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Editorial: New perspectives in benthic-pelagic coupling in marine and transitional coastal areas

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Editorial on the Research Topic
New perspectives in benthic-pelagic coupling in marine and transitional coastal areas

Shallow environments and transitional habitats are among the world's most productive ecosystems (Odum, 1983; Cloern et al., 2014) where light penetration to the bottom and nutrient availability fuel multiple primary producers including phytoplankton, benthic microalgae, macroalgae and seagrasses (Kirk, 2000; Sundbäck et al., 2000; Sala et al., 2012; Papathanasiou et al., 2015; Orfanidis et al., 2021) that sustain higher trophic levels and provide important ecosystem services (Barbier et al., 2011; Queirós et al., 2019). In these ecosystems, pelagos and benthos have been classically studied as distinct domains of the marine environment, although they cannot be considered as separate entities (Boero et al., 1996; Marcus & Boero, 1998). The compartmentalization of these ecosystems into their benthic and pelagic components in experimental studies and models often limits our understanding of the scope and strength of interactions between these habitats, their role in maintaining the ecosystem function, and their sensitivity to future change (Griffiths et al., 2017). The benthic–pelagic coupling involves all those processes that connect the bottom and water column habitats through the exchange of mass, energy, and nutrients. Matter and energy flow between the two domains in both directions, along food webs, involving the movement of planktonic and benthic organisms at different life stages (Kiljunen et al., 2020). Indeed, many physical, chemical and biological processes bind these two domains, where benthic-pelagic coupling concurs to maintain high rates of primary production and decomposition (Kennish et al., 2014). While primary producers compete for the same resources (light and nutrients), benthic filter feeders are well adapted to efficiently filter bacteria, phytoplankton and zooplankton, dissolved organic matter

(Hughes et al., 2005; Karuza et al., 2016), as well as pollutants from the water column (Giandomenico et al., 2016). An in-depth knowledge of the life cycles of meroplanktonic species is an indispensable prerequisite for understanding the functioning of the ecosystem in shallow areas. Besides this, benthic primary producers and invertebrates provide several ecosystem services and drive important processes such as nutrient cycling, bio-irrigation and organic matter decomposition in coastal areas (Bremner et al., 2006; Olsgard et al., 2008).

Lately, efforts have increased to describe and understand the diversity of processes that couple benthic and pelagic habitats, especially those mediated by biota (Griffiths et al., 2017), but many aspects of the "benthic-pelagic unicum" are still to be discovered. Moreover, anthropogenic pressures like organic enrichment, eutrophication, hypoxia events and contamination (Mozetič et al., 2012), are increasingly affecting the status and functioning of these highly biodiverse, shallow water environments (Kennish et al., 2014). Given the pressing goal of sustainable management of natural marine resources, there is an urgent need to advance our knowledge of the overall picture of processes and flows between pelagos and benthos.

This Research Topic aims to update the current knowledge on benthic-pelagic coupling in shallow marine and transitional waters, covering recent investigations on biologically mediated processes that interconnect benthic and pelagic habitats. The Research Topic comprises a collection of 9 contributions, 8 of which include original research and one is a review article.

One paper is focused on the function and structure of eukaryotic phototrophs. In the publication by Cibic et al., the benthic and pelagic contributions to total primary production were estimated experimentally at a 17-m deep site in the Gulf of Trieste, northern Adriatic Sea. The authors found that the mean benthic contribution to the total primary production was 11.3% but reached 43% when phytoplankton in the water column was scarce. Further, they reported that the seasonal development of pelagic and benthic phototrophs and primary production was more affected by nutrients availability than the physical variables, except for the surface layer of the water column where temperature and salinity were the main drivers.

Two articles present data on angiosperms and macrophytes, and their use as bioindicators to assess the environmental status of coastal areas, formerly or still affected by eutrophication and hypoxia events. In the paper by Sfriso et al. the latest results on the environmental recovery of aquatic angiosperms in the Venice Lagoon and their net primary production are presented. A decrease of anthropogenic impacts, such as eutrophication and clam harvesting, favored a sharp decline of Ulvaceae that were replaced by species of higher ecological value. Surveys carried out by the authors in 2021 revealed that the recolonization of aquatic angiosperms is further expanding, leading to increased biodiversity and production of both macroalgae and aquatic angiosperms, and improving the overall ecological conditions of the Venice Lagoon. In the second article, Gerakaris et al. used a large dataset from three Mediterranean sub-basins (Adriatic, Ionian and Aegean Seas) with different trophic conditions to investigate, on a large scale, the coupled responses of benthic and pelagic primary producers (phytoplankton as Chl *a*, and macrophytes) to eutrophication. Their results show that increasing nutrient concentrations lead to increased coverage of opportunistic macroalgal species at the expense of canopy-forming species. Further, structural traits of *Posidonia oceanica* showed opposite trends to increasing levels of pressure indicators such as ammonium, nitrate, phosphate, Chl-*a*, and light attenuation. Overall, they found that the coupling of pelagic and benthic primary producers across trophic gradients showed consistent patterns at subregional scales.

The next two articles cover the aspects on the life cycle of some specific planktonic organisms, on their dormant phase or the subsequent germination/rejuvenation stages. In the paper by Ishii et al., the life cycle strategies of centric diatoms from a shallow area of Ago Bay (central Japan) were studied using the plankton emergence trap/chamber (PET chamber). The authors compared their experimental data on geminated/rejuvenated cells to the vegetative cells sampled in the water column but did not find a clear relationship. Their findings indicate that the magnitude of the vegetative population depends on the vegetative cells' growth rather than on the recruitment of cells from the surface sediment. They also proposed different patterns of life cycle strategies of centric diatoms in shallow coastal waters. The article by Dzhembekova et al. investigated the distribution of some cyst morphotypes of the dinoflagellate *Scrippsiella acuminata* in surface sediments of the Black Sea. The authors followed a basin scale approach, collecting samples from 34 sites, and linked the spatial distribution and abundance of cyst morphotypes to some selected physical and chemical variables measured in the water column. They found that salinity, temperature, and nutrients, particularly nitrates and phosphates, were the most important drivers of the occurrence, density, and geographical distribution of *Scrippsiella acuminata* in the Black Sea.

The article by Matsuoka et al. reports on the marine environmental changes induced by anthropogenic activities recorded in the sediments of Beppu Bay, western Japan, by analyzing the palynomorph assemblages (microfossils of dinoflagellate cysts and other planktonic organisms with organic walls). The authors' stratigraphic analysis of these assemblages preserved in the sediments, together with the age determination of the cores, revealed a rapid eutrophication due to anthropogenic activities from the mid-1960s in the area, that induced the most drastic change in the biota over the past 1000 years in Beppu Bay.

The next paper relates to the use of foraminifera as bioindicators in a contaminated port area. Rožič et al. applied a multiparametric approach to link the geoenvironmental variables in the sediments of the Bay of Koper (north-eastern

Adriatic Sea) to the benthic foraminifera assemblage. They reported moderate to high species diversity, and a dominance of pollution tolerant species. Their findings revealed a possible influence of some potentially toxic heavy metals on the foraminifera diversity and taxonomic composition. The authors further evaluated the ecological status by using the Foram-AMBI and EcoQs indices; the first highlighted a good to moderate quality of ecological conditions, whereas the second a high to poor ecological status.

The review article by Dimitriou et al. is a synthesis of the results of the project HYPOXIA "Benthic–pelagic coupling and regime shifts". The aim of this project was to investigate how nutrient input in the water column leads to ecological processes of eutrophication, which may in turn lead to significant, irreversible changes in the eastern Mediterranean ecosystems. The project included analysis of historical water and benthos data, field sampling, and mesocosm experiments. After reanalyzing the project results, the authors reported that, unlike other regions of the world, eutrophication did not cause water hypoxia or benthic dead zones in the eastern Mediterranean coastal ecosystems. They concluded that this region shows high resilience to the adverse effects of eutrophication, preventing hypoxia and azoic conditions when eutrophication is the only source of environmental disturbance.

The last paper presents the main outputs of the food web modelling in two areas of the northern Ionian Sea. The study by Ricci et al. investigated the contribution of intermediate and high trophic level species to benthic-pelagic coupling in a region subjected to large-scale oceanographic changes, e.g., the Adriatic-Ionian Bimodal Oscillating Systems (BiOS), that might result in relevant spatial and temporal changes in the benthic-pelagic coupling. The authors' findings highlight the pivotal role of deep faunal communities, in which demersal and benthopelagic species sustain upward energy flows towards the pelagic domain and shelf faunal communities. They also reported that temporal changes driven by BiOS affect the trophic state of the deep communities resulting in considerable variations in their amount of consumption flows.

In summary, this Research Topic contributes to the advancement of our knowledge of biologically mediated processes that interconnect shallow-water benthic and pelagic habitats. These sensitive ecosystems are often subjected to management policies designed to improve their ecological status, or to enhance the ecosystem services they provide. Yet, the environmental quality targets and the ecosystem approach to the management of these ecosystems are often based upon the current compartmentalization of benthic and pelagic habitats. Environmental quality indicators, such as those used in the European Water Framework Directive (WFD; Directive 2000/60/EC) and the Marine Strategy Framework Directive (MSFD; EU Directive 2008/56/EC), commonly describe the status of pelagic or benthic habitats separately. However, many anthropogenic activities affect fundamental benthic–pelagic linkages and disrupt the flow of ecosystem services in shallow coastal and transitional ecosystems (Griffiths et al., 2017). Thus, understanding the interdependence between benthos and pelagos, and the processes involved in the benthic-pelagic unicum, is pivotal to help maintain the function of these shallow water ecosystems and ensure the services they will continue providing under increasing anthropogenic pressure. Therefore, it is of paramount importance to consider benthic and pelagic habitats as a unicum and include them as such in future management frameworks.

Author contributions

TC: conceptualization, original draft, editing; MO-B and FR: conceptualization, writing, review. All authors contributed to the article and approved the submitted version.

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Conflict of interest

The authors declare that the research was conducted in the absence of any commercial or financial relationships that could be construed as a potential conflict of interest.

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