Coral reef conservation gaps under a socioeconomic perspective

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Abstract

Despite their ecological importance and the essential ecosystem services they offer, coral reefs are under unprecedented threat from climate change and human pressures. The socioeconomic significance of these ecosystems should be analyzed with particular attention

paid to their roles in fisheries, tourism, cultural heritage, and coastal preservation. Cases studies, like the Red Sea's climate-resilient coral reefs, highlight the necessity of specialized conservation tactics. Aspects such as gender equity, interdisciplinary partnerships, and community-based restoration projects might improve conservation results. Furthermore, the importance of deep-sea coral reefs—which are frequently disregarded—must be considered. Emerging frameworks, such as the IPBES (The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services) "Nature Futures Framework," may offer integrated approaches to align biodiversity protection with socioeconomic benefits.

Importantly, it was underlined that identifying and evaluating ecosystem services are essential to increasing public awareness, guiding policy choices, and luring private-sector investment to close the funding gaps in coral reef conservation. By combining different viewpoints, the paper emphasizes how urgently inclusive, scalable, and sustainable conservation initiatives are needed to protect these important ecosystems and the populations that rely on them.

Keywords: ECRS, Coral reefs, Ecosystem services, Climate change, Inclusive conservation, Funding gap Despite covering only 1% of the seabed, coral reefs support more than one-fourth of all marine life (Hilmi et al.

2019). More than supporting the marine environment, coral reefs deliver primordial ecosystem services to human

civilization; coastal protection, fisheries, tourism, biotechnology supply, cultural heritage, research, and educational opportunities are just a few of these vital contributions to our society (Sebastian et al. 2024). Productive and healthy ecosystems generate a flow of goods and services, intended for consumption or essential to human well-being or survival (Turner 2015). Therefore, the benefits of ecosystem services constitute an "export" from the ecosystem sector to the human economic and social sectors (Boyd & Banzhaf 2005; Turner 2015). At least 500 million individuals rely on coral reefs for food, coastal protection, and livelihoods (Wilkinson

2004). In addition, more than 275 million people live in close proximity to coral reefs—defined as within 30 km of reefs and less than 10 km from the coast—highlighting their significance for coastal communities (Burke et al. 2011). It is estimated that they contribute approximately $30 billion annually in goods and services, including fisheries, tourism, and coastal protection (Hoegh-Guldberg 2004; Moberg and Folke 1999). However, over the last four decades, anthropogenic pressures such as coastal development, pollution, overfishing, and unsustainable tourism practices combined with the increasing effects of climate change have put coral reefs in critical danger worldwide (Hoegh-Guldberg et al. 2018; Pratchett et al. 2014; Tamburini et al. 2022; Yunitawati and Clifton 2021). Alarmingly, 44% of reef-building coral

species are now at risk of extinction, a stark increase from 2008, when only one-third were classified as threatened (IUCN 2024). As a result, the need to conserve coral reefs is becoming increasingly framed in a socioeconomic context as their degradation accelerates and the ecosystem services, they deliver become increasingly threatened. Specifically, assessing the many ecosystem services coral reefs provide is crucial for supplying policymakers with data, supporting conservation efforts, and effective management practices (Pascal et al. 2016), consequently ensuring the well-being of the people who rely on them.

An important case study is the Red Sea coral reefs, which are regarded as some of the most climate change resilient due to the Red Sea paleogeographic history. Particularly in the northern region, viewed as a climate change sanctuary, they flourish remarkably and withstand significant sea surface temperature anomalies while most coral reefs worldwide undergo severe bleaching events (Fine et al. 2019; Kleinhaus et al. 2020). These thermally tolerant holobionts highlight the crucial importance of the Red Sea not only as a biodiversity hot spot and a climate refuge but also as a natural laboratory for understanding and protecting coral resilience on a global scale. However, while Red Sea corals are naturally adapted to higher temperatures and are not expected to disappear this century, local anthropogenic pressures are altering their bleaching sensitivity (Fine et al. 2019; Kleinhaus et al. 2020). Overfishing, coastal development, and pollution are increasingly pushing these reefs closer to their ecological limits (Fine et al. 2019; Hughes et al. 2007; Savary et al. 2021). Given current climate projections and unsustainable practices, many of the world's coral reefs are at risk of near-total loss in the coming decades. This makes the northernmost Red Sea coral reefs one of the potential last strongholds, reinforcing the urgency of their protection. Safeguarding these reefs is not only critical for the 28 million people who depend on them for their livelihoods and well-being but also for the future of coral reef conservation globally. Understanding their resilience and safeguarding these holobionts can provide essential insights for developing restoration strategies, including assisted evolution and reef rehabilitation, to counteract widespread coral decline.

Equally important but frequently disregarded are deep-sea coral reefs, another unusual reef assemblage made up of cold-water corals, bivalves, and sponges. These ecosystems provide critical services including fisheries, carbon storage, and biodiversity support. They are among the most widespread and fragile ecosystems of the marine compartment. Both the marine biodiversity they host and the ecosystem services they supply are seriously threatened by unsustainable practices like deep-sea mining or oil and gas exploration and exploitation and (Ramirez- Llodra et al., 2011). A study on the economic assessments of restoration of these deep- sea reefs has suggested favorable returns of the first monetary investment, especially through carbon sequestration services, given the rising social cost of carbon due to climate change (Ali 2023). This implies that interdisciplinary collaboration and technology developments may provide further incentives for private-sector involvement. The chances of upscaling restoration activities together with the removal of anthropogenic threats obtained

through appropriate conservation measures could be economically viable in the future, leading to a rise in business interest.

Community engagement is also essential to long-term conservation efforts. Community-based restoration initiatives have shown that when the whole local community is actively involved in conservation efforts, results improve significantly, especially in island states like Indonesia (Sebastian et al. 2024). These initiatives ensure that restoration efforts are both economical and sustainable by fostering a sense of responsibility and ownership over coral reef resources (McLeod et al. 2022). These projects are also more successful, as the local community and stakeholders can use restoration techniques more effectively because of better practical knowledge. Furthermore, fostering gender equity within these programs can enrich coral conservation strategies (Alexander et al. 2022, Al-Gergawi et al. 2024). Women, deeply connected to the Ethics of Care, can provide unique perspectives and approaches that prioritize empathy and relational interdependence in managing natural resources (Whyte and Cuomo 2016). Empowering women in coral reef restoration not only diversifies the knowledge base but also introduces an ethical framework that strengthens the social dimension of conservation

efforts (Whyte and Cuomo 2016).

An emerging framework designed to envision positive futures for coral reefs and the communities that depend on them is the “Nature Future Framework,” developed by IPBES (The Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services). This framework explores potential desirable futures through three axes: prioritizing biodiversity protection (Nature for Nature), leveraging biodiversity for human benefit (Nature for Society), and emphasizing the integration of biocultural systems (Nature as Culture) (Martin et al. 2024). Conserving biodiversity for the sake of biodiversity had little success in the past, but trying to attract public attention to nature well-being and, in consequence, its conversion into human well-being is what researchers should do now, broadening the number of engaged stakeholders and pushing for biodiversity conservation. NFF has been applied in many ways, but doing it on marine ecosystems remains a big challenge (Pereira et al. 2023). Projects that foresee the conservation or restoration of coral reefs are probably the easiest on which start to apply NFF principles in the sea.

Key ecosystem services provided by coral reefs which grab the attention of conservationists are mainly the provision of fishing resources and tourism, which, even if they are not easy to be translated into monetary values, are the ones which benefits are the easiest to be converted into socioeconomic gains. As an example, recent studies of tropical reef fish

communities have demonstrated that fish communities can simultaneously provide high levels of different contributions whether benefiting nature, people, or both without necessarily facing major trade-offs. High levels of contributions to both nature and human well-being have been identified in tropical reefs across all oceans, indicating that desirable futures for coral reefs and people are achievable globally. Conserving coral reefs can, in some cases, yield returns through tourism, leading to financial gains and job creation.

Interdisciplinary collaboration in coral reef science and conservation requires moving beyond traditional siloed approaches to create integrated frameworks where natural sciences, social sciences, economics, and local knowledge systems actively inform each other (Alexander et al. 2022). While research and practice often separate ecological monitoring from socioeconomic assessments due to capacity and funding constraints, effective conservation demands simultaneous consideration of both dimensions for a more accurate assessment of coral reefs and their direct and indirect impacts on communities. The success of community-based restoration in Indonesia demonstrates how such integration strengthens outcomes—where traditional ecological knowledge enhanced scientific monitoring, and social science insights improved community engagement (Sebastian et al. 2024). Moving forward, all reef conservation initiatives should (1) establish cross-disciplinary research teams from project inception, (2) create standardized platforms for data sharing across disciplines, (3) implement regular forums between scientists, local communities, and policymakers, and (4) develop clear mechanisms for translating research findings into management decisions that benefit both ecosystems and communities (Al- Gergawi et al. 2024). This shift from compartmentalized to integrated thinking is essential for addressing the complex challenges facing coral reefs in the Anthropocene.

Ultimately, the identification and evaluation of the ecosystem services sustained by coral reefs can be key in increasing public awareness, providing evidence to decision-makers, and attracting the private sector to bridge the financial gap of coral reef conservation (Costanza et al. 2014; Spalding et al. 2017). While significant progress has been made in quantifying the economic value of reef-associated industries, such as fisheries and tourism in the Great Barrier Reef and Coral Triangle (Stoeckl et al.2011; Spalding et al. 2017), these insights have not always translated into proportional investment (Hoegh-Guldberg et al. 2019, Kurukulasuriya 2025). A key challenge lies in demonstrating how private-sector involvement can yield tangible benefits, given that many reef conservation projects primarily generate broad ecological rather than direct economic returns (Pascal et al. 2017). To bridge this gap, innovative financing instruments and mechanisms, such as blended finance, blue bonds, and coral reef insurance, must be further developed and incentivized (Pascal et al. 2017, Reguero et al. 2020). Achieving a future in which coral reefs continue to thrive as biodiversity hot spots while supporting human societies will require a holistic approach that integrates economic, social, and cultural dimensions of conservation (Moberg & Folke 1999).

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Declarations

Conflict of interest

The authors declare that they have no competing financial or non-financial interests directly or indirectly related to the work submitted for publication.

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