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Sachithanandam Veeraragavan,
National Centre for Sustainable Coastal Management, India
Ganesh Thiruchitrambalam,
Port Blair Campus, India

*CORRESPONDENCE
Khaled Mohammed-Geba
khaledmohammed@science.menofia.edu.eg;
khaled-mohamed.geba@fulbrightmail.org

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Editorial: Current genetic diversity in the Red Sea and related aquatic environments

Khaled Mohammed-Geba[1*], Asmaa Galal-Khallaf[1], Waleed Hamza[2], Ahmad Al-Harby[3], Eric J. Schott[4] and Gonzalo Martínez-Rodríguez[5]

[1]Molecular Biology Division, Faculty of Science, Menoufia University, Shebin El-Kom, Egypt, [2]Biology Department, College of Science, United Arab Emirates University, Al-Ain, Egypt, [3]Sustainability and Environment Sector, King Abdulaziz City for Science and Technology, Riyadh, Saudi Arabia, [4]Institute of Marine and Environmental Technology, Center for Environmental Science, University of Maryland, College Park, Baltimore, MD, United States, [5]Institute of Marine Sciences of Andalusia (ICMAN), Department of Marine Biology and Aquaculture, Spanish National Research Council (CSIC), Puerto Real, Spain

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Editorial on the Research Topic
Current genetic diversity in the Red Sea and related aquatic environments

The Indian Ocean occupies a top position in the world's aquatic biodiversity. It contains about 30% of the global coral reef cover, 40,000 km^2 of mangrove forests, large estuaries, and very diverse and large marine ecosystems that are considered hotspots for speciation and genetic diversity (Wafar et al., 2011; Saraswat et al., 2022). Some of its extensions, mainly the Red Sea and the Arabian Gulf, share many organisms and ecosystems with it. Although the Arabian Gulf was flooded by Indian Ocean waters and organisms relatively recently, i.e. 14-8 thousand years ago (KYA), the Red Sea connection to Indian Ocean waters and biotas dates back to about 5 million YA (DiBattista et al., 2016; Smith et al., 2022; Griffiths et al., 2024). Over millennia, complex geological and oceanographic events in the Red Sea have resulted in extraordinarily high levels of organismal diversity and endemism. Speciation of Red Sea creatures and their genetic differentiation from their Indian Ocean conspecifics probably occurred due to water levels drop in the last glacial maxima, which closed its connection to the Indian Ocean and created a harsh environment with extreme salinity (DiBattista et al., 2016). This extirpated some marine taxa and accelerated the speciation of many others (DiBattista et al., 2016; Griffiths et al., 2024).

Currently, the Red Sea encompasses very diverse ecosystems, and it harbors 14.7% of world endemic fishes (Bogorodsky and Randall, 2019), 16.5% of ascidians, 8.1% of echinoderms, 12.6% of polychaetes, and 5.8% of scleractinian corals (DiBattista et al., 2016). These are located in very diverse environments, such as pelagic zones, offshore islands and atolls, fringing reefs, deep-sea habitats, salt pans and sabkhas, seagrass beds, mangroves, coral reefs and many others (El-Regal and Satheesh, 2023). Some of the remarkable biodiversity hotspots there are Ras Mohammed in Egypt, Farasan archipelago in Saudi Arabia, Dahlalk archipelago in Eritrea, and Sungnab and the Dungnab in Sudan (Bertzky and Abedalhaleem, 2016). These areas provide habitats for versatile marine organisms, such as invertebrates, sharks and other fishes, reptiles (e.g. marine turtles), many cetaceans (e.g. Dugongs), and even several migratory birds (Bertzky and Abedalhaleem, 2016; Moustafa et al., 2023). Most of these taxa are genetically tolerant to highly variable environmental conditions, including high salinity, high temperature, and the surrounding arid climate.

For millennia, fishing kept affecting the cultures and interactions among human populations along the Red Sea. This has been supported by the diverse and rich finfish and shellfish wealth there. In the modern world, the Red Sea represents a major contributor to fisheries-based economies in the bordering countries. It accounts for 56% of the total fisheries production in Sudan, slightly less than 50% for Saudi Arabia, and about 38% for Egypt, with most harvest from artisanal fisheries (FAO, 2020; Shellem et al., 2021; Mehanna, 2022).

In recent decades, the Red Sea marine bioactive compounds attracted serious interest. The world pharmaceutical products market at least 48 marine-derived pharmacological compounds in different stages of clinical trials (Rateb and Abdelmohsen, 2021). Nearly 677 natural products with various biological activities were recorded from Red Sea organisms, including antiepileptic and anticonvulsant activities from sponges, antiviral and antibacterial activities from sea hares and seagrasses, and anticancer activities for compounds derived from most of these taxa (El-Hossary et al., 2020). Metagenomic studies revealed that Red Sea organisms harbor a vast diversity of microbiomes, with unique biosynthetic gene clusters (BCGs) and pathways, compared to other marine environments (El-Hossary et al., 2020). These unique BCGs are responsible for production of many biologically active substances that can benefit both human and marine organismal health (El Samak et al., 2023; Raimundo et al., 2024).

The marvelous nutritional, cultural and pharmaceutical potential of Red Sea taxa are facing critical challenges from regional anthropogenic activities and global climate change. The late 20th century witnessed major advancements in economic activities based on the Red Sea (Carvalho et al., 2019). Key drivers of these activities included improvements in seawater desalination systems, energy availability (Fine et al., 2019), maritime and land-based transport (Fine et al., 2019; Hawash et al., 2021), and touristic construction (Cziesielski et al., 2021). Accordingly, pollution due to anthropogenic activities increased severalfold (Hilmi et al., 2012). Reef destruction occurs through the building of new resorts and during intense snorkeling and diving activities Cziesielski et al., 2021). There is an elevated incidence of antibiotic-resistant microbes and parasitic infections in native organisms (Al-Hasawi, 2019; Ullah et al., 2019), and increased accumulation of heavy metals in sediments and marine organisms (Tamele and Vázquez Loureiro, 2020). An acceleration of biological invasions is also a result of more human activity (Mohammed-Geba et al., 2020; Fernandez et al.; Galal-Khallaf et al.).

Finally, the Red Sea holds a significant geopolitical influence in our modern world. It serves as a fundamental maritime avenue for the passage of 8-12% of the global maritime-transported trade between its Northern and Southern supreme international passages, i.e. Suez Canal and Bab El-Mandeb Strait, respectively (Lee and Wong, 2021; Gresh, 2023). As a crossroad for global trade with a value of about 1 trillion USD, it remains highly sensitive to political instabilities, such as the wars in Yemen and Sudan. In addition to the direct effects of these conflicts on geoeconomics and security (Chorev, 2023), they also have led to profound, marine life-threatening potential impacts on the unique ecosystems of the Red Sea. For instance, the oil tanker Safir, was detained in the port of Al-Hudaydah. This tanker had the potential to leak an amount of oil several times greater than that of the Exxon Valdez tanker in Alaska in the late 1980s. This situation encouraged the UN to invest significant resources and efforts in its safe discharge (UN, 2023). Despite the success of the completed stages so far in that mission, still, the conflicts in different parts of the Red Sea remain a major concern for many countries with economic interests in the region.

Current status of the Red Sea genetic diversity studies, gaps and future directions

Many life aspects in the Red Sea are subjects of intensive molecular research, including genetic diversity, population structures, DNA barcoding of different economically/environmentally important organisms, BCGs, antibiotic resistome, and other disciplines. However, the increasing anthropogenic and changing global climate impacts on the Red Sea provide strong justification for the expansion and globalization of these research efforts in the face of those threats. The Red Sea was one of the impacted regions from the 4th global reef bleaching event that hit many marine regions in summer 2023 (NOAA, 2024). Even its Northeastern part, i.e. the Gulf of Aqaba that was heretofore one of the few global coral refugia against the previous bleaching events, was in 2023 one of the affected regions (Osman et al., 2018). Although many research groups are working to study and protect sensitive environments and diversity hotspots in the Red Sea, still more cooperative work is needed to facilitate the interdisciplinary exchange of knowledge to develop solutions for these problems.

In conclusion, the Red Sea is a hub for biodiversity, which is of primary interest to conservationists, and for sustainable economic activities, being touristic, pharmaceutical, or others. Some aspects of these disciplines have been covered by this *Frontiers in Marine Science research topic*, yet the Red Sea and related environments still hold a vast store of potential discoveries about the identity, characteristics, and interactions of its biodiversity. Establishing a global network of Red Sea expert groups is strongly recommended to support these efforts. Also, a database for the exchange and collection of data, findings, and results in general of Red Sea-related genetic research can advance the power of this suggested network

This can provide the decision-makers in the region with more effective, wide-view-based data for assuring the best conservation strategies and sustainable use of Red Sea resources.

Author contributions

KM-G: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AG-K: Conceptualization, Data curation, Formal analysis, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. WH: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. AA-H: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. ES: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, Writing – review & editing. GM-R: Conceptualization, Data curation, Formal analysis, Funding acquisition, Investigation, Methodology, Project administration, Resources, Software, Supervision, Validation, Visualization, Writing – original draft, 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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