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Editorial: Drivers and consequences of ocean deoxygenation in tropical ecosystems

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Editorial on the Research Topic
Drivers and consequences of ocean deoxygenation in tropical ecosystems

Project description

Coastal habitats are under increasing anthropogenic pressures that jeopardize the survival and persistence of ecologically important marine life. One such stressor, increasingly recognized as a significant threat to marine coastal habitats, is deoxygenation (Breitburg et al., 2018; IPCC, 2023). The United Nations Decade of Ocean Science for Sustainable Development has identified deoxygenation as a top international priority for ocean research, with efforts being led by the Global Ocean Oxygen Network (GO$_2$NE) and affiliated programs (Global Ocean Oxygen Decade program). Despite the international and global significance of the deoxygenation threat, much of the research on impacts of decreasing oxygen concentrations in the ocean has focused on temperate or estuarine habitats, and the deep sea or oxygen minimum zones (Altieri et al., 2017; Breitburg et al., 2018). However, emerging evidence indicates that the threat of deoxygenation to tropical habitats is escalating and has dire consequences for the persistence of some of our most vulnerable ecosystems: coral reefs, seagrass habitats, and mangroves (Altieri et al., 2019; Hughes et al., 2020). Studies from colder water habitats have illustrated how persistent and acute deoxygenation can decrease marine biodiversity, alter ecosystem dynamics, and potentially lead to ecosystem collapse (Levin et al., 2009; Diaz and Rosenberg, 2011). Although studies from these habitats provide a foundation for understanding the role of oxygen in the ocean, results from temperate systems may not directly translate to analogous deoxygenation responses in tropical ecosystems (Altieri et al., 2021). Understanding the specific drivers and consequences of ocean deoxygenation in tropical ecosystems is crucial for predicting its consequences and is the first step in implementing effective management strategies (Hughes et al., 2020; Sutherland et al., 2021).

Tropical ecosystems may be more susceptible to deoxygenation than colder water habitats because of the warmer climate regime (Deutsch et al., 2024). Climate change-induced warming of surface waters further reduces the solubility of oxygen, while enhanced stratification limits the exchange of oxygen-rich surface waters with deeper layers (Breitburg et al., 2018). Additionally, nutrient runoff from land-based sources fuels algal blooms and oxygen consuming microbial processes, exacerbating oxygen depletion in coastal areas (Breitburg et al., 2018). Understanding and exploring the consequences of deoxygenation for tropical marine organisms and ecosystems is, therefore, essential to predicting and preparing for the growing threat of deoxygenation in the tropics.

One major consequence of deoxygenation for marine life is the impairment of biological performance (e.g., hypoxia), and possible mortality, with decreasing oxygen concentrations. Organismal hypoxia response refers to a physiological state where the available oxygen is insufficient to maintain required homeostasis (Hughes et al., 2020). Notably, hypoxia onset will be specific to the tolerance of an individual to decreasing oxygen concentrations and can vary widely across species (Camp et al., 2017; Johnson et al., 2021). This variability in hypoxia responses confounds our ability to extrapolate deoxygenation impacts from cold water habitats to tropical ecosystems. The complexities of organismal and ecosystem responses to deoxygenation in the tropics must therefore be explicitly evaluated through a combination of *in situ* and laboratory approaches.

The Research Topic, "*Drivers and consequences of ocean deoxygenation in tropical ecosystems*" compiles five studies that delve into this pressing issue. Together they evaluate impacts of deoxygenation and biological hypoxia responses, seeking to unravel the complex interplay between oxygen dynamics and biological responses on coral reefs. This body of work is comprised of laboratory-based studies that test the biological response of tropical marine taxa, from corals to macroalgae, to varying oxygen concentrations in seawater, and one field study of *in situ* oxygen dynamics and the occurrence of deoxygenation on coral reefs.

Four of the studies in this Research Topic were conducted in the laboratory, where focal taxa were exposed to varying concentrations of dissolved oxygen in seawater over different durations. Pontes et al. and Swaminathan et al. exposed Caribbean reef-building corals to a range of oxygen levels, from severe deoxygenation to normoxia, for acute (~3 hours) or intermediate (4 days) periods in the laboratory, respectively. Mallon et al. used a similar approach, but exposed larvae of three Caribbean coral species to chronic deoxygenation (1.5 months) and evaluated impacts on coral settlement and survivorship. These complementary studies documented varying levels of hypoxia response and tolerances that were species-specific, and potentially influenced by history of environmental stress exposure (Swaminathan et al.). Alamoudi et al. explored similar questions, but with a focus on response of Red Sea macroalgae to nighttime hypoxia at peak summer temperature. Acute exposure to deoxygenation at night (12 hours) did not cause mortality in the three macroalgal species tested, but did impair photochemical efficiency, respiration, and cellular activity. Collectively, these studies highlight the complexities of disentangling deoxygenation impacts on coral reef taxa and the importance of conducting targeted field and laboratory studies. Each study contributes a piece of information to the puzzle of differential responses to deoxygenation.

The field study, "*Small-scale oxygen distribution patterns in a coral reef*" investigated fine-scale oxygen dynamics on a coral reef ecosystem, to understand how oxygen concentrations vary across different microhabitats. Candy et al. revealed significant variability in oxygen concentrations at small spatial scales within a coral reef. Oxygen levels varied between different microhabitats, such as within coral branches, among coral colonies, and in the surrounding seawater. These oxygen distribution patterns were influenced by biological activity, including photosynthesis by symbiotic algae living within coral tissues and respiration by coral and other reef organisms. Areas with higher densities of coral colonies tended to have higher oxygen concentrations due to photosynthetic activity. Overall, Candy et al. illustrated the complexity of oxygen dynamics within coral reef ecosystems and the importance of considering small-scale variability as we seek to understand the ecological processes that govern these environments.

This Research Topic collates a series of coral reef studies exploring organismal responses to deoxygenation in corals and macroalgae, and a study of oxygen dynamics *in situ*. The patterns that emerge from this work are that oxygen variability in nature is, indeed, complex, which may contribute to the variability in sensitivities and tolerances to deoxygenation reported in the laboratory-based studies. By combining insights from studies like these, we can gain insight to the drivers and consequences of oxygen loss in tropical marine environments and develop science-based solutions for sustainable ocean management. Advancing our understanding of ocean deoxygenation and its impacts allows us to chart a course towards a more sustainable future for our oceans and the communities that depend on them.

Author contributions

MJ: Conceptualization, Writing – original draft, Writing – review & editing. SK: Writing – review & editing. NL: Writing – review & editing. ASt: Writing – review & editing. ASh: Writing – review & editing. EC: Writing – review & editing.

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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Publisher's note

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