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Editorial: Emerging Topics in Coastal and Transitional Ecosystems: Science, Literacy, and Innovation

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Editorial on the Research Topic

Emerging Topics in Coastal and Transitional Ecosystem: Science, Literacy and Innovation

Marine coastal and transitional ecosystems are facing increasing impacts, and often reflect the most immediate effects of environmental change, habitat destruction, and biodiversity loss. With over half of the population currently living in coastal areas, these areas are of interest for multiple uses and resources, as well as subjected to multiple stressors and associated impacts derived from local and upstream anthropogenic activities. The challenges coastal and transitional ecosystems now face is not new and have far-reaching implications for the ocean (Borja et al.). Nevertheless, significant knowledge gaps on their functioning and structure still exist and new solutions or approaches to this old problem are still needed, from blue biotechnological innovations to improved ocean literacy (Borja et al.). This Research Topic aimed to contribute to the sustainability of coastal and transitional environments, providing a broad overview of ecosystem resources and functioning, assessment and monitoring tools, restoration, biotechnology, and ocean literacy. A growing human population has also increased the reliance on the sea for food and feed resources. Despite soaring demand, the management of seafood resources is still hampered by key knowledge gaps on many life-history traits of target species as well as on ecosystem's functioning (Golden et al., 2021). From tropical regions, where mangroves function as nursery habitats for various crustaceans and fish species, contributing to maintaining adjacent marine stocks, a poorly studied system on Príncipe Island, Gulf of Guinea, evidenced the importance of seasonality and mangrove zone on fish assemblages (Cravo et al.). In the deep sea, a particular challenge to commercial exploitation of fish species is how changing environmental conditions affect these organisms, which are generally characterized by high longevity, late reproduction, and low fecundity. A study over four decades, on the commercially important deep-sea fish species blackspot seabream (Pagellus bogaraveo) in the Northeast Atlantic, showed that temperature-at-depth was the best predictor of growth, suggesting that rising ocean temperature may have important repercussions on growth, and consequently on blackspot seabream fishery production (Neves et al.). Fisheries can also have a strong impact on non-target or bycatch species. Elasmobranchs were initially characterized as of low economic value, albeit some species are now important targets, and yet due to their specific life-history traits, sharks and rays are particularly vulnerable to overexploitation, with several species classified as overexploited status. A case study on Portuguese landings showed that several national and European-levelmanagement measures (e.g. total allowable catches, minimum landing size), reduced landings of these species, albeit it also revealed a lack of awareness by fishers about the state of elasmobranchs populations, and their basic biology, which is an essential step to shared management responsibilities and improved conservation (Silva et al.). Bivalve species are also an important seafood resource, with growing exploitation of both indigenous and non-indigenous species. Predicting species occurrence and abundance can improve sustainability and management of exploited bivalve populations (Santos et al.), albeit overexploitation, diseases, increased predation, and competition with non-indigenous species have all been pointed to as factors in the decline of these populations in Europe. The management of non-indigenous species can be a challenge. The Manila clam (Ruditapes philippinarum) is a good example, this non-indigenous species was introduced in Europe in the 1970s for commercial purposes, and is currently highly abundant in various estuarine systems, with significant illegal exploitation of this resource. Coelho et al. proposed a co-management model for this activity toward creating a legal framework for sustainable harvesting, which can be applied to the different systems where exploitation occurs.

Globalization and aquaculture development have also brought about the exploitation of less traditional resources in a given region (Naylor et al., 2021), such as echinoderms on the Atlantic coast. Sea urchins' harvest and aquaculture are increasing, and information on their feeding biology (Luís and Gago) can greatly improve cultivation conditions. Another example are sea cucumbers, which are a highly-priced commodity in Asian markets, but their intrinsic biological and ecological characteristics show that these echinoderms are vulnerable to overfishing, and there is a need for stock management in NE-Atlantic (Félix et al.).

Management and valorization of other biological resources are also key to sustainable exploitation of marine resources. A keen example is the need to manage the impacts of more frequent Sargassum events on the Atlantic shores, with evident ecological and socioeconomic impacts on the nearshore (Robledo et al.). Coupling mitigation efforts with the potential exploitation of the excess macroalgae biomass, which may provide potentially valuable compounds of interest (e.g. polysaccharides), could be key to balancing the valorization of natural resources and coastal management in the affected areas.

Assessing the environmental status of an environment, as easy as it sounds, encompasses a myriad of approaches and compartments. In the last years, this became a primal objective of several marine directives, resolutions, and acts worldwide (Borja et al.). One of the first approaches in this regard is the evaluation of the physic-chemical characteristics of a certain ecosystem and its biotic compartments. Changes in these traits lead to inevitable shifts and impacts on the biotic communities. This can go from the evaluation of the trace element composition of sediments coupled with risk assessment tools to evaluate the risk that these elements pose to the ecosystem but also the degree of impact that can be attributed to anthropogenic activities concerning geological baselines (Vilhena et al.). But not all changes are due to direct human impacts and can be due to simple system hydrodynamic variability. Phytoplankton for example is highly affected by the system tidal and hydrodynamic regime, and these key communities can suffer drastic changes during extreme phases of the ecosystem tidal cycle, such as springtides, not only in terms of community diversity but also planktonic biomass (Cereja et al.). In the case of closed estuarine systems, the effective management promoted will have similar implications. Human-driven interventions such as the diversion of wastewater treatment works discharges and restoration of hydrodynamic variability have important effects on the phytoplankton community dynamics, being pointed out as priorities for improving the health and biodiversity of small, closed microtidal systems (Lemley et al.). Climate change also emerges as another key factor shaping marine communities, like macroinvertebrates, a key group for environmental quality assessment. Environmental management actions have been contributing to an overall improvement of the systems' ecological quality. Nevertheless, time-series analysis also reveals that in Atlantic systems there has been an increase of subtropical species in shallower areas, while in deeper areas the propensity is for species that prefer temperate climates (Goulding et al.). All these changes in the communities of the estuarine systems have cascading effects not only at the species and population level but with cascading effects throughout the trophic web, from the primary producers to top predators. Anthropogenic drivers such as fishing affect directly fish communities, although several other such as climate anomalies, eutrophication, and chemical contamination also impose shifts in fish communities and trophic webs, with significant regional patterns due to different reporting efforts made by different countries, reinforcing, therefore, the need for monitoring all biotic compartments and their relationships (Machado et al.). Ecosystem changes at different levels of complexity and intensity degree, lead to inevitable impacts, especially in shelf ecosystems, more prone to anthropogenic disturbance. These have more serious impacts on sensitive small pelagic fish and lower trophic levels that lead to internal triggers related to indirect trophic interactions benefiting organisms from upper trophic levels and impacting the pelagic communities. Nevertheless, not all changes come from negative impacts, and the reduction of the fishing pressure can also enhance these internal triggers. Thus, for a correct understanding of the changes occurring in shelf ecosystems Szalaj et al. proposes that regime-specific harvest rates and environmental reference points should be considered when an indication of abrupt change in the ecosystem exists.

Earth observation technologies and advanced computational methods such as artificial intelligence have boosted in the last years the marine research capacity (e.g. Salcedo-Sanz et al., 2020). Coupled with long time-series open access data these approaches appear as powerful tools to investigate changes in marine ecosystems in wider time frames. Satellite imagery has been used to monitor the Earth System in several components, for example, macroalgal blooms. Karki et al. Earth Observation data sets to map green algal cover and crossed it with the ecological status of several transitional ecosystems. This approach allowed to train artificial neural networks using the *in situ* historical biomass samples and satellite imagery, developing a model that allowed to efficiently estimate macroalgae bloom species biomass amounts leveraged the benefits of Earth Observation (EO) data sets, providing a tool for addressing the ecological status of transitional ecosystems. These artificial intelligence approaches can also be leveraged on large monitoring datasets to address not only the ecological status of a certain water body but also its chemical status. Feeding a machine learning limnological feature model Concepcion et al. developed an approach to evaluate the contamination and eutrophic degree of transitional systems that could efficiently and automatically classify the transitional water's chemical status within the legislated classification thresholds and produced numerical index values that can easily be communicated to the general public and managers alike. Satellite imagery has been extensively used to monitor ocean productivity namely in terms of chlorophyll *a* abundance. Phytoplankton comprises organisms with very different size classes which in turn leads to differential carbon fixation capacities. Understanding the relationship between EO-derived chlorophyll *a* data and phytoplankton size classes and carbon fixation is, therefore, a challenge. Brotas et al. fitted chlorophyll *a* data to carbon *in situ* measurements including different size class organisms for the first time, producing an accurate model that allows using Earth Observation (EO) products to monitor the ocean carbon cycle, including also for the first time typically disregarded size classes such as pico- and nanoplankton species. As abovementioned, in some cases, these approaches rely in part on long-term monitoring datasets. Open access databases such as the CoastNet's Environmental and Biological Monitoring System (EBMS) presented by Castellanos et al. provide continuous *in-situ* autonomously collected data being a fundamental tool to comply with environmental management and monitoring policies. França et al. present an example of a public long-term monitoring dataset for application for documenting fish assemblages in estuarine systems. The use of this dataset allows disentangling the relationship between fish communities and estuary abiotic conditions while encompassing the dynamics of these ecosystems using integrative and holistic approaches, highlighting the importance of the comparability of open-access datasets, due to the high degree of variability in terms of data acquisition methodologies. Another approach that has proved to provide key data for ecosystem monitoring is the reconstruction of environmental archives such as the ones trapped in marine sediments, allowing researchers to look back into the past conditions and organisms and providing key insights into the future of our oceans. This is the case of planktonic dinoflagellates resting cysts, sunk to the seabed where they can remain viable for a long time. García-Moreiras et al. (2021) took advantage of this marine archive and provided the first detailed modern distribution of dinoflagellate cysts in the Northwest Iberian Atlantic margin. The results from this team showed that there is a good correspondence between the upwelling hydrographic features and water column characteristics and the resting cysts assemblages, pointing out that these features can be used as supporting evidence for the interpretation of stratigraphic cyst records for the reconstruction of past marine ecosystems.

Marine ecosystems are changing and in the worst-case scenarios already present a high degree of degradation. Thus, Ecosystem Restoration arises as a hot topic in marine sciences (Waltham et al.). In some cases, certain habitats have been substituted by other ones, and thus the study of these last becomes of utmost importance. Marine forests are among the most threatened marine ecosystems on a global scale and in many temperate areas of the planet, these ecosystems have been replaced by "sea-urchins barrens." These substitutions often occur in ecosystems with a higher degree of anthropogenic pressure, whilst protected areas and pristine environments show marine forest ecosystems preserved in good status. Bernal-Ibáñez et al. propose that the degree of anthropogenic pressure as well as the status of the invasive populations are critical for marine environmental management and reinforce the urgent need for implementation of appropriate control mechanisms and restoration actions of marine forests. Additionally, to this bioinvasion pressure, macroalgae and seagrass ecosystems are also among the most threatened due to climate change due to heatwave events. Recent studies show that seagrass and macroalgae can become less susceptible to heat upon priming by previous heat stress events, due to the formation of a stress memory in these organisms. Jueterbock et al. suggest that these priming mechanisms can be used as a bioengineering tool to boost the resilience of both seagrass and macroalgae to secure their ecological and economic values in future oceans, having a high potential for future restoration efforts of marine forests and seagrass prairies. As macroalgal forests, also salt marshes are among the most degradation threatened ecosystems due to the expansion of invasive species. Species distribution modeling can act as a preventive approach to tackle this problem. Using the most recent climate change scenarios Borges et al. developed ecosystem models for one of the most abundant and successful salt marsh plants, *Spartina* spp. The projections point to a global trend for increasing *Spartina* species co-occurrence, with a general range expansion potentiated by increasing climate change scenario severity, suggesting that *Spartina* species can potentially benefit from climate change, with predicted poleward expansions in the Northern Hemisphere for most *Spartina* species, increasing the conflict and invasion potential in Northern Europe and East Asian shorelines, already under strong invasive pressure. Thus, becomes of utmost importance to develop environmentally friendly strategies for controlling this bioinvasion process. By evaluating the physiological drawbacks of certain Spartina invasive species, Cruz de Carvalho et al. developed an approach to control and reduce the populations of this invasive species in Mediterranean salt marshes. These authors explored the low tolerance of this species to waterlogging and used it as an ecoengineering solution that was revealed to lead to a significant degree of physiological stress in affected plants pointing towards a reduction in its ecophysiological fitness leading to the eventual invasive species drawback and removal.

The marine environment has been regarded as a potential source of bioactive compounds produced by different organisms and has been targeted in the last years for its potential for blue biotechnology (Rotter et al.). Harsh environments such as intertidal areas like salt marshes, impose serious pressures on the organisms that inhabit them, leading to the development of adaptations that can be of added value. For example, bacteria inhabiting salt marsh halophytes rhizospheres, have proven to have significant growth-promoting abilities, and are used as biopromotors in the agricultural production of terrestrial plants, in a "from sea to farm" perspective, enhancing very significantly the growth of urban orchards (Pajuelo et al.). Other organisms such as the sea urchins have developed very specific adaptations to their habitat, such as the ability to adhere to the rocky substrate. This ability is promoted by the existence of specific molecules (such as proteins and glycans), that are now being explored as reversible adhesives for human applications, as novel biomimetic adhesives with capabilities beyond the synthetic glues currently available to consumers (Gaspar et al.). These two examples highlight the potential of marine organisms known but also hidden within the ocean "dark box" to harness blue biotechnology from agriculture to medicine.

A direct consequence of scientific and technological advancement in the marine environment is the growth of the Blue Economy, linked to various economic activities, namely aquaculture, renewable energies, blue biotechnology, deep-sea mining, and nautical tourism (Jouffray et al., 2020). The growth of these sectors implies increased competition for maritime space, due to new uses, which is a significant and global challenge to maritime governance. Over the last decade, a profound conceptual change in marine policies and governance of the maritime space was observed (Guerreiro), which has also led to increased awareness of the need to improve Ocean literacy, not just at the government level but in all levels of society. Understanding the ocean's influence on people and their influence on the ocean is key to the sustainable use and conservation of this vital environment. Local engagement actions and participatory citizen-science initiatives are key approaches to improving our collective understanding of the marine environment, and to making informed and responsible decisions regarding the sustainable use and conservation of its resources and services. Harnessing the power of properly trained citizen scientists can contribute to high-quality data and monitoring initiatives in the coastal environment (Kasten et al.), albeit it is vital to develop an effective communication strategy to provide feedback on results and applicability to society, to keep the engagement of citizen scientists. It is also fundamentally important to educate the new generation, which can influence their peers and families in the present, but also ensure that in the future society will be better informed and able to make responsible decisions on the management of the marine environment. Local engagement activities with elementary school students demonstrated an overall improvement in students' knowledge of the issues of climate change and the impact of other anthropogenic pressures (Boaventura et al.; Aurélio et al.). Notably, they also identified the need to bridge the gap in students' backgrounds to improve communication and education results as an effective tool for Ocean literate citizens.

Marine sciences are undoubtedly a hot topic nowadays (e.g. Borja et al.; Borja et al.). More and more often marine research encompasses multi-disciplinary approaches including Science and Literacy taking advantage of the most recent technological Innovations. Climate change, bioinvasions, anthropogenic pressures, ecosystem monitoring, ocean literacy, and blue biotechnology are among the hot topics highlighted in the present work collection. Merging these key research areas with state-of-the-art novel approaches (satellite imagery, artificial intelligence, long-term time-series, molecular techniques) has provided to be a perfect combination to advance marine science research. Public engagement has also arisen as a key factor for marine ecosystem conservation and monitoring. The engagement of the public in citizen science programs has raised the awareness of populations to the need to protect the environment and provide conservation measures for the future oceans bringing citizens, science, and technology close together within a common effort to protect our oceans.

AUTHOR CONTRIBUTIONS

BD and VF wrote the first draft of the manuscript. CT and RM revised the first draft of the manuscript. All authors contributed to manuscript revision, read, and approved the submitted version.

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