The Gulf of Naples as a model system for plankton ecology studies

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Plankton play a fundamental role in coastal and oceanic ecosystems as a key element of biogeochemical cycles and pelagic trophic webs and contribute to determine and maintain the health of the oceans. Half of the world's population leaving along the coasts (Vitousek et al., 1997) relies on services offered by plankton in terms of seafood availability and sea water quality. Therefore, monitoring, quantifying, and understanding the responses of plankton to the variability of the coastal ecosystem represent an urgent challenge to the scientific community, and even more so in an epoch of rapid environmental changes. Yet, because of the prevalently microscopic nature of planktonic organisms and logistic hindrances, research in this field has start developing only in the second half of the XIX century.

One of the first marine sites where plankton were studied was the Gulf of Naples (GoN), a coastal embayment of the mid Tyrrhenian Sea in the western Mediterranean. The GoN is in the temperate zone but with subtropical characteristics, under the anthropogenic impacts from one of the most densely populated areas of the Mediterranean Sea contrasted by the influence of the open oligotrophic Tyrrhenian waters. Consequently, the GoN marine ecosystem is a mosaic of areas with different ecological conditions, where highly impacted habitats coexist with relatively pristine localities and marine protected areas. Studies on the plankton of the GoN were fostered by scientists working at the Stazione Zoologica (SZN), the first marine institution in Europe funded in 1872 by Anton Dohrn.

Plankton of the GoN were initially analysed to unveil their extraordinary diversity (e.g., Giesbrecht, 1892) and phenology (De Angelis, 1958; Indelli 1944; Issel, 1934). In the second half of the last century, studies also focused on plankton taxonomy, life cycles, and distribution in space and time, until regular monitoring was started in 1984 with a long-term ecological research program at the site*MareChiara* (LTER-MC) since 2006 part of the Italian, European and international LTER networks. LTER-MC is located two nautical miles off the coast of the city of Naples in an area that can be alternatively influenced by the eutrophic coastal zone and the oligotrophic waters of the Tyrrhenian Sea. Over the years, LTER-MC has proved to be not only a valuable observatory of the diversity, complexity and temporal variability of plankton but also a precious natural laboratory to test hypotheses that emerged from field observations (reviewed by Zingone et al., 2019).

In this Special Issue we have collected the results of the most recent ecological investigations conducted on the plankton of the GoN with the intent to celebrate the 150^{th} anniversary of the SZN foundation, an important occasion that has been widely celebrated (Boero et al., 2023). This special issue focuses on phyto- and zooplankton and their environment studied in both field and lab investigations, with classical methods as well as taking advantage of advanced technologies such as the recent developments of molecular approaches. With this collection, we gather the most updated knowledge on the plankton of the GoN, with a special

attention to features that may shed light on general aspects going beyond the local scale of the sampling site.

The topics investigated in this Special Issue span over different temporal scales. Some studies took into consideration a large period of the LTER-MC time-series and examined trends of environmental variables (Kokozska et al., 2023; Romillac et al., 2023), revealing that, in the case of plankton, hydrographic changes including inshore–offshore exchanges, the residence time of freshwater and the shallowing of the mixed layer depth are more important than simple temperature increase recorded in summer. The response of plankton is seen in the increased contribution over the years of the autumnal blooms deriving from a lengthening of the stratification period, and in significant trends in specific elements of the phyto- and meso-zooplankton (Saggiomo et al., 2023; Mazzocchi et al. 2023). Interestingly the observed environmental changes are contrasted by the overall stability of the whole mesozooplankton community (Mazzocchi et al., 2023), which parallels the resistance to interannual variation recently highlighted for phytoplankton (Longobardi et al., 2022). When it comes to individual key taxa, the need emerges to consider different aspects of their life cycle, such as fecundity and egg hutching success, to understand the important role played by biology in shaping the observed seasonal and long-term trends in copepod populations (Carotenuto et al., 2023).

At the seasonal scale, the annual patterns of seven different and stable phytoplankton associations, identified by leveraging the multiannual data on species distribution from the LTER-MC time series, showed a close relationship with variables related to astronomical factors (Zingone et al., 2023). Their functional diversity varied across the seasons, with divergent or convergent traits within each association reflecting the variable strength of the environmental filtering. A high seasonal signal was also found in dinoflagellate communities investigated in a three-year metabarcoding dataset, along with the identification of a species-rich winter community, so far neglected by the current views of dinoflagellate preference for stable and warm summer conditions (Mordret et al., 2023).

A whole range of classical and advanced approaches were used to address plankton variability, including the analysis of physical-chemical, biological and diversity data from the natural environment (Kokozska et al., 2023; Mazzocchi et al., 2023; Romillac et al., 2023; Zingone et al., 2023), laboratory experiments (e.g., Carotenuto et al., 2023; René et al. 2023; Traboni et al., 2023) and more sophisticated chemotaxonomic (Saggiomo et al., 2023) and biomolecular approaches (Di Capua et al., 2023; Mordret et al., 2023; Russo et al., 2023). The latter studies have addressed temporal trends in groups of species hardly detected by morphological studies, unveiling, for example, a high amount of dinoflagellate diversity not assigned to any described taxa (Mordret et al., 2023). This unknown diversity may reveal novel species to be discovered and described, but may also be the effect of massive gaps in reference datasets, i.e., the dictionaries that allow translating the environmental DNA data into biologically meaningful information. In this respect, the delivery of novel reference sequences from several crustacean zooplankters of the GoN represents a relevant contribution to help interpret metabarcoding data and decipher the hidden diversity of plankton communities and their role in the ecology of the system (Di Capua et al., 2023).

Molecular approaches are also proven useful and usable to address interspecific relationships of different natures. Co-occurrences derived from a three-year metabarcoding time-series coupled with background biological information on size and trophic habits of their components revealed a trophic hierarchy and modularity in the network, which would allow quick food-web re-arrangements under shifting hydrographic conditions that are typical of the coastal area of the GoN (Russo et al., 2023). The same three-year time series was also explored in the first investigation on diatom parasites of the GoN, where incubation experiments were combined with microscopy observations and contextual metabarcoding analyses (Renè et al., 2023). This multi-approach study revealed that chytrid fungi (Chytridiomycota) are a common component of the protist community in the GoN and would deserve quantification with specific techniques to assess their role in the mortality of their hosts. Besides metabarcoding, another special technique, the stable isotope analysis, provided relevant details of trophic interactions to unveil the complexity of planktonic food webs, which can buffer the environmental variability due to the specific hydrographic features of the GoN (Merquiol et al., 2023). Finally, laboratory experiments conducted with microplastics, which are presently one of the most concerning threats

for marine organisms, have revealed that copepod daily intake of food was not significantly affected by their presence, likely because of their ability to avoid those particles and flexible feeding habits (Traboni et al., 2023).

The studies presented in this Special Issue have provided many new pieces to the complex puzzle of the plankton ecosystem in the GoN, at the same time opening new questions and providing indications for new studies to be developed in the future. Mainly the topic of trophic and non-trophic interactions has only started to be explored. The discovery of a high amount of parasitic Syndiniales and highly dynamic chytrid fungi populations highlights the need to take into consideration all levels of the network that connects the existence of marine planktonic organisms. While trends are observed in some components of the system, it is necessary to go beyond descriptions and take into consideration the life cycles and reproductive traits of plankton species along with other functional aspects that allow unveiling the mechanism underlying those trends, thus opening the way to the forecast of future scenarios under changing environmental conditions. In this respect, results from both classical, laboratory studies and extensive molecular information obtained from natural populations, interpreted in the light of background knowledge, are expected to provide a formidable new asset to understand plankton and predict their changes in the coming years.

In addition to the contribution to the knowledge of the GoN ecosystem, the studies collected in this Special Issue shed light on several aspects of the plankton ecology that go beyond the local scale, emphasizing the specificity of the area and pointing to the pivotal role of long-term investigation sites as testbeds for wide-ranging ecological questions.

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