EXECUTIVE SUMMARY


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Meeting 30 by 30: The Role of Coral Reef Restoration

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The next 10 years are a critical window of opportunity for action to protect and restore ocean health. Governments, NGOs, researchers, philanthropists, private sector, and communities have come together to set ambitious global goals and plans of actions to safeguard and restore ocean health and associated ecosystem services. These include, for example, the 30 by 30 initiative to protect 30% of the world's oceans, lands, and freshwaters by 2030, and the recognition that ecosystem restoration is essential to support resilience and adaptation. However, effective implementation of marine habitat restoration, specifically coral reef restoration, requires guidance to inform if, when, and where, investing in restoration is appropriate. Here, we review the role of coral reef restoration in the context of climate change and global 30 by 30 targets arguing that while restoration should not be used as a silver-bullet in the face of global declines, it has an important role to play to deliver social and ecological goals. By carefully reviewing current limitations barriers and opportunities, we provide avenues for improving the effectiveness of coral reef restoration and assist evidence-based investment and decision making. These include a list of best practices for coral reef restoration, as well as targeted guidance on how to overcome policy barriers, build capacity, and support investments and research and development. We conclude with specific recommendations for governments, funders, conservation organizations, and stakeholders on how to meet 30 by 30 targets through promoting the persistence, survival, and where necessary the restoration of tropical coral reefs to secure valuable ecosystem services that they provide. These recommendations include:

- **Knowledge sharing and standardized monitoring to:**
  - **reduce the spread of poorly planned and implemented projects**
  - **improve effectiveness of restoration to better achieve intended outcomes**
- **Assessments of current restoration projects and funding sources to highlight geographic and ecosystem biases in funding and inform future prioritization**
- **Diversification of funding opportunities, particularly private funding with the potential to scale up existing efforts in space and time**
- **Guidance for countries developing new (or modifying existing) policies to enable restoration based on global best practices and measure the effectiveness of restoration**
- **Strengthening local and national policies and legislation to provide an enabling environment for restoration, streamlining policies and permits, and improving coordination across agencies that support restoration**
- **Clear articulation of costs, benefits, and risks of specific restoration interventions including the ecosystem services recovered from restorative actions**
- **Support for small-scale restoration projects to apply innovations/technology**
- **Inclusive and participatory processes that engage stakeholders, right-holders, and under-represented groups in all phases of restoration**
- **Multi-habitat restoration projects and development of maps showing global restoration potential for coral reefs and other critical marine habitats to support projects with the greatest opportunity for success**

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MEETING 30 BY 30:
THE ROLE OF CORAL REEF RESTORATION

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Background

The next 10 years have been identified as a critical window of opportunity for action to protect and restore ocean health. Ocean ecosystems around the world are threatened by pollution, lack of oxygen, coastal development, destructive fishing practices, overharvesting, and the growing impacts of climate change. We have already lost one-third of the world's mangroves and seagrasses, half of the world's coral reefs and saltmarshes, and 85% of the world's shellfish reefs. With these losses, we lose the critical benefits that these habitats provide. The most recent Intergovernmental Panel on Climate Change (IPCC) report predicts that 70% to 90% of coral reefs globally could be lost by 2050 (IPCC 2022).

In response, governments, NGOs, researchers, philanthropists, private sector, and communities have come together to set ambitious global goals and plans of actions to safeguard and restore ocean health and associated ecosystem services. For example, 30 by 30 is a global initiative to protect 30% of the world's oceans, lands, and freshwaters by 2030. It has been incorporated in the CBD post-2020 Global Biodiversity Framework (GBF) and is championed by over 70 countries. Other global initiatives have been developed specifically for the oceans, such as the United Nation's launch of the Decade of Ocean Science for Sustainable Development, which focuses on supporting efforts to reverse the decline in ocean health. Further, ecosystem-specific commitments also have been developed, such as the International Coral Reef Initiative's Plan of Action for 2021-2024.

Throughout these global commitments and plans of action, *restoring* coastal and marine ecosystems is increasingly recognized as essential, specifically restoring ecosystems to support resilience and adaptation (Duarte et al. 2020, Kleypas et al. 2021, Knowlton et al. 2021). For the first time, a specific target on ecosystem restoration (Target 2) was proposed in the post-2020 GBF. The support for and number of marine restoration projects has increased significantly over the past decade, specifically coral reef restoration (Duarte et al. 2020, Boström-Einarsson et al. 2020). Restoration is also being increasingly integrated into international policies and investment strategies (e.g., restoration target in GBF; new EU law with targets to restore terrestrial and marine habitats; focal pillar in International Coral Reef Initiative's Plan of Action for 2021–2024 and key outcome for the Global Fund for Coral Reefs).

Effective implementation of marine habitat restoration, specifically coral reef restoration, requires guidance to inform if, when, and where, investing in restoration is appropriate. Here, we review the role of coral reef restoration in the context of climate change and global 30 by 30 targets and provide targeted recommendations for more effective ocean conservation investment and management strategies.

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Coral reef restoration

Evolution of concept of coral reef restoration

Coral reef restoration includes a wide range of actions from growing and planting nursery grown corals onto reefs, ensuring habitat is suitable for coral growth, harvesting naturally produced eggs and sperm to create millions of new genetic individuals, and building reef resilience to climate change and other threats.

The first documented restoration efforts date back to the 1970s-80s and initially focused on installing artificial structures or restoring reef structure following ship groundings (Precht 2006; Young et al. 2012). Subsequently, such were complemented by the transplantation of coral fragments or colonies, which was often part of endangered species recovery efforts (e.g., *Acropora palmata, Acropora cervicornis* in the Caribbean; Johnson et al. 2011, Young et al. 2012). Coral gardening efforts started in the 1990s and led to the implementation of larger scale restoration efforts in the Red Sea and Indo-Pacific regions (Rinkevich et al. 1995, Oren and Benayahu 1997, Treeck and Schuhmacher 1997). Over the last two decades, the number of restoration efforts rapidly increased in most reef regions of the world, along with more diverse methods such as larval enhancement and coral micro-fragmentation (Boström-Einarsson et al. 2020).

Reef restoration is now undertaken for a variety of reasons including ecological (e.g., restoring reef structure and function) and socio-economic (e.g., supporting coral reef tourism industry, sustaining local fisheries) goals (Hein et al. 2021). Further, reef restoration efforts are increasingly seeking to restore coral reef ecosystem function, resilience, and adaptation to local and global threats. Building on global ecosystem restoration guidance (e.g., SER), coral reef restoration has recently been defined as "*an active intervention aimed to assist the recovery of reef structure, function, and key reef species in the face of rising climate and anthropogenic pressures, promoting reef resilience and the sustainable delivery of reef ecosystem services.*" (Hein et al. 2021).

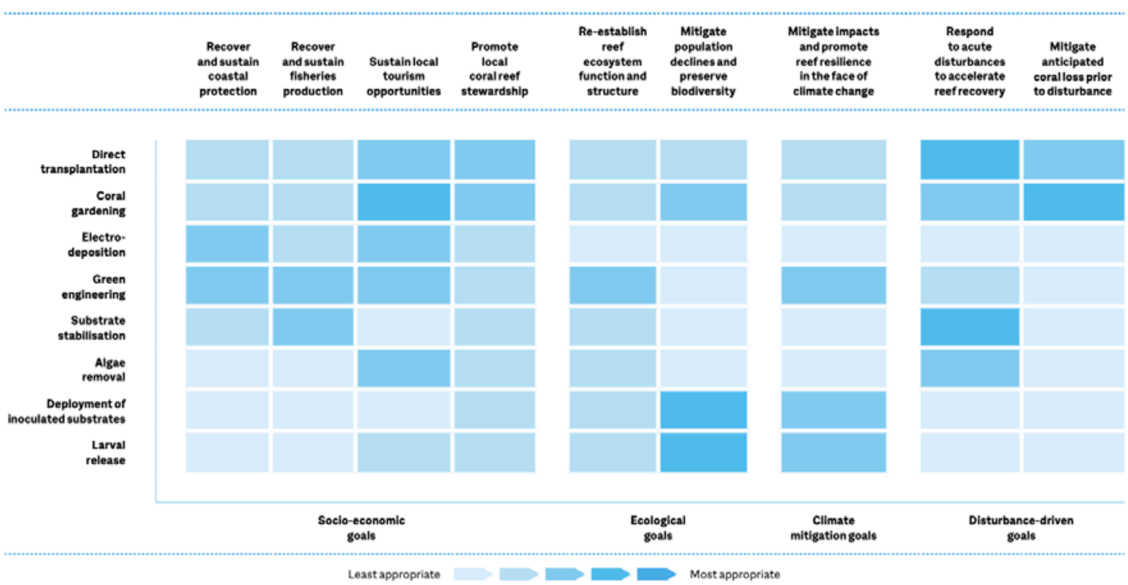

Fig 1. Current goals of coral reef restoration and restoration methods ranked from least to most appropriate to address these goals.
Source: Hein et al. 2020.

Coral reef restoration in the face of climate change

The science is clear that coral reef restoration will fail if it does not consider the impacts of climate change and other threats (e.g., poor water quality; Edwards and Clark 1999). Guidance for how to develop climate-smart coral reef restoration efforts has been developed including recommendations for site and species selection (Shaver et al. 2021). In addition, a number of recent reviews have explored how current and future interventions may be used to improve the adaptation capacity and resilience of coral reef ecosystems (e.g., through innovative methods such as selective breeding, assisted evolution, probiotics; NASEM 2019, Bay et al. 2019, Suggett and Van Oppen 2022). Large investments in research and development through programs such as the Australian Reef Restoration and Adaptation Program (RRAP) and the G20 Coral Research and Development Accelerator Platform (CORDAP) are also facilitating exciting new initiatives to develop and scale-up coral adaptation solutions for coral reef conservation and restoration.

> “Current limitations in coral reef restoration require a major R&D effort to advance technologies to make them affordable, scalable and successful. This is a global challenge we must tackle under the UN Decade for Ecosystem Restoration”
>
> *Carlos M. Duarte, Executive Director of the Global Coral R&D Accelerator Platform*

In addition, reef restoration is increasingly recognized as a vital management tool, alongside other marine conservation strategies such as MPAs and other effective area-based conservation mechanisms (OECMs) to deliver social and ecological goals. Restoration should not be considered as a solution on its own, nor as a first line action. However, when integrated within broader management strategies, restoration can be a valuable and necessary tool to support coral reef resilience (Hein et al. 2021, Kleypas et al. 2021, Knowlton et al. 2021, Shaver et al. 2022). Reef restoration must also be considered alongside the restoration of other critical marine habitats. The integration of coral reef restoration with coastal habitats such as mangroves and seagrass beds has been shown to maximize positive outcomes by harnessing ecological connections and feedback processes (Milbrandt et al. 2015, Shaver et al. 2022).

> “Degraded coral reefs can no longer provide the goods and services that functional coral reefs provide and active interventions to support recovery may needed in some areas. ICRI recognizes that reef restoration is a valid management option in areas when natural recovery is eroded but is not a ‘silver bullet’ and should be accompanied by other actions that support reef resilience.”
>
> *Francis Staub, Global Coordinator, International Coral Reef Initiative (ICRI) Secretariat*

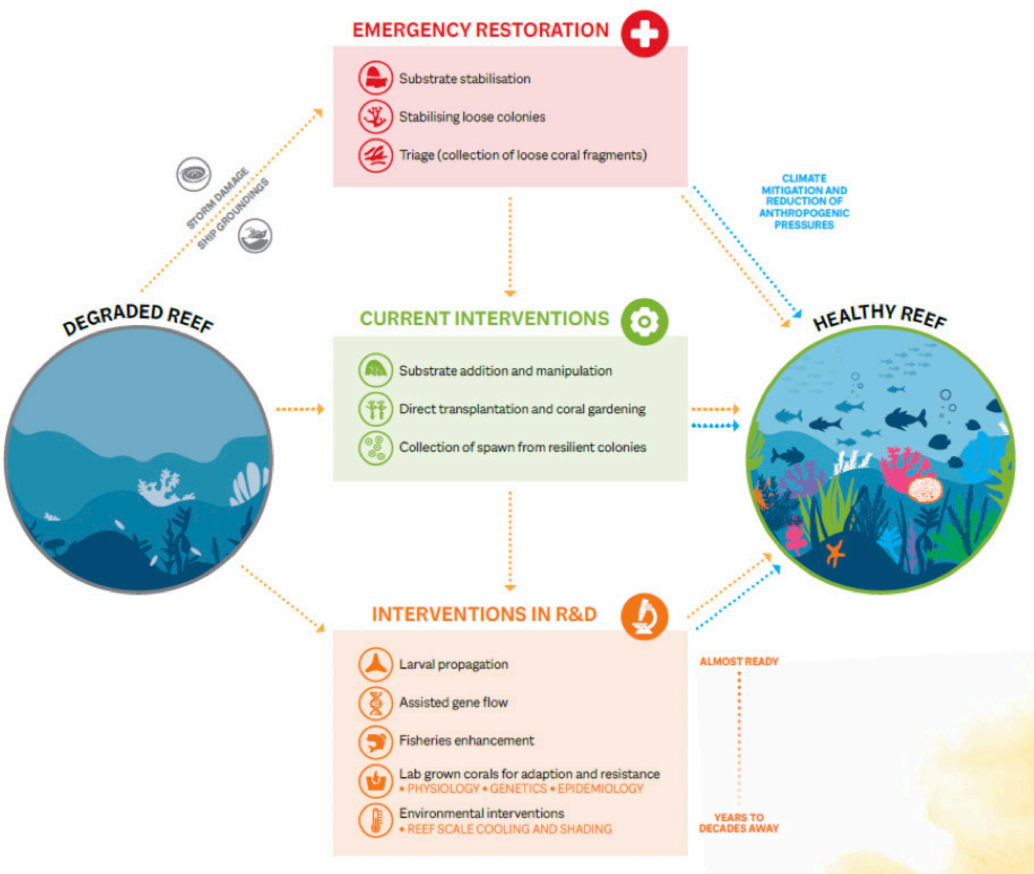

Figure 2. Overview of current and in-development interventions that can be used to assist the recovery of a degraded reef. Source: Hein et al. 2020.

The framework of 30 by 30

Defining global 30 by 30 target

The global 30 by 30 target aims to conserve at least 30% of the world's lands, oceans, and freshwater by 2030. It provides a key framework for accelerating global commitments for ocean conservation globally. The 30% target is a notable increase from the previous targets set from Aichi Target 11 for 17% of terrestrial and inland waters, and only 10% of marine and coastal habitats, which were deemed inadequate to conserve biodiversity, preserve ecosystem services, and support socio-economic priorities (e.g., O'leary et al. 2016, Woodley et al. 2019). Increasing the target to 30% was broadly supported by international experts including the Intergovernmental Science-Policy Platform on Biodiversity and Ecosystem Services (IPBES; IPBES 2019) and the International Union for Conservation of Nature (IUCN; Woodley et al. 2019) with the rationale that these protected areas need to be effectively managed, and representative of key habitats (Mcleod et al. 2009; Jung et al. 2019, Hannah et al. 2020).

30% of what?

Protecting a representative suite of critical marine habitats

The 30% protection target has existed for decades in the marine conservation literature, thus important lessons for applying 30 by 30 can be gleaned from this early work. For example, guidance for designing marine protected areas (MPA) called for the protection of 20–30% of each marine habitat type in a given location (e.g., Roberts et al. 2003; Fernandes et al. 2005; Green et al. 2007; Mcleod et al. 2009; Bonsack et al. 2020). By protecting a representative range of habitat types, MPAs have greater potential to protect a region's biodiversity, biological connections between habitats, and ecological functions (Mcleod et al. 2009).

In addition to protecting a representative range of habitat types, it is also important to protect ecosystems that are biologically or ecologically important (e.g., such as those that protect coastlines from waves, sequester carbon sink, and are biodiversity hotspots; Ferrario et al. 2014; Jung et al. 2019, Dinerstein et al. 2109). For example, coral reefs are a critical ecosystem to prioritize for protection under 30 by 30, and other global conservation frameworks, as they support ¼ of all marine life and the needs of 1 billion people globally and can reduce wave energy by up to 97% (Ferrario et al. 2014). Other critical coastal ecosystems that provide vital ecosystem services (fisheries, livelihoods, nursery habitats, carbon storage, etc.) include mangroves, shellfish reefs, seagrasses, saltmarshes and kelp forests.

Protecting climate refugia and promoting evolutionary adaptation under 30 by 30

The protection of climate refugia refugia, as well as likely sources of heat-adapted coral larvae, within 30 by 30 conservation targets is an urgent priority. In the context of coral reefs, refugia are reefs that have avoided climate-change related stresses and are predicted to experience less future acceleration of stresses (e.g., Mcleod et al. 2009; McClanahan et al. 2011; Keppel et al. 2012; Chollett and Mumby 2013; Mcleod et al. 2019). Indeed, global efforts have sought to identify climate refugia to inform coral reef conservation efforts (e.g., 50 Reefs initiative; Beyer et al. 2018). More recently, researchers suggest that conservation strategies should incorporate resistance and recovery refugia, i.e., reefs that can also display resistance to climate exposure or show rapid recovery after bleaching events (McClanahan et al. 2022), as well as reefs that are likely sources of heat-adapted larvae (Colton et al. 2022).

Embedding 30 by 30 approaches under a resilience framework

Conservation strategies that do not consider climate change impacts are destined to fail as climate change impacts intensify and further degrade habitats and communities globally. In response, conservation management strategies are increasingly turning to resilience-based management (RBM) to address the shortcomings of traditional MPAs. In RBM, MPAs do not stand-alone but are part of a network incorporating a variety of management actions that enhance system resilience (e.g., local threat mitigation such as pollution and sedimentation) and support ecosystems and human well-being in adapting to changing conditions (McLeod et al. 2019). Some of the key recommendations for effective RBM include protecting a diversity of species, habitats, and functional groups, maintaining pathways of connectivity across key habitats, and investing in experimental approaches that support resilience, particularly those that may facilitate the adaptation and transformation of ecological and social systems (McLeod et al. 2019). While still relatively new, early examples of RBM on reefs suggest that deploying multiple interventions are more effective management strategies than any single intervention alone (Condie et al. 2021). Effectively meeting the 30 by 30 challenge for coral reefs necessitates thinking outside of the protection target box to move towards strategies that integrate multiple interventions with climate-driven prioritization frameworks.

Challenges of achieving 30 by 30

Limitations of MPAs

The success of meeting 30 by 30 goals depends on the ability of conservation tools (e.g., MPAs, MPA networks) to achieve their intended objectives. Unfortunately, less than 3% of existing MPAs are effectively managed (Marine Protection Atlas 2022). A recent global study showed that 65% of MPAs assessed had insufficient budget to cover management needs and over 90% lacked the necessary staff capacity (Gill et al. 2017). Other studies have shown that nearly half of the MPAs worldwide are ineffective at reducing overfishing (Burke *et al.*, 2011). A key need moving forward is ensuring that MPAs have the funding and capacity to safeguard biodiversity and address threats such as overfishing (Gill et al. 2017). Further, some MPAs have failed to deliver equitable outcomes to local stakeholders, are limited by non-compliance and do not achieve biodiversity outcomes. In such cases, other tools such as other effective area-based conservation mechanisms (OECMs) have an important and complementary role to play (Gurney et al. 2021). Therefore, achieving 30 by 30 goals requires bolstering the effectiveness of existing MPAs and incorporating additional tools (e.g., OECMs).

Expanding the toolbox to include restoration

In response to escalating threats, conservation strategies to achieve 30 by 30 goals that aim to protect ecosystems are no longer enough to maintain biodiversity, especially for marine ecosystems such as coral reefs. Urgent climate mitigation efforts and more effective marine strategies are needed, alongside marine habitat restoration. Management efforts strive to include both proactive (e.g., MPAs, water quality control, fisheries subsidies) and reactive interventions (e.g., predator control, coral transplantation, artificial reefs). However, there is currently no decision framework available to guide coral reef managers in choosing which strategy or strategies to prioritize when, where, and how. Given limitations in funding and capacity, such guidance is critical to develop strategies that will generate the best return-on-investments to meet international conservation targets.

Causes of restoration failures

Reasons for coral reef restoration failures are highly variable. They vary over spatial scales and can be affected by local to regional factors relating to environmental, socio-economic, institutional and policy conditions. Considering the potential reasons for failure is essential for reef restoration. Improper site selection is one of the most commonly cited failures. For example, coral fragments may be out-planted in areas that are unsuitable for coral settlement and growth (e.g., areas with high sedimentation rates that can smother recruits, strong currents, unsuitable substrates for settlement such as sand, or warm or cold-water anomalies that can kill corals). It is important to select areas where stressors can be minimized; long term survival of reefs can be achieved; and stakeholders, policies and legislation support restoration. Additionally, poorly designed projects or projects using improper methods can lead to restoration failures (e.g., use of fast-growing single species in restoration projects that are less resilient to climate change). Other barriers to restoration success include lack of clear criteria to define restoration success (lack of reference sites, metrics that do not consider recovery of ecosystem function and services), lack of knowledge of local drivers of decline, inconsistent monitoring and reporting, and socioeconomic considerations (e.g., lack of community support for restoration, lack of political will or policies that support restoration, lack of coordination across agencies involved in restoration). Ultimately, the restoration methods, costs and potential for success, depend on the threat(s) to be addressed, surrounding biological and social conditions, and the degree of damage to the ecosystem.

Key factors to consider before implementing a restoration project include:

- Whether active or passive restoration is needed (e.g., whether removing the pressure would result in natural recovery or more active human-interventions are required);
- Whether all factors limiting recovery have been removed, minimized or mitigated;
- Whether restoration is feasible based on cost, local capacity, regulatory environment, local support; and
- Consideration as to whether there are risks of harmful side effects from restoration activities that could adversely affect local communities or remaining habitats (e.g., sediment resuspension from active re-construction, increasing erosion rates, ecological impacts on endangered species). This might imply the need for an environmental impact assessment before restoration activities are implemented.

Improving coral reef restoration effectiveness

The field of coral reef restoration is moving at a very fast pace to keep up with the coral reef crisis and increased interest from the public and private sectors (e.g., Escovar-Fadul et al. 2022). With that comes growing pains and a risk for projects to be implemented without careful planning and design that are essential to support long-term effectiveness and integration within broader reef management strategies (Shaver et al. 2020). Improving the effectiveness of coral reef restoration requires a better understanding of current barriers and opportunities to assist evidence-based investment and decision making.

Implementing best practices in reef restoration

Best practices in coral reef restoration have been identified based on consolidated guidance from the UN Decade on Ecosystem Restoration, and other sources (e.g., Hein et al. 2020; Escovar-Fadul et al. 2022; Quigley et al. 2022; Shaver et al. 2022).

Implement robust restoration planning

- Set realistic and achievable short-, medium- and long term ecological, cultural and socio-economic objectives and goals for reef restoration projects and ensure goals include ecosystem services (e.g., coastal protection, job creation) that benefit local stakeholders
- Tailor reef restoration to local ecological, cultural, and socioeconomic contexts to address local pressures that threaten restoration success and utilize inclusive and participatory approaches (see below)
- Select appropriate sites for restoration – i.e., where local threats are effectively addressed; climate resilient sites (where possible); no/limited conflict over reef resources; sites integrated in broader management frameworks

Protect existing reefs and support natural recovery

- Protect healthy reefs where possible
- Ensure causes of reef degradation are addressed prior to implementing reef restoration
- Support natural recovery (e.g., larval supply, stable/suitable substrate for coral settlement and growth)
- Consider connectivity of restoration sites with other reefs (source/sink reefs) and critical habitats (mangroves, seagrasses)
- Get restoration plans in place (ideally national scale) as soon as restoration is identified as a necessary approach to conserve coral reefs locally

Use inclusive and participatory processes:

- Support inclusive and participatory processes to engage stakeholders, right-holders, and under-represented groups (e.g., Indigenous peoples, local communities, women, youth, etc.) through all phases of restoration project
- Incorporate diverse types of knowledge (e.g., indigenous, local, and scientific ways of knowing) and promote knowledge exchange and integration in reef restoration projects

Monitoring, evaluation, and adaptive management

- Develop long-term monitoring plans specific to objectives and goals to enable adaptative management
- Engage stakeholders in M&E planning and implementation
- Collect baseline data on species and habitats, their condition, human uses, and causes of degradation
- Define restoration measures of success that include social, economic, and ecological metrics, including ecosystem functions and services

Integrate climate risk and maximize resilience

- Define restoration objectives that consider current and future conditions
- Identify sites where local threats are effectively managed and climate vulnerabilities are minimal relative to other sites
- Implement methods that promote genetic and species diversity (diverse coral species including different functional roles; genotypes and species more resilient to threats (heat stress, disease)
- Support alternative livelihoods that reduce pressure on reefs and create revenue to support restoration
- Regularly revisit restoration objectives to accommodate changes in response to changing conditions

Support durable restoration projects that consider climate change

- Identify and secure sustainable financing for restoration that includes public and private sources of funding
- Assess risks, opportunities, and trade-offs to inform restoration policy priorities with clear articulation of costs and benefits of restoration actions including ecosystem services
- Ensure economic benefits of restoration are equitably distributed
- Support local financial capacity building for restoration practitioners to improve their ability to identify and access funding (e.g., blended finance; climate funding where restoration provides mitigation or adaptation benefits).

- Support restoration projects that span multiple ecosystems and consider whole seascapes to maintain ecosystem function and services
- Consider climate impacts in all stages of restoration planning, implementation, and monitoring and evaluation

A key component of implementing best practices in coral reef restoration is the consideration of climate impacts in all stages of restoration planning, implementation, and monitoring and evaluation. For example, it is important in the planning process to define restoration objectives that consider both current and future conditions and to identify sites where local threats are managed and climate vulnerability are minimal relative to other sites. Restoration suitability models (e.g., https://tnccaribgis.users.earthengine.app/view/caribbean-reef-restoration-tool) can be helpful to choose sites with the best chance of success and where reefs are most likely to survive under future climate change scenarios. Restoration methods should promote coral species and genotypic diversity including those more resilient to threats (heat stress, disease, etc.) and connectivity between reefs (including sources and sinks) and habitats (reefs, mangroves, seagrasses) to support recovery. In vulnerable areas, it may be necessary to incorporate management actions that reduce the impacts of climate change prior to implementing a restoration project (e.g., replanting coastal vegetation to reduce flood risk in response to sea level rise and storm impacts). Where projects contribute to national climate mitigation and adaptation goals, it is important to communicate this to communities, governments, and funders. Social resilience considerations are also important such as support for alternative livelihoods that reduce pressure on reefs and can create revenue to support restoration. Finally, it is necessary to regularly revisit restoration objectives to accommodate changes as knowledge advances and in response to changing conditions to support adaptive management.

Tackling policy barriers to reef restoration

The policy framework around coral reef restoration is essential to regulate and inform what interventions can be implemented, where, how, and by whom. However, the policy landscape of coral reef restoration is complex and varies greatly around the world. Regulations vary across countries and often require collaboration across multiple agencies. For example, in the USVI, permitting for reef restoration involves federal and national agencies – NOAA (due to use of endangered coral species), US Army Corp (due to structure in the water that affect shipping), and local government (Department of Land and Natural Resources). In Indonesia, coral reef restoration permitting is governed regionally, whereas in Australia, permits fall under a mix of federal and regional agencies (Razak et al. 2021, Fidelman et al. 2019). In some instances (e.g., World Heritage Areas), interventions on reefs may be regulated by international agencies (UNESCO 2017). Additionally, decision makers are burdened with the difficult task of navigating risks and uncertainties associated with new coral reef restoration technologies, fast development of restoration techniques, and marketing by for-profit restoration companies. Regulatory systems that do not have sufficient controls in places (e.g., environmental impact assessments, systems that mitigate adverse effects from deployment of restoration actions), may risk permitting poorly designed and monitored projects that may either fail to deliver conservation outcomes (e.g., Indonesia, Razak et al. 2021) or more seriously, may result in adverse ecological or social impacts. On the other hand, permitting systems that are too strict may fail to deliver efficient and timely approvals to intervene on degraded reefs (e.g., Australia, Fidelman et al. 2019).

Increased recognition that coral reef restoration is increasingly a component of the success of coral reef conservation projects (e.g., Duarte et al. 2020, Kleypas et al. 2021, Knowlton et al. 2021) is encouraging regulators to facilitate and streamline permitting to address roadblocks. For example, in Australia, the Great Barrier Reef Marine Park Authority, has released new permitting guidelines for coral reef restoration and adaptation projects along a gradient of low to high risk of interventions (GBRMPA 2018). Global working groups (RRAP, CORDAP, CRC) are developing globally applicable guidelines for regulating risks associated coral reef restoration. In addition, experts are calling for regulators to embrace risks and uncertainties through the development of more adaptive and flexible policies and regulations (Kroon et al. 2014, Fidelman et al. 2019), a key tenet of RBM (Mcleod et al. 2019). Incorporating principles of adaptive

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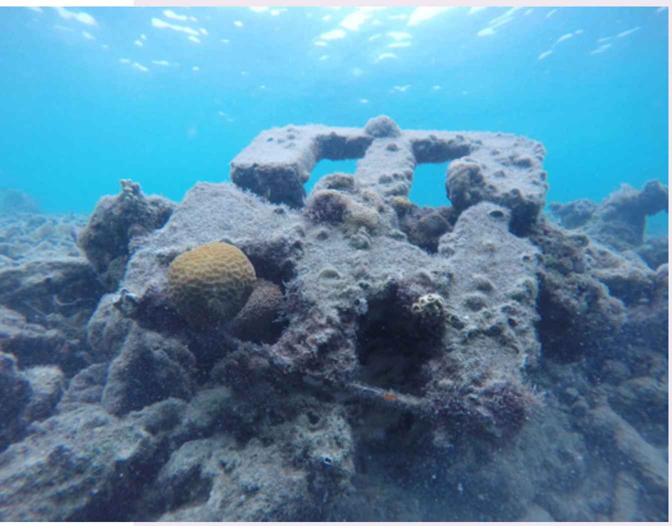
management within regulatory systems for coral reef restoration would allow for less focus on the type of intervention that is to be permitted, and more on the process and design of the proposed intervention(s) favouring projects planned around specific goals and objectives and with robust, science-based monitoring programs in place (Kroon et al. 2014). Such an approach would also facilitate the permitting of integrated, multi-faceted, and multi-scaled interventions across coastal habitats. In addition, incorporating adaptive management within coral reef restoration practices would allow regulators to better manage risks and uncertainties of new technologies and approaches.

A key priority going forward is to develop guidance for countries who are developing new (or modifying existing) policies to enable coral reef restoration based on global best practices. Guidance may target reef management agencies, researchers, and restoration practitioners and include support for researchers and practitioners to navigate the local, regional, and international policy landscape. Examples of guidance documents may include an overview of policies that effectively support restoration and/or mitigate potential adverse effects of restoration, and a detailed decision-support framework outlining costs, benefits, and risks analysis of different restoration technologies. It may be helpful in some countries, like Indonesia, to have a centralized advisory body to support planning and monitoring reef restoration projects (e.g., national reef restoration task force; Box 1). Such a governing body may be helpful to reduce the risk of poorly planned restoration projects that can result in damage to surrounding reef areas.



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BOX 1 | **Coral restoration in Indonesia**

Over the last 30 years, 533 reef restoration projects have been initiated across Indonesia comprising over 170,000 units of artificial reef and coral nurseries, and nearly 1 million outplanted fragments of hard coral (Razak et al. 2022). More coral restoration projects and outplanted coral fragments have been documented in Indonesia than any other country globally. Unfortunately, only 7% of these restoration projects incorporated a long-term monitoring programme to assess how coral, fish and invertebrate populations are responding to restoration interventions.

Indonesian reef restoration projects share many of the same growing pains that have been experienced by coral reef restoration globally, and coastal restoration in general. An emphasis on deployment without a requirement for clearly defined objectives and measurable targets, as well as lack of long-term maintenance and monitoring plans, increases the risk that restoration projects will not deliver conservation benefits. Establishment of a *national reef restoration task force*, as a scientific authority, may help to improve the effectiveness of reef restoration programs in Indonesia. The task force could support restoration effectiveness through (1) facilitating collaboration between relevant authorities, restoration practitioners and communities, (2) socializing regulations and best practices, (3) minimizing overlapping and abandonment of projects, (4) advising/clarifying regulations and permit requirements, and (5) working closely with restoration working groups (e.g., School of Coral Reef Restoration (SCORES) at IPB University and Bali Reef Rehabilitation Network led by the Coral Triangle Center). Consistent monitoring and evaluation must be conducted to ensure that artificial reefs constructed in the name of coral restoration are functioning effectively, rather than simply serving as underwater structures that play no active role in regenerating coral populations.

Supporting evidence-based investments in coral reefs

Research suggests that US$1.9 billion has been allocated to the conservation of coral reefs and associated ecosystems between 2010 and 2016 (UNEP et al. 2018). In addition, US$ 258 million has been invested in coral reef restoration efforts globally over the last 10–15 years (Hein and Staub 2021). It is essential to consider the return on investment for coral reef conservation and restoration dollars to ensure that investments are providing the greatest social and ecological outcomes. Evidence-based approaches should be applied to determine whether limited dollars for reefs should be allocated to threat mitigation, new protected areas, improving management effectiveness, supporting local livelihoods, or implementing restoration projects, or likely a combination of activities.

Barriers to sustainable funding for coral reef restoration include a mismatch between the timeline required to demonstrate restoration success or failure (5–10+ years for ecosystem wide recovery) and the timeline of most grants (1–3 years) making it difficult to show results to justify continued funding. However, in some cases, recently outplanted corals are shown as "successes" used to justify additional funding, and the longer-term outcomes of the project are not monitored or reported on. This is a major challenge in reef restoration efforts; a recent review demonstrated that over half of restoration projects assessed reported less than 18 months of monitoring (Boström-Einarsson et al. 2020); highlighting the urgent need to implement and invest in longer-term monitoring efforts.

The timeline and scope of funding also needs to be tied to specific return-on-investment objectives. For example, investments in high-level research and development projects for coral reef restoration and adaptation (e.g., RRAP, CORDAP) are critical. However, as new interventions can take years to decades before implementation at scale is possible, parallel investments in conservation strategies that address direct threats and support short-term recovery are essential to maintain functioning reef ecosystems and deliver ecosystem services. To support funding prioritization, it is also helpful to conduct assessments of current restoration projects and funding sources (e.g., https://restorationfunders.com/funding-ecosystem-restoration-in-europe.pdf) to highlight geographic and ecosystem biases in funding patterns. Such efforts help inform future prioritization and secure essential funding for under-represented ecosystems and geographies. Additionally, maps showing the global restoration potential for critical marine habitats also can help identify projects with the greatest opportunities for restoration success.

In addition, restoration practitioners need to communicate accurate expectations of restoration outcomes to funders to better assist funding bodies in defining realistic targets and timelines for their investments. Robust monitoring and evaluation strategies are essential to support adaptive management and monitoring the full cost of restoration interventions is necessary to ensure projects have sufficient resources to deliver restoration outcomes or to decide the restoration is not the right approach to deliver the intended outcomes.

The recent diversification of funding sources for coral reef conservation (e.g., government grants, philanthropic foundations, local business), through blended finance approaches (e.g., Global Fund for Coral Reefs), offers exciting new opportunities for coral reef restoration. These allow practitioners to secure larger amounts of money for restoration projects (UNEP 2022). The engagement of the private sector is a particularly promising avenue for generating new funding opportunities for coral reef restoration (Hein and Staub 2021; Box 2). A recent report led by The Nature Conservancy reveals significant interest from the Caribbean tourism industry in engaging in coral reef conservation efforts, to protect ecosystems that the industry depends on, and to satisfy an increased demand for sustainable tourism experiences (Escovar-Fadul et al. 2022). Similar trends also have been observed on the Great Barrier Reef in Australia (Hein et al. 2020). In addition, the development of reef insurance schemes may be another source of innovative funding as the value of reefs for coastal protection is increasingly recognised (Storlazzi et al. 2021).

"When paired with efforts to address local drivers of coral reef degradation, the expansion of coral restoration activities offers a strong pathway for supporting the resilience and function of reef ecosystems. The Global Fund for Coral Reefs is designed to test and scale restoration approaches that, if proven, will help achieve Global Biodiversity Framework goals and targets, particularly Target 2, which seeks to restore ecosystems and halt species extinction."

Chuck Cooper, GFCR Executive Board Chair representing the Paul G. Allen Family Foundation

BOX 2 | **Coral Vita, a unique commercial model for land-based coral farming**

Coral Vita grows coral to restore dying reefs. Their mission is to grow diverse, resilient, and affordable coral in months rather than decades to help preserve marine life. Through a mission-based commercial model, they are transitioning this nascent grant and donation-driven field to a self-sustaining restoration economy to help achieve the ecosystem-scale impact needed to keep coral reefs alive amidst the threats they face.

Their approach to coral reef restoration involves land-based coral farms equipped with high-tech aquaculture systems. These facilitate the integration of novel methods to accelerate coral growth up to 50x faster (microfragmenting) while strengthening coral resilience to climate change (assisted evolution). On-site features such as laboratories, workshops, and studios also allow for the development or integration of specialties not traditionally found in this space such as artificial intelligence, machine learning, and 3D printing. A unique commercial model unlocks funding beyond traditional grant support including:


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- Selling restoration as a service to customers that depend on corals' valuable and threatened benefits;
- Tapping into conservation financing mechanisms such as reef insurance policies, biodiversity credits, and blue bonds;
- Using the farms as interactive tourism attractions (as well as education centers for local communities); and
- Giving everyone from individuals to companies ways to sponsor the growth and outplanting of coral.

"When paired with efforts to address local drivers of coral reef degradation, the expansion of coral restoration activities offers a strong pathway for supporting the resilience and function of reef ecosystems. The Global Fund for Coral Reefs is designed to test and scale restoration approaches that, if proven, will help achieve Global Biodiversity Framework goals and targets, particularly Target 2, which seeks to restore ecosystems and halt species extinction."

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Specific guidance around funding strategies needs to be developed to help coral reef restoration practitioners identify and access sustainable funding for restoration. This may include access to financial literacy training to improve the understanding of blended-finance instruments and how to access and use them, capacity building to develop partnerships with the private industry, or support to improve access to climate funding for adaptation where restoration provides risk-reduction benefits. It may be helpful to consider the potential to have a restoration project partner in the private sector (e.g., hotel with reef-based tourism) to support long-term funding of the project and potential upscaling.

Building capacity to restore coral reefs

Effective coral reef restoration is hindered by the lack of capacity of many practitioners to deploy projects at meaningful spatial and temporal scales. As of 2020, the median scale of coral reef restoration projects was ~100 m^2, with very few projects in place over ten years (but see, Fox et al. 2019), and the median reported monitoring time is 12 months (Boström-Einarsson et al. 2020). In addition, most reef restoration projects (70%) are focused on planting corals, and often only include single-species assemblages (28%) or are focused on fast-growing species (59%) that are highly sensitive to disturbances (e.g., *Acropora* sp.; (Boström-Einarsson et al. 2020). Only 1% of projects reports methods of larval-based enhancement (Boström-Einarsson et al. 2020), which show the greater potential for recovery at scale and maximizing genetic diversity. Socio-cultural and economic outcomes of coral reef restoration are also not typically monitored (Hein et al. 2017). There is thus a disconnect between the ambitions and realities of the field of coral reef restoration, with a need for projects to better plan for the long-term, integrate climate projections into project design, and facilitate the integration of restoration within broader reef conservation planning (Shaver et al. 2022).

"Restoration must be part of a comprehensive management strategy and tailored to local conditions. Restoration of coastal watersheds is as important as the restoration of corals to ensure conditions support natural recovery."

Jennifer Koss, Director, NOAA Coral Reef Conservation Program

Knowledge sharing is vital so practitioners can be informed of and can apply the latest research and restoration techniques, including best-practice guidelines. A number of networks exist with the mission of providing free resources to reef managers globally including TNC's Reef Resilience Network and the Coral Restoration Consortium. ICRI also has an ad-hoc committee comprised of reef managers, scientists, and leaders in the field focused on sharing latest science and advances to maximize knowledge sharing, collaborations across groups and countries, and minimize the duplication of efforts. A key focus for these groups is to improve planning and monitoring tools for coral reef restoration (Box 3). TNC and NOAA developed the Manager's Guide to Coral Reef Restoration Planning and Design to assist practitioners in identifying restoration sites, selecting restoration techniques, and developing an action plan (Shaver et al. 2020). The CRC released guidelines dedicated to monitoring the outcomes of coral reef restoration efforts (Goergen et al. 2020) to support standardized monitoring systems and allow comparisons of outcomes across various techniques and regions.

BOX 3 | **The Reef Resilience Network: Reef restoration capacity building in the Western Indian Ocean**

The Nature Conservancy's Reef Resilience Network and Africa Program are leading a partnership with Northern Rangelands Trust and Mwambao Coastal Community Network to design innovative solutions for nature and people with a focus on two objectives—reef restoration and community capacity building. The goal of this work is to restore coral reefs to enhance local fisheries, support livelihoods, and produce climate adaptation benefits.

To achieve this, TNC and local partners have:

- Trained a cohort of 58 coral reef practitioners and community members from Kenya and Tanzania in reef restoration planning and best practices including constructing cost-effective artificial reef structures that support community fisheries and improve coastal resilience
- Provided expert guidance on project implementation and monitoring
- Facilitated a training to engage restoration practitioners and community members to learn and share experiences, information, and best practices in reef restoration

The training was held as part of the Western Indian Ocean Marine Science Association Symposium with additional support from Kenya Marine and Fisheries Research Institute, Kenya Wildlife Research Training Institute, and Nature Seychelles. Participants – representing community, fishers, science, and management – discussed restoration projects throughout the Western Indian Ocean (WIO) and what it would take to promote increased conservation benefits and adoption of best practices. Recommendations from the workshop include: develop a WIO Network of reef restoration practitioners; compile a regional database of reef restoration projects; continue to build capacity and skills of reef restoration practitioners in the region; and explore funding opportunities to support these activities and pilot reef restoration best practices projects in other WIO sites.

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Efforts are underway to simplify and standardize coral reef monitoring techniques from data collection to analysis and communication (e.g., MERMAID, ReefCloud), but most are not currently able to support reef restoration (but see, REEFhabilitation). Efforts that utilize remote-sensing and AI may help to reduce costs and capacity needs for coral reef restoration monitoring. In addition, best-practice guidelines stress the importance of early and targeted stakeholder engagement in coral reef restoration efforts (Shaver et al. 2020, Hein. et al. 2021, Quigley et al. 2022). Local communities, Indigenous communities, and traditional owners often have extensive local knowledge of reef systems. Their active engagement in coral reef restoration efforts is key to incorporate local knowledge into the design and planning of projects, as well as minimize conflicts around resources use, maximize long-term support and stewardship (Hein et al. 2021; Box 4), and facilitate the integration of restoration into broader management strategies (e.g., involvement of local fishing communities could foster more compliance in local MPAs).

BOX 4 | **Fragments of Hope, a community-based coral reef restoration programme in Belize**

Fragments of Hope Ltd. (FOH) is a Belizean community-based organization that focuses on the restoration of coral reef habitats and advocates for the sustainable management of associated habitats. FOH began its operations Belize's Laughing Bird Caye National Park (LBCNP) in 2006, and recent monitoring revealed a 10-20% annual increase in coral cover 3-4 years after outplanting. Today, many experts consider LBCNP one of the best examples of reef restoration in the world.

Ecologically, FOH aims to use genetically diverse species of the critically endangered Caribbean acroporids to increase coral cover and associated ecosystem services like biodiversity and shoreline protection. This work is mainly done in areas that show dramatic declines associated with hurricane damage to the reef in 2001. Throughout Belize, FOH currently has 28 in-situ coral nurseries, and 26 different restoration sites, including in seven Marine Protected Areas (MPAs).

Socially and economically, FOH prioritizes engagement of the local community, including local fishers and tour guides and staff from the Belize Fisheries Department, and global community of researchers, practitioners, and educators. Examples of FoH's capacity building efforts include:

- Training and employing local fishers and tour guides to restore and protect coral reef - 100 people have completed a reef restoration certification program offered by FOH and vetted by the Belize Fisheries Department, including over 90 Belizeans, 7 Hondurans, and 3 Jamaicans;
- Developing, curating, and disseminating educational products like videos and manuals on reef restoration methods to local Belizean schools and via websites like The Earth Museum; and
- Offering capacity building workshops and information products on restoration and sustainable reef habitat management to Belizean coastal community members.
- Providing research opportunities and partnerships to co-create knowledge on reef restoration using FOH's sites and work in Belize.

The local community's consistent involvement in and direct ownership of the restoration process has been a critical contributor to the long-term success and stability of FOH.

© Fragments of Hope

Increased support for knowledge sharing in the field of coral reef restoration is essential so restoration practitioners do not recreate the wheel as innovation is happening so quickly. Knowledge sharing is a vital part of building an evidence-based framework regarding what works and doesn't work and helps to improve the capacity to deploy cost-effective restoration efforts. Networks need to be supported at global and regional scales to ensure that best practices are tailored to local context. Existing guidance and manuals (e.g., Goergen et al. 2020; Shaver et al. 2022) should be adapted to local contexts and translated into local languages to support broader uptake. Importantly, knowledge sharing should present realistic expectations of what coral reef restoration can and cannot achieve including clarifying that restoration is not always appropriate and projects need robust monitoring plans to track progress over time.

Research and development

Research and development (R&D) in coral reef restoration and adaptation is essential to ensure projects achieve their goals in the face of increasing threats to coral reefs including climate change impacts. In 2018, The National Academy of Science, Engineering, and Medicine (NASEM) reviewed the feasibility and readiness of genetic, ecological, and environmental interventions to enhance the resilience of coral reefs. They released a decision framework for interventions highlighting important R&D needs around modelling and risk analysis (NASEM 2019). For example, choosing appropriate sites for restoration may involve climate modelling at small spatial scales, connectivity modelling across reefs (e.g., source and sink reefs), as well as risk-benefit assessments based on socio-economic and cultural values. The cost and timeline of such assessments may prohibit the capacity of managers to implement science-based, climate smart designs for coral reef restoration. In such cases, the climate adaptation planning tools may be used.

Reports and best-practice guidelines for coral reef conservation and restoration are calling for greater investment in R&D to improve the effectiveness of interventions (Anthony et al. 2017, NASEM 2019, Hein et al. 2020). Programs such as RRAP and CORDAP have clear action plans and strategies to develop specific tools to scale up the implementation and efficacy of interventions for coral reefs (Bay et al. 2019; CORDAP strategic plan 2022). Advances in remote-sensing are also supporting improved site-selection for coral reef restoration projects (Schill et al. 2021). The CRC also emphasizes the need to scale research and capacity for larval-based restoration (Vardi et al. 2021).

A key priority is to link the outcomes and learnings from R&D effort with restoration projects globally to ensure that new discoveries can be applied to improve restoration effectiveness. R&D efforts associated with modelling and risk analysis are needed to support improved site selection (e.g., based on remote sensing, larval dispersal, current movements, etc.) to increase the likelihood of restoration success. Increased support is necessary to understand the risks and uncertainties around new technologies so implementation can be scaled up in a timely manner to address current and near-future challenges for coral reefs. Support is also necessary to help facilitate the transfer of R&D to field implementation and ensure research is applicable in the field and integrated with multi-faceted management strategies to support coral conservation. In many cases, high-tech approaches used in restoration may not be applicable in places where most coral reefs are located, thus it is essential to support R&D efforts that can be applied in low-capacity settings to ensure application and scalability.



The Nature Conservancy's Virgin Islands Coral Innovation Hub joins cutting-edge science with strong partnerships to bring reefs back to life on a large scale—aiming to restore tens of thousands of corals across the Caribbean over the next decade.

Photos (Left And Right): © Alex Novak/TNC; Center: ©Jessica Ward/TNC

The move toward multi-species and multi-habitat restoration

Calls for multi-species and multi-habitat restoration are increasing (moving from single-species or single-habitat restoration). Where multiple species and/or habitats can be restored together, ecosystem recovery can happen faster and more effectively due to positive interactions, increased recruitment, and habitat connectivity. For example, restoring coral reefs along with restoring mangroves and seagrasses can lead to improved restoration outcomes as mangroves and seagrasses can improve water quality that supports reef recovery. Multi-species approaches to restoration have been shown to boost recruitment and restoration success. In addition, ecological theory reinforces the potential for multi-species and multi-habitat restoration to achieve ecological functions, productivity, and resilience that are greater than could be accomplished with single-habitat restoration. Therefore, practitioners should seek to where possible, restore multiple habits concurrently to improve the effectiveness and efficiency of restoration efforts. Decision support tools, such as maps identifying restoration potential for multiple marine habitats, can help to inform priority sites for restoration.

Conclusions and Recommendations

In response to the increasing threats facing oceans globally, restoring coastal and marine ecosystems, specifically coral reefs, is recognized as a global conservation priority. Reef restoration is now recognized as a vital management tool alongside MPAs and other effective area-based conservation mechanisms (OECMs). This paper reviewed the role of coral reef restoration in the context of climate change and 30 by 30 targets. It provided recommendations to support more effective ocean conservation investments and management strategies based on recent research and global best practices.

To meet ambitious global 30 by 30 targets, the protection and restoration of critical coral reef ecosystems is essential, as reef support over one quarter of all marine life. In addition to MPAs and OECMs, restoration strategies also are needed. Reef restoration efforts are increasingly applied to restore coral reef structure, ecosystem function, resilience, and the sustainable delivery of reef ecosystem services. Due to the current challenges implementing reef restoration, it should not be applied as a first line of action, where other conservation strategies may be more effective. However, when applied within broader management frameworks, it can be an important tool to support reef resilience.

Improving the effectiveness of reef restoration requires a clear understanding of barriers and opportunities to support evidence-based investment and decision making. It includes the implementation of robust restoration plans, best practices, and monitoring and evaluation frameworks that support adaptive management. It requires strengthening of local and national policies and legislation to provide a better enabling environment for restoration including mitigating potential adverse effects, streamlining policies and permits, and improved coordination across agencies that support restoration. Building political will for restoration also requires articulation of the costs, benefits, and risks of restoration approaches.

Evidence-based approaches are necessary to determine how funding should best be allocated to conserve coral reefs (i.e., threat mitigation, protected areas, management effectiveness, local livelihoods, restoration, etc.). Long-term monitoring is critical to ensure that restoration success and failures are effectively tracked and to support adaptive management. The timeline and scope of restoration funding should be tied to return-on-investment. Finally, support for capacity building of restoration practitioners to improve restoration planning and implementation to ensure application of best practices is essential to reduce recreating the wheel and the risk of failure. Building on these needs, we identify the following recommendation to support more effective investment in coral reef restoration:

Key recommendations for investment in coral reef restoration include support for:

- Knowledge sharing and standardized monitoring to:
  - reduce the spread of poorly planned and implemented projects
  - improve effectiveness of restoration to better achieve intended outcomes
- Assessments of current restoration projects and funding sources to highlight geographic and ecosystem biases in funding and inform future prioritization
- Diversification of funding opportunities, particularly private funding with the potential to scale up existing efforts in space and time
- Guidance for countries developing new (or modifying existing) policies to enable restoration based on global best practices and measure the effectiveness of restoration
- Strengthening local and national policies and legislation to provide an enabling environment for restoration, streamlining policies and permits, and improving coordination across agencies that support restoration
- Clear articulation of costs, benefits, and risks of specific restoration interventions including the ecosystem services recovered from restorative actions
- Support for small-scale restoration projects to apply innovations/technology (e.g., from CORDAP)
- Inclusive and participatory processes that engage stakeholders, right-holders, and under-represented groups in all phases of restoration
- Multi-habitat restoration projects (seagrasses, mangroves, coral reefs) and development of maps showing global restoration potential for coral reefs and other critical marine habitats to support projects with the greatest opportunity for success

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