A PHYTOPLANKTON TIME SERIES IN THE NORTHWESTERN ADRIATIC SEA: STRUCTURE AND DYNAMICS OF THE ASSEMBLAGES IN A COASTAL ECOSYSTEM

Abstract - Phytoplankton is responsible for nearly half of the photosynthetic fixation of CO$_2$ and represents the first level of the food web in oceans. Due to phytoplankton fundamental ecological role, the aim of this study was to assess whether the phytoplankton assemblage structure could vary in time and space and if this variation could be due to such environmental forcing. Surface seawater samples were collected monthly from 2008 to 2019 at two coastal sites in the Northwestern Adriatic Sea together with physico-chemical and biological parameters recorded by a multiparametric probe. Phytoplankton identification and quantification were performed together with chlorophyll $a$ and dissolved inorganic nutrient concentrations determination. Data analysis indicated that Skeletonema marinoi, Thalassionema nitzschioides, Dactyliosolen fragilissimus, and undetermined Dinophyceae, showed a non-random pattern in the binary time series. Moreover, the observed phytoplankton assemblage structure was driven by seasonal and environmental factors.

Key-words: Assemblage structure, environmental variables, Northwestern Adriatic Sea, phytoplankton, time series

Introduction - Phytoplankton is responsible for atmospheric carbon fixation and represents the first level of the food web in marine ecosystems (Treguer et al., 2018). The study of the ecological structure of phytoplankton assemblages, and in particular the variations in time and space is crucial due to their role in primary production (Legendre et al., 2015). In this context, time series of phytoplankton data can provide information on spatial and temporal patterns of species populations and assemblages variation due to changes in meteorological and environmental variables, caused by climate change and human disturbances. Since phytoplankton can be considered a good proxy for quantifying environmental changes due to its rapid turnover, also in response to environmental changes, the study of time series assemblage structure may be crucial to move towards water quality targets, as required by both the European Water Framework Directive and Marine Strategy Framework Directive. In this study, phytoplankton assemblage structure was analyzed based on time series data (2008–2019) together with environmental variables in two coastal sites in the northwestern Adriatic Sea to test whether it could be influenced by environmental forcings.

Materials and methods – Sampling was carried out monthly from 2008 to 2019 along two transects in front of Foglia and Metauro river mouths (northwestern Adriatic Sea). In each transect, stations were located at 0.5 and 3 km from the coast. Physico-chemical parameters such as seawater temperature ($^\circ$C), salinity, density ($\sigma_t$), oxygen concentration (mg L$^{-1}$) and saturation (%), pH and redox were recorded by a CTD multiparametric probe. Surface seawater samples (0.5 m depth) were collected by Niskin bottles for phytoplankton (stored by adding 0.2% Lugol solution) and nutrient
analyses (determined on filtered seawater samples). Phytoplankton identification and quantification were carried out by light microscopy (Zeiss Axiovert 40 CFL), according to the Utermöhl method (Edler and Elbrächter, 2010). Counting was performed at 200 or 400× magnification along transects, after settling a variable volume of seawater (10–25 mL), depending on cell abundance, to count a minimum of 200 cells. Chlorophyll a (Chl a) and dissolved inorganic nutrients (ammonia-NH₄, nitrite-NO₂, nitrate-NO₃, orthophosphate-PO₄ and orthosilicate-Si(OH)₄) determinations were carried out spectrophotometrically (mod. UV-1700, Shimadzu, Japan) on seawater sub-samples.

Concerning the statistical analyses, Wald-Wolfowitz runs tests were performed to evaluate deviation from random occurrence in the time series for each phytoplankton taxon. An ordination of phytoplankton assemblage data constrained by environmental variables was obtained by distance-based Redundancy Analysis (dbRDA). Association between phytoplankton taxa was analyzed by means of a species co-occurrence network. All the analyses, except runs tests, were carried out under R 4.1.1 (2021).

**Results** – Among the 98 identified phytoplankton taxa, four consistently showed a non-random pattern in the binary time series, such as *Skeletonema marinoi* Sarno & Zingone, *Thalassionema nitzschioides* (Grunow) Mereschkowsky, *Dactyliosolen fragilissimus* (Bergon) Hasle and undetermined Dinophyceae (Fig. 1). The latter taxon was excluded by the analyses as it did not occur frequently and did not convey interpretable ecological information.

![Fig. 1](image_url)

**Fig. 1** - Bar plots show seasonal (blue bars) and annual (green bars) occurrences at the four sampling stations (F3000, F500, M3000 and M500) of *Skeletonema marinoi, Thalassionema nitzschioides, and Dactyliosolen fragilissimus*. These taxa are the only ones which deviate from randomness in their time series of occurrence at all sampling stations.
S. marinoi was more frequent in winter and early spring, whereas T. nitzschioides showed an opposite pattern with high frequency in late spring and summer. This was due to a clear and stationary annual cycle. Concerning D. fragilissimus, its deviation from randomness depended on the long-term trend of this species time series, as this diatom appeared more frequently since 2016. The phytoplankton assemblages and environmental variable time series were analyzed by distance-based Redundancy Analysis (Fig. 2). Temperature, dissolved oxygen, nitrate, and nitrite concentrations were responsible for the ordination of phytoplankton assemblage data indicating that in the Northwestern Adriatic Sea, phytoplankton assemblage structure was likely driven by seasonal and environmental factors.

Moreover, a similarity network of the more representative phytoplankton taxa was performed to evaluate the association among them (Fig. 3). The pairwise similarities were shown as black and red solid lines indicating within- and between-clusters similarity, respectively. Only three of the resulting clusters included more than a single taxon (2, 6 and 7, respectively). The smallest and completely separated group from the others clusters was composed by Ditylum brightwellii (T.West) Grunow and Thalassiosira rotula Meunier. The two clusters, one including Alexandrium minutum Halim, Chaetoceros spp., Gymnodinium spp., Proorocentrum micans Ehrenberg, Proorocentrum cordatum (Ostenfeld) J.Dodge and S. marinoi and the other composed by Cylindrotheca fusiformis Reimann & Lewin, Guinardia striata (Stolterfoth) Hasle, Heterocapsa niei (A.R.Loeblich) L.C.Morrill & A.R.Loeblich, Leptocylindrus danicus Cleve, Navicula spp. (Bory, 1822), Pseudo-nitzschia spp. and T. nitzschioides were not completely independent showing multiple inter-cluster connections. The remaining 13 taxa did not form clusters.

Conclusions - In conclusion, it was shown that in the northwestern Adriatic Sea, the regular periodic pattern of phytoplankton assemblage structure was driven by seasonal and environmental factors as for the species Skeletonema marinoi, Heterocapsa niei and Thalassionema nitzschioides (Casbianca et al., 2022). The study of long-term monitoring confirmed the efficacy of time series data which showed a regular pattern...
even in areas subjected to human pressures (i.e., low precipitation induced by climate change, European regulations of nutrient loadings and anthropogenic use) such as the Northwestern Adriatic Sea. Thus, any future change in the pattern of phytoplankton assemblage structure will be considered as a warning about possible changes in the environmental parameters taken into account. These potential changes could have an impact on the functioning of the coastal ecosystem and its ability to provide ecosystem services.

Fig. 3 - Network of phytoplankton taxa association based on Jaccard similarities. Three taxa groups emerged, one of which included only two species. (Cha, Chaetoceros spp.; Pse, Pseu-do-nitzschia spp.; Hnie, Heterocapsa niesi; Smar, Skeletonema marinoi; Nav, Navicula spp.; Tnit, Thalassionema nitzschiooiides; Gstr, Guinardia striata; Tfu, Tripos fusus (Ehrenberg) F. Gômez; Ldan, Leptocylindrus danicus; Gym, Gymnodinium spp.; Pcor, Prorocentrum cordatum; Gfsu, Gyrodinium fusiforme Kofoid & Swezy; Trot, T. rotula; Tfur, Tripos furca (Ehrenberg) F. Gômez; Pcor, Prorocentrum spp.; Str, Scrippsiella trochoidea (F. Stein) A. R. Loeblich III; Cpel, Cerataulina pelagica (Cleve) Hendey; Rhi, Rhizosolenia spp.; Pste, Protoperidinium steinii (Jørgensen) Balech; Gfia, Guinardia flaccida (Castracane) H. Peragallo; Ple, Pleurosigma spp.; Dfra, Dactyliosolen fragilissimus; Dbri, Ditylum brightwellii; Gon, Gonyaulax spp.; Tha, Thalassiosira spp.).

Network di associazione di taxa di fitoplancton basato su somiglianze di Jaccard. Sono emersi tre gruppi, uno dei quali comprendeva solo due specie. (Cha, Chaetoceros spp.; Pse, Pseu-do-nitzschia spp.; Hnie, Heterocapsa niesi; Smar, Skeletonema marinoi; Nav, Navicula spp.; Tnit, Thalassionema nitzschiooiides; Gstr, Guinardia striata; Tfu, Tripos fusus; Ldan, Leptocylindrus danicus; Gym, Gymnodinium spp.; Pcor, Prorocentrum cordatum; Gfsu, Gyrodinium fusiforme; Trot, T. rotula; Tfur, Tripos furca; Pro, Prorocentrum spp.; Str, Scrippsiella trochoidea; Cpel, Cerataulina pelagica; Rhi, Rhizosolenia spp.; Pste, Protoperidinium steinii; Gfia, Guinardia flaccida; Ple, Pleurosigma spp.; Dfra, Dactyliosolen fragilissimus; Dbri, Ditylum brightwellii; Gon, Gonyaulax spp.; Tha, Thalassiosira spp.).

As phytoplankton is considered a good proxy for quantifying environmental changes, the monitoring phytoplankton assemblage structure through the analysis of time series may be therefore crucial to achieve the Good Environmental Status in compliance to environmental directives.

References


Casabianca et al., 2024