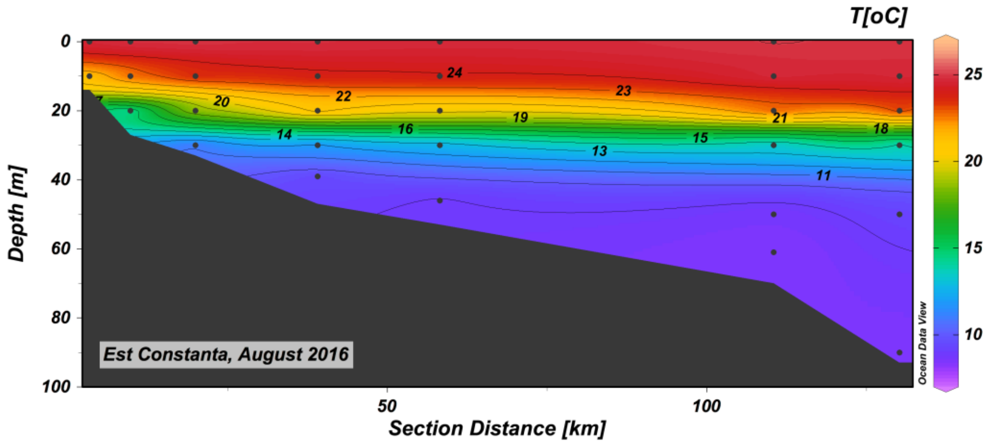

Fig. 9. Water column temperature - East Constanta, August 2016.

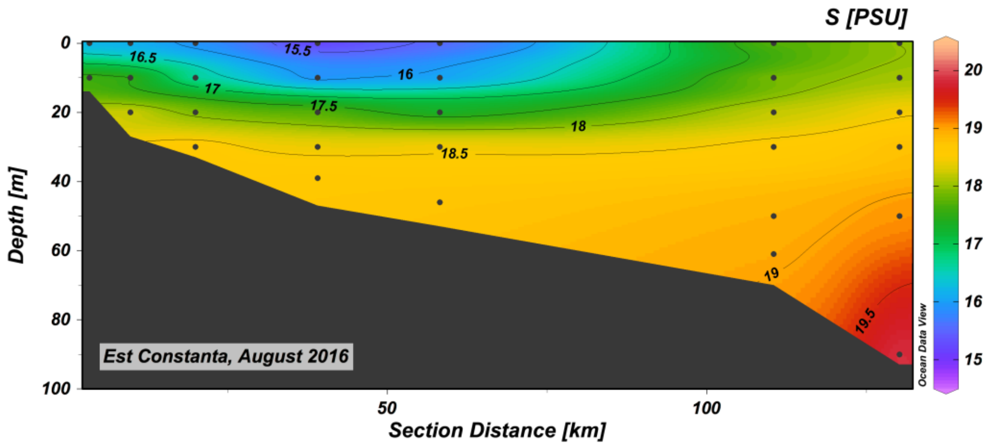

Fig. 10. Water column salinity - East Constanta, August 2016.

The model outlined also *Prorocentrum minimum* as one of the important components (C=3.76) influenced by phosphate, total phosphorus and ammonium concentrations and influencing copepods and meroplankton development. Recent experiment showed that a stronger thermal stratification can potentially influence dinoflagellate distribution, behavior, and survival in a species-specific way: for *H. triquetra* leading to ceased vertical migration and live/swimming cell population decrease, and for *P. minimum* leading to a more pronounced diel vertical migration (DVM) behavior. Thus, was found that for ΔT° = 17 °C *H. triquetra* did not migrate and cell densities in the water column decreased over time. Opposing results were observed for *P. minimum*, where a DVM pattern was found exclusively below the thermocline of ΔT° = 17 °C (Souza, 2014). From the zooplankton community, meroplankton and copepods were the most influenced components. Thus, *P. minimum* and *H. triquetra* are the best correlated with meroplankton. So, it is assumed that the increasing of stratification coupled with phosphorus and ammonium increasing could be followed by meroplankton development. So, the scenario of increasing temperature by 4% (1°C) and 10% increasing for phosphate, total phosphorus, nitrate, ammonium, total nitrogen and 1% for nitrite run by our model showed meroplankton increasing by 74%, copepods by 70% and *Noctiluca scintillans* by 24% and *Hillea fusiformis* by 32% (Fig. 10).

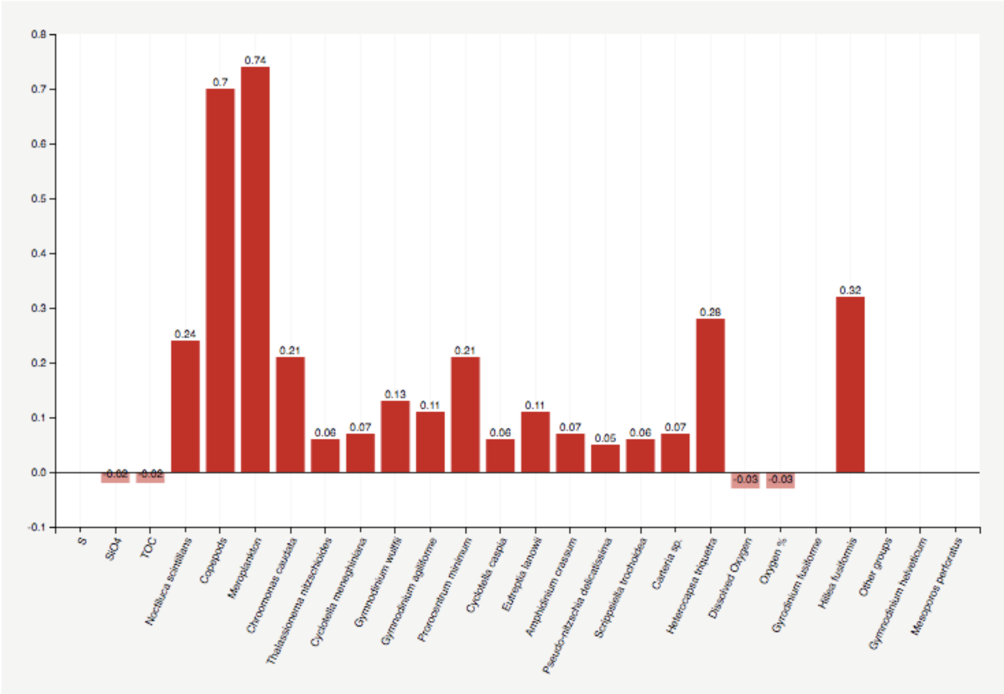

Fig. 10. Scenario of increasing temperature and nutrients based on semi-quantitative model (eutrophication summer 2016).

CONCLUSIONS

The paper aim to analyze natural variability of the most important parameters involved in the Black Sea eutrophication in one of the warmest last years, 2016 respectively. From the abiotic parameters we found seasonal variability, between spring (end of March - April) and summer (August) only for temperature due to highly increased temperature recorded in August 2016. The water masses stratification was significant in August 2016, too. Nutrients and chlorophyll *a* had reached normal levels. Phytoplankton developed normally without any harmful blooms and the macrophytobentos perennial species were community showed a recovery trend.

In an apparent non-eutrophic ecosystem, with mainly criteria fulfilling the good ecological status criteria, we assessed the natural variability from spring to summer 2016, two statistically different seasons. Based on statistically significant correlations between physical (T, S), chemical (O_2, nutrients) and biological parameters (phytoplankton and zooplankton) involved in eutrophication, grouped by season, considering the medium influence for all, and introduced into Mental Modeler software we obtained two semi-quantitative models for eutrophication which capture our knowledge in a standardized format that can be used for scenario analysis. The models' findings show different drivers for the two seasons. In spring, salinity is shaping the ecosystem dynamics while in summer the ammonium levels are of mainly importance. The model showed that the ammonium is particularly influencing the eutrophication status in summer due to the nitrogen fixation of the cyanobacteria and its transformation into available nutrients.

The semi-quantitative models open specific pathways for the researches on the Black Sea's eutrophication and the cumulative effects of different parameters on its status and might represent a tool for decisions based on different scenarios.

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