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CORAL RESEARCH & DEVELOPMENT ACCELERATOR PLATFORM

STRATEGIC PLAN 2022-2025

CREDITS

This plan was created in 2022 by CORDAP's Scientific and Advisory Committee (SAC) and approved by CORDAP's Initiative Governing Committee (IGC).

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Strategic Plan 2022-2025

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1 Executive Summary

In 2020, 17 G20 nations launched the Coral Research & Development Accelerator Platform (CORDAP) to accelerate global research and development of coral restoration and conservation in order to secure a future for corals and reefs in the face of climate change and other pressures.

Over two-thirds of the world's tropical coral reefs have been lost because of human activity.[1,2] The remaining 70% to 90% of tropical coral reefs are likely to decline in the next decades.[3,4] For the first time, an entire ecosystem that supports millions of species and people may be lost at the hands of humans.[5] Many of the world's tropical coral reefs remain resilient, however, and can recover if conditions permit.[6] Corals also respond to active stewardship.[7] However, the global and local threats to both tropical and deep-water corals and reefs add up to a rapidly closing window of opportunity for securing their future.[8] We must act now.

By bringing together the best minds worldwide in a transdisciplinary approach, CORDAP will advance the next generation of science and technology needed to improve the survival, conservation, resilience, adaptation, and restoration of both tropical and deep-water corals and reefs.

CORDAP also aims to increase support of and complement existing national, regional, and international initiatives that are currently working on coral and reef conservation, resilience, adaptation, and restoration.

CORDAP in brief:

Focuses on research and development. Unique in its time-sensitive mission, CORDAP is the only international organization fully dedicated to funding global research and development for coral restoration and conservation.

Commits to scalability. By integrating the problem-solving abilities of the world's best scientific minds in collaborative projects, CORDAP aims to develop effective, scalable solutions that can be transferred to, and scaled up by, coral conservation practitioners.

Aims for broad impact, globally. Most coral restoration methods are suitable only for small-scale intervention. CORDAP-funded projects will accelerate the research and development of next-generation solutions to conserve and restore coral reefs at much broader scale, delivering far greater impact.

Is open to all. CORDAP's open-source platform will allow anyone to advance and use the platform's technologies. We welcome the participation of anyone with workable ideas for solving this issue, regardless of their nationality or resources.

Is transdisciplinary. The CORDAP platform is designed to foster new, holistic solutions by combining input from inside and outside of marine science, including mechanical engineering, 3D printing, biology, structural engineering, architecture, and other disciplines.

Is research-led. CORDAP was inspired by the scientific consensus that the window for saving corals and reefs is closing. CORDAP is guided by its international Scientific Advisory Committee (SAC).

Strives for efficiency. Every penny of international funding that CORDAP receives will go directly to its R&D and other projects. Administration expenses are covered by King Abdullah University of Science and Technology (KAUST) as an in-kind contribution from Saudi Arabia.

Will be equitable and inclusive. Coral and reef restoration and conservation technologies are currently limited to certain regions and research centers. The outcomes of CORDAP will be accessible to everyone, allowing that coral and reef efforts and technologies to be deployed wherever they are needed—particularly in developing countries.

2 Our Mission

CORDAP will bring together the best minds worldwide, in a transdisciplinary approach, to accelerate international research and development to supply the technologies and innovations required to secure a future for corals and reefs.

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3 Our Values

All processes must be transparent, collegial, ethical,and fair.

We recognize the importance of corals and coral reefs in the lives of stakeholders and rights-holders, particularly of indigenous and other local communities, where conservation and restoration interventions may be applied.

We collaborate and share knowledge to catalyze progress beyond the current state of the art.

We will support the development of novel technologies, methods, and processes that may be deployed across different coral ecosystems (e.g., tropical and deep water), adapting as needed to the range of socioeconomic contexts where they may be applied.

We are committed to R&D co-design and development with the custodians of corals and reefs and with those who may ultimately deploy ideas generated through CORDAP.

We embrace the contribution of all types of research from basic to applied and across all disciplines from natural and social sciences to engineering.

We encourage approaches that aim to make big advances rather than incremental progress in current capacity. This may include high-risk, high-gain investments enabled by appropriate social and ecological safeguards.

We support a gender-balanced, interdisciplinary, global community of scientists committed to our mission.

We will make the knowledge and technologies that CORDAP enables freely available in order to conserve and restore tropical coral reefs and deep-water corals.

4 Strategic Context

4.1 The Current and Forecasted State of Corals and Reefs

Global state of corals and reefs

Tropical coral reefs occur in more than 100 countries and contribute an estimated US$2.7 trillion per year in goods and services.[9] Tropical coral reefs underpin the safety, coastal protection, well-being, and food and economic security of hundreds of millions of people.

Corals and reefs are also among the most vulnerable ecosystems on the planet to anthropogenic pressures—particularly those pressures influenced by climate change and associated factors. These stressors include increased sea surface temperatures that trigger coral bleaching and mass mortality, increased wave energy and storms, ocean acidification, sea level rise, and changing patterns of currents and precipitation, among others.[10] These pressures interact negatively with, and often exacerbate, a slew of local stresses, such as poor water quality, disease and predator outbreaks, invasive species, overfishing, and destructive fishing practices, resulting in widespread coral ecosystem losses.

As the water becomes deeper and cooler with less light, corals become mesophotic and use a combination of photosynthesis and zooplankton for nutrition. They then transition to deep-water corals and no longer have a symbiotic relationship with photosynthetic zooxanthellae. This transition typically occurs between 30 m and 150 m depending on the local context. Deep-water coral habitats occur on continental platforms, shelf breaks, slopes, seamounts, and ridge systems as deep as 6,000 m all over the world.

Descending from mesophotic to deep-water corals, our knowledge decreases substantially, largely because access is so difficult. Although deep-water corals grow slowly, they represent about 65% of the total known diversity of corals[11] and comprise highly biodiverse environments with a heterogeneous habitat and a rich associated fauna.[12] Although deep-water corals typically do not form reefs, some species of colonial scleractinian corals are known to form reefs, including *Enallopsammia rostrate, Goniocorella dumosa, Desmophyllum pertusum, Madrepora oculata, Oculina varicose* and *Solenosmilia variabilis*.[11] Deep-water corals also include solitary scleractinians, antipatharians, stylasterids, and octocorals (the last of which may also be framework-forming corals). Damage to deep-water corals has been reported, but our current understanding of the extent of global losses as well as our projections of future trajectories are incomplete due to the difficulty of observing deep-water corals. To date, little is known about the current status or future of these corals.

The greatest disturbances to tropical coral reefs have been large-scale coral bleaching events caused by global warming. “The Status of Coral Reefs of the World: 2020” report found that the 1998 global bleaching event killed 8% of the world’s coral, while subsequent events between 2009 and 2018 killed an additional 14%,[12] while algae cover increased by 20%. Local stressors, such as abundances of macroalgae and sea urchins, exacerbated coral declines, magnifying coral losses in the years following bleaching.[13] As a result, many species of coral and the reefs they create are now highly threatened. [14,15,16]

Projections of increased sea surface temperatures (SST) suggest that coral reefs will continue to decline in the next few decades. The Intergovernmental Panel on Climate Change’s (IPCC) Sixth Assessment Report indicates that within the next two decades the world likely will have reached or exceeded 1.5°C of warming since the pre-industrial era.[17]

Not only is ocean warming occurring faster than it has since the last ice age, but also the current rate of ocean acidification is at its highest levels in the last 26,000 years.[18] The amount of ocean warming observed since 1971 will likely double by 2100 under a low-warming scenario (SSP1-2.6) and will increase four to eight times under a high-warming scenario (SSP5-8.5).[19] The projected 1.5°C global mean temperature warming will be avoided only with massive and immediate cuts in greenhouse gas emissions, as recommended by the SSP1-1.9 shared socioeconomic pathway (SSP) emissions scenario. Other scenarios that exclude immediate and additional efforts to constrain emissions project that the global mean temperature will rise by 1.4°C to 4.4°C by the late 21st century.[20]

Sea levels are projected to rise between 0.28 m and 1.02 m, depending on the emissions scenario, which will exacerbate coastal flooding and erosion.[21] Vertical reef accretion rates will lag relative to the higher projected rates of sea level rise by the end of the century,[22,23,24] resulting in the flooding of coral reefs and reducing their capacity for coastal protection.

A doubling of atmospheric carbon dioxide (SSP2-4.5) is projected to further decrease ocean pH by 0.1 units. The saturation horizons of aragonite and calcite, which compose corals and a variety of other marine invertebrates, are already shoaling rapidly at 1-5 m/year, threatening both tropical coral reefs and deep-water corals.[25]

Forecasts

CORDAP was formed to address the bleak future forecasted for corals and reefs. Climate change alone presents a global existential threat to corals and reefs. And regional anthropogenic pressures, which are currently not adequately managed, exacerbate this threat.

For example, on the Great Barrier Reef, discrete disturbances are predicted to increase the prevalence of algae relative to hard coral, while the interaction between cyclones and heat stress is predicted to increase soft coral cover relative to algae and hard coral cover.[26] In the western Indian Ocean, the risk that coral reef ecosystems will collapse over the next 50 years is significant, largely due to global warming and overfishing.[27] These reefs and those in the central western Indian Ocean are predicted to lose 20% to 80% of their current (2020) coral cover, depending on which emissions scenario prevails in 2050, even with the best possible fisheries management.[28]

Coral reefs in the Galápagos and in the Comoros are expected to continue experiencing local and archipelago-wide mortality and degradation, caused by a range of anthropogenic disturbances.[29, 30] In the Caribbean, projected sea level rise and increased ocean acidification will make corals more vulnerable to severe storms. This will impact coastal infrastructure, affecting both the tourism and fishing industries, particularly in small island nations.[31]

The Coral Triangle reefs, which span six countries (Indonesia, Malaysia, the Philippines, Papua New Guinea, Timor-Leste, and Solomon Islands) and compose more than 40% of the world's tropical reefs, are currently more threatened by anthropogenic pressures from the large nearby population of 225 million people, 95% of whom live along the 131,254-km coastline and depend on the productivity and ecological services of coral reefs. Indeed, virtually every reef region experiences local and regional anthropogenic threats that reduce the capacity of reefs to resist or recover from the threats associated with climate change.

Despite all this, increases in global coral cover between 2002 and 2009 and again in 2019 suggest that many of the world's tropical coral reefs remain resilient and can recover if conditions permit. Effective local management employing a wide range of solutions, along with global efforts to mitigate climate change, can help corals and reefs survive the Anthropocene. [33, 34, 35]

A radical approach that has not been widely applied to corals and reefs involves a change from passive ecosystem management to active ecosystem intervention. Examples of these techniques include propagating sexual recruits and coral fragments, assisted migration, and selective breeding.[37,38,39,40] Active interventions should also target urgent action today to support resilience and adaptation of corals that will help reduce expected losses over the next few decades. These approaches generally have yielded limited success because of the challenges in scaling up the interventions over large spatial scales, undermining their effectiveness.

Like tropical corals, deep-water corals are threatened by human activities that disturb the ocean floor (e.g., fishing, gas and oil exploitation, mining). These stressors are compounded by the impacts of climate change, including rising temperatures and ocean acidification. By the year 2100, projections indicate that about 70% of current deep-water coral habitats will become undersaturated with aragonite, likely altering their global distribution and abundance.[42] Using high emissions scenarios, models predict a decrease of 28% to 100% in suitable habitat for deep-water corals, for declines of at least 79% and, for some key species in the North Atlantic Ocean, 99% by the end of the century, all due to ocean acidification and reduced food availability.

Traits such as long lifespans, slow growth rates, delayed sexual maturity, and limited recruitment success make deep-water corals particularly vulnerable to these threats and make restoration efforts expensive and complicated. The loss of any deep-water coral is particularly concerning because these ecosystems are expected to have recovery time scales on the order of decades to centuries. Because recolonization of an impacted area may not occur naturally within a reasonable time frame, direct human intervention will be needed to restore at least part of this fauna.[43]

Securing a future for corals and coral reefs requires an intensive, coordinated effort. We must mobilize scientists, technologists, innovators, policymakers, community leaders, philanthropists, and the productive capacity of the private sector. We need to develop and deploy at scale the approaches and the science that will enable us to conserve and restore corals and reefs, not just to avoid future losses, but to achieve partial recovery of tropical reefs and deep-water corals.[44, 45]

4.2 The Urgency

Even under optimistic emissions scenarios, the oceans will continue to warm for several decades, and the vast majority of coral reefs will experience increasingly frequent and intense ocean heat waves.[46] If corals cannot adapt to these conditions, coral bleaching will become unsustainably frequent and widespread. But if corals can adapt, either through adaptation or through interventions that help them adapt, then under more optimistic warming scenarios more corals may survive and reefs may better cope with other anthropogenic pressures.

The situation is no better for deep-water corals. Human activities involving direct contact with the seafloor are expected to increase in the future. New deep-sea offshore oil extraction projects are under development, and with rising demand for minerals and metals, commercial deep-sea mining is likely to begin soon. According to the International Seabed Authority there were 31 exploration contracts in place by 2018, compared to 17 active contracts in 2013 and eight in 2010.[47]

Progress over the next 15 years in enhancing the resistance, resilience, and restoration of deep-water corals at an ecologically relevant scale will determine the future of corals, reef restoration, and coral reef rebuilding.

We must deliver new and better science and technology to support conservation and restoration efforts. The window to secure a future for corals and reefs is narrow and rapidly closing. What we do in the coming decade will decide the future of corals and coral reefs.[48, 49]

4.3 What We Have and What We Need

Climate action is critical for the future of corals and reefs. But even if greenhouse gas emissions are drastically and immediately reduced, global ocean temperatures could still take decades to stabilize.

Established conservation practices, such as marine protected areas and managed land-based pollution, are vital for supporting coral and reef resilience. But we need bolder, more active management practices—predator control, coral reef restoration, and coral adaptation—to protect coral and coral reef ecosystems, enhance their resilience, and rebuild them.

We face many challenges to achieving even a partial recovery of coral reefs and deep-water corals. First, we need a reliable assessment of the extent and status of corals and reefs. This has been greatly improved for tropical reefs by the release of the Allen Coral Atlas and the more recent GCRMN Status of Coral Reefs of the World: 2020.[50] Nevertheless, a lack of knowledge remains a hurdle for managing deep-water coral habitats because many have been damaged or lost before we could document them.

We also lack policy instruments and resources across many regions that can remove pressures and improve management of tropical and deep-water corals—yet another significant limitation on the conservation and protection of corals and reefs. Restoration efforts for tropical corals are still in their infancy, have small footprints, and are expensive and inefficient compared to our restoration capabilities in other critical marine ecosystems, such as salt marshes and mangroves.[51] Our capabilities are even weaker for deep-water corals, where restoration has scarcely been attempted.

The maximum size of completed restoration projects for tropical and deep-water corals are 10- to 100-fold smaller than the largest successful seagrass and mangrove restoration projects[52] —more evidence of the wide gap in our capability. The largest coral restoration thus far is 8.4 ha, in the Caribbean.[53] While there is limited evidence of long-term, ecologically relevant success in coral restoration, ongoing investments in research and development are likely to improve the scale and cost-efficiency of current methods.[54]

Given the challenge of rebuilding tropical coral reefs, the International Coral Reef Society (ICRS), an advisory member of CORDAP´s Initiative Governance Committee (IGC), sponsored a report identifying three critical pillars for improving coral restoration:

1. Reduce climate change threats
2. Improve local conditions to build resilience
3. Invest in active restoration to enhance recovery

The report[55] asks three things of the international policy community in support of these pillars. One is that policy makers must "Drive Innovation: Develop new approaches where current solutions are insufficient to tackle the emergency facing coral reefs." CORDAP responds directly to this imperative by complementing efforts that are currently in place to reduce climate change threats (for example, the Paris Agreement), by improving local conditions and building resilience through sharing best practices and building capacity (the International Coral Reef Initiative (ICRI)), and by delivering the financial resources to conserve resilient reefs (the Global Fund for Coral Reefs (GFCR)).

A second review was recently completed by the ICRI, a partnership of organizations and countries striving to preserve coral reefs (ICRI member nations host over 75% of the world's coral reefs).

The ICRI report revealed that:

88% of ICRI members are interested in the development of new international commitments and policies specifically dedicated to coral reef restoration.

When surveyed about their needs regarding coral restoration and adaptation, most ICRI members (79%) want more research to help them understand what to do, and most (71%) say they need a plan of action. Sixty one percent said they need more dedicated funding and training. Just under half (46%) said they need more international collaboration.[57]

ICRI nations estimated that they need a more than 200-fold increase in the scale of coral restoration to meet their future restoration goals. Even these aspirational goals are extremely small compared to the total reef area within their national boundaries.

Finally, to further highlight the importance of efficiency, the Coral Restoration Consortium's six priority actions to increase restoration efficiency include improved deployment scale and cost-effectiveness.[58]

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5 CORDAP Goals and Scope

CORDAP will draw together a multidisciplinary group of scientists, engineers, technologists, and practitioners to collaboratively identify, develop, and deliver innovative, practical, and sustainable solutions to enhance coral reef and deep-water coral survival, conservation, resilience, adaptation, restoration, and rehabilitation. Solutions will be shared with coral conservation initiatives, such as ICRI, for further use and translation into conservation and restoration actions across the world by existing national and international implementation efforts (including UNEP, GFCR, Reef Resilience Network, the Coral Triangle Initiative on Coral Reefs, Fisheries and Food Security – CTI-CFF, and others).

Our main priorities are to:

1. Further develop and enhance R&D solutions currently being explored for coral reefs and deep-water coral protection, restoration, and adaptation.
2. Develop new R&D solutions for coral reef and deep-water coral protection, restoration, and adaptation.
3. Move potential solutions from concept to proof of concept, and from pilot scale to ready for deployment.
4. Develop protection, restoration, and adaptation solutions that can be deployed across the full socioeconomic spectrum and associated stakeholders, aided by a decision support system.
5. Partner with local stakeholders to adapt and deploy existing R&D tools and approaches to protect, restore, and adapt corals and coral reefs to local conditions.

To deliver these priorities, CORDAP will:

- Establish a coordinating mechanism to connect existing national, regional, and international R&D programs, as well as international panels and the diverse expertise of G20 members; learn from their efforts and diverse R&D approaches; realize potential synergies; and identify and pursue R&D priorities to enhance resilience and conservation of corals and reefs globally.
- Support a gender-diverse, internationally inclusive, transdisciplinary, global community of scientists, technologists, community leaders, and innovators to develop scalable end-to-end solutions that contribute to CORDAP objectives.
- Seek opportunities for engagement with the R&D capacity of the private sector and for collaboration on corals and reef conservation, resilience, and restoration.
- Facilitate information access and sharing between a network of field, research, and testing facilities across participating institutions.
- Provide advanced R&D training and access to cutting-edge research facilities and infrastructure in a gender-balanced, internationally inclusive way to scientists from developing and least developed countries to complement existing capacity-building efforts.
- Develop and share scientific tools for assessing the social and ecological costs and benefits of scalable applications, based on proof-of-concept and pilot projects.
- Deliver novel science and technology approaches, tested at pilot scale, to address specific needs and gaps as articulated by relevant stakeholders. Findings will be proactively shared with ICRI and UNEP, and with implementing mechanisms and initiatives such as those funded by the GFCR.

6 Engagement and Communication

6.1 Partner Engagement

Since launching in June 2020, CORDAP has built a powerful alliance of partners. Members of CORDAP's governing committee (IGC) include most of the G20 governments, the International Coral Reef Initiative (ICRI), the Global Fund for Coral Reefs (GFCR), the United Nations Environment Programme (UNEP), the International Coral Reef Symposium (ICRS), the Coral Restoration Consortium (CRC), the Japanese Coral Reef Society (JCRS), and the Great Barrier Reef Foundation (GBRF).

CORDAP and GFCR are aligned and plan to jointly source resources that cover the full spectrum of research, technology development, deployment, and on-the-ground restoration programs. CORDAP will continue to expand and develop its partnerships to enhance our ability to fund programs and the optimal transfer of technologies and knowledge developed through our funded activities.

6.2 Related Program Engagement

A number of R&D efforts already in place provide a springboard for CORDAP to build, connect, and learn from. CORDAP is also uniquely positioned to create links and foster global efforts, with many collaborative opportunities to build critical mass and accelerate R&D. CORDAP will engage with these programs and foster collaboration using mechanisms such as landscape scoping studies to identify gaps in current efforts and to guide our investments. Examples include:

- The Australian Reef Restoration and Adaptation Program (RRAP), a 10-year R&D program for developing new methods to protect, adapt, and restore coral reefs. It was designed to progressively make available a suite of new methods that have impact at scales from single reefs to whole systems. While the program is focused on the Great Barrier Reef (GBR), the technologies and methods it is developing are applicable globally, and the knowledge it generates will be made freely available.

  This designed R&D program will deliver against set goals over different timeframes through multidisciplinary teams from national and international R&D organizations, industry, stakeholders, and traditional owners. The first four-year A$135 Million R&D block commenced in 2020 and was funded by the Australian Government, R&D providers, and third parties.

  This initial block seeks to deliver 1) operational coral restoration and adaptation methods in the 1-million- to 10-million-corals-per-year range, 2) shading methods that protect individual reefs, 3) advances in rubble stabilization methods, 4) critical fundamental knowledge for understanding risk, and 5) in combination with models and decision systems, a capability guide for future deployments that maximizes effectiveness and impact. The program also intends to develop partnerships with stakeholders (including the establishment of new intervention industries) and traditional owners. More details can be found at www.gbrrestoration.org. RRAP has expressed a strong desire to partner with CORDAP, sharing information, avoiding redundancy, and collaborating on R&D projects.

- United States Department of Defense agency DARPA (Defense Advanced Research Projects Agency) is establishing Reefense—a program to develop self-healing, hybrid biological and engineered reef-mimicking structures to mitigate the coastal flooding, erosion, and storm damage that increasingly threatens civilian and U.S. Department of Defense infrastructure and personnel. Although the program has specific defense goals, their overlap with our goals is considerable, creating opportunities for collaboration and information sharing.

Reefense's planning documents state that *"under Reefense, custom wave-attenuating base structures will be designed and fabricated to promote calcareous reef organism (coral or oyster) settlement and growth, which will enable the system to self-heal and keep pace with sea level rise over time. Systems must be designed and put in place that will also attract non-reef building organisms necessary to help maintain a healthy, growing system. Finally, adaptive biology (other than synthetic biology) will enable improved coral and oyster resilience against disease and temperature stress, to ensure compatibility with a changing environment."* These are all areas that align well with CORDAP's goals.

- United States Department of Commerce agency NOAA (National Oceanic and Atmospheric Administration) and the U.S. National Academies of Sciences, Engineering, and Medicine (National Academies) both recognize that coral reef ecosystems are deteriorating globally. NOAA is committed to intervening in U.S. reefs where it has the authority to act, and to support and promote the restoration and intervention of reefs worldwide. Given the accelerating threats to reef ecosystems, effective, judicious, and timely interventions must be made.

  In response to a study by the National Academies on coral interventions, NOAA has developed the NOAA Action Plan on Coral Interventions, which will guide NOAA's approach to coral interventions over the next few years. The plan recommends four actions: (1) research and test priority interventions, (2) develop local or regional structured decision support, (3) review policy implications of coral interventions, and (4) invest in infrastructure, research, and coordination.

- The Coral Restoration Consortium (CRC) was formed as a community of practitioners dedicated to using the best science and ingenuity to support the persistence of coral reef ecosystems. The CRC includes academic researchers, restoration practitioners, natural-resource managers, and policymakers, among others. The CRC seeks to foster the communication of science and ingenuity to improve the efficacy and increase the scale of coral reef restoration, all intended to "maintain and rebuild remnant coral populations."

  The United States of America's National Science Foundation's Established Program to Stimulate Competitive Research (EPSCoR) RII Track-1: Guam Ecosystems Collaboratorium for Corals and Oceans (GECCO) will implement a systematic research agenda incorporating new knowledge of biodiversity, population genetics, genomics, phylogenetics, ecology, microbiology, oceanography, and mathematical modeling to document and predict the taxonomic and functional diversity of reef-builders and associated taxa in a changing environment.

- The United States of America's Deepwater Horizon Natural Resource Damage Assessment and Restoration Draft Open Ocean Restoration Plan 2, developed after more than 770-square miles of deep-sea habitat and four-square miles of mesophotic (middle light) habitat were injured by the Deepwater Horizon (DWH) oil spill, focuses on the following mesophotic and deep benthic communities restoration approaches:

- Protect and manage mesophotic and deep benthic communities
- Place hard-ground substrate and transplant coral

Robust resource-level monitoring and adaptive management will address critical uncertainties identified in the DWH Oil Spill Final Programmatic Damage Assessment and Restoration Plan and Final Programmatic Environmental Impact Statement. Implementation will include an initial one- to two-year planning and design stage, followed by a five-year field and lab-based implementation stage, and a one-year final stage for final evaluation and reporting.

- The NEOM Shushah Coral Garden Project will build several square kilometers of coral reefs in the northern Red Sea using advanced restoration techniques, through a partnership between King Abdullah University of Science & Technology (KAUST) and NEOM.[59]

6.3 Outputs: Who Will Use Them and How?

As an R&D accelerator, CORDAP will support field activities. Deployment is not one of our core activities, however. Instead, CORDAP will deliver technologies, methods, and processes that can be applied in conservation and restoration efforts across the world through existing national and international efforts.

CORDAP is committed to the principles of co-design, and will include end users in the research, design, and development of our solutions.

A key criterion in our R&D proposal assessments will be whether we can identify suitable partners and groups that can deploy the proposed technologies (Table 1).

Table 1. Potential partners of CORDAP

Category	Examples
Contributors/Partners	G20 nations Non-G20 nations Philanthropic organizations Individual philanthropists
Partners	International coral conservation and restoration organizations (ICRI, GFCR, UNEP, CRC, CORDIO, Regional Seas) International coral conservation and restoration efforts (Reef Restoration and Adaptation Program, Reef Resilience Network, International Union for the Conservation of Nature, International Coral Reef Society) National coral reef restoration and conservation organizations and activators (NOAA, Great Barrier Reef Foundation, JCRS, RRAP, Defense Advanced Research Projects Agency) Indonesia Reef Health Monitoring - Coral Reef Rehabilitation and Management Program - Coral Triangle Initiative (RHM - COREMAP CTI) CORDAP R&D providers and researchers
Partners/Beneficiaries	Global and regional coral conservation and restoration organizations and networks (The Nature Conservancy, Reef Resilience Network, MARFund, Mesoamerican Reef Restoration Network, SAM-Puerto Rico, Healthy Reefs Initiative, Wave of Change, Corales de Paz, Raising Coral Costa Rica, Ecomares) Secretariat of the Pacific Regional Environment Programme Great Barrier Reef Marine Park Authority IFRECOR - French Initiative for Coral Reefs National Academy of Science, Engineering and Medicine, United Nations Environment Programme World Conservation Monitoring Centre Commonwealth Blue Charter Action Group for Coral Reef Protection and Restoration Resilient Reefs Initiative The Indonesia Coral Reef Garden (ICRG) project
Beneficiaries	Reef owners, custodians, managers, and users Deployment providers (from communities to industrial corporations) Owners of coastal infrastructure protected by coral reefs Global communities

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6.4 Communications

To attract attention and drive engagement with researchers, innovators, international policy makers, partners, and investors, CORDAP's communications strategy includes:

- Positioning CORDAP with today's top organizations and scientific minds.
- Educating scientific and general audiences on our mission and goals.
- Encouraging global researchers, engineers, innovators, organizations, and institutions to contribute and help accelerate the goal of coral and coral reef restoration.
- Promoting our successes.

To accomplish this strategy, CORDAP is developing an integrated and multi-dimensional communications plan designed to maximize global and scientific media exposure while connecting directly to the target audiences through digital campaigns (social media, digital ads, email campaigns, and other tactics). CORDAP will also develop communications policies and partner with communications teams at established organizations to amplify awareness of the platform and the work our members are doing in coral reef conservation and restoration.

CORDAP is connected with high-level influencers in marine science, coral reef conservation and restoration, engineering, and climate change philanthropy, as well as with G20 officials. As we work with these thought leaders, our audience reach will continue to grow and expand into mainstream media.

7 Delivering the Program

CORDAP's areas of investment are likely to evolve over time as gaps are addressed and new technologies and science become available. This strategic plan therefore focuses on the most pressing investment needs for directing the program over its first three years of operation.

To maximize innovation and diversity of thinking, CORDAP's calls for proposals will be open to all submissions within our scope and investment criteria.

Each call for proposals will have a theme or recommended areas of R&D set by the SAC. Prior to each call, the SAC will use a range of methods to identify these areas, including:

- SAC members' knowledge and expertise
- Guidance from outside experts
- Reviews of R&D already being funded by CORDAP
- Systems assessments that fill gaps around interventions and associated technologies, methods and processes already being funded
- Input from those investing in or deploying methods or other R&D programs

This mix of novel innovation driving new ideas and systems thinking to identify gaps will strengthen our impact, enabling us to guide investments where they are needed and to make ideas operational.

7.1 Investment Types

Respondents will be asked to submit proposals tagged against different investment types. Each call for proposals will have a notional allocation of funding by type, with strict limits. The CORDAP SAC and IGC reserve the right to adjust funding based on the quality and quantity of submissions.

CORDAP will invest in novel early-phase ideas through to final proof-of-concept development and testing. Six investment types have been identified and detailed in Table 2 below to help guide proposal calls, submissions, and assessments.

Types 1 and 2 are designed to facilitate step change advances. Types 2 and 3 create early or lower-cost benefits from the program by more heavily leveraging other R&D programs. Type 4 recognizes that some areas will require further planning before investment to be effective. And types 5 and 6 recognize that for some projects to achieve impact, a broader suite of R&D and engagement will be required.

Table 2. CORDAP Investment Typology

Investment Type		Description
1	Novel R&D projects	These include the development and implementation of tools, technologies, methods, or whole new interventions designed to better protect, manage, adapt, or restore corals and coral reefs (innovations in coral and reef monitoring, threat reduction, assisted evolution, or restoration). Given the objective of step changes, the program will require that new and innovative interventions be developed, so we anticipate that this will become the predominant investment area.

2	Improving or scaling up existing interventions	This R&D will make a “significant” improvement to an existing intervention, technology, or method, including scaling up. These investments should be designed to create an immediate impact, with the possibility that the improvement can be implemented by existing restoration and adaptation projects. “Significant” is not fixed, but the expectation is that these investments will at least double current productivity or coral survival levels. This criterion is based on the fact that current methods make impacts at orders of magnitude below our requirements—and that CORDAP wants to focus on major improvements.
3	Translation R&D	This R&D adapts an existing technology or intervention to a different labor or capacity context. Technologies and interventions are developed based on local costs, technologies, and labor structures, and will need to be adapted to other socioeconomic conditions. This type supports the translation of R&D methods developed or in development from one location to another.
4	Scoping and planning studies	These are planning studies (for example, landscape analysis of R&D interventions) that inform the highest-priority opportunities for R&D investment. They could build on existing guidance (e.g., the U.S. National Academies Study: Decision Framework for Interventions to Increase the Persistence and Resilience of Coral Reefs) or they could be new studies. These are short projects (six months) and will involve sufficient representation of those currently working in the area.
5	Foundation science to support implementation of interventions	As a mission-driven program, CORDAP typically does not invest in R&D outside of our mission. Nevertheless, there are critical gaps in fundamental knowledge that, if left unaddressed, could limit the impact or increase the risk of restoration and adaptation programs. This investment type accepts proposals to address these shortfalls, and may include: Quantifying/understanding natural adaptation, coral demographics, and advanced taxonomy to aid intervention designs. Novel ecosystem design for application where restoring corals and reefs to their former state is no longer feasible. Models, decision systems, and monitoring technologies to assess risk and to guide deployments and improve the effectiveness of deployment investments. Cryopreservation (biobanking as an R&D or invention production tool) Proposals of this type must articulate how the research will directly inform the implementation of tools, technologies, methods, or new interventions that better protect, manage, adapt, or restore corals and reefs.
6	Capacity building and local implementation	This type is for managers and practitioners to apply novel or scaled-up R&D technologies or to build local capacity to implement approaches that improve coral and reef protection, reduce threats, or enhance restoration. Because capacity to take on R&D in these areas is often limited to large-scale research facilities and some practitioner groups, this type supports implementation by local NGOs, research organizations, and community groups of technologies that can improve or scale up their ongoing efforts. This may also include funding for technology training or support for its application in new locations.

7.2 Innovation and Systems Thinking Integration

CORDAP is committed to creating impact, and innovation is especially crucial to filling the significant gap between current and required capabilities. Impact also requires a strong focus on systems. For example, interventions such as re-seeding corals are not a single technology but an integrated system of technologies, methods, and processes, all of which must be attuned to the local context.

Many requests for CORDAP funding will be for innovative new technologies that form part of these larger systems, and in these instances, we must be able to see the broader context to understand what else is necessary for the investment to have impact. The system's components may already exist, they may be in development by others, or they may require novel R&D investment.

Project teams will be required to present their novel ideas framed inside simple "whole system" descriptions, allowing quick systems reviews during the assessment process.

This will not apply to all investment types, but where it is appropriate, methods such as flow diagrams describing the primary components (e.g., materials supply, production, transport, deployment, and associated infrastructure and human resources assumptions) will be required. In each instance, applicants will be asked to indicate if a component exists, is in development, or requires R&D investment.

This approach will bring a number of benefits to the program, by:

- Encouraging systems engineering thinking by R&D teams, who may adjust R&D proposals prior to submission.
- Helping R&D teams to think about scale from the start, rather than assume (often incorrectly) that an idea can be scaled later.
- Enabling us to identify partnerships within the program and with R&D programs outside of CORDAP.
- Facilitating "eyes open" investment decisions by CORDAP.

7.3 Intellectual Property

The core of CORDAP´s mission is to generate innovative, practical, and sustainable solutions for further use and translation by conservation and restoration efforts across the world. We will therefore manage intellectual property (IP) so that it can be applied by coral restoration efforts worldwide, and so that resulting technologies will be accessible and affordable to those who need them.

- CORDAP does not seek to own any of the IP resulting from its funded activities. Ownership vests as agreed by the organizations collaborating on the research.
- Owners of IP resulting from CORDAP-funded activities must provide a free license for all commercial and non-commercial coral restoration use, including free license to any background IP the project relies on.
- CORDAP-funded developments and technologies should be made available and accessible at an affordable price to all coral restoration projects.
- Publications and underlying data generated by CORDAP-funded activities will be made openly accessible, allowing others to build upon and re-use this knowledge and information.

Building on current available IP with similar availability criteria for coral restoration, CORDAP will seek to establish an IP "Coral Commons" where all freely available IP generated globally for coral restoration can be accessed, examined, and licensed.

7.4 R&D Proposal Submissions and Review Processes

Eligibility

CORDAP seeks to fund those who can most appropriately provide and deliver research and development. All parties will need to agree on IP ownership and any co-investment and charging rate provisions of the specific call for proposals. The call will detail these provisions along with collaboration and diversity requirements. This does not preclude commercial entities from applying, provided they meet the stated rules.

Submission Documents

The Platform Central Node (PCN) of CORDAP will create proposal submission documents customized to the investment type and assessment criteria. These documents may change over time and will be endorsed by the SAC prior to each call for proposals.

Proposal Submission Process

Respondents will initially submit short concept notes which, if approved, will be the basis for full proposal submissions. This two-step process allows for early identification of ineligible applications or those that do not meet the required standards. It will also enable the SAC to make recommendations to respondents for their full proposal. Concept notes will be structured to feed into full proposals, minimizing work. This approach will result in higher-quality proposals and will avoid time spent on unsuccessful proposals.

Proposal Reviews and Awarding of Contracts

The SAC will review and rank both concept notes and full proposals and will provide recommendations for investment to the IGC. The IGC will make the final decision on which projects are awarded funding.

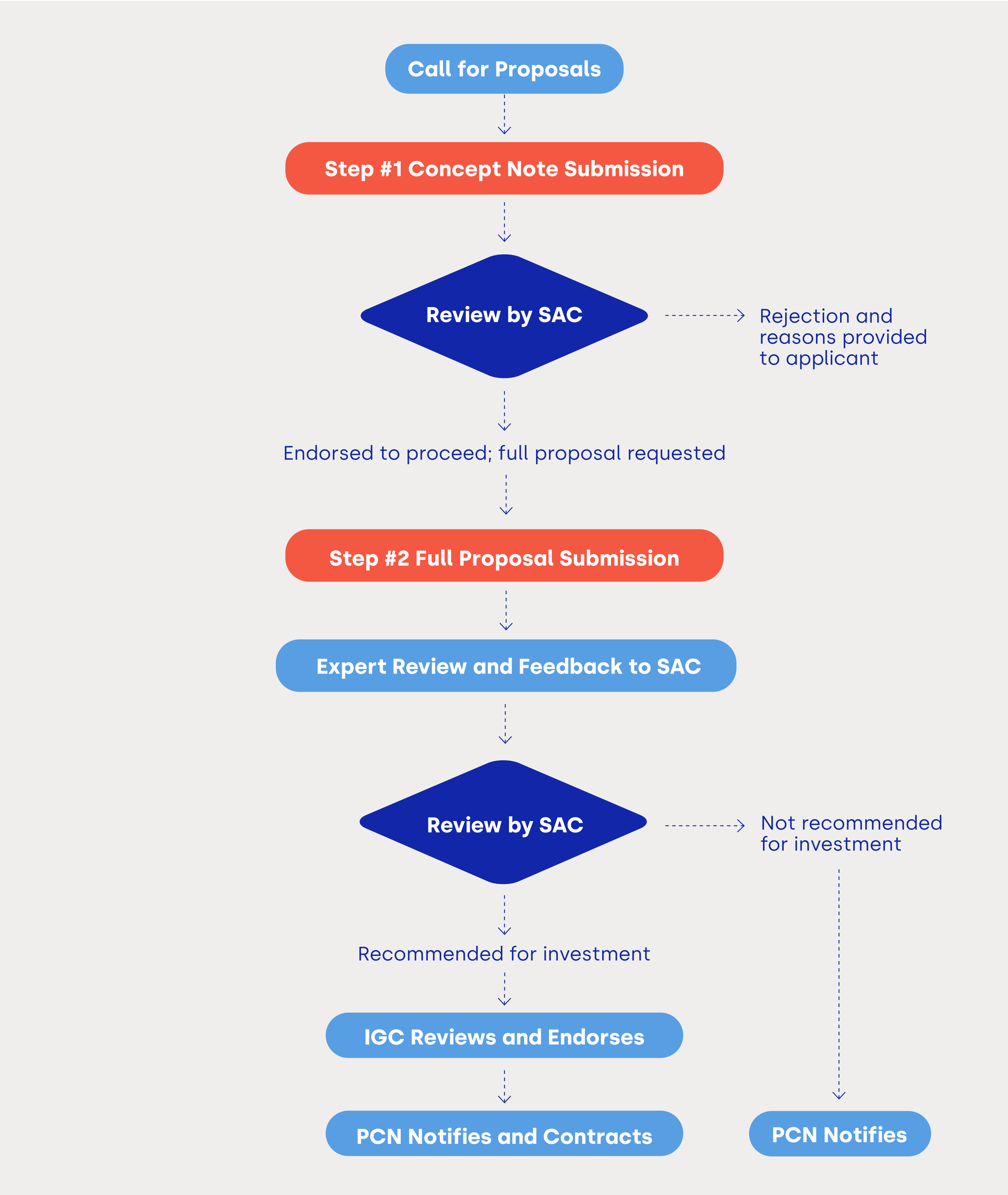
Before the SAC rates the full proposals, each proposal will be assessed by independent experts and their commentary provided to the SAC.

The assessment and ranking criteria will factor in:

- Eligibility of the proposal and team
- Targeted impact
- Pathway and timing to impact (systems engineering reviews if required)
- Alignment with nominated R&D investment themes or areas
- Applicant's capacity to deliver results, and applicant diversity
- Cost / benefit / risk analysis
- Innovation or novelty of the idea
- Breadth of socioeconomic applicability

A detailed review process and associated governance will be developed and documented before the first call for proposals. CORDAP will adopt best practices including full transparency on how projects are rated. This will include SAC and IGC member participation rules and requirements for decisions.

Process Outline



8 Monitoring and Evaluation

Monitoring and evaluation will apply to CORDAP's overall program and to each funded project.

For CORDAP, the monitoring and evaluation cycle will allow for adaptive management. It will also be staged so that information from the process can feed into CORDAP's strategic plan renewal. The process and structure will be overseen by an SAC subcommittee, and the analysis and reporting will fall to the PCN. This will be complemented by a less in-depth annual review cycle.

A digital dashboard will be developed by the PCN that provides up-to-date information, key metrics, and data stories for review by the IGC, SAC, and PCN in monitoring CORDAP's performance. This will reduce the administrative burden on the PCN as it requires fewer "board papers" and no separate reporting. Key metrics may include:

- Number of projects funded
- Tropical vs. deep-water coral projects
- Funds committed to CORDAP with a breakdown of donors
- Funds distributed and their location
- Areas of research
- Whether the most promising research is finding a path to delivery or is dying before roll-out
- Gender of PIs (a specific goal in CORDAP's Founding Committee Report)

For each project, we will track investment and monitor success and impact. Monitoring and evaluation will be integrated into the call for funding proposal guidelines and will be customized to the proposal. At minimum this will include yearly financial and technical status reporting. A final report summarizing the project and tasks will be required at the conclusion of the performance period for the award, even though the research may continue.

In all events, our requirements will be kept to the minimum necessary for effective governance and adaptive learning because we want the majority of effort put into R&D and not on onerous reporting.

9 Resourcing the Platform

The CORDAP foundational document charges the IGC with the responsibility of resourcing the platform and "allocating resources to the program." Specifically, the IGC is charged to "request financial and in-kind contributions to the Platform, direct the PCN to accept contributions and consider and approve co-funding arrangements with partner agencies with support from the PCN" (3.4, Platform Governance, Closure Report from the Founding Committee. V 4.0, April 2021). Building on the founding contribution to the Platform of US$10 million per year from Saudi Arabia, CORDAP aims to raise and invest US$30 million per year in the first global R&D initiative dedicated to securing a future for corals and coral reefs.

In collaboration with CORDAP's strategic partners, such as the Global Fund for Coral Reefs, the Great Barrier Reef Foundation, and ICRI, CORDAP will develop an aligned Platform Resourcing Strategy, which will include efforts to raise funds from the philanthropic sector, the emerging impact investment market, and blue capital markets. This strategy will outline how additional capital will be leveraged using G20 member and non-member country contributions to accelerate implementation and deployment of large-scale, long-term, viable restoration activities.

Appendices

Appendix 1:
CORDAP 2022 Priority Investment Areas

The following will form the basis of the 2022 call for proposals.

As described in Section 7 of the Strategic Plan, each call will be open to any submissions in order to maximize innovation and diversity of ideas. In addition, the SAC will provide guidance on which areas they see as investment priorities.

For this call, the SAC recommends a two-fold approach:

Part A: Scoping and Design Studies:

In several of the priority investment areas the SAC recommends that short (fewer than six months) and low-cost (US$10K to $150K) scoping and design studies are completed before CORDAP invests further. Overall, this would provide actionable roadmaps to guide future activities and investments and would be a relatively small part of the R&D investment.

These studies need to engage a broad range of participants and so will not be undertaken as competitive proposals. Their purpose is to provide guidance to the SAC with a flexible delivery approach. Some will be run directly by the PCN and others will be contracted. A mixture of CORDAP networks and the CORDAP call for proposals will be used to generate interest in participation and leadership of each study.

Each study candidate will be requested to provide a summary of current knowledge, options for R&D investment, and recommended priorities. In each instance a white paper would be produced and published, creating a direct output that third parties can benefit from.

The specific areas for nomination and the rationale for using a scoping and design study rather than moving directly to a call for R&D proposals are detailed in the table 3:

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Table 3.

Area	Rationale for Approach
Deep-water coral R&D scoping study	Deep-water corals are far less studied than shallow-water/warm corals. It is currently unclear whether R&D should be focused on protecting remaining corals or on restoration/adaptation methods. If the latter, then deep-water corals need the same amount of R&D as shallow water corals. But since the challenges of deep-water coral R&D are far greater (depth, very slow growth rates, etc.), a very different R&D approach will be required. Note: This should be completed with NOAA representation as there are tens of millions of dollars committed as a result of Deep Water Horizon, which should be factored into the assessment.
Assisted adaption technologies and methods	This is a complex and difficult challenge. For example, increasing bleaching resistance (degree heating weeks, or DHW) and passing this to subsequent generations without significant performance or resilience trade-offs is a major challenge. Significant R&D is already being done, and new groups seeking to research the area may not be aware of findings to date or of current efforts. CORDAP can help bring these efforts together and invest in agreed priority gaps.
Frameworks for decision-making	Stakeholders, managers, and decision-makers urgently need tools to justify investment and prioritize different interventions. For example, will investing in coral restoration provide greater economic and ecological benefits than upgrading a sewage treatment plant? This requires valuing corals and reefs under various management scenarios. These frameworks are needed globally, and their methods should apply to a wide range of contexts (information, capability, etc.). Such a scoping study would ideally bring some of the larger existing development efforts (working in their own contexts) together with broader users to identify approaches that can be developed and applied globally. These approaches could then be funded in future calls.
Reef cluster site selection tools and methods (deployment guidance systems)	It is not feasible to restore all reefs, or all areas of an individual reef, to their historical baseline values. We need to be strategic about where to prioritize conservation and restoration efforts so that they support self-sustaining coral populations that supply larvae to the restored reef and adjacent reefs. Doing so will require tools and methods that consider connectivity, circulation patterns, wave action, benthos and structure, temperatures, coral demographics, and social, cultural, economic, and ecological values. Such a scoping study would ideally bring some of the larger existing development efforts (working in their own contexts) together with broader users to identify approaches that can be developed and applied globally. These approaches could then be funded in future calls.

Part B: Specific Areas of Initial R&D Focus:

The following are areas the SAC considers 'high need' at this point. They cover the full spectrum of investment types (Section 7.1).

1. **Innovative ideas for restoration and adaptation interventions.** Capture the best "outside-the-box" ideas.

2. **Low infrastructure, high throughput rate coral production and deployment methods.** Several methods in development have the potential to operate at larger scale. These include single aquaculture facilities that generate tens of millions of corals per year. These methods will be infrastructure investment-heavy, however, and therefore difficult to establish. We need new ideas that operate at scale (including deployment) and that don't require major infrastructure or unlimited cheap resources.

3. **New methods to protect existing corals.** Most existing deployments and R&D focus on replacing corals and not on retaining existing corals. Saving local colonies is preferable to replacing them. Only a few engineering methods are being explored—for example, fogging / cloud brightening to shade reefs. We urgently need innovative new ideas—for example, treatments that can be applied to existing corals, innovative ways to improve local water quality, biomarkers for resilient corals, and the like.

4. **Limiting mortality of early life corals.** Corals commonly have high mortality during their early-life phases, which limits the efficiency of existing restoration methods. We need new substrates and treatments that mimic natural substratum and promote coral settlement while reducing mortality (e.g., crustose coralline algae, competitor inhibitors, as well as survival and growth supplements). These could be applied as part of a mariculture process or in the field to improve natural recruitment.

5. **Automation systems.** Automation is key to increasing production and deployment scales. Although some aspects of automation are process- or intervention-specific, there are areas common to many intervention types, and which should receive the focus of our investment.

6. **Reef monitoring.** This includes translation of large-scale emerging reef monitoring techniques such as photomosaics/photogrammetry and drones/aerial imaging for assessing key reef metrics (coral cover, reef health, rugosity, etc.), aimed at managers, conservation, and restoration practitioners in developing nations or those with limited funding. Efforts here may result in reduced costs of monitoring or in identification of low-tech methods for monitoring reefs at large spatial scales.

7. **Methods to meld natural and artificial reef recovery processes.** Many islands and coasts will be submerged unless they are defended by artificial structures, including hybrid reefs. Research in this field would identify ways to create such structures that can integrate with minimal damage into existing reefs, creating a rapid change in surge protection and actively enhancing the restoration and recovery of adjacent coral communities.

8. **Developing country R&D methods.** R&D in developing countries is often hampered by the absence of support infrastructure. We must support the identification and development of practitioner-oriented, possibly low-tech restoration techniques, whether they are new, they improve or scale up existing techniques, or they translate techniques

across different contexts. This will greatly enhance the scaling up of restoration efforts in communities and other settings where scientific and R&D infrastructure may be absent. Such techniques might reduce drivers, enhance ecological functions, improve the survival of coral colonies, or combine these goals, and can be site-specific.

9. **R&D capacity building.** We must build the capacity of marine managers and practitioners to use novel R&D techniques to better protect, manage, and restore corals.

10. **Reefs.** This begins with identifying key practices needed by local practitioners to sustain and grow their efforts and to build their capacity—without which many restoration and recovery efforts will never get off the ground.

Appendix 2: Glossary of Terms

Adaptive management: A structured, iterative process of robust decision making in the face of uncertainty, with an aim to reducing uncertainty over time via system monitoring.

Anthropocene: A proposed new geological epoch resulting from significant human-driven changes to the structure and functioning of the Earth System, including the climate system. It is being formalized within the geological community based on the stratigraphic evidence that human activities have changed the Earth System to the extent of forming geological deposits with a signature that is distinct from those of the Holocene, and which will remain in the geological record. Both stratigraphic and Earth System approaches to defining the Anthropocene consider the mid-20th century to be the most appropriate starting date, although other dates have been proposed and continue to be discussed. [IPCC--altered]

Anthropogenic: Resulting from or produced by human beings. [IPCC].

Antipatharians: An order of soft deep-water corals, also known as black corals or thorn corals.

Aragonite: A mineral species of calcium carbonate (CaCO3) with a crystal structure different from the other two forms of CaCO3 (vaterite and calcite). It is precipitated from ocean surface waters mainly by organisms (e.g., coral) that use it to make their shells and skeleton. [CORIS-NOAA]

Assisted migration: The translocation of species beyond their historical range to locations that are expected to be more suitable under future climate change. (Backus, Baskett 2019)

Benthic: On, or very near, the bottom of the sea, river, or lake (the benthos). [IPCC]

Biobanking: Generally, a collection of biological samples and associated information organized in a systematic way for research purposes. [Science Direct—altered]

Biodiversity: The numbers and relative abundances of different genes (genetic diversity), species, and ecosystems (communities) in a particular area.

Calcite: A mineral made up of a crystalline form of calcium carbonate. Calcite coral skeletons are composed of the calcite form of calcium carbonate. [CORIS-NOAA]

Colonial scleractinian: A coral composed of many individuals. [CORIS-NOAA]

Continental platform: Also known as continental shelf, the section of continental margin between the shoreline and the shelf break, or, where there is no noticeable slope, between the shoreline and the point where the depth of the superjacent water is approximately between 100 and 200 meters. [UN]

Coral: Clonal marine invertebrates within the class Anthozoa of the phylum Cnidaria, which occur along a range of geographies and depths.

Coral bleaching: The paling in color of corals resulting from a loss of symbiotic algae. Bleaching occurs in response to physiological shock in response to abrupt changes in temperature, salinity, and turbidity. [IPCC]

Crustose coralline algae: Red algae of the division Rhodophyta. They are very important members of a reef community in which they cement and bind the reef together. They are particularly common in high wave energy areas but can also be found throughout all reef zones. Crustose corallines resemble pink or purple pavement. Morphology can range from smooth and flat, to rough and knobby, or even leafy. [CORIS-NOAA]

Cryopreservation: The process of preserving cells and tissues at very low temperatures. [GBR—altered]

Deep-water corals: Corals that grow at depth, extending down to 6,000 m, along the shores of all continents at depths where reduced light levels does not allow them to support photosynthetic symbionts. Deep-water corals typically form habitats consisting of lose, branching corals that do not conform reefs, but nevertheless represent an important habitat for many organisms.

Ecological services: Ecosystem processes or functions which have value to individuals or society [IPCC—altered]

Ecosystem: A distinct system of interacting living organisms, together with their physical environment. The boundaries of what could be called an ecosystem are somewhat arbitrary, depending on the focus of interest or study. Thus the extent of an ecosystem may range from very small spatial scales to, ultimately, the entire Earth.

Fauna: All animals living in an area or in a particular period of history. [OLD]

Framework-forming corals: Any corals that form a rigid, wave resistant calcareous structure in a high-energy environment. [CORIS-NOAA]

Greenhouse gas emissions: Greenhouse gases are those gaseous constituents of the atmosphere, both natural and anthropogenic, that absorb and emit radiation at specific wavelengths within the spectrum of infrared radiation emitted by the Earth's surface, the atmosphere, and clouds. This property causes the greenhouse effect. Water vapor (H2O), carbon dioxide (CO2), nitrous oxide (N2O), methane (CH4), and ozone (O3) are the primary greenhouse gases in the Earth's atmosphere. Moreover, there are a number of entirely human-made greenhouse gases in the atmosphere, such as the halocarbons and other chlorine- and bromine-containing substances which are dealt with under the Montreal Protocol. Beside CO2, N2O, and CH4, the Kyoto Protocol deals with the greenhouse gases sulfur hexafluoride (SF6), hydrofluorocarbons (HFCs) and perfluorocarbons (PFCs). [IPCC]

Heterogeneous habitat: An ecological area of higher environmental and species complexity. Heterogeneous environments are predicted to support more complex and diverse biological assemblages. (Hasemann and Soltwedel, 2011—inferred]

Hybrid reef: The combination of an existing or introduced submerged breakwater with an artificial coral reef. [Kim, Baek, et al 2020--inferred]

Intellectual Property (IP): Creations of the mind, such as inventions; literary and artistic works; designs; and symbols, names and images used in commerce. (WIPO)

Macroalgae: Algae that project more than one centimeter above the substratum. [CORIS-NOAA]

Mariculture: The cultivation of marine organisms under controlled conditions; a synonym for marine aquaculture. [CORIS-NOAA]

Mesophotic: The deepest half of the photic zone (starting at 30-40 m and extending to over 150 m) where photosynthetic rates are much reduced relative to the upper half of the photic zone.[CORIS-NOAA]

Ocean acidification: The reduction in the pH of the ocean over an extended period, typically decades or longer, which is caused primarily by uptake of carbon dioxide (CO2) from the atmosphere, but can also be caused by other chemical additions or subtractions from the ocean. Anthropogenic ocean acidification refers to the component of pH reduction that is caused by human activity. [IPCC[

Octocorals: A subclass of the Anthozoa that contains sea pens, sea pansies, sea fans, whip corals, and pipe corals. Octocorals always possess eight tentacles and eight complete septa (hard corals and anemones possess 12 or more tentacles and septa). They are colonial cnidarians whose polyps are connected by a tissue mass called the coenenchyme. This tissue connects the gastrovascular (digestive) cavities of all the polyps in the colony. [CORIS-NOAA]

Photogrammetry: A technique for obtaining three-dimensional measurements using photography as the fundamental medium for measurement. [Sajinkumar, Oommen 2018]

Photomosaics: An assemblage of photographs, each of which shows part of a region, put together in such a way that each point in the region appears once and only once in the assemblage, and scale variation is minimized. [CORIS-NOAA]

Pre-industrial era: The multi-century period prior to the onset of large-scale industrial activity, which began in England during the second half of the 18th century and spread to Europe and later to other countries including the United States. The Industrial Revolution marks the beginning of a strong increase in the use of fossil fuels and emissions in particular of fossil carbon dioxide. [IPCC--altered]

Reef: The three-dimensional structure developed by the accumulation of carbonate that tropical, warm-water corals deposit over time. Coral reefs represent one of the most biodiverse habitats in the planet, playing a fundamental role in coastal geomorphology and protection in tropical regions.

Reef accretion rate: The change in mass over time of a coral reef, vertically, horizontally, or in combination. [Blanchon, Richards et al 2017—inferred]

Resilience: The amount of change a system can undergo without changing state. [IPCC]

Ridge systems: An underwater mountain range, usually in mid-ocean, formed by plate tectonics. [Science Daily--altered]

Rubble stabilization: Innovative techniques that help secure loose rubble (large areas of broken-down coral fragments) to allow young corals to survive and grow in the rubble beds and form stable new reefs.

Rugosity: An important coral reef parameter that describes the amount of "wrinkling" or roughness of the reef profile. It is an index of substrate complexity. Areas of high complexity are likely to provide more cover for reef fishes and more places of attachment for algae, corals, and various sessile invertebrates. [CORIS-NOAA]

Scale: To increase or decrease performance and cost in response to changes in application and system processing demands. Scalability is the measure of a system's ability to scale. [Gartner]

Scleractinians: An order of Cnidaria, usually producing calcareous skeletons with hexameral symmetry. [CORIS-NOAA]

Sea surface temperature (SST): The subsurface bulk temperature in the top few meters of the ocean, measured by ships, buoys, and drifters. From ships, measurements of water samples in buckets were mostly switched in the 1940s to samples from engine intake water. Satellite measurements of skin temperature (uppermost layer; a fraction of a millimeter thick) in the infrared or the top centimeter or so in the microwave are also used, but must be adjusted to be compatible with the bulk temperature.

Seamounts: A submarine mountain, usually conical in shape and volcanic in origin, that rises 1,000 meters or more above the sea floor. Some definitions of seamounts do not include the height criterion. [CORIS-NOAA]

Selective breeding: The process by which humans choose individuals with specific heritable phenotypic traits to breed together and produce offspring. For corals, selective breeding is the process of producing and rearing corals from eggs through to colonies that are recruited into the population. [Humanes, Beauchamp et al 2021—altered]

Sexual recruits: Coral larvae that have successfully established themselves in suitable settlement substrate and are ready to begin forming a colony by dividing into clones. [Secore—altered]

Shared Socioeconomic Pathway: Shared Socioeconomic Pathways (SSPs) are scenarios of projected socioeconomic global changes up to 2100. They are used to derive greenhouse gas emissions scenarios from different climate policies.

Shelf breaks: Near-shore bathymetry (undersea topography) characterized by rapid and substantial increases in depth that are continuous with the deeper parts of the ocean. [CORIS-NOAA—altered]

Shoaling: Relating to ocean acidification and describing the upward movement of the aragonite saturation horizon (the boundary between shallower, saturated waters and deeper, undersaturated waters that are corrosive to aragonitic organisms) through the water.

Slope: The sloping sea bottom of the continental margin that begins at a depth of about 100 to 150 m at the shelf edge and ends at the top of the continental rise or in a deep-sea trench. [CORIS-NOAA]

Stressors: A physical, chemical, or biological factor that adversely affects organisms; an agent, condition or similar stimulus that causes stress to an organism.

Stylasterids: A widely-occurring group of deep-sea corals that build their skeletons from either calcite, aragonite, or both. [Samperiz, Robinson et al 2020—altered]

Substrate: The material making up the base upon which an organism lives or to which it is attached. [CORIS-NOAA]

Substratum: The sediment at the sediment-water interface on and in which organisms live. [Walker]

Sustainably: In a way that meets the present generation's needs without compromising the ability of future generations to meet their needs. [IPCC—altered]

Symbiotic: Describes a relationship between two species of organisms in which both members benefit from the association (mutualism), or where only one member benefits but the other is not harmed (commensalism), or where one member benefits at the expense of the well-being of the other (parasitism).

Transdisciplinary approach: A research effort conducted by investigators from different disciplines working jointly to create new conceptual, theoretical, methodological, and translational innovations that integrate and move beyond discipline-specific approaches to address common problems.

Undersaturated: The condition in which the amount of a substance currently dissolved in water is less than the maximum possible dissolvable amount. [Roger Williams Univ.]

Zooxanthellae: A group of dinoflagellates living endosymbiotically in association with one of a variety of invertebrate groups (e.g., corals). In corals, they provide carbohydrates through photosynthesis, which are used as one source of energy for the coral polyps. They also provide coloration to corals. [CORIS-NOAA]

Glossary sources

IPCC	https://www.ipcc.ch/site/assets/uploads/2018/03/wg2TARannexB.pdf, https://www.ipcc.ch/site/assets/uploads/2018/11/sr15_glossary.pdf
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UN	https://www.un.org/depts/los/clcs_new/continental_shelf_description.htm
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