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Pathways to link biodiversity and ecosystem functioning: from monitoring to complex ecological interactions studies

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Abstract: Environmental changes have been rapidly increasing in the last decades, causing unprecedented shifts in biodiversity. The impacts of biodiversity changes on ecosystem processes depend on the traits of affected species and their functional redundancy at the community level. The generated data on biodiversity-functioning in marine environments are still fragmentary and predictions on how species, communities and ecosystems will respond to the ongoing global changes are still uncertain. This selection of manuscripts presents the efforts of researchers around the world towards a better understanding on the mechanisms driving biodiversity and functioning patterns in marine ecosystems. The issue is composed of studies about first records of diversity and single species patterns in overlooked marine communities, effects of pollution in shaping species composition, foundation species and the impact of their loss on local communities, and the relevance of ecological interactions and species' traits in structuring marine food webs. We conclude that more field and experimental studies combined to modelling are needed for understanding mechanisms that currently determine the structure and functioning of ecosystems and for improving predictions under global change scenarios.

Introduction

Throughout geological history, environmental changes due to natural Earth cycles shaped ecosystems (Hoegh-Guldberg and Bruno 2010). However, in the last decades, the rate of these changes has increased dramatically due to human-induced environmental impacts representing major threat for life on Earth. Modification and intensification of land use that alter biogeochemical cycles, the high emissions of carbon dioxide that enhance climate change and the transportation of species around the globe are some of the pressures that have been causing shifts in biodiversity (Chapin et al. 2000). Alterations of biodiversity patterns have been leading to irreversible ecological shifts (Hooper et al. 2012, Tilman et al. 2012). Most of the information on the effects of the loss of biodiversity on ecosystem processes has been generated for terrestrial environments, being still fragmentary in the sea (Worm et al. 2006). In this context, future predictions on how the functioning of marine ecosystems will respond to the loss of species remain uncertain.

Mechanisms that determine biodiversity

In 1959, Hutchinson provided a major contribution to ecology by publishing one of the first attempts to summarize the main mechanisms that modulate biodiversity. Even though ecological research has been developed towards a better understanding of how species diversity responds to environmental changes, many questions remain unsolved.

Hutchinson (1959) highlighted the role of environmental conditions in shaping biodiversity. Disturbances caused by natural or human imposed fluctuations (e.g., seasonal temperature and nutrient inputs due to agricultural activity) are responsible for selecting species based on their range of tolerance in terms of physiology, morphology and behavior (Price et al. 2003). Although there is evidence that species may deal with future changes in temperature regime by shifting the timing of life cycle events (Bradshaw and Holzapfel 2006), it is still difficult to predict how species will cope with multiple disturbances under global change (Williams et al. 2008).

The niche model, i.e., the multi-dimensional representation of the biotic and abiotic requirements of a species (Hutchinson 1957), provides a theoretical framework for the study of future distribution (and diversity) patterns given the expected changes in resources and conditions. Further extensions of Hutchinson's model went beyond the simple species' occurrence approach and incorporated demography (i.e., population growth, Maguire 1973) and species requirements (Pironon et al. 2018), improving the determination of niche dimension. These theoretical developments contributed to understand how the environment affects species' populations and to predict how niche boundaries are going to change under future scenarios.

Interspecific interactions, and changes in their type and strength, define the nature of ecosystem processes (Hooper et al. 2005). According to Paine (1966), "*local species diversity is related to the efficiency with which predators prevent the monopolization of the major environmental requisites by one species*". This statement is related to another concept discussed by Hutchinson (1959): the food web. Food web analyses describe the energy flows determined by "who eats whom" (Ulanowicz 2004), which embeds food chains that depict the energy transfer efficiency from one trophic level to another. Paine (1966) suggests that predation is pivotal for maintenance of biodiversity as it avoids that one food chain prevails over the others. The identity and diversity of the predators are responsible for trophic cascade interactions (Bruno and O'Connor 2005). In addition, changes in environmental conditions may alter non-linearly the interaction strength between species (Hoegh-Guldberg and Bruno 2010). Thus, the complexity of how food webs will react to global change increases the uncertainties in the predictions for ecosystem functioning. Besides feeding, other classes of ecological interactions (e.g., competition and symbiosis) are responsible for determining the structure and functioning of communities (Hooper et al. 2005). Among others, an important concept for explaining ecological structure in many regions is foundation species. Foundation species are defined as species that present disproportional influence on the structure of communities, since they provide habitat to many other species (Dayton 1972, Bruno et al. 2003).

Importance of biodiversity for the functioning of ecosystems

In the last years, research has been focusing not only on mechanisms regulating biodiversity but also on the mechanisms regulated by biodiversity. The contribution of biodiversity to ecosystem functioning in terms of flux and cycling of energy is determined by traits of the species that occur in the ecosystem. A trait is any feature measurable at species level (Violle et al. 2007) that unravels how species capture and use different resources, and interact with the environment. Trait-based biodiversity metrics provide information about functional biodiversity (i.e., sets of species that exhibit certain functional traits), assisting studies on the consequences of species reshuffling (loss or invasions) on ecosystem functioning (Reiss et al. 2009). The insurance hypothesis suggests that high biodiversity contributes to the maintenance of functioning in ecosystems (Yachi and Loreau 1999). In this framework, the higher the biodiversity in an ecosystem, the higher the chance of having species with overlapping traits (i.e., species that belong to the same functional group) and different ranges of tolerance to biotic and abiotic factors. The loss of functional groups, beyond species, compromises ecological processes and the capacity of ecosystems to continue providing services to humanity (Díaz et al. 2006). Thus, identifying traits that determine the susceptibility of species to environmental changes, and how they directly or indirectly (i.e., through the correlation with other traits) influence ecosystem processes, is essential to predict the consequences of biodiversity loss on ecosystem services (Cardinale et al. 2012).

This selection of manuscripts intends to bring together efforts made around the world towards a better understanding of biodiversity patterns and effects of disturbances that lead to changes in ecosystem functioning. Therefore we would like to invite the readers to navigate through the ecological assessment path.

Contributions to the present selection of manuscripts

The information on species inventories and its update through time provide the required baseline for the evaluation of the effects of environmental changes. To date, blind spots of biodiversity assessments, i.e., regions lacking proper monitoring programs, exist. Thus, surveys describing community compositions of those understudied areas are still of extreme importance and can help to gauge current and future developments in biodiversity research. Golinia et al. (2019) presented the first record of biofouling communities in the Caspian Sea (Iran). In this region, the fouling pressure has been disregarded over many years, even though it represents a potential economic threat, which is predicted to increase due to shipping traffic in combination with global warming. The authors described community and single species dynamics and how they are modulated by seasonality (the main factors were temperature and chlorophyll *a*) and biological factors (the community was dominated by barnacles and bryozoans).

Besides climate change, marine pollution (e.g., caused by heavy metals, hydrocarbons, nutrients generated in agriculture) represents a major anthropogenic impact that concerns industrialized countries. For studying the impacts of global change on biodiversity, it is important to understand the interactions between ecological communities and the condition of the environment they are exposed to. Abessa et al. (2019) detected that beyond the effect of natural environmental changes, the impacts of wastewater discharge in the Santos Estuarine System (Brazil) is shaping ecological communities. The results demonstrate that even though hydrological features could select the species inhabiting the area, degraded sites lower the complexity of the community.

The loss of foundation species may increase the vulnerability of communities by triggering a sequence of extinctions (Berg et al. 2015). Cadier and Frouws (2019) demonstrated that the removal of seagrass in Gazi Bay (Kenya) has negative impacts on associated benthic species that depended on this primary producer as habitat. The seagrass modifies the characteristics of the ecosystem by creating 3D structures above and below ground, increasing oxygenation of the sediment, increasing the trap of sediment and consequently carbon sequestration. The removal of aboveground seagrass reshuffled the structure of the biological community, jeopardizing ecosystem functioning since ecological traits connected to the species were shifted.

Network analysis is able to bring together ecological interactions through energy flow. This integrated study is able to reveal how the disturbances can affect directly or indirectly species composition in an ecosystem. Going beyond the use of single species for the analysis, Olmo Gilabert et al. (2019) constructed the food web of the Gulf of California (Mexico) and calculated centrality indices using functional traits. This approach was used for focusing on general patterns that control the processes responsible for shaping the community. They found that body size and mobility were the main traits in explaining intensity and direction of energy flows in the food web. Indeed, body size plays an important role in predicting how the community structure can respond to extinctions. The deletion of large body-sized organisms may have detrimental effects comparable to removal of primary producers on a food web (Berg et al. 2015). The study of traits in food webs is able to provide important information about how ecosystem functioning can be impacted due to global changes.

Conclusions

The study of global change effects on biodiversity has received increased attention in the past decades. Nevertheless, the consequences of human-mediated alterations on marine species and ecosystems are still poorly understood. Information on the current status of biodiversity and its responses to environmental changes will be the base to improve our knowledge on the mechanisms that control biodiversity. Thus, in order to improve environmental management strategies, researchers will have to integrate data across scales and levels of biological organization to predict future scenarios more reliably.

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