Title: Coral Reefs Span Borders, So Must Solutions: A Blueprint for International Cooperation for Coral Reef Conservation in Complex Political Environments

Authors: Bohorquez, John[1]; Fine, Maoz[2]; Grieco, Dana I.[3]; Gill, David A.[3]; Al-Swalimih, Ali[4]; Padilla-Gamiño, Jacqueline[5;] Bolden, Isaiah W[6]; Hein, Margaux[7]; Backstrom, Callum[5]; McField, Melanie[8]; Martinez, Raphael[9]; Midberry, Benjamin[10]; Al-Guthmy, Fahd[11]; Pikitch, Ellen[1]; Benejam, Natalia[1]; Azulay, Chen[2]; Ronen, Britt[2]**;** Levy, Oren[12]; McElroy, Anne[1]; Kleinhaus, Karine[1].

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[1] Stony Brook University, Stony Brook, NY, USA
[2] Hebrew University of Jerusalem, Interuniversity Institute for Marine Science in Eilat, Eilat, Israel
[3] Duke Marine Laboratory, Nicholas School of the Environment, Duke University, Beaufort, NC USA
[4] Marine Science Station (MSS), The University of Jordan, 77110 Aqaba, Jordan
[5] University of Washington, School of Aquatic and Fishery Sciences, Seattle, WA, USA
[6] Georgia Tech, School of Earth and Atmospheric Sciences, GA, USA
[7] Marine Ecosystem Restoration Research and Consulting, USA
[8] Healthy Reefs for Healthy People, USA
[9] Healthy Reefs for Healthy People, Belize
[10] United Nations Capital Development Fund, New York, NY USA
[11] Wildlife Conservation Society - Kenya, Mombasa, Kenya
[12] Bar-Ilan University, Israel

Abstract: Coral reefs face escalating threats from climate change, yet reducing greenhouse gas emissions alone will not ensure their survival. Local and regional conservation efforts are urgently needed to address immediate, human-induced stressors and build resilience. Although conservation often begins locally, the interconnected nature of reef systems that span borders demands transboundary management, international coordination, and robust governance frameworks. In 2024, a multidisciplinary group of coral reef scientists and conservationists convened at Stony Brook University to develop strategies for strengthening reef resilience globally and regionally, with an emphasis on the Red Sea and Caribbean reefs. Using participatory systems mapping, the group produced a framework identifying six priority areas for international and transboundary action: (i) conservation finance; (ii) knowledge management; (iii) regional political coordination; (iv) area-based management; (v) ecosystem restoration; and (vi) strengthening stakeholder capacity and engagement. The findings demonstrate commonalities as well as regional nuances for coral conservation, and the approach can be replicated elsewhere.

1. Introduction

1.1. The state of coral reefs

Coral reefs support an estimated 25% of all marine species at some point in their life cycle and provide hundreds of billions of dollars annually in goods and services, including coastal protection, fisheries, tourism, and medicine, among other benefits[1–5]. However, coral reefs and the ecosystem services they provide are being lost at an alarming rate. Historically this has been due to degradation from localized threats such as pollution and overexploitation, but warming from climate change is now the greatest threat[6,7]. More than half the world's coral reefs have been lost since the 1950s, and 70-90% of what remains is projected to be lost this century even if international measures keep warming below 2ºC[8,9]. Coral reefs may be the first ecosystem to be eliminated from Earth in the Anthropocene, and this is likely to occur within some of our lifetimes.

Furthermore, the years 2023-2024 saw the fourth and most extensive global mass-bleaching event in recorded history[10,11], with 2024 being the hottest year on record and the first to exceed 1.5ºC above pre-industrial average global temperatures[12,13]. The 2024 bleaching event drew special attention to coral reefs, including a Special Emergency Session for coral reefs at CBD COP 16 in Cali, Colombia in 2024[14]. Given the record bleaching in 2023-2024, projected future warming, and ongoing reef degradation, scientists and conservationists must consider the complexities of coral reef protection and identify specific, actionable pathways that can be pursued with the support currently available. This process is crucial to garner the necessary political and financial backing to protect remaining reefs and prioritize those that have been shown to be more resilient.

To protect coral reefs, it is essential to both recognize and communicate that there is reason for *hope*. Some reefs have shown remarkable resilience, with high tolerance to warming or acidifying conditions due to inherent resilience or unique geological factors (Table 1). And through dedicated research, the scientific community is gaining a better understanding of the mechanisms behind this resilience, from genetics to local oceanographic features. These insights offer the potential to enhance resilience at larger scales.

Table 1: Demonstrated examples of potential climate change resilient reefs

Location	Description
Rock Islands, Palau	Woods Hole Oceanographic Institute's "Super Reefs" program has identified potential resilient reefs in four countries in the tropical Pacific[15]. One example is the Rock Islands in Palau where a 2015 study found that corals in Palau's naturally low-pH reefs have adapted to acidic conditions, maintaining calcification rates similar to those in higher-pH environments, suggesting potential resilience to future ocean acidification scenarios[16]. Another 2022 study found that corals in the same archipelago also demonstrated remarkable heat tolerance[17].
Great Barrier Reef, Australia	The Great Barrier Reef has made news from suffering multiple mass bleaching events in the last decade[18]. However, recovery within the reef has varied significantly at local levels. Research has identified local areas of unique heat tolerance potentially linked to genetic adaptations[19].
Kenya-Tanzania Transboundary Conservation Area (TBCA)	In the Pemba Channel within the Kenya-Tanzania Transboundary Conservation Area, deep-water channels and proximity to open ocean currents have helped regulate water temperatures over some coral reefs during marine heatwaves. These reefs have escaped bleaching suffered by surrounding reefs without these cooler waters and could be an important climate change refuge[20].
Gulf of Aqaba, the Red Sea	A series of studies found that corals in the Gulf of Aqaba (GoA), a northeastern extension of the Red Sea, exhibit remarkable resistance to rising water temperatures, surpassing the resilience of many corals in other regions worldwide[21–26]. During the 2024 global mass bleaching event, only a small handful of species experienced bleaching despite prolonged exposure to temperatures as high as 31.9°C (30 Degree Heating Weeks)[11,27,28,29].

Climate change is the greatest threat to coral reef health and reducing greenhouse gas emissions is the most critical step to ensure long-term survival. However, it is equally important to reduce additional threats and pressures, both locally and regionally, for reefs that show the potential for resilience in the face of climate impacts (especially warming)[30–32]. Examples of addressable site- or regional-level threats include wastewater pollution, sedimentation and other forms of land-based pollution, coastal development, destructive tourism, destructive fishing such as dynamite fishing, and overfishing of key species that maintain reef stability, such as apex predators and grazers. In parallel, coral restoration might help to rebuild damaged reefs and enhance reef resilience[13,33,34]. Ultimately, securing a sustainable future for coral reefs requires effective local management alongside global efforts to mitigate greenhouse gas emissions.

1.2. Managing for coral reef resilience

Resilience broadly refers to the capacity of a system to maintain key functions and processes in the face of pressures by resisting, recovering, and adapting to change[35,36]. Coral reef resilience to climate change can be described as the instances of coral tolerance of warming or acidifying conditions, in terms of survival, reproductive viability, and overall health of both corals and coral dependent species that comprise the ecosystem. To foster resilience for coral reefs, managers should also widen their focus beyond ecological processes to also include the resilience of coastal human communities. Social resilience includes the capacity of local communities to respond and adapt to change, as well as the capacity of governing structures to support the resilience of the socio-ecological reef system through changing social and environmental contexts[37].

Management for coral reef resilience therefore requires prioritizing actions across social, ecological, and governance dimensions. Some of these actions are globally applicable and may include implementing area-based conservation such as marine protected areas (MPAs), protecting a diversity and redundancy of species, habitats, and functional groups, supporting research into innovative strategies to support resilience, and building adaptive management in governance systems[38]. However, while many coral reef resilience-based management strategies have commonalities across the globe, varied states of coral reef health, distinct governance, and ecological and socio-economic contexts call for actions that are tailored to specific local and regional contexts.

1.3. Ecosystem connectivity and the importance of transboundary governance and coordination for coral resilience

Tiny individual coral polyps together form collective coral skeletons, which aggregate with other coral skeletons to form large reef structures that span across international boundaries, sometimes for thousands of square miles. Coral reefs require healthy ocean ecosystems around them to provide crucial habitat to their many dependent organisms, relying on interconnected ecological processes and habitat connectivity. For example, reef health and resilience rely on the dispersal of coral larvae and other species, such as fishes, that contribute to reef stability and biodiversity[39,40]. Genetic exchange supported by ecosystem connectivity can promote resilience through higher overall genetic diversity as well as the exchange of specific genes that may promote resilience[41]. Connectivity with other tropical ecosystems, such as healthy mangroves and seagrass beds, can also affect coral reef health[42]. Biodiversity within reefs with strong ecosystem connectivity have shown greater resilience to human pressures in several regions around the world[40]. Connectivity is also projected to influence the potential for reefs to recover from harmful events[43].

Considering the importance of connectivity across reefs and other ecosystems, and the fact that many reef systems span several countries (e.g. Coral Triangle), coral reefs require multi-national approaches for conservation.

1.4. Global and Regional Actions to Date

Many global and regional policy frameworks and multinational initiatives could potentially galvanize international cooperation for coral reef conservation and resilience via control of greenhouse gas emissions and other threats to reef health. The United Nations Framework Convention on Climate Change (UNFCCC) is the chief forum for global climate change mitigation. The Paris Agreement, formalized in 2015 by the 196 countries party to the UNFCCC, is the main body of United Nations (UN) legislation that sets goals for reducing greenhouse gas emissions and mitigating warming to limit global temperature below 1.5ºC above pre-industrial levels[44]. Other relevant international frameworks are specific to global socioeconomic development, such as the UN Sustainable Development Goals (SDGs) that include the ocean-specific SDG 14 with relevant targets such as SDG 14.5, to protect 10% of the ocean by year 2020[45]. Parts of the UN SDGs overlap with the Convention on Biological Diversity (CBD)'s 2022

Global Biodiversity Framework (GBF), in where member countries agreed to several targets to halt biodiversity loss by 2030 and reverse declines by mid-century, including a target to protect 30% of land and sea by 2030 (Target 3)[46].

There are also several international platforms or programs specific to coral reefs, such as the Global Fund for Coral Reefs[47], International Coral Reef Initiative (ICRI)[48], and the Coral Reef Breakthrough[49]. These programs can help mobilize funding, build global awareness, advocate for coral reef conservation, or establish national-level programs. At the regional level, efforts such as the Coral Triangle Initiative in the Indo-Pacific, the Regional Organization for the conservation of the Environment of the Red Sea and Gulf of Aden, the Mesoamerican Reef, and the Kenya-Tanzania Marine Transboundary Conservation Area, provide frameworks for coordinated action tailored to specific ecosystems and governance contexts.

Despite global and regional initiatives, in 2024 global temperatures exceeded the Paris Agreement's temperature threshold of 1.5°C above pre-industrial levels for the first time. The SDGs remain largely unmet despite their approaching 2030 deadlines, and none of the CBD Aichi Targets (the predecessor to the GBF) were fully achieved[50]. As coral reefs continue to decline, effective international governance to support reef resilience and conservation is critical. With many 2030 targets looming, and conversations beginning on post-2030 agendas[51], 2025 is a timely moment to review opportunities to enhance international governance and transboundary coordination for these ecosystems.

1.5. Goals of This Paper

As part of an NSF-funded research program investigating coral reproduction and resilience in the Gulf of Aqaba, an international workshop was conducted at Stony Brook University in New York, USA in June 2024, titled, "Blueprints for Resilience: A workshop on coral reef resilience, conservation, and charting a roadmap for scaling effective conservation interventions for climate resilient reefs." The initiative aimed to harness the collective expertise of a multi-disciplinary cohort of global experts in coral reef science and conservation to forge pathways to support climate change resilience and the conservation of coral reefs worldwide through international coordination and transboundary management. The workshop brought together 20 scientists from 12 institutions and six countries, representing universities, NGOs, and governance institutions. Using participatory systems mapping, among other methods, workshop participants charted road maps for effective conservation and building resilience of coral reefs at the global level and at the seascape level for two different coral reef regions: the Red Sea and Caribbean.

2. June 2024 Workshop

Inspired by work in the Red Sea, the workshop's primary aim was to integrate diverse expert insights to fortify coral reefs against escalating threats from climate change through global and regional action. The researchers were divided into groups according to their expertise; one global group and two regional groups focused on the Red Sea and Caribbean. The workshop priorities included:

1. Participatory systems mapping: Participatory systems mapping is an interdisciplinary approach which can successfully engage stakeholders from diverse disciplines and backgrounds to create a visual representation of a system[52,53]. In this case, we brought together workshop participants to map our coral reef social-ecological systems of interest. The workshop included detailed sessions using participatory systems mapping to assess and prioritize threats to coral reefs, develop actionable plans to mitigate these threats, and apply these insights as the basis for each case study. Through these exercises, experts in each group assessed the impacts of the variety of threats undermining coral reef resilience, the mechanisms through which these impacts occur, and coupled those threats with conservation actions that can be addressed to support resilience within their focal area.

2. Prioritization: Based on the outputs from the participatory systems mapping work, the groups prioritized threats, linkages, or conservation actions that should be pursued to scale globally considering a balance of potential impact, feasibility, and other factors.

3. Development of an action plan: Each group then developed action plans to address the previously identified priorities. Questions considered included: What is needed to achieve goals? Do they require action on a global, regional, or local scale (or cross-scale)? What are the roadblocks to achieving them that need to be addressed, and do they require additional financial investment, political attention, or social interest?

3. Outcomes - Case Studies for Building Coral Reef Resilience

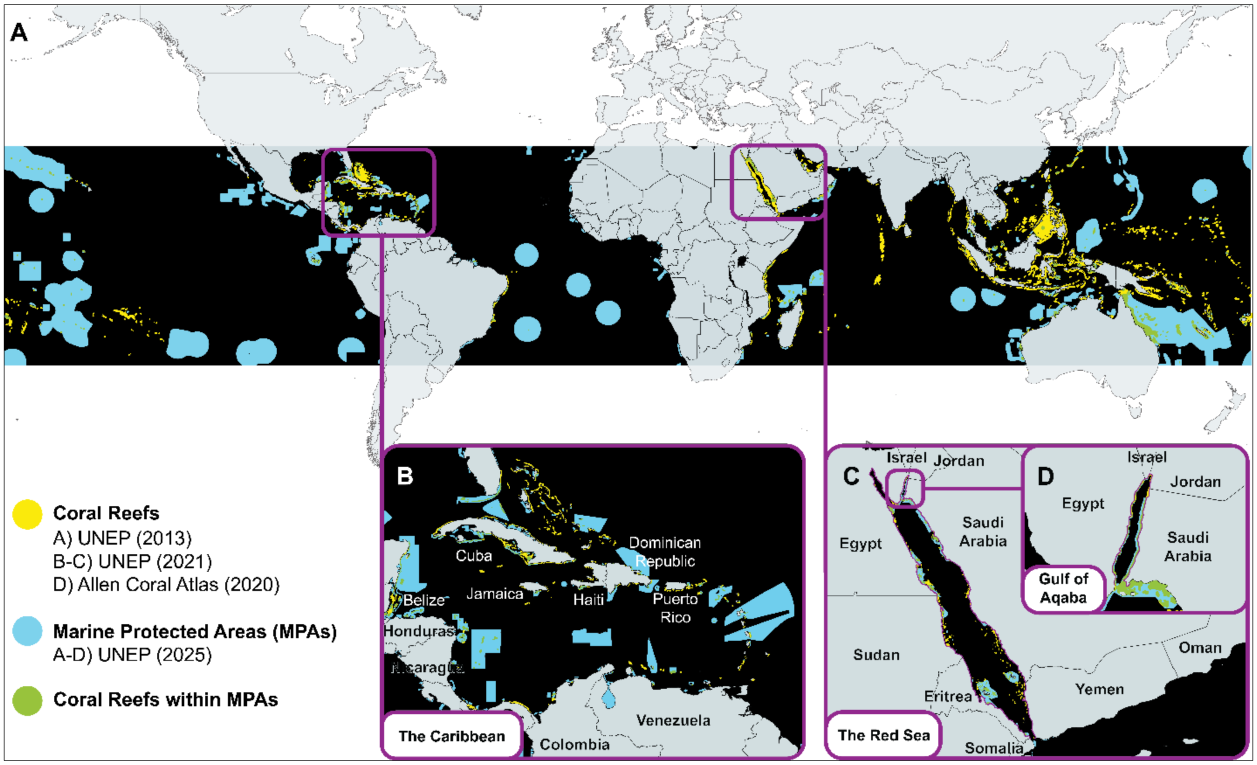

Figure 1: Maps of coral reefs across the globe (A) and in case study areas of the Caribbean (B) and the Red Sea (C), with an insert of the Red Sea's Gulf of Aqaba (D). The tropical oceans from latitudes 30° north to south, where virtually all coral reefs are located are denoted in black; other ocean regions have been omitted for clarity. Similarly, the Red Sea (C) and Gulf of Aqaba (D) are isolated by purple outlines, and all other surrounding reefs/MPAs have been omitted for clarity. Recorded coral reef and marine protected area (MPA) locations are denoted in yellow and blue respectively, with coral reefs located within MPAs denoted in green. Reef and MPA location sources for each panel are listed by letter under each category. Map .svg files from MapChart. Overlays sourced from UNEP 2013 (as available in Teh et al. 2013), UNEP 2021, Mittal et al. 2021, UNEP-WCMC / Protected Planet, and imagery from MapChart.net and Allen Coral Atlas[4,54–58].

3.1 Action at the Global Level

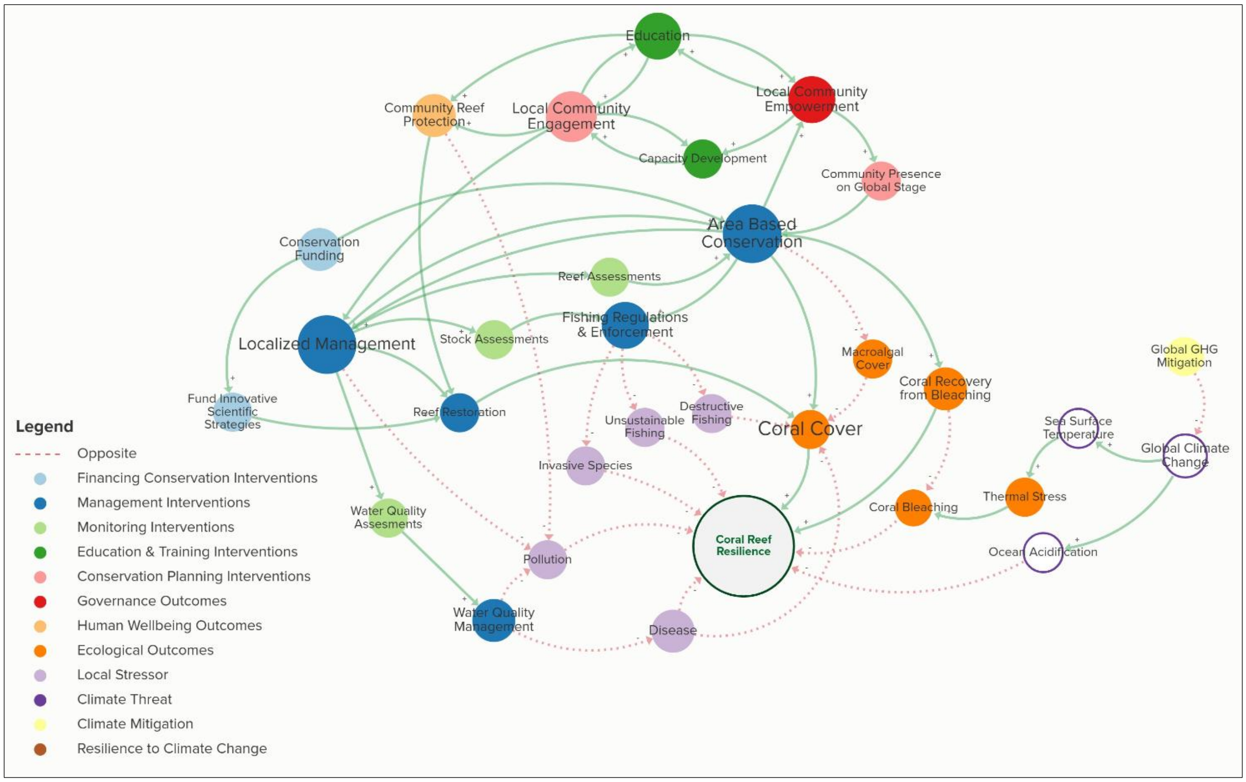

Figure 2: Systems map from the global case study.

Global policy frameworks for biodiversity conservation can support on-site efforts for coral conservation. For example, several targets developed under the Global Biodiversity Framework (GBF) have global scope but require commitments at local scales. GBF Target 3 aims to protect at least 30% of marine and coastal areas (30 by 30) and Target 2 aims to restore at least 30% of degraded marine and coastal areas[46], neither of which can be completed without local action. The International Coral Reef Society (ICRS) also calls for mitigation of local threats to improve reef condition and for investment in coral reef restoration alongside global climate action[59].

Local management strategies require tailoring management plans to specific reef conditions and threats to ensure targeted and effective conservation efforts. But there is the potential for action at the local level to benefit from targets, standards, or other guidance at the global level, such as best practices for marine protected areas[60]. Here, we outline some priority areas for action by the global community that can help build resilience at various levels of coral reef governance and management:

1. Global Climate Change Mitigation

There are many international agreements and initiatives that can serve as important vehicles to reduce greenhouse gas emissions, the primary driver of coral reef degradation. The UNFCCC has served as the foundation for multiple global commitments, such as the Kyoto protocol adopted in 1997 that went into effect in 2005 and introduced emission reduction commitments for developed countries[61]. Later, in 2016, the countries party to the UNFCCC implemented the Paris Agreement, described above[44,61]. However, there is growing evidence that current mitigation efforts, as well as future emissions commitments, are not sufficient to achieve the temperature goals set by the Paris Agreement[13,62,63]. Further measures must be explored, such as strengthening international agreements, implementing carbon pricing and regulations, expanding renewable energy, supporting climate adaptation and resilience, and strengthening protections for carbon-sequestering ecosystems like rainforests and mangroves.

2. Area Based Conservation

Effective Marine Protected Areas (MPAs) can mitigate threats like overfishing, habitat destruction, pollution, and other threats that can undermine coral reef resilience[60,64–67]. MPA networks can facilitate the movement of coral larvae between reefs, which can promote genetic diversity and introduce traits that enhance resilience. For example, larvae from thermally tolerant populations could seed vulnerable reefs, potentially spreading adaptive traits. Other effective area-based conservation measures play a complementary role to MPAs in coral reef conservation. For example, OECMs are areas that achieve effective conservation of biodiversity without being formally designated as protected areas[68]. These areas have the potential to contribute to coral reef resilience, biodiversity, and ecosystem service protection through sustainable practices or traditional stewardship.

Global key actions to enhance area-based conservation efforts' ability to build climate resilience include expanding and strengthening MPAs and OECMs by prioritizing climate-resilient sites and improving enforcement mechanisms using technology (i.e. satellite monitoring, AI-assisted tracking), strengthening global and regional MPA governance, improving financing and incentives for conservation and enhancing monitoring, compliance, and adaptive management. Global policies to strengthen MPAs, such as UN Sustainable Development Goal 14.5 and the CBD Aichi Targets 3 and 11 mentioned above, will continue to be essential for advancing reef conservation efforts globally. However, the global community should consider that some critical ecosystems such as surviving, resilient coral reefs may merit more than 10% or even 30% protection.

3. Community Engagement

Global policy frameworks should help empower local communities, who rely on healthy reefs, to implement sustainable practices and participate in conservation efforts. Education on sustainable fishing, pollution reduction, and sustainable tourism can enhance resilience. Addressing overfishing and promoting sustainable practices ensures both ecological and socioeconomic benefits.

Global initiatives to support community engagement in coral reef conservation can include education and awareness campaigns, incentivizing sustainable practices, strengthening policy and legislation, supporting community-led conservation and incorporating science and traditional knowledge[69]. Integrating indigenous and local knowledge into conservation planning can improve effectiveness and community buy-in[69–71]. Collaboration across sectors (governments, NGOs, scientists, and the private sector) is critical and successful partnerships should incorporate different stakeholders, such as tourism operators, local governments, Indigenous Peoples and local communities, and the private sector, to take shared responsibility for reef conservation.

International policies can ensure the integration of coral reef education into curricula and promote sustainable coastal management at all levels of government.

One example of how community engagement at a global scale can support coral conservation is the International Year of the Reef (IYOR)[72]. Initiated in 1997 and revived in 2018 by the International Society for Reef Studies (ISRS), IYOR brought together communities, organizations, governments, and the private sector to focus on coral reef conservation globally. During IYOR 2018, various communities across the world were encouraged to take part in local and regional activities such as coral reef monitoring, restoration projects, beach cleanups, and awareness campaigns. This initiative facilitated broad collaboration between local communities, scientists, environmental NGOs, and governmental bodies. Through this example, community engagement on a global scale has helped to strengthen local conservation efforts, raised awareness, and showcased the power of collective action in supporting coral reef protection.

4. Research and Innovation

One key focus within reef resilience research is the development and evaluation of coral reef restoration techniques. When planned appropriately, coral reef restoration can play an important role in building resilience for coral reef ecosystems[69]. Coral reef restoration broadly refers to a suite of interventions aimed at improving reef structure and ecosystem function and increasing the populations of key reef species[73]. Some examples of global restoration efforts to combat coral reef degradation include those applied by the Coral Triangle Initiative (CTI), Great Barrier Reef's Coral Reef Restoration and Adaptation Program, The Ocean Agency´s "Mission 2020", restoration of *Acropora* corals in the Caribbean, and Bahamas Coral Restoration Initiative. Several World Heritage coral reefs are undergoing restoration, with specific focus on enhancing their resilience to climate change through coral gardening and restoration programs[74].

Coral gardening is the most widely used intervention, but other common interventions include larval-based restoration, reef substrate enhancement (e.g., artificial reefs), reef substrate manipulation (e.g., rubble stabilization and algae removal), as well as coral disease and predator management[34,73]. Recommendations for restoration include considering local ecological and socio-economic resilience factors during planning, particularly around the choice of site and coral species to restore[75]. Restoration should also prioritize lasting and effective impacts on reefs and their associated local economies.

However, coral restoration should be considered an additional effort and not a substitute for maintaining intact coral reef biodiversity. Current restoration efforts are expensive and have yet to be scaled to ensure long-term, substantial impacts[76]. These remain as key challenges for coral restoration efforts globally[77,78]. Nonetheless, some isolated examples have demonstrated improved resilience to bleaching[13]. A suite of international commitments is also underscoring restoration's importance by calling for increases and improvements of the practice on degraded reefs including the UN Decade of Ecosystem Restoration, Target 2 of the Kunming-Montreal Global Biodiversity Framework that calls for restoring 30% of all degraded marine and terrestrial ecosystems by 2030, and the Coral Reef Breakthrough. Global standards of practice are also being developed to translate decades of restoration work in terrestrial systems for coral reefs[73,78,79]. However, more scientific research of restoration methods, best practices, and effectiveness are needed to deliver broadly scalable solutions.

Scientists are also exploring ways to accelerate adaptation through interventions like selective breeding, hybridization, or introducing heat-tolerant algal strains to corals. Exploring initiatives like a Global Cryo Preservation Coral Bank could safeguard genetic diversity if immediate restoration goals are unmet, serving as a long-term resource similar to the Global Seed Vault.

Studying mesophotic reefs, which are far less understood than their shallower counterparts, is important because they represent a significant portion of global coral reef habitat, play a crucial role in marine biodiversity and ecosystem services, and, growing in deeper waters, may be less exposed to heat stress from climate change now and in the future[80,81]. Mesophotic reefs are important for commercial fisheries and may possess unique adaptations to environmental stressors, which could provide valuable insights for coral conservation and restoration. Understanding these ecosystems is essential for developing effective conservation strategies across different reef depths.

Global engagement, cooperation and impact financing are essential to fund these interventions. Stronger collaboration between government agencies, private industries, conservation organizations, and local communities is needed for coordinated research strategies for reef conservation.

Environmental organizations can play a key role by supporting pilot restoration programs to test and evaluate new technologies in real-world settings. Additionally, scientists can develop standardized global monitoring protocols, which will allow for better comparison and aggregation of data on reef health and coral bleaching events.

3.2. Case Study #1: The Red Sea

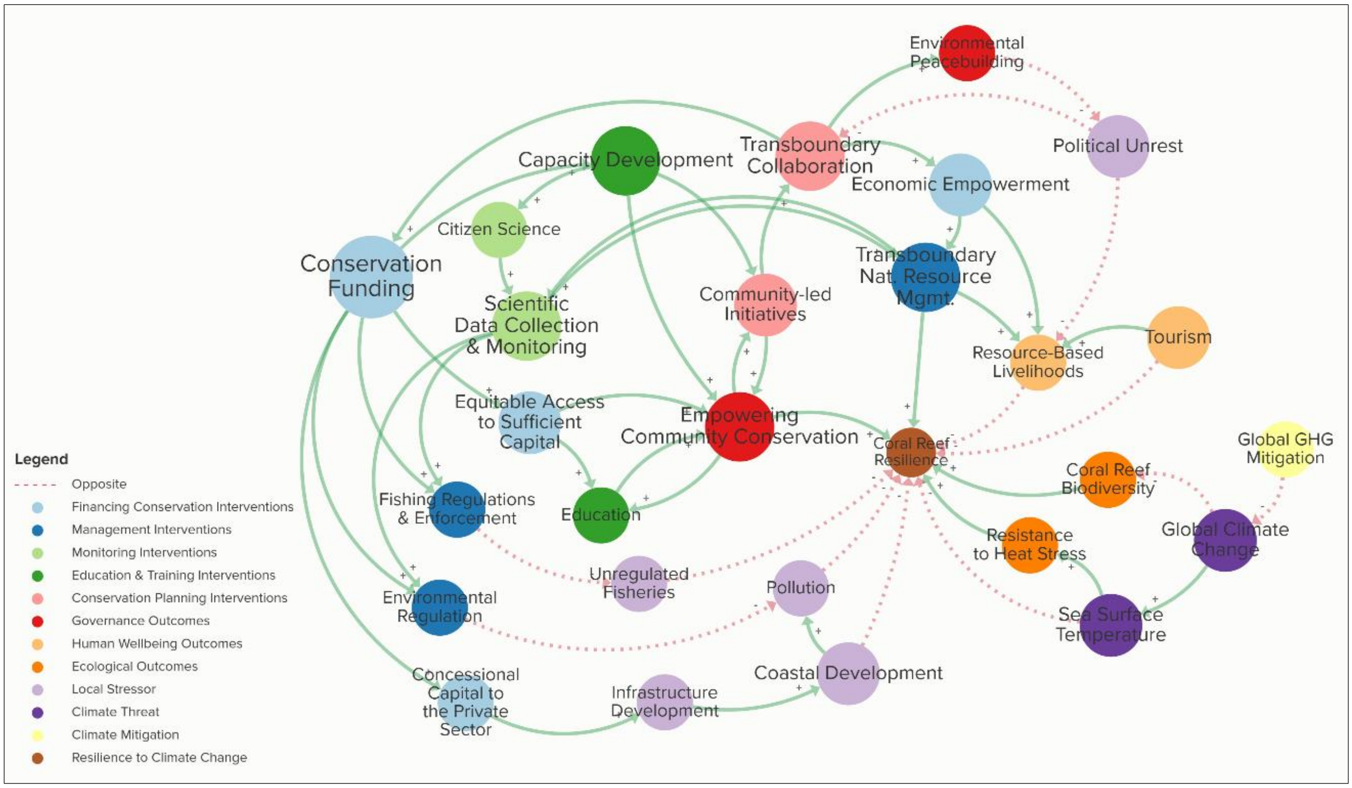

Figure 3: Systems map for the Red Sea regional case study.

The Red Sea contains over 12,600 km² of coral reefs and over 265 coral species, making its reefs a global biodiversity hotspot. A series of studies found that corals in the Gulf of Aqaba (GoA), a northeastern extension of the Red Sea, exhibit remarkable resistance to rising water temperatures, surpassing the resilience of many corals in other regions worldwide[21–26]. This unique thermal resilience of corals from the GoA is hypothesized to result from the repopulation of naturally selected, heat-tolerant genotypes in the Red Sea following the last glacial maximum[25,82]. Consequently, the GoA is considered a thermal refuge for corals in the face of warming oceans. Nevertheless, the warming rate of the GoA is faster than the global average (nearly 0.5°C per decade)[83]. Along with consistent long-term warming, there has been an increase in the intensity and frequency of extreme temperature events, known as marine heatwaves[84]. The first marine heatwave in the GoA was documented in 2015[85]. In 2017, two consecutive marine heatwaves resulted in fish mass mortality, although without recorded coral bleaching in the GoA[86]. Moreover, following a strong heatwave in 2021, common coral species demonstrated remarkable metabolic resilience[87].

Then during the fourth global mass bleaching event in 2024, the GoA experienced unprecedented thermal stress with a recorded 30 Degree Heating Weeks (DHW, an index for heat stress on coral reefs, where values above 20 DHWs historically associated with near-complete coral mortality) — nearly double the previous local record in 2020 — with water temperatures peaking at 31.9°C[11,27]. Despite such extreme thermal stress, the impact in the GoA was relatively contained, with bleaching documented only in a small handful of species comprising about 5% of corals within the shallowest reefs (<5m) in the northern GoA, and most affected corals having recovered within a few months[28,29].

This exceptional resilience presents an opportunity to safeguard at least one major coral reef ecosystem. However, this hope rests on the ability to protect the Red Sea reefs from local environmental stress and pollution. Studies show that local disturbances compromise coral's resilience to elevated temperature and determine the fate of corals under increased frequency and amplitude of marine heatwaves[30–32]. Increased urbanization and industrialization of the coastal Red Sea may put reefs at immediate threat under climate change scenarios[88,89].

The GoA is bordered by Egypt, Israel, Jordan, and Saudi Arabia, and additional countries including Eritrea, Djibouti and Yemen surround other portions of the Red Sea. Political unrest in the Red Sea region often impedes regional-scale collaboration and conservation efforts for its transboundary reefs, putting the livelihood and future of millions of people in the region at risk[90]. Unilateral management of natural resources is often ineffective and may exacerbate environmental challenges, especially with common-pool resources. In the Red Sea region, where countries share natural resources, valuable ecosystems, and a history of conflicts, transboundary environmental cooperation offers a pathway to improving livelihoods of numerous communities. Furthermore, as demand for tourism in pristine environments continues to grow, unsustainable ecosystem management poses a risk to local economies, especially in regions where ecological integrity is a key factor in destination choice. This underscores the importance of transboundary conservation efforts to sustain both livelihoods and economic stability[91]. It is key for standardized coastal zone management to be insulated from geopolitical conflicts.

Resolution for the Red Sea Region

The 2024 International Coral Reef Initiative (ICRI) General Meeting in Saudi Arabia adopted a resolution emphasizing the Red Sea's global significance[92]. Acknowledging the Red Sea as an "open-sky laboratory" for studying biodiversity and coral resilience to climate change, the resolution underscores its critical importance for over 28 million coastal residents who rely on these ecosystems for fisheries, tourism, and coastal protection.

Key elements of the resolution include:

1. **Regional Collaboration:** Strengthen partnerships among nations to enhance the collection, monitoring, and sharing of coral reef data, fostering a unified approach to conservation.
2. **Marine Protected Areas:** Expand the network of protected zones to achieve regional and global targets, such as the 30 by 30 initiative, safeguarding critical coral reef habitats.
3. **Capacity Building:** Empower conservation and restoration efforts by developing skills at all levels, from local communities to scientific and policy-making circles.
4. **Citizen Science:** Promoting ocean literacy, community involvement, encouraging engagement with private industries, and fostering stewardship of marine resources.
5. **Community Participation and Economic Empowerment:** Actively engage local communities in conservation and restoration efforts, emphasizing co-management of resources and sustainable practices. Promote diversified economic opportunities, such as

eco-tourism, sustainable fisheries, and coral-friendly industries, to support livelihoods while reducing pressure on coral reef ecosystems.

This resolution provides a strong framework for protecting and restoring coral reefs in the Gulf of Aqaba and the broader Red Sea.

Proposed Resolution: Establishing the GoA as a World Heritage Site

To secure the Gulf of Aqaba as a coral reef refuge, the four bordering nations of Jordan, Egypt, Israel, and Saudi Arabia must collaborate. Establishing a UNESCO World Heritage Site encompassing the GoA's uniquely resilient coral reefs, complementary to a proposal for reefs within Saudi Arabia[93], would:

1. **Promote Conservation:** Provide legal and institutional frameworks for the preservation and sustainable management of coral reefs.
2. **Encourage International Cooperation:** Strengthen collaboration between the four countries through joint research, monitoring, and enforcement efforts.
3. **Enhance Global Awareness:** Highlight the Gulf's unique role as a coral refuge, attracting global attention and funding for conservation efforts.
4. **Support Local Communities:** Develop sustainable tourism and alternative livelihoods to reduce dependency on extractive activities.
5. **Provide legal and institutional framework for long-term protection**

Steps Toward Securing World Heritage Status may include:

1. **Scientific Documentation:** Consolidate existing research on the GoA's coral resilience and biodiversity, highlighting its global importance.
2. **Regional Agreement:** Engage stakeholders from Jordan, Egypt, Israel, and Saudi Arabia to agree on boundaries, governance, and management objectives.
3. **UNESCO Nomination:** Prepare and submit a comprehensive nomination dossier that aligns with UNESCO's criteria for natural heritage sites.
4. **Adaptive Management Plans:** Develop and implement adaptive management strategies addressing both regional and local stressors.
5. **Capacity Building:** Train local and regional personnel in reef monitoring, enforcement, and eco-tourism development.

Broader Implications for Global Coral Conservation
Establishing the Gulf of Aqaba as a coral reef refuge will serve as a model for other regions, showcasing how international cooperation can safeguard critical ecosystems. Furthermore, the GoA can serve as a living laboratory for studying coral resilience and informing global strategies for coral restoration and protection.

Conclusion

The Gulf of Aqaba represents a beacon of hope for coral reef conservation in an era of climate uncertainty. By protecting it, studying its unique resilience, and fostering regional collaboration, we can ensure the long-term survival of this critical ecosystem and its invaluable contributions to biodiversity, science, and human well-being locally and globally.

3.3. Case Study #2: Caribbean

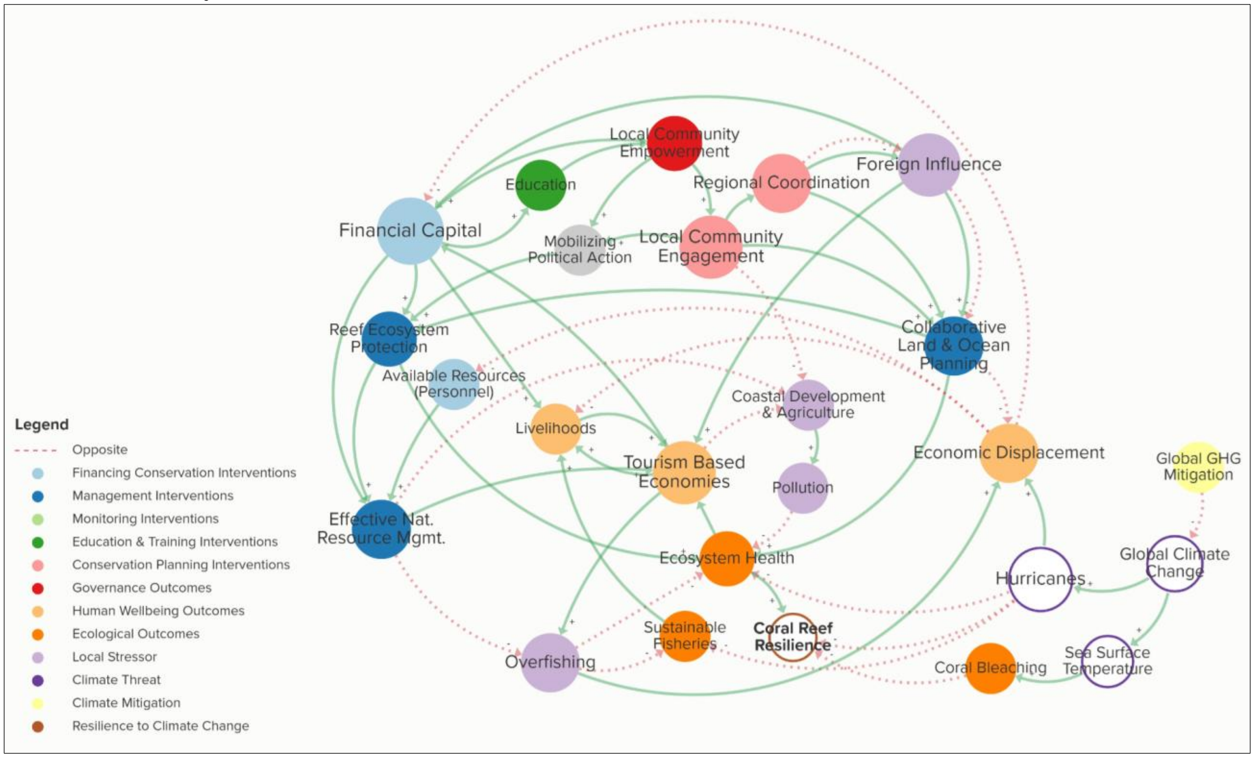

Figure 4: Systems map for the Caribbean regional case study.

Caribbean coral reefs provide countless ecosystem services for the 40+ million people that call the region and its 7,000+ individual islands home. In addition to non-monetary benefits, coral reef tourism in the Caribbean dominates the local economies of the region and generates ~$5.7 billion basin-wide per year (>10% of total regional GDP)[94], and coral reefs contribute hundreds of millions of dollars annually to fisheries in the region[95]. The economic benefits of coral reefs to some Caribbean countries can total 14% of GDP[96]. Despite the high costs of restoration, cost-benefit analyses have identified that the cost of reef restoration in some parts of the Caribbean is outweighed by the benefits of coastal protection alone[97].

However, the Caribbean has been subjected to a range of pressures including poorly regulated tourism and coastal development, pollution, overfishing, invasive species, disease, hurricanes, and climate change induced warming that have reduced live coral cover in the region from 50% fifty years ago to 10% today[98]. The Caribbean is one of the most vulnerable regions of the world to anthropogenic climate change, yet is one of the smallest contributors to fossil fuel emissions. Future warming here is projected to amplify local stressors, especially hurricanes and coral bleaching[99,100]. Caribbean coral reefs are at high risk from extreme hurricanes that are increasing in severity, such as Hurricanes Irma and María (2017) that caused simultaneous mechanical destruction of corals, altered seawater chemistry, and buried reef-building corals under rubble and sediment loads in the northern and northeastern Caribbean[101].

For this region, the systems mapping approach identified a subset of tangible action points that are key to promoting ecosystem health and reef resilience: (1) collaborative spatial planning and management; (2) empowerment and mobilization of local communities around reef resilience; and (3) equitable access to sufficient financial capital for reef management. Additionally, the Caribbean is politically complex, with 35 recognized entities including 22 countries and 13 overseas territories or dependencies with Caribbean coastlines. Consequently, any collective effort to advance coral resilience across the region requires significant political coordination. Such coordination could enable the implementation of the identified action points as discussed below:

1. Collaborative Spatial Planning and Management: Unsustainable coastal development and deforestation is a major stressor to Caribbean coral reef ecosystems[98]. Coastal sedimentation associated with deforestation, other types of land-use conversion, and dredging increases the sediment, nutrient, and other toxic pollution burdens on reefs[102]. At sea, overfishing of predatory and herbivorous species in the Caribbean contributes to trophic cascades that lead to ecosystem destabilization and algae overgrowth[98,103,104]. Addressing these issues requires ecosystem-based approaches that address multiple stressors such as coastal and marine spatial planning. This includes coastal development plans to address land-based sources of pollution and sedimentation and area-based conservation. However, only 20% of land and 40% of coral reefs in the Caribbean are protected (especially important ecosystems may call for higher protection than global targets of 30%[105,106]), and only 4.6% of reefs are within highly or fully protected areas that provide the most effective protection[60,107].

Considering the transboundary nature of watersheds, ocean circulation, and migratory fish stocks, sustainable resource management and spatial planning are shared responsibilities for the region and would be best served by collaborative, multinational approaches that consider the transboundary implications of both marine and terrestrial protected area networks. A good example of regional coordination is the Healthy Reefs Initiative that works within the Mesoamerican Reef System (MAR) spanning the Caribbean waters of Mexico, Belize, Guatemala, and Honduras[108]. Here, the Healthy Reefs Initiative, which comprises over 70 local and international NGOs, academic, and governmental institutions, has been catalyzing conservation for two decades, as well as other transboundary initiatives such as the Mesoamerican Reef Fund (MAR Fund). Another example is the Caribbean Challenge, led by The Nature Conservancy, where 11 Caribbean countries committed to protect 20% of their coastal waters by 2020 through various forms of capacity support[109]. However, while the Caribbean Challenge sets a model for international coordination, these types of efforts must be scaled to include more countries to sufficiently protect the Caribbean.

2. Empowerment and Mobilization of Local Communities, Governments, and NGOs: Healthy coral reefs are critical for the social and economic wellbeing of many communities throughout the Caribbean basin[95,96]. While tourism is a key economic driver in the region, attracting significant foreign investment, it has also been a driver of overfishing, unsustainable coastal development, and pollution[98]. Additionally, foreign investment in industries like agriculture and tourism can incentivize corruption, a lack of political will to address unsustainable coastal tourism development, and the capture of economic benefits by powerful elites, leading to social injustices and harm in many areas[110–115].

Empowering and mobilizing local actors by increasing their role in reef governance can enable them to counter negative influences from foreign capital. Additionally, many reef-dependent Caribbean communities have shown support for coral reef management when directly involved in governance processes[116,117]. Local actors and organizations have also advanced sustainable reef management and rights advocacy and possess rich contextual knowledge around coral reefs and successful management approaches that can be applied to other locations[117–120]. Therefore, fostering stronger regional coordination between community stakeholders, local NGOs, and policymakers can advance sustainable practices, promote transparency, and address shared challenges.

At the regional scale, the Caribbean Large Marine Ecosystem Project (CLME; 2009-2014 and revamped 2015-2020 as CLME+) is an example of an initiative which developed a framework for regional ocean governance in the Wider Caribbean Region[121]. The framework focused on accommodating the geopolitical realities of the region and the need for local participation in governance to outline interventions. The resulting comprehensive Strategic Action Program served as a roadmap for sustainable living marine resources management through strengthened and consolidated regional cooperation[122]. Continued coordinated efforts around knowledge sharing that focus on organizational engagement could therefore serve to unify countries across the Caribbean as a single entity with shared reef resources in international policy forums. This type of political coordination across Caribbean nations on the international stage can also further empower local and national organizations by building political alliances for global political platforms and negotiations, which can provide Caribbean nations with greater agency when acting collectively rather than alone.

3. Equitable Access to Financial Capital: The mobilization of Caribbean communities around reef stewardship and collaborative spatial planning necessitates not only intellectual capital but also the financial capital necessary to coordinate, implement, and support reef management strategies. Unfortunately, like ocean conservation globally[123,124], the financial resources being allocated to conserving reefs in the Caribbean are severely inadequate[125]. Given the number of small island states in the Caribbean, multi-national efforts to raise and allocate more substantive funding reflective of the socioeconomic importance of coral reefs to the region can help strengthen the collective efforts for building regional resilience. For example, the Bridgetown Initiative is a finance reform initiative aimed at reducing the climate debt burden for developing nations by increasing trust- and climate "bail-out" funding from international development banks as well as funding reconstruction efforts following climate-related disasters in "at risk" communities[126]. Alongside raising funds, the focus on "at risk" communities can help direct funds in a more equitable manner than current markets and economic systems would typically allow. Another example of capital allocation is Belize's successful Blue Bond program, which reduced national debt by 12% while securing approximately $180 million of long-term financing for ocean conservation through grant funding to national NGOs, government reef management agencies, and results-based private financing[127].

However, only three of the 35 Caribbean countries including Belize have benefitted from such a transaction[128,129], and these initiatives need to be rapidly scaled to support the region. The pursuit of such regionally focused initiatives will allow smaller states, which independently might be unsuitable for institutional investment due to small economies and informal sectors[130], to benefit from innovative conservation finance tools. Regional financial incentives might also prevent perverse economic incentives and corruption and encourage equitable access to funds for implementation in this politically decentralized region. Regionally focused environmental funds, such as the Caribbean Biodiversity Fund and Mesoamerican Reef Fund, are key partners in managing and allocating structures like public funds used in Blue Bonds and Debt-for-Nature Swaps. Networks like the RedLAC Congress support regional coordination by linking environmental funds across Latin America and the Caribbean.

Conclusion: Effective regional coordination in the Caribbean is essential, especially as climate change and local pressures outpace adaptive capacity. These challenges are compounded by unequal resources, governance gaps, and competing agendas across conservation, tourism, and the blue economy. Strengthening and scaling efforts like Healthy Reefs for Healthy People and the Bridgetown Initiative can help address these issues. A growing global push for a sustainable blue economy—backed by organizations like the OECD—presents an opportunity to direct funding toward reef conservation, which underpins regional economies. By leveraging existing platforms, Caribbean actors can build capacity, share solutions, and secure a stronger, more unified voice in global climate and biodiversity efforts.

4. Discussion

4.1. Pathways for promoting coral reef resilience

The global and two regional analyses presented above had several commonalities as well as key differences. Based on these outputs, we grouped the recommendations provided into a series of pathways for building coral reef resilience through both global and regional action. Figure 5 depicts how these connect as part of a larger holistic approach for international and transboundary efforts to support coral reef resilience. There are both actions that directly support resilience such as area-based conservation and restoration, as well as actions that build the supporting framework such as finance and science. Below we discuss how these pathways are relevant, support one another as part of a holistic approach, and apply to global or regional action.

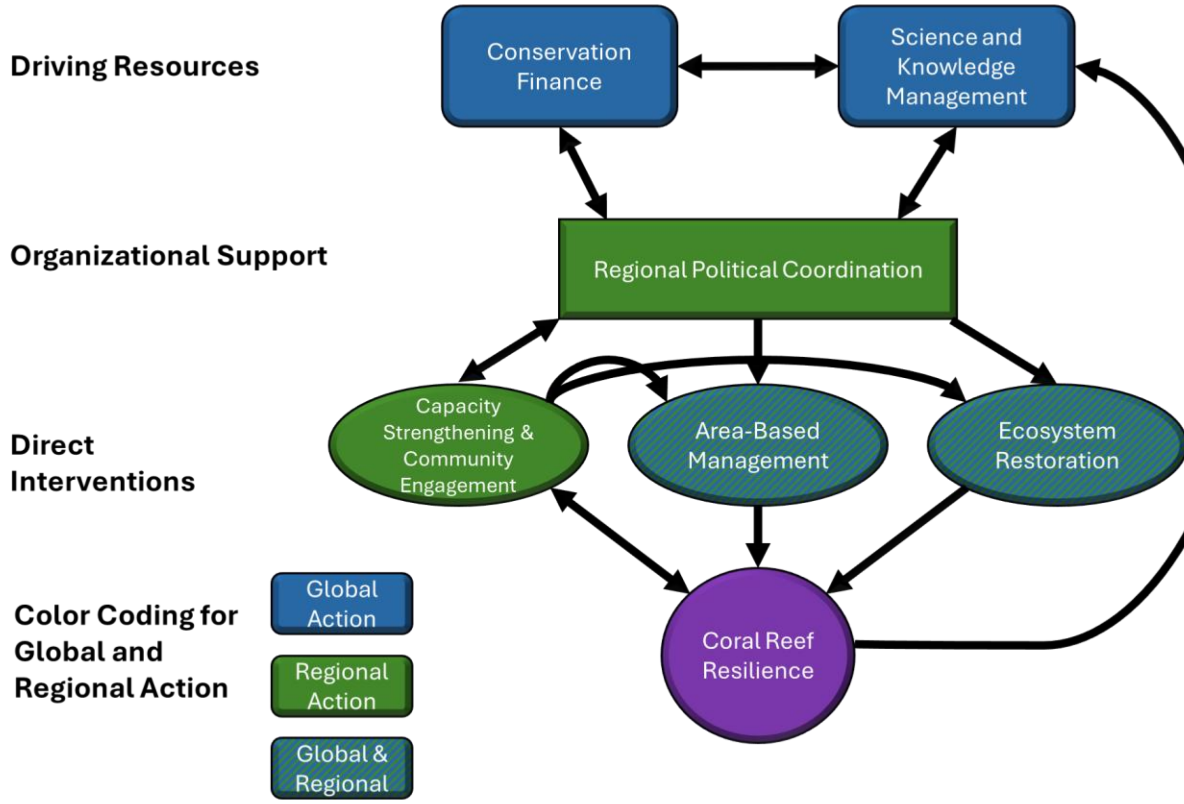

Figure 5: Holistic framework for international cooperation and transboundary management for building coral reef resilience. Arrows reflect flows of support, communication, and information across elements, which include scientific knowledge that originates at local levels but is consolidated and re-disseminated at the global level.

4.1.1. Driving Resources

Driving resources includes securing the financial needs and technical knowledge to support coral reef conservation and build resilience.

4.1.1.1. Conservation Finance

Global action for building coral reef resilience begins with conservation finance, which includes the raising and allocation of financial resources that support all other aspects of this holistic, global approach. Both the Red Sea and Caribbean case studies identified the need for access to financial resources. The Red Sea has some high-income countries such as Saudi Arabia and Israel that can provide finance from within the region, although several Red Sea countries such as Sudan and Eritrea are Least Developed Countries. Globally, coral reefs are often located in developing countries and small island states (SIDS), so most will rely on the international community to help source funds or provide capacity support to help unlock financing as demonstrated by several prominent coral reef and marine conservation finance initiatives[47,124,127,131].

For regions comprising mostly low- and middle-income countries, finance primarily needs to be addressed at the global level and delivered to regional financial management bodies (e.g., regional funds acting as conduits) to support direct and coordinate actions for reef resilience. Under this dynamic, the global community plays the role of supplying funds, with regional level governance developing the necessary capacity and institutional frameworks to receive and distribute funds. Platforms such as the Global Environment Facility, which hosts the Global Biodiversity Framework Fund, and the CBD, through which countries recently agreed to a global biodiversity finance roadmap as an outcome of COP16 and establishment of a new "Cali Fund" that raises contributions from the private sector[132], are instrumental bodies for raising and delivering funds.

Finance is critical to supporting science, as referenced in the global case study. Finance also benefits from science through improved understanding of ecosystem services and marine resources that can be the basis of innovative financial mechanisms. Examples include leveraging the value of coral reefs for coastal protection to support mechanisms such as coral reef insurance funds, offsets or credits for carbon sequestration in connected ecosystems such as mangroves or seagrass beds, biopharmaceuticals from coral reef genetic resources, and others[5,47,130,133–137].

4.1.1.2. Science Driving Management

Science is critical for identifying, developing, and applying innovative approaches to support resilience. Area-based management tools such as MPAs, and increasingly forms of coral restoration, are examples of widely applied approaches that have been informed by quality science needed for successful implementation and long-term management[60,73]. Other approaches such as coral reef engineering (e.g., hybridization) discussed in the global case study are also being investigated and may become more available and increasingly applied to support resilience as science on these matters advances.

Incorporating science into management practices at the global level drawing on knowledge exchange from coral reef research around the world can then inform more local applications. However, global reef management also requires a bottom-up flow of knowledge, including from Indigenous Peoples and Local Communities, throughout coral reef regions[71]. The Red Sea case study also highlighted the importance of citizen science for capacity strengthening and additional community engagement.

4.1.2. Organizational Support: Regional Political Coordination

With seascapes and coral reef regions often divided amongst several countries, regional political coordination (in the form of regional political bodies or alliances for conservation) is vital to ensuring that coral reef management accounts for the transboundary nature of these ecosystems. As part of a comprehensive multinational framework, regional political coordination plays an important role in moving resources from the global community (or in some cases across regions), including finance and scientific knowledge, to support the implementation of more direct local and regional measures including area-based management efforts, restoration, and capacity strengthening in an equitable and coordinated approach. This includes the potential institutional frameworks for supporting or applying conservation initiatives such as a regional or seascape level transboundary MPA network. Furthermore, political coordination can also foster bottom-up communications such as advocating for finance or transferring knowledge from respective regions to the global community.

Both the Red Sea and Caribbean case studies identified concrete benefits or priorities for regional political coordination for multinational approaches. The Red Sea case and the ICRI Red Sea resolution emphasized the benefits of political coordination to support scientific knowledge and data sharing as well as joint efforts for monitoring and enforcement, and the Caribbean case showcased Healthy Reefs for Healthy People, the Mesoamerican Reef Fund, Caribbean Challenge Initiative, and Caribbean Biodiversity Fund as examples of influential transboundary initiatives. However, while there were some commonalities around political coordination across the Red Sea and Caribbean cases, the meaning of political coordination, including its intended purpose and desired effect for coral reef health, also differed across these two examples.

The Red Sea, as compared to the Caribbean, is a smaller region of fewer, larger neighboring countries with a longer history of cultural and political interaction but also direct conflict that has stymied collaboration on many levels. Country economies vary from low-income countries on mainland Africa to wealthy countries such as Saudi Arabia and Israel. Political coordination for reef conservation should advance agreements on governance and management objectives, as well as potential coordination around the nomination of a multinational UNESCO World Heritage Site. When compared to the Red Sea, the Caribbean is a politically more disparate and decentralized region with 22 countries and 13 territories, many of them small island states with smaller economies where there has historically been limited interaction and communication across nations. Considering the decentralization and capacity of Caribbean economies, the Caribbean case study also found bottom-up political coordination offers important benefits. By creating a unified regional voice, Caribbean nations can strengthen their agency in international forums on climate and biodiversity, including efforts to advocate for conservation financing.

4.1.3. Direct Interventions

Direct interventions include regional or sub-regional actions that directly support coral reef resilience.

4.1.3.1. Area-Based Management

Area-based management, both marine and terrestrial, was referenced as an important area of action for supporting coral reef resilience highlighted at both the global level and for the two regional case studies. The global community primarily supports area-based management through the creation, monitoring, and oversight of policies directed at tools such as MPAs. Examples also referenced in the global case study include UN SDG 14.5 (protect 10% of the ocean by 2020) and, more recently, Target 3 under the CBD Global Biodiversity Framework that calls for protecting 30% of land and sea by 2030[45,46]. While the global community helps create policies and targets that help direct area-based management, the actual implementation of PA networks is best directed at the regional level. The global community can further support these efforts by providing guidance and resources, including establishing best practices, that can help drive the implementation of PAs and other spatial management tools at more local levels in efforts to meet national commitments[60,138]. Regional coordination in spatial planning, PA designations, management, and enforcement is further needed to provide comprehensive seascape or landscape scale protection for transboundary ecosystems including coral reefs and watersheds[139,140]. Examples include the Mediterranean Protected Areas Network (MedPAN) which among other initiatives could be a model for regional MPA networks in the Red Sea and Caribbean[141,142]. Additional tools such as international designations of important sites can also be helpful for area-based management (e.g., UNESCO World Heritage Site designation).

4.1.3.2. Ecosystem Restoration

Ecosystem restoration is an example of another conservation tool or approach that, like spatial management, benefits from guidance, leadership, or direction from the global community but requires more local or regional efforts for implementation. One example is Target 2 from the Global Biodiversity Framework as discussed in the Global case study that sets a global target for ecosystem restoration efforts. While coral reef restoration remains expensive and challenging to scale via current methods[76], these policies or targets at the global level can be helpful for raising and allocating the necessary resources to advance and mainstream coral restoration practices to achieve the necessary scale. Other practices in addition to restoration and area-based management may also become more widely utilized as the science investigating novel approaches continues to develop.

4.1.3.3. Communities: Capacity and Engagement

Capacity refers to the knowledge, skills, and institutional ability of conservation practitioners, Indigenous Peoples, local communities, and other stakeholders to design, implement, and manage activities that support reef resilience, including area-based management and restoration. Capacity strengthening involves building this ability through education, peer learning, access to funding and tools, and other forms of support. It is considered a direct intervention because it enables local actors to lead or contribute to conservation efforts. Community engagement also includes the upward flow of knowledge, facilitated by regional political coordination, to allow more local knowledge and experiences to inform global policies. While capacity strengthening and community engagement is primarily developed through regional efforts, the global community also has a responsibility to provide platforms for this engagement.

In the Caribbean case study, widespread cultural awareness of the importance of coral reefs, and some isolated cases of successful local management were evident. However, greater international communication and political coordination could promote this knowledge more widely. Greater local economic agency is also essential in a region where foreign investment, particularly in tourism, often dominates.

Economic empowerment was also highlighted in the Red Sea case study. This included the benefits of diversified reef-based economies aligning with sustainable management, and training and employing community members as conservation practitioners to support monitoring, protection, and restoration, alongside historic efforts for citizen science in the region.

4.2. Global Action: Setting the Tone and Providing Leadership

Our review highlights the global community's critical role in shaping conservation by integrating scientific and local knowledge into targets and commitments. Policies developed at the global level, such as through the Global Biodiversity Framework, help guide conservation interventions regionally. Encouragingly, recent global commitments increasingly reflect priorities identified through our social-ecological approach, including stronger emphasis on area-based protection, ecosystem restoration, sustainable finance, and Indigenous and local knowledge. The alignment with outputs from our workshop, compiled by a diverse coalition of coral reef experts, suggests that global policies can incorporate best available science and regional knowledge. Global policies could drive coral reef conservation if effectively enforced. The global community can also help mainstream emerging tools, such as coral hybridization and protections for mesophotic reefs, as their scientific foundations strengthen.

4.3. Regional Action: Implementation of Seascape Level Conservation Strategies

The framework for regional and global efforts to build coral reef resilience highlights shared priorities across case studies, such as the need for well-designed area-based management, community engagement, and climate change-focused restoration. However, effective implementation of conservation depends on regional context, even for similar ecosystems like coral reefs.

For example, Caribbean MPAs often rely on international resources due to smaller economies spread over many islands, while the Red Sea, while still requiring international support, can benefit from wealthier countries in the region like Saudi Arabia and Israel. Both regions face political coordination challenges, but in different forms: the Caribbean must build communication and alliances among SIDS with limited formal ties, while the Red Sea faces coordination amid conflict. Community engagement also differs: Caribbean efforts elevate existing reef knowledge, while Red Sea initiatives focus more on building awareness through community engagement such as with citizen science and global designations like UNESCO World Heritage Site. These differences may reflect that the Caribbean's coastal populations often depend heavily on coral reefs for tourism[2], storm protection[3,143,144], fisheries[4], and other benefits, whereas in the Red Sea, although some communities rely on reef services such as tourism in Egypt[145], most countries have more diversified economies and a larger proportion of their populations and political centers are physically and culturally distant from coastal regions.

Ultimately, regional differences underscore the need for tailored approaches to transboundary reef management. Regional institutions can play a key role in interpreting global guidance and translating it into action that aligns with each region's social, political, and environmental realities.

4.4. Replication of This Approach

A broader goal of this work is to demonstrate how knowledge exchange among experts can help prioritize needs and actions within a clear framework. The workshop and subsequent case study groups brought together researchers, practitioners, and funders with global and regional experience in coral reef conservation, as well as expertise spanning topics from coral physiology to sustainable finance. This diversity of knowledge was applied through plenary sessions and cross-group discussions to enhance the participatory systems mapping process. The resulting case studies offer a model for how global and regional insights can be combined to guide conservation strategies. This approach can be replicated for coral reef management in other regions, and more broadly across marine conservation.

5. Conclusions

This work demonstrates how structured expert collaboration, using tools like participatory systems mapping, can help identify actionable strategies for ocean conservation, including climate change adaptation and resilience building. In this application, the approach identified pathways for global and regional coordination, with a focus on the Red Sea and Caribbean. Global recommendations include scaling conservation finance, supporting science and knowledge exchange, and reinforcing guidance on interventions such as area-based management and restoration.

At the regional level, the Red Sea was identified as a system with high resilience potential, but threatened by coastal development, overexploitation, and limited public awareness. Enhanced political coordination and public engagement, including the potential for UNESCO World Heritage designation, could strengthen conservation there. In contrast, the Caribbean suffers from extensive reef degradation driven by pollution, overdevelopment, and exploitation. Priority actions there include strengthening political coordination, leveraging local knowledge, improving area-based management, and ensuring equitable access to financing.

Among these case studies, six common levers emerged for supporting transboundary efforts for building resilience: finance, science-based management, political coordination, community engagement, area-based management, and restoration. These were organized into a comprehensive approach indicating where and how these variables factor into global or regional efforts, and how they reinforce one another to ultimately deliver results for coral reefs. However, the work also demonstrates how these areas of action can be tailored to local contexts. The differences between the Red Sea and Caribbean underscore the need for flexibility in interpreting global targets through the lens of local knowledge and capacity. Long-term political commitment from participating states is also essential to initiate and sustain transboundary conservation[146].

Coral reefs are in a state of emergency. Given that global action to curb climate change has not yet led to meaningful reductions in greenhouse gas emissions, leadership from coral reef nations is essential. By reducing direct pressures on reef ecosystems and strengthening regional coordination, these nations can safeguard their reefs through this critical period and preserve the foundation for a future recovery of this ecosystem.

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References

1. Costanza, R. *et al.* The value of the world' s ecosystem services and natural capital. *Nature* **387**, 253–260 (1997).
2. Spalding, M., Burke, L., Wood, S. A., Ashpole, J. & Hutchison, J. Mapping the global value and distribution of coral reef tourism. *Mar Policy* **82**, 104–113 (2017).
3. Beck, M. W. *et al.* The global flood protection savings provided by coral reefs. *Nat Commun* **9**, (2018).
4. Teh, L. S. L., Teh, L. C. L. & Sumaila, U. R. A Global Estimate of the Number of Coral Reef Fishers. *PLoS One* **8**, (2013).
5. Erwin, P. M., López-Legentil, S. & Schuhmann, P. W. The pharmaceutical value of marine biodiversity for anti-cancer drug discovery. *Ecological Economics* **70**, 445–451 (2010).
6. Hughes, T. P. *et al.* Global warming and recurrent mass bleaching of corals. *Nature* **543**, 373–377 (2017).
7. Hughes, T. P. *et al.* Global warming transforms coral reef assemblages. *Nature* **556**, 492–496 (2018).
8. Eddy, T. D. *et al.* Global decline in capacity of coral reefs to provide ecosystem services. *One Earth* **4**, 1278–1285 (2021).
9. Hoegh-Guldberg, O. *et al.* Impacts of 1.5°C Global Warming on Natural and Human Systems. in *Global Warming of 1.5°C. An IPCC Special Report on the impacts of global warming of 1.5°C above pre-industrial levels and related global greenhouse gas emission pathways* 175–312 (Cambridge University Press, Cambridge, UK and New York, NY, USA, 2018). doi:10.1017/9781009157940.005.
10. NOAA. NOAA confirms 4th global coral bleaching event. *National Oceanic and Atmospheric Administration* https://www.noaa.gov/news-release/noaa-confirms-4th-global-coral-bleaching-event (2024).
11. Reimer, J. D. *et al.* The Fourth Global Coral Bleaching Event: Where do we go from here? *Coral Reefs* vol. 43 1121–1125 Preprint at https://doi.org/10.1007/s00338-024-02504-w (2024).

12. WMO. WMO confirms 2024 as warmest year on record at about 1.55°C above pre-industrial level. *World Meteorological Organization* https://wmo.int/news/media-centre/wmo-confirms-2024-warmest-year-record-about-155degc-above-pre-industrial-level (2024).
13. Smith, K. E. *et al.* Ocean extremes as a stress test for marine ecosystems and society. *Nature Climate Change* vol. 15 231–235 Preprint at https://doi.org/10.1038/s41558-025-02269-2 (2025).
14. Spring, J. With coral reefs in jeopardy, UN emergency meeting seeks to raise money to aid them. *Reuters* (2024).
15. Woods Hole Oceanographic Institute. Super Reefs. *Woods Hole Oceanographic Institute* https://superreefs.whoi.edu/ (2025).
16. Barkley, H. C. *et al.* Changes in coral reef communities across a natural gradient in seawater pH. *Sci Adv* **1**, (2015).
17. Rivera, H. E. *et al.* Palau's warmest reefs harbor thermally tolerant corals that thrive across different habitats. *Commun Biol* **5**, (2022).
18. Henley, B. J. *et al.* Highest ocean heat in four centuries places Great Barrier Reef in danger. *Nature* **632**, 320–326 (2024).
19. Naugle, M. S. *et al.* Heat tolerance varies considerably within a reef-building coral species on the Great Barrier Reef. *Commun Earth Environ* **5**, (2024).
20. McClanahan, T. R. Coral community life histories and population dynamics driven by seascape bathymetry and temperature variability. in *Advances in Marine Biology* vol. 87 291–330 (Academic Press, 2020).
21. Kochman, N. R., Grover, R., Rottier, C., Ferrier-Pages, C. & Fine, M. The reef building coral Stylophora pistillata uses stored carbohydrates to maintain ATP levels under thermal stress. *Coral Reefs* **40**, 1473–1485 (2021).
22. Savary, R. *et al.* Fast and pervasive transcriptomic resilience and acclimation of extremely heat-tolerant coral holobionts from the northern Red Sea. *PNAS* **118**, (2021).
23. Evensen, N. R., Fine, M., Perna, G., Voolstra, C. R. & Barshis, D. J. Remarkably high and consistent tolerance of a Red Sea coral to acute and chronic thermal stress exposures. *Limnol Oceanogr* **66**, 1718–1729 (2021).
24. Bellworthy, J. & Fine, M. Beyond peak summer temperatures, branching corals in the Gulf of Aqaba are resilient to thermal stress but sensitive to high light. *Coral Reefs* **36**, 1071–1082 (2017).
25. Fine, M., Gildor, H. & Genin, A. A coral reef refuge in the Red Sea. *Glob Chang Biol* **19**, 3640–3647 (2013).
26. Osman, E. O. *et al.* Thermal refugia against coral bleaching throughout the northern Red Sea. *Glob Chang Biol* **24**, e474–e484 (2018).
27. Hoegh-Guldberg, O. *et al.* Coral reefs in peril in a record-breaking year. *Science (1979)* **382**, 1238–1241 (2023).
28. Zevuloni, A., Fine, M. & Shaked, J. Coral bleaching in the Gulf of Eilat - Reefs on the verge of a tipping point? *Ecology and Environment* vol. 15 https://magazine.isees.org.il/?p=59196 (2024).
29. Ben Zion, I. Even the Gulf of Aqaba's 'supercorals' bleached during 2024 heat wave. *Mongabay* (2025).

30. Starko, S. *et al.* Impacts of marine heatwaves in coastal ecosystems depend on local environmental conditions. *Global Change Biology* vol. 30 Preprint at https://doi.org/10.1111/gcb.17469 (2024).
31. Hall, E. R. *et al.* Eutrophication may compromise the resilience of the Red Sea coral Stylophora pistillata to global change. *Mar Pollut Bull* **131**, 701–711 (2018).
32. Banc-Prandi, G. & Fine, M. Copper enrichment reduces thermal tolerance of the highly resistant Red Sea coral Stylophora pistillata. *Coral Reefs* **38**, 285–296 (2019).
33. Saunders, M. I. *et al.* Bright Spots in Coastal Marine Ecosystem Restoration. *Current Biology* **30**, R1500–R1510 (2020).
34. Bostrom-Einarsson, L. *et al.* Coral restoration – A systematic review of current methods, successes, failures and future directions. *PLoS One* **15**, (2020).
35. Holling, C. S. Resilience and Stability of Ecological Systems. *Annu Rev Ecol Syst* **4**, 1–23 (1973).
36. Folke, C. *et al.* Resilience Thinking: Integrating Resilience, Adaptability and Transformability. *Ecology and Society* **15**, (2010).
37. Adger, W. N., Hughes, T. P., Folke, C., Carpenter, S. R. & Rockstrom, J. Social-Ecological Resilience to Coastal Disasters. *Science (1979)* **309**, 1034–1036 (2005).
38. Mcleod, E. *et al.* The future of resilience-based management in coral reef ecosystems. *J Environ Manage* **233**, 291–301 (2019).
39. Warmuth, L. M. *et al.* Environmental change and connectivity drive coral reef fish abundance in the Western Indian Ocean. *ICES Journal of Marine Science* (2024) doi:10.1093/icesjms/fsae125.
40. Fontoura, L. *et al.* Protecting connectivity promotes successful biodiversity and fisheries conservation. *Science (1979)* **375**, 336–340 (2022).
41. van Woesik, R. *et al.* Coral-bleaching responses to climate change across biological scales. *Glob Chang Biol* 1–22 (2022) doi:10.1111/gcb.16192.
42. Mumby, P. Mangroves enhance the biomass of coral reef fish communities in the Caribbean. *J Geophys Res* **108**, 533–536 (2003).
43. McManus, L. C. *et al.* Evolution and connectivity influence the persistence and recovery of coral reefs under climate change in the Caribbean, Southwest Pacific, and Coral Triangle. *Glob Chang Biol* **27**, 4307–4321 (2021).
44. UNFCCC. *Paris Agreement*. https://unfccc.int/files/essential_background/convention/application/pdf/english_paris_agreement.pdf (2015).
45. United Nations Department of Economic and Social Affairs. *The Sustainable Development Goals Report*. *United Nations* (2017) doi:10.18356/3405d09f-en.
46. Convention on Biological Diversity. *The Kunming-Montréal Global Biodiversity Framework*. *United Nations Environment Programme* vol. Fifteenth https://www.cbd.int/doc/c/e6d3/cd1d/daf663719a03902a9b116c34/cop-15-l-25-en.pdf (2022).
47. Meyers, D., Bhattacharyya, K., Bray, B., Bohorquez, J. & Leone, S. *The Global Fund for Coral Reefs: Investment Plan 2021*. https://static1.squarespace.com/static/57e1f17b37c58156a98f1ee4/t/60dcad139c3f6276dabb9b06/1625074968533/GFCR+Investment+Plan+2021_final.pdf (2021).

48. ICRI. *New Global Coral Reef Partnership Supports Biodiversity Goals*. https://icriforum.org/documents/icri-creation/ (1994).
49. ICRI. *The Coral Reef Breakthrough*. https://icriforum.org/documents/coral-breakthrough/ (2023).
50. Secretariat of the Convention on Biological Diversity. *Global Biodiversity Outlook 5*. (2020).
51. Nerini, F. F. *et al.* Extending the Sustainable Development Goals to 2050 - a road map. *Nature* **630**, 555–558 (2024).
52. Mahajan, S. L. *et al.* Systems thinking for planning and evaluating conservation interventions. *Conservation Science and Practice* vol. 1 Preprint at https://doi.org/10.1111/csp2.44 (2019).
53. Heemskerk, M., Wilson, K. & Pavao-Zuckerman, M. Conceptual Models as Tools for Communication Across Disciplines. *Conservation Ecology* **7**, (2003).
54. UNEP-WCMC. Global distribution of coral reefs, compiled from multiple sources including the Millennium Coral Reef Mapping Project. Preprint at https://data-gis.unep-wcmc.org/portal/apps/mapviewer/index.html?layers=0613604367334836863f5c0c10e452bf (2021).
55. Mittal, H. V. R. *et al.* Hazard assessment of oil spills along the main shipping lane in the Red Sea. *Sci Rep* **11**, (2021).
56. World Database on Protected Areas. Discover the world's protected and conserved areas. *Protected Planet, UN Environment Programme* https://www.protectedplanet.net/en (2025).
57. MapChart.net. World Map: Simple. *MapChart.net* https://www.mapchart.net/world.html.
58. Allen Coral Atlas. Imagery, maps and monitoring of the world's tropical coral reefs. (2022) doi:doi.org/10.5281/zenodo.3833242.
59. Knowlton, N. *et al. Rebuilding Coral Reefs: A Decadal Grand Challenge*. (2021).
60. Grorud-Colvert, K. *et al.* The MPA Guide: A framework to achieve global goals for the ocean. *Science (1979)* **373**, (2021).
61. Fawzy, S., Osman, A. I., Doran, J. & Rooney, D. W. Strategies for mitigation of climate change: a review. *Environmental Chemistry Letters* vol. 18 2069–2094 Preprint at https://doi.org/10.1007/s10311-020-01059-w (2020).
62. Lawrence, M. G. *et al.* Evaluating climate geoengineering proposals in the context of the Paris Agreement temperature goals. *Nature Communications* vol. 9 Preprint at https://doi.org/10.1038/s41467-018-05938-3 (2018).
63. Nieto, J., Carpintero, Ó. & Miguel, L. J. Less than 2 °C? An Economic-Environmental Evaluation of the Paris Agreement. *Ecological Economics* **146**, 69–84 (2018).
64. Rising, J. & Heal, G. Global Benefits of Marine Protected Areas. *Statewide Agricultural Land Use Baseline 2015* **1**, (2015).
65. Lynham, J. & Carlos Villaseñor-Derbez, J. Evidence of spillover benefits from large-scale marine protected areas to purse seine fisheries. **386**, 1276–1281 (2025).
66. Roberts, C. M., O'Leary, B. C. & Hawkins, J. P. Climate change mitigation and nature conservation both require higher protected area targets. *Philisophical Transactions of the Royal Society* **375**, (2020).

67. O'Leary, B. C. *et al.* Addressing Criticisms of Large-Scale Marine Protected Areas. *Bioscience* **68**, 359–370 (2018).
68. Gurney, G. G. *et al.* Biodiversity needs every tool in the box: use of OECMs. *Nature* **595**, (2021).
69. Dawson, N. M. *et al.* The role of Indigenous peoples and local communities in effective and equitable conservation. *Ecology and Society* **26**, 19 (2021).
70. Goolmeer, T. *et al.* Recognizing culturally significant species and Indigenous-led management is key to meeting international biodiversity obligations. *Conserv Lett* 1–9 (2022) doi:10.1111/conl.12899.
71. Dawson, N. M. *et al.* Is it just conservation? A typology of Indigenous peoples' and local communities' roles in conserving biodiversity. *One Earth* vol. 7 1007–1021 Preprint at https://doi.org/10.1016/j.oneear.2024.05.001 (2024).
72. ICRI. International Year of the Reef (IYOR). https://icriforum.org/international-year-of-the-reef/ (2018).
73. Hein, M. *et al. Coral Reef Restoration as a Strategy to Improve Ecosystem Services - A Guide to Coral Restoration Methods*. (2020).
74. Coral Restoration Consortium. Map of Global Coral Restoration. https://www.crc.world/restoration-map (2025).
75. Shaver, E. C. *et al.* A roadmap to integrating resilience into the practice of coral reef restoration. *Glob Chang Biol* **28**, 4751–4764 (2022).
76. Mulà, C. *et al.* Restoration cannot be scaled up globally to save reefs from loss and degradation. *Nat Ecol Evol* (2025) doi:10.1038/s41559-025-02667-x.
77. Hughes, T. P. *et al.* Coral reefs in the Anthropocene. *Nature* **546**, 82–90 (2017).
78. Hughes, T. P., Baird, A. H., Morrison, T. H. & Torda, G. Principles for coral reef restoration in the anthropocene. *One Earth* vol. 6 656–665 Preprint at https://doi.org/10.1016/j.oneear.2023.04.008 (2023).
79. Quigley, K. M., Hein, M. & Suggett, D. J. Translating the 10 golden rules of reforestation for coral reef restoration. *Conservation Biology* **36**, (2022).
80. Hinderstein, L. M. *et al.* Theme section on 'Mesophotic Coral Ecosystems: Characterization, Ecology, and Management'. *Coral Reefs* vol. 29 247–251 Preprint at https://doi.org/10.1007/s00338-010-0614-5 (2010).
81. Lesser, M. P., Slattery, M. & Leichter, J. J. Ecology of mesophotic coral reefs. *Journal of Experimental Marine Biology and Ecology* vol. 375 1–8 Preprint at https://doi.org/10.1016/j.jembe.2009.05.009 (2009).
82. Chakraborty, M. I. *et al.* Deep-water corals indicate the Red Sea survived the last glacial lowstand. *Proc Natl Acad Sci U S A* **122**, (2025).
83. Chaidez, V., Dreano, D., Agusti, S., Duarte, C. M. & Hoteit, I. Decadal trends in Red Sea maximum surface temperature. *Sci Rep* **7**, (2017).
84. Hobday, A. J. *et al.* A hierarchical approach to defining marine heatwaves. *Prog Oceanogr* **141**, 227–238 (2016).
85. Genevier, L. G. C., Jamil, T., Raitsos, D. E., Krokos, G. & Hoteit, I. Marine heatwaves reveal coral reef zones susceptible to bleaching in the Red Sea. *Glob Chang Biol* **25**, 2338–2351 (2019).

86. Genin, A., Levy, L., Sharon, G., Raitsos E , D. E. & Diamant, A. Rapid onsets of warming events trigger mass mortality of coral reef fish. *PNAS* **117**, 25378–25385 (2020).
87. Kochman-Gino, N. R. & Fine, M. Reef building corals show resilience to the hottest marine heatwave on record in the Gulf of Aqaba. *Front Mar Sci* **10**, (2023).
88. Davies, T. W. *et al.* Global disruption of coral broadcast spawning associated with artificial light at night. *Nat Commun* **14**, (2023).
89. Rosenberg, Y. *et al.* Urbanization comprehensively impairs biological rhythms in coral holobionts. *Glob Chang Biol* **28**, 3349–3364 (2022).
90. Kleinhaus, K., Voolstra, C. R., Meibom, A., Amitai, Y. & Gildor, H. A Closing Window of Opportunity to Save a Unique Marine Ecosystem. **7**, 2018–2020 (2020).
91. Gallegati, S., Masiá, P., Fanelli, E. & Danovaro, R. The impact of natural capital loss on blue-tourism economy: The Red Sea case study. *Mar Policy* **172**, 106507 (2025).
92. ICRI. *Resolution for the Red Sea Region*. *International Coral Reef Initiative* https://icriforum.org/documents/resolution-red-sea-region/ (2024).
93. UNESCO. Coral Reefs of the Gulf of Aqaba and the Red Sea in the Kingom of Saudi Arabia. *Permanent Delegation of the Kingdom of Saudi Arabia to UNESCO* https://whc.unesco.org/en/tentativelists/6701/ (2024).
94. The Nature Conservancy. *Executive Summary: Reef-Adjacent Tourism Value of Caribbean Coral Reefs*. https://www.nature.org/content/dam/tnc/nature/en/documents/Reef_Tourism_Study_Summary.PDF (2019).
95. Conservation International. *Economic Values of Coral Reefs, Mangroves, and Seagrasses: A Global Compilation*. https://icriforum.org/wp-content/uploads/2019/12/Economic_values_global compilation.pdf (2008).
96. ICRI. *Communicating the Economic and Social Importance of Coral Reefs for Caribbean Countries*. https://icriforum.org/wp-content/uploads/2019/12/ICRI_Sweden-Caribbean%20_Factsheet_0.pdf (2019).
97. Storlazzi, C. D. *et al.* Hybrid coral reef restoration can be a cost-effective nature-based solution to provide protection to vulnerable coastal populations. *Sci Adv* **11**, (2025).
98. Jackson, J., Donovan, M., Cramer, K. & Lam, V. *Status and Trends of Caribbean Coral Reefs: 1970-2012*. (2014).
99. Robinson, S. ann & Wren, C. Geographies of vulnerability: a research note on human system adaptations to climate change in the Caribbean. *Geografisk Tidsskrift - Danish Journal of Geography* **120**, 79–86 (2020).
100. Nurse, L. *et al.* Small Islands. in *Climate Change 2014: Impacts, Adaptation, and Vulnerability. Part B: Regional Aspects. Contribution of Working Group II to the Fifth Assessment Report of the Intergovernmental Panel on Climate Change* 1613–1654 (Cambridge University Press, 2014).
101. Hernández-Delgado, E. A. *et al.* Stronger Hurricanes and Climate Change in the Caribbean Sea: Threats to the Sustainability of Endangered Coral Species. *Sustainability (Switzerland)* **16**, (2024).
102. Wakwella, A. *et al. Managing Watersheds for Coral Reef and Public Health*. https://repository.fnu.ac.fj/id/eprint/42/1/Managing%20Watersheds%20for%20Coral%20R

eefs%20and%20Public%20Health.%20A%20Vibrant%20Oceans%20Initiative%20Whitepaper%202022.pdf (2022).
103. Mumby, P. J. *et al.* Fishing, Trophic Cascades, and the Process of Grazing on Coral Reefs. *Science (1979)* **311**, 98–98101 (2006).
104. Rassweiler, A. & Wall, L. M. Rotational fishery closures could enhance coral recovery in systems with alternative states. *Conservation Letters* vol. 17 Preprint at https://doi.org/10.1111/conl.13008 (2024).
105. Bohorquez, J. J. *et al.* China's little-known efforts to protect its marine ecosystems safeguard some habitats but omit others. *Sci Adv* **7**, (2021).
106. Fischer, A., Bhakta, D., Macmillan-Lawler, M. & Harris, P. Existing global marine protected area network is not representative or comprehensive measured against seafloor geomorphic features and benthic habitats. *Ocean Coast Manag* **167**, 176–187 (2019).
107. Resource Watch. Coral Reefs: Caribbean. *Resource Watch* https://resourcewatch.org/dashboards/coral-reefs-caribbean.
108. Healthy Reefs for Healthy People. *MESOAMERICAN REEF REPORT CARD*. https://www.healthyreefs.org/en/healthy-reefs-data/report-cards (2024).
109. The Nature Conservancy. Caribbean Challenge Initiative. *The Nature Conservancy* https://www.nature.org/en-us/about-us/where-we-work/caribbean/stories-in-caribbean/caribbean-challenge/ (2020).
110. MacNeill, T. & Wozniak, D. The economic, social, and environmental impacts of cruise tourism. *Tour Manag* **66**, 387–404 (2018).
111. Pantin, D. A. The challenge of sustainable development in small island developing states: Case study on tourism in the Caribbean. *Nat Resour Forum* **23**, 221–233 (1999).
112. Naseem, S., Hui, W., Sarfraz, M. & Mohsin, M. Repercussions of Sustainable Agricultural Productivity, Foreign Direct Investment, Renewable Energy, and Environmental Decay: Recent Evidence from Latin America and the Caribbean. *Front Environ Sci* **9**, (2021).
113. Hippolyte, A. & Haynes, J. Asymmetrical Approaches to Environmental Regulation in the Caribbean: A Critique of the Region's Foreign Investment Landscape. *Manchester Journal of International Economic Law* **21**, 122–152 (2024).
114. Duffy, R. Shadow players: Ecotourism development, corruption and state politics in Belize. *Third World Q* **21**, 549–565 (2000).
115. Laurance, W. F. The perils of payoff: Corruption as a threat to global biodiversity. *Trends in Ecology and Evolution* vol. 19 399–401 Preprint at https://doi.org/10.1016/j.tree.2004.06.001 (2004).
116. Turner, R. A. *et al.* Measuring good governance for complex ecosystems: Perceptions of coral reef-dependent communities in the Caribbean. *Global Environmental Change* **29**, 105–117 (2014).
117. Camargo, C. *et al.* Community involvement in management for maintaining coral reef resilience and biodiversity in southern Caribbean marine protected areas. *Biodivers Conserv* **18**, 935–956 (2009).
118. Rivera, A. *et al.* Community-based natural resource management in Roatan: Strengths and challenges. *Ambio* (2024) doi:10.1007/s13280.

119. Chirico, A. A. D., McClanahan, T. R. & Eklöf, J. S. Community- and government-managed marine protected areas increase fish size, biomass and potential value. *PLoS One* **12**, 1–19 (2017).
120. Fidler, R. Y. *et al.* Participation, not penalties : Community involvement and equitable governance contribute to more effective multiuse protected areas. *Sci Adv* **8**, (2022).
121. UNDP. UNDP/GEF CLME+ Project. *United Nations Development Programme* https://www.clmeproject.org/.
122. Fanning, L. & Mahon, R. *Caribbean Large Marine Ecosystem+ Strategic Action Plan (SAP) Monitoring Report: Baseline 2011-2015*. www.clmeplus.org (2021).
123. UNEP. *MPA Finance: Status and Future Directions*. (2022).
124. Deutz, A. *et al. Financing Nature: Closing the Global Biodiversity Financing Gap*. (2020).
125. Gill, D. A. *et al.* Capacity shortfalls hinder the performance of marine protected areas globally. *Nature* **543**, 665–669 (2017).
126. World Economic Forum. The Bridgetown Initiative: here's everything you need to know. *World Economic Forum* https://www.weforum.org/stories/2023/01/barbados-bridgetown-initiative-climate-change/ (2023).
127. The Nature Conservancy. *Case Study: Belize Debt Conversion for Marine Conservation*. https://www.nature.org/content/dam/tnc/nature/en/documents/TNC-Belize-Debt-Conversion-Case-Study.pdf (2022).
128. The Nature Conservancy. The Nature Conservancy Announces Innovative Nature Bonds project in The Bahamas. *The Nature Conservancy* https://www.nature.org/en-us/newsroom/tnc-announces-new-nature-bonds-project-bahamas/ (2024).
129. The Nature Conservancy. *Case Study: Barbados Blue Bonds for Ocean Conservation*. https://www.nature.org/en-us/what-we-do/our-insights/perspectives/an-audacious-plan-to-save-the-worlds-oceans/ (2023).
130. Victurine, R. *et al. Conservation Finance for Coral Reefs: A Vibrant Oceans Initiative Whitepaper*. wcs.org/coral-finance-whitepaper (2022).
131. Pew Bertarelli Ocean Legacy. *To Protect Galapagos Islands, Ecuador Turns to Innovative Financing*. https://www.pewtrusts.org/-/media/assets/2023/09/to_protect_galapagos_ecuador_turns_to_innovative_funding.pdf (2023).
132. Convention on Biological Diversity. COP16 Agenda item 11: Resource mobilization and financial mechanism. in (UNEP, CBD, Rome, Italy, 2025).
133. Hares, S. Mexican coral reef and beach get unique insurance policy against hurricane damage. *Reuters* 4 (2018).
134. Reguero, B. G. *et al.* Financing coastal resilience by combining nature-based risk reduction with insurance. *Ecological Economics* **169**, (2020).
135. The Nature Conservancy. *Insuring Natural Infrastructure Against Climate Impacts: 2024 Hawai'i Reef Insurance Policy Benefits from Upgrades*. https://www.nature.org/content/dam/tnc/nature/en/documents/2024_Hawaii-Reef-Insurance-fact-sheet.pdf (2024).
136. Mcleod, E. *et al.* A blueprint for blue carbon: toward an improved understanding of the role of vegetated coastal habitats in sequestering CO2. *Front Ecol Environ* **9**, 552–560 (2011).

137. Macreadie, P. I. *et al.* Can we manage coastal ecosystems to sequester more blue carbon? *Front Ecol Environ* 206–213 (2017) doi:10.1002/fee.1484.
138. WWF and IUCN WCPA. *30x30: A Guide to Inclusive, Equitable and Effective Implementation of Target 3 of the Kunming-Montreal Global Biodiversity Framework*. https://www.worldwildlife.org/publications/30x30-a-guide-to-inclusive-equitable-and-effective-implementation-of-target-3-of-the-kunming-montreal-global-biodiversity-framework (2023).
139. Schill, S. *et al.* No Reef Is an Island: Integrating Coral Reef Connectivity Data into the Design of Regional-Scale Marine Protected Area Networks. *PLoS One* **10**, (2015).
140. Wenzel, L. *et al. Marine Protected Areas 2020: Building Effective Conservation Networks*. https://nmsmarineprotectedareas.blob.core.windows.net/marineprotectedareas-prod/media/docs/2020-mpa-building-effective-conservation-networks.pdf.
141. UNDESA. UNDESA Regional Marine Protected Areas networks in action. *United Nations Department of Economic and Social Affairs* https://sdgs.un.org/partnerships/regional-marine-protected-areas-networks-action.
142. Binet, T., Diazabakana, A., Laustriat, M. & Hernandez, S. *Sustainable Financing of Marine Protected Areas in the Mediterranean: A Financial Analysis*. http://www.rac-spa.org/sites/default/files/doc_medmpanet/final_docs_regional/55_study_on_the_sustainable_financing_of_mediterranean_mpas.pdf (2016).
143. UN Environment, ISU, ICRI & Trucost. *The Coral Reef Economy: The Business Case for Investment in the Protection, Preservation and Enhancement of Coral Reef Health*. (2018).
144. Brathwaite, A., Clua, E., Roach, R. & Pascal, N. Coral reef restoration for coastal protection: Crafting technical and financial solutions. *J Environ Manage* **310**, (2022).
145. Kleinhaus, K., Bohorquez, J. J., Awadallah, Y. M., Meyers, D. & Pikitch, E. Boost Egypt’s coral reef conservation efforts. *Science (1979)* **378**, 608–609 (2022).
146. Mackelworth, P. C. *et al.* Geopolitics and Marine Conservation: Synergies and Conflicts. *Front Mar Sci* **6**, (2019).