University of Genoa & Stazione Zoologica Anton Dohrn of Naples

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Plankton food webs: new tools for management and assessment of the marine ecological status

Ph.D. Thesis

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ABSTRACT (English)

Plankton represents a fundamental component of marine ecosystems, encompassing both unicellular organisms (such as bacteria, and protists) and multicellular organisms (such as copepods and other metazoans). These organisms play a key role in biogeochemical cycles and in the structure of marine food webs, acting as the primary channel for transferring energy produced in the water column to higher trophic levels. Planktonic communities are characterized by high taxonomic, functional, and trophic diversity, including photoautotrophs, heterotrophs, and mixotrophs. This heterogeneity supports the formation of complex and dynamic trophic networks, whose structure can vary significantly in response to environmental factors such as temperature, terrestrial inputs, nutrient availability, and hydrodynamic conditions.

Despite their central role in marine ecosystems, planktonic communities remain underrepresented in environmental monitoring programs established under the Marine Strategy Framework Directive (MSFD), particularly within Descriptor 4, which addresses trophic networks. In particular, the traditional dichotomy between phytoplankton and zooplankton tends to oversimplify the ecological complexity of the planktonic compartment, limiting the effectiveness of tools used to assess marine ecological status.

This PhD project was based on the analysis of a large dataset collected during two sampling surveys conducted in coastal marine environments characterized by different ecological conditions and levels of anthropogenic pressure. Sampling activities took place along the coasts of the Campania region (during autumn 2020 and summer 2021), within the framework of the FEAMP-ISSPA project, and in the North Sea, off the Belgian coast, in July 2022 during an oceanographic cruise as part of the international S4GES – JPI Oceans project.

The main objective of this thesis was to understand how the structure and functioning of planktonic trophic networks respond to different environmental gradients, using an integrated and multidisciplinary approach. Firstly, ecological models based on *Ecopath with Ecosim* (EwE) were developed to quantify biomass flows among planktonic functional groups and identify major structural changes in trophic networks in response to varying environmental conditions. Secondly, molecular techniques based on environmental DNA (*eDNA*

metabarcoding) were applied to obtain a high-resolution description of plankton biodiversity, with particular attention to the spatiotemporal dynamics of communities and their connectivity influenced by coastal dispersion processes. Finally, the *emergy* approach (*emergy accounting*) was employed as a tool for environmental accounting, providing a biophysical assessment of planktonic natural capital by estimating, in energetic terms, the contribution of plankton communities to ecosystem processes.

The results showed that the structure of planktonic trophic networks is strongly influenced by local environmental factors, such as riverine inputs, water column stratification, and tidal conditions. The application of food web models allowed the identification of specific ecological indicators sensitive to these pressures, with potential relevance for MSFD ecological assessments. Although eDNA molecular data are not directly usable for indicator development, they offered a detailed picture of plankton community composition and dynamics, enriching the ecological interpretation of model outcomes. The emergy approach, finally, enabled a functional valuation of plankton in different environmental contexts, contributing to a more comprehensive understanding of its ecological role within marine natural capital.

Overall, this work demonstrates that integrating biological data, ecological modelling, and biophysical accounting tools represents an effective strategy for addressing current gaps in the assessment of Good Environmental Status. This integrated perspective can support the sustainable management of coastal areas and enhance the systemic valuation of marine natural capital.