

Mapping Current and Future Priorities for Coral Restoration and Adaptation Programs

International Coral Reef Initiative (ICRI) Ad Hoc Committee
on Reef Restoration 2019 Interim Report



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International Coral Reef Initiative

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Larval enhancement trials on the Great Barrier Reef. Photography by Ross Miller.

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Abbreviations

- AIMS - Australian Institute of Marine Science
- CoP - Conference of the Parties
- CMS - Conservation of Migratory Species of Wild Animals
- CBD - Convention on Biological Diversity
- CITES - Convention on International Trade in Endangered Species of Wild Fauna and Flora
- CRC - Coral Restoration Consortium
- CSR - Corporate social responsibility
- FAO - Food and Agriculture Organization
- GBR - Great Barrier Reef
- GBRF - Great Barrier Reef Foundation
- GBRMP - Great Barrier Reef Marine Park
- GBRMPA - Great Barrier Reef Marine Park Authority
- GEF - Global Environment Facility
- ICRI - International Coral Reef Initiative
- ICRS - International Coral Reef Society
- IFRECOR - French Initiative for Coral Reefs
- IUCN - International Union for Conservation of Nature
- IPCC - Intergovernmental Panel on Climate Change
- NASEM - National Academy of Science, Engineering and Medicine
- NESP - National Environment Science Program
- RRAP - Reef Restoration and Adaptation Program
- NGO - Non-governmental organisation
- NOAA - National Oceanic and Atmospheric Administration
- SACEP - South Asia Co-operative Environment Programme
- SPC - Secretariat of the Pacific Community
- SPREP - Secretariat of the Pacific Regional Environment Programme
- TNC - The Nature Conservancy
- TRI - The Restoration Initiative
- UNEA - United Nations Environment Assembly
- UNEP - United Nations Environment Program
- UNEP - WCMC - United Nations Environment Programme World Conservation Monitoring Centre
- UNFCCC - United Nations Framework Convention on Climate Change
- UNWHC - United Nations World Heritage Convention
- WWF - World Wildlife Fund

Executive summary

Coral reefs are some of the most beautiful, biologically-diverse and economically valuable ecosystems on the planet. They are also among the most threatened. As coral reef health declines, there is increased appetite for active management and interventions, such as coral restoration or coral predator control, as well as growing recognition that established approaches to managing coral reefs are insufficient in a changing climate.

The International Coral Reef Initiative (ICRI) is an informal partnership of 80 countries and organisations striving to preserve coral reefs and related ecosystems around the world. The ICRI Plan of Action 2018-2020 called for the promotion of leading reef restoration practices by facilitating partnerships, investment and capacity-building among ICRI members. An ICRI ad hoc committee on reef restoration (henceforth referred to as the committee) was formed to progress this in 2019.

An online survey was distributed to ICRI members to identify common interests, facilitate global and regional collaborations, and help identify opportunities for co-investment in research and development. Of the 28 ICRI members who completed the survey: 17 were countries, eight were non-government organisations, one was a foundation and two were regional intergovernmental organisations. The survey results were supplemented by a series of meetings with relevant experts and coordinators.

Most ICRI countries who responded to the survey were using coral restoration as a tool to manage their reefs. The most commonly used techniques were coral gardening and direct transplantation, followed by artificial structures. Of the non-country members, less than half were using coral restoration, and just over a quarter reported research projects only. The most common objectives were engaging local communities and supporting tourism and fisheries production. ICRI members also highlighted the importance of research into coral adaptation or climate protection.

Almost all ICRI country-members stated that new policy relevant to restoration was needed, and many noted that it should be integrated with existing policy. Improving water quality was identified by ICRI countries as the most important future management action, while a global reduction in greenhouse gas emissions emerged as the primary future priority for non-country members. Coral restoration was not ranked in the top three priority management actions for either ICRI member group.

The two most common barriers and enablers driving coral restoration were funding and political will. Most respondents highlighted a need for more research to understand what they need to do, and to establish a plan of action. Most also articulated a need for more funding and training.

There is a substantial mismatch between current and aspirational coral restoration and adaptation projects in terms of scale, capacity and funding. The average area of restoration projects was a third of a hectare, while the annual area required was more than 80 hectares. Likewise, while funding ranged from tens of thousands to millions of US dollars, this is generally insufficient to meet future goals.





Recommendations

This report summarises the findings of an initial scoping study which aimed to identify common interests, facilitate global and regional collaborations, and help identify opportunities for co-investment in research and development. This study is a starting point for a wider global review and conversation into how active interventions should fit within coral reef management in a changing world.

This interim report recommends:

- **Strong action on climate change and other stressors:** Coral restoration should not be viewed as a replacement for reducing local, regional and global stressors acting on reefs.
- **Invest in research and development:** Substantial research and development is required to scale up and improve all facets of restoration and adaptation.
- **Promote knowledge-sharing and collaboration:** There would be great benefit in global cooperation, collaboration and knowledge-sharing to ensure efficient use of resources.
- **Develop best practice guidelines:** Science-based guidance for restoration practitioners is critically needed, and the UNEP and collaborating organisations have committed to facilitating the production of guidelines in the near future.
- **Develop policy and plans:** New or refined policy and plans relevant to restoration and adaptation are needed.
- **Promote 'blue restoration':** the UN Decade of Ecosystem Restoration represents an opportunity to promote 'blue restoration' including restoring coral reefs. Further, the goal of large-scale restoration, to sequester carbon and reduce anthropogenic climate change, could help mitigate the main threat to coral reefs.

Working with ICRI members, reef-bearing nations and relevant partners in 2020 and beyond, the Committee will:

- Continue to assess and document global needs and priorities for current and future reef restoration and adaptation programs.
- Continue to assess and document global research and development priorities.
- Provide a coordinating mechanism for international collaboration on coral reef restoration research and development.
- Advocate for the use of best-practice restoration techniques as part of a broader strategy that involves traditional management and reducing carbon emissions to maintain coral reef function and resilience.
- Facilitate the transfer of new knowledge of restoration techniques to managers and restoration practitioners.
- Update the global database on coral restoration methods and integrate it with the ICRI website, if resources are available.

Resumen ejecutivo

Los arrecifes de coral son uno de los ecosistemas más bellos, biológicamente diversos y valiosos del planeta, pero al mismo tiempo se encuentran entre los más amenazados. A medida que la salud de los arrecifes de coral disminuye, aumenta la motivación de manejar e intervenir activamente en esta situación, por medio de la restauración de los corales o el control de sus depredadores, así como reconocer paulatinamente que los enfoques establecidos hasta el momento para el manejo de los arrecifes de coral son insuficientes en un clima que está cambiando.

La Iniciativa Internacional de Arrecifes de Coral (ICRI por sus siglas en inglés) es una asociación informal de 80 países y de organizaciones que luchan por preservar los arrecifes de coral y los ecosistemas relacionados con ellos en todo el mundo. El Plan de Acción ICRI 2018-2020 pidió la promoción de prácticas de vanguardia de restauración de arrecifes facilitando asociaciones, inversiones y desarrollo de capacidades entre los miembros del ICRI. En 2019 se formó un comité ad hoc de ICRI sobre la restauración de arrecifes (de aquí en más “el comité”) para avanzar en este tema.

Una encuesta en línea distribuida recientemente a los miembros de ICRI tuvo como objetivo identificar intereses comunes, facilitar colaboraciones mundiales y regionales, y ayudar a identificar oportunidades de inversión conjunta para investigación y desarrollo. De los 28 miembros de ICRI que completaron la encuesta: 17 eran a nivel de países, ocho a nivel de organizaciones no gubernamentales, uno era una fundación y dos eran organizaciones intergubernamentales regionales. Los resultados de la encuesta se complementaron con una serie de reuniones de expertos y coordinadores.

La mayoría de los países del ICRI utilizan la restauración de corales como herramienta para gestionar sus arrecifes. Las técnicas más utilizadas son la jardinería de corales y el trasplante directo, seguidas de estructuras artificiales. De los miembros que no son a nivel de países, menos de la mitad usan la restauración de corales, y poco más de una cuarta parte informaron que solamente llevan a cabo proyectos de investigación. Los objetivos más comunes son involucrar a las comunidades locales y apoyar el turismo y la producción pesquera. Los miembros del ICRI también destacaron la importancia de la investigación sobre la adaptación de corales o la protección del clima.

Casi todos los países miembros de ICRI declararon que se necesitaba una nueva política relevante de restauración, y muchos señalaron que debería integrarse con las ya existentes. Los países miembros del ICRI identificaron la mejora de la calidad del agua como la acción de gestión futura más importante, mientras que una reducción global en las emisiones de gases de efecto invernadero surgió como la principal prioridad futura para los miembros que no son países. La restauración de corales no se clasificó entre las tres principales acciones de gestión prioritarias para ninguno de los dos tipos de miembros del ICRI.

Las barreras y al mismo tiempo facilitadores más comunes que impulsan la restauración de corales son el financiamiento y la voluntad política. La mayoría de los encuestados resaltaron la necesidad de realizar más actividades de investigación para comprender lo que deben hacer y establecer un plan de acción. La mayoría también manifestó la necesidad de contar con más fondos y capacitación.

Hay un desajuste sustancial entre los proyectos actuales y aspiraciones de restauración y adaptación de corales en materia de escala, capacidad y financiamiento. El área promedio de los proyectos de restauración actuales son de menos de un tercio de hectárea, mientras que el área anual requerida para ser restaurada es de más de 80 hectáreas. Del mismo modo, y si bien el financiamiento oscila entre miles y millones de dólares, generalmente es insuficiente para cumplir con las metas futuras.



Recomendaciones

Este informe resume los hallazgos de un estudio inicial que tuvo como objetivo identificar intereses comunes, facilitar las colaboraciones mundiales y regionales, y ayudar a identificar oportunidades de inversión conjunta en investigación y desarrollo. El estudio es un punto de partida útil para continuar con una revisión y conversación global sobre cómo las intervenciones activas deberían encajar dentro del manejo de los arrecifes de coral en un mundo cambiante.

Este informe provisorio recomienda:

- **Una acción contundente sobre el cambio climático y otros estresores:** La restauración de corales no debe ser vista como un reemplazo para reducir los estresores locales, regionales y globales que actúan en los arrecifes.
- **Invertir en investigación y desarrollo:** Se requiere investigación y desarrollo sustancial para ampliar todas las facetas de restauración y adaptación.
- **Promover el intercambio de conocimientos y la colaboración:** Sería beneficioso para la cooperación global, la colaboración y el intercambio de conocimientos, para garantizar el uso eficiente de los recursos.
- **Desarrollar guías de mejores prácticas:** Es crítica la necesidad de contar con una guía científica para ser usada por los profesionales de restauración: la ONU y las organizaciones colaboradoras se han comprometido a facilitar su producción en un futuro próximo.
- **Desarrollar políticas y planes:** Son necesarias políticas y planes nuevos o mejorados de restauración y adaptación.
- **Promover la “restauración azul”:** El objetivo de la Década de Restauración del Ecosistema de las Naciones Unidas (2021-2030) a gran escala para secuestrar carbono y reducir el cambio climático antrópico, puede ayudar a mitigar la principal amenaza para los arrecifes de coral.

Trabajando en conjunto tanto los miembros de ICRI, como las naciones que cuentan con arrecifes y otros socios, en el 2020 el Comité:

- Continuará evaluando y documentando las necesidades y prioridades globales actuales y futuras de restauración y adaptación de arrecifes.
- Continuará evaluando y documentando las prioridades globales de investigación y desarrollo;
- Proporcionará un mecanismo de coordinación para la colaboración internacional en investigación y desarrollo sobre la restauración de arrecifes de coral.
- Abogará por el uso de mejores prácticas de restauración como parte de una estrategia más amplia que involucre el manejo tradicional y la reducción de las emisiones de carbono para mantener el funcionamiento y la resiliencia de los arrecifes de coral.
- Facilitará la transferencia de nuevos conocimientos de técnicas de restauración a gerentes y profesionales que trabajen en estos temas.
- Actualizará la base de datos global sobre métodos de restauración de corales y la integrará al sitio web de ICRI, siempre y cuando haya recursos disponibles.



Résumé

Les récifs coralliens sont parmi les écosystèmes les plus beaux et les plus importants de la planète, ils offrent une diversité biologique incomparable, mais ils sont également parmi les plus menacés. Tandis que la santé des récifs coralliens décline, le besoin d'intervenir et de gérer activement la situation (restauration récifale, lutte contre les prédateurs...) s'intensifie, de même que la prise de conscience que les approches de gestions actuelles restent insuffisants dans un contexte de réchauffement climatique.

L'International Coral Reef Initiative (ICRI) est un partenariat informel entre 80 pays et organisations dans leurs combats pour préserver les récifs coralliens et leurs écosystèmes associés de par le monde. Le Plan d'Action établi par ICRI pour 2018-2020 appelle à promouvoir les initiatives et pratiques les plus efficaces quant à la restauration récifale en facilitant les partenariats, les investissements financiers et le renforcement des capacités entre les membres ICRI. Un comité spécial dédié à la restauration des récifs coralliens a été établi en 2019 pour la gestion du Plan.

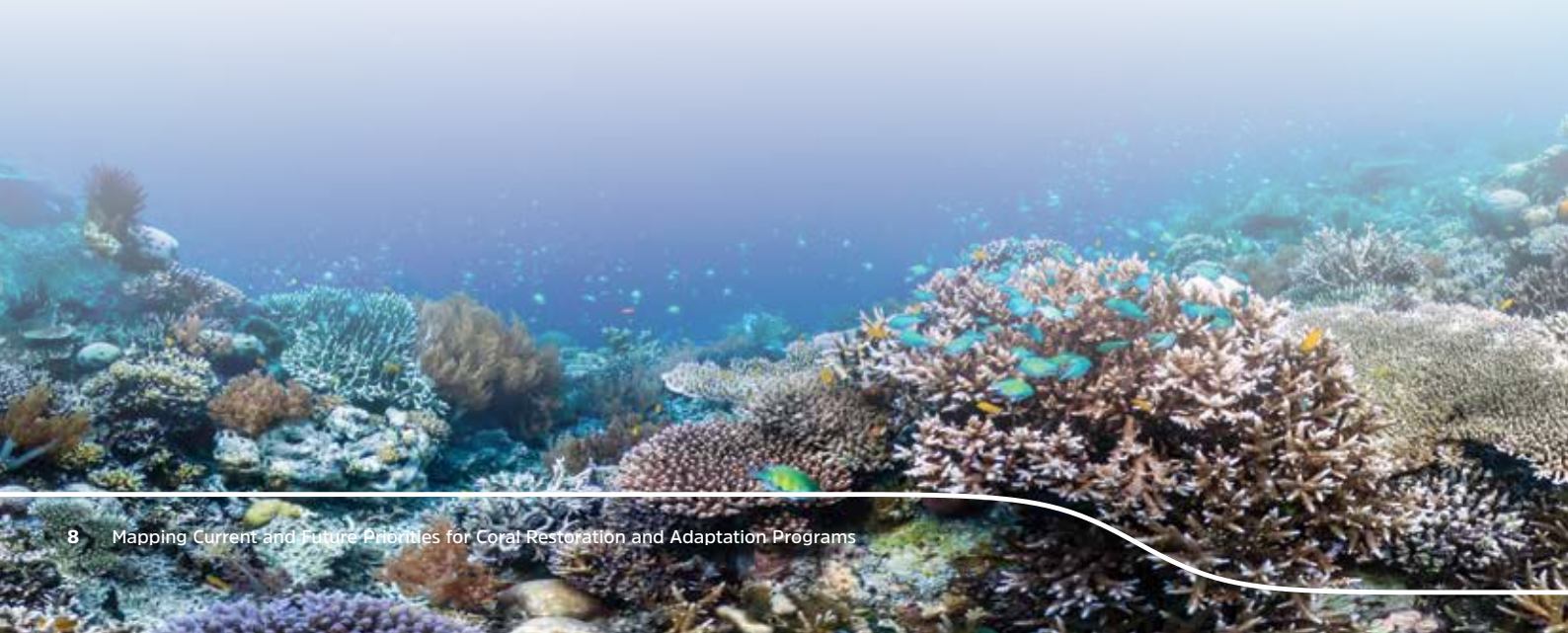
Un sondage en ligne, récemment réalisé auprès des membres ICRI, avait pour but d'identifier les intérêts communs des membres, de faciliter les collaborations régionales et globales, et d'identifier les opportunités de partenariats de co-investissement pour la recherche et le développement. Le sondage fut complété par 28 membres ICRI, dont 17 pays, 8 organisations non-gouvernementales, une fondation, et 2 organismes régionaux inter-gouvernementaux. Les résultats furent supplémentés d'une série d'entretiens avec des experts et des coordinateurs.

Les résultats ont montré que la plupart des pays membres utilisent la restauration récifale comme un outil de gestion des récifs coralliens. Les techniques les plus employées sont le jardinage corallien (multiplication corallienne asexuée) et la transplantation directe, suivies par les structures artificielles. Quant aux autres membres, moins de la moitié employait des techniques de restauration récifale et un peu plus d'un quart n'en était qu'au stade de projets de recherche. Les objectifs les plus récurrents étaient d'impliquer les communautés locales, et de soutenir le tourisme et la production piscicole. Les réponses avançaient également l'importance de la recherche dans l'adaptation corallienne et la protection liée au changement climatique.

Presque tous les pays membres affirmèrent qu'une politique plus pertinente liée à la restauration était nécessaire, et plusieurs ajoutèrent que cela pouvait être intégré aux lois actuellement en vigueur. Les pays membres ont identifié l'amélioration de la qualité de l'eau comme étant prioritaire sur la liste des stratégies à mettre en place à l'avenir, tandis que la réduction globale des gaz à effet-de-serre était prioritaire pour les autres personnes interrogées. La restauration corallienne n'atteignait pas le top 3 des stratégies à mettre en place en priorité.

Les deux obstacles et catalyseurs à la restauration les plus courants étaient l'apport financier et la volonté politique. La plupart des personnes interrogées reconnaissaient le besoin de plus de recherche afin de comprendre ce qu'elles avaient à faire pour mieux protéger les récifs et la nécessité d'établir un plan d'action. Elles exprimaient aussi le besoin de plus de financements et de plus de formations.

Il y a un décalage considérable entre les attentes en termes d'échelle, de capacité et de financement, et l'état d'avancement actuel des projets d'adaptation et de restauration coralliennes. La superficie moyenne des projets de restauration couvre un tiers d'hectare, alors que plus de 80 hectares par an sont nécessaires. De même, bien que les financements offerts vont de dizaines de milliers de dollars américains à plusieurs millions, cela reste insuffisant pour réaliser les projets à venir.



Recommandations

Ce rapport résume les résultats d'une étude préliminaire qui avait pour but d'identifier, les intérêts communs, de faciliter les collaborations régionales et globales, et d'identifier les opportunités de partenariats de financement pour la recherche et développement. Cette étude constitue un point de départ utile pour poursuivre un examen global et une conversation sur la manière dont les interventions peuvent s'accorder à la gestion des récifs coralliens dans ce monde changeant.

Le rapport intérimaire recommande les actions suivantes :

- **Agir avec force sur le changement climatique et autres facteurs de stress:** La restauration corallienne ne doit pas être perçue comme un substitut à la réduction des facteurs de stress locaux, régionaux et globaux.
- **Investir dans la recherche et le développement:** D'importantes recherches sont nécessaires pour accroître toutes les facettes de la restauration et de l'adaptation corallienne.
- **Promouvoir le partage de connaissances et la collaboration:** La coopération, la collaboration, et le partage de connaissances à l'échelle globale ont la capacité d'assurer efficacement l'usage des ressources.
- **Développer les lignes directrices de pratiques exemplaires:** Des conseils appropriés issus de faits scientifiquement prouvés sont essentiels pour les gestionnaires des projets de restauration corallienne. L'ONU et les organisations collaborant au projet se sont engagés à aider à l'établissement de consignes claires dans un avenir proche.
- **Développer les lois et les plans légaux:** De nouvelles lois, mieux adaptées au contexte actuel, et une réévaluation des lois en vigueur sont nécessaires.
- **Promouvoir la « restauration bleue » (blue restoration):** Le but principale de la restauration à grande échelle établi dans le cadre de la « Décennie des Nations Unies pour la restauration des écosystèmes » (2012-2030), pour capturer le carbone et réduire le réchauffement climatique anthropique pourrait atténuer la menace principale des récifs coralliens.

En 2020, avec l'aide des membres d'ICRI, des nations responsables et de partenaires appropriés, le comité a l'intention de:

- Continuer à contrôler et à rendre publics les priorités et nécessités, à l'échelle globale, concernant les programmes d'adaptation et de restauration récifales.
- Continuer à contrôler et à rendre publics à l'échelle globale, et les priorités liées à la recherche et le développement.
- Etablir un mécanisme coordinateur pour les collaborations internationales dans la cadre de la recherche et le développement.
- Promouvoir l'usage des meilleures techniques de restauration dans le cadre d'une stratégie de plus grande échelle, impliquant un encadrement traditionnel de gestion de récifs coralliens et la réduction d'émissions de carbone afin de perpétuer la résilience et la santé du corail.
- Faciliter le partage des connaissances nouvelles sur les techniques de restauration avec les gestionnaires et responsables des projets de restauration.
- Mettre à jour la base de données mondiale sur les méthodes de restauration, et l'intégrer au site web d'ICRI au fur et à mesure de la disponibilité des données.



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The coral reef challenge

Coral reefs are some of the most beautiful, biologically- diverse, and valuable ecosystems on the planet. The global economic value of coral reefs from goods and services is estimated to be worth US\$375 billion per year (UN Environment et al. 2018), supporting the livelihoods of at least 500 million people through activities such as fisheries and tourism (Hoegh-Guldberg, 2017). Healthy coral reef ecosystems can reduce up to 97% of wave energy, acting as barriers to storms and are the first line of defence for millions of people in coastal communities (Ferrario et al. 2014).

Coral reefs are also among the most threatened ecosystems on the planet. Reductions in coral reef health have been recorded in all major tropical oceans since the 1980s, with an average of 30-50 percent reduction in coral cover globally (NASEM, 2019a). The drivers of these declines include local and regional stressors such as pollution, overfishing and habitat destruction (Pandolfi et al. 2003). Global climate change is now recognised as the key driver of coral reef declines, associated with bleaching events, disease outbreaks and ocean acidification (Hoegh-Guldberg et al. 1999, Hughes et al. 2019).

In 2018, the Intergovernmental Panel on Climate Change (IPCC) forecasted the world's coral reefs would decline by a further 70-90% with a 1.5°C increase in global mean temperature from pre-industrial levels, while losses would exceed 99% with a 2°C increase (IPCC, 2018). Global temperatures are already 1°C above pre-industrial levels. We are facing the very real prospect that, without concerted action to reduce emissions and help drive adaptation and faster recovery from damage, the world's coral reefs, as we know them, will cease to exist within a generation. The increased frequency of disturbances impacting coral reefs further exacerbate this problem by not allowing sufficient time between events for recovery (Ortiz et al. 2018).

As coral reef health declines, there appears to be an increased appetite for active management interventions such as coral restoration or coral predator control to complement traditional management focused on reducing stressors or spatial planning. There is also a growing recognition that established approaches to managing coral reefs are insufficient on their own to support coral reef persistence and function in a changing climate (Anthony et al. 2017). This has led to the generation of new interventions and approaches globally and has prompted calls for greater coordination and collaboration to manage coral reefs in the Anthropocene.



A healthy coral reef supports a diverse group of reef organisms in Raja Ampat, Indonesia. Photo by Yen-Yi Lee.

ICRI and reef restoration and adaptation

The International Coral Reef Initiative (ICRI) began in 1994 and has grown into an informal partnership of 80 members (37 countries and 43 non-country). ICRI was formed to preserve the world's coral reefs and related ecosystems and has been formally acknowledged by the United Nations (UN) as an important coordinating organisation. ICRI strives for cooperation, collaboration and advocacy in the international arena. The 2018-2020 ICRI Plan of Action set out plans for a committee on reef restoration. The committee on reef restoration was made up of representatives from Australia, France, ICRI Secretariat, Indonesia, International Coral Reef Society, Monaco, Reef-World Foundation, the Secretariat for the Pacific Regional Environmental Programme (SPREP), The Nature Conservancy (TNC), United Nations Environmental Programme (UNEP) and USA/NOAA.

Chaired by Australia, the committee gathered experts from the ICRI membership across reef-bearing regions of the world to assess and document:

- global needs and priorities for current and future reef restoration and adaptation programs
- global research and development priorities to deliver the methods, productivity and cost breakthroughs needed to support restoration and adaptation program objectives
- priority drivers and areas for reef investment.

Additionally, the committee gathered expert views to:

- identify mechanism(s) to improve joint planning and delivery of reef restoration and adaptation research and development
- identify (at a high level) opportunities to partner on reef restoration and adaptation research and development activities.

Further, in 2019, the committee was tasked with the following aims:

1. To establish an inventory of existing and future reef restoration activities throughout the world.
2. To identify leading and innovative practices, techniques and strategies (including their limits, conditions of implementation, financing, and an assessment of their results).
3. To revise the 2005 ICRI resolution on coral reef restoration in light of new scientific and management knowledge.
4. To seek active collaboration and participation with organisations in the field including International Coral Reef Society (ICRS), Commonwealth Blue Charter, the Coral Restoration Consortium (CRC), and Australia's Reef Restoration and Adaptation Program (RRAP).

Aims one and two were completed through complementary research programs described in the 'What is Coral Reef Restoration and Adaptation' of this report. A motion to review the 2005 resolution (aim three) was tabled at the 34th ICRI General Meeting (2019). The committee has established ongoing active collaboration and participation with the organisations described in aim four.

During phase one of this project (2019), the committee gathered information through an online survey of ICRI members, expert elicitation through meetings, and a desktop review. This report describes the current coral restoration landscape, and identifies gaps in knowledge between management practices, policy and future plans. The findings will guide future work to establish joint research and development programs and encourage collaboration, knowledge-sharing and capacity-building.

Online survey of ICRI members

An online survey was distributed to all ICRI members. Questions were focused on existing coral restoration and adaptation research and action, future plans and needs, capacity, barriers and enablers, scale, financing, and opportunities for future collaboration. The survey was designed to challenge respondents to reflect on methods, costs, scale and timelines required to implement restoration and adaptation programs. Respondents were encouraged to collaborate with local experts when required. In some cases, up to 20 people completed the survey within an individual country.

Twenty-eight ICRI members, including 17 countries (Australia, Barbados, Belize, Colombia, Costa Rica, Dominican Republic, Egypt, Fiji, France, Japan, Indonesia, New Caledonia (categorised as a country member

by ICRI), Panama, Seychelles, Thailand, The Netherlands, United States of America), eight NGOs (Coral Cay Conservation, Coral Triangle Center, Fondation pour la Protection de la Biodiversité Marine, Project AWARE Foundation, Reef Check International, Reef-World Foundation, World Resources Institute, WWF International), one foundation (Vulcan), and two regional intergovernmental organisations (Secretariat of the Pacific Community and South Asia Co-operative Environment Programme) completed the survey. Survey respondents ranged from senior government officials, leading scientists, directors and other senior staff.

The survey was supported by one-on-one interviews with relevant experts and coordinators. Seven in-depth semi-structured interviews were conducted with representatives from ICRI members Costa Rica, Indonesia, Monaco, Mexico, Seychelles and the USA, and Blue Charter (Figure 1). These interviews often included committee members.



Figure 1: Word cloud from interview data of ICRI members. Of the most common words, the top three words were unsurprisingly: 'restoration', 'coral' and 'ICRI'. Ecological terms such as 'climate', 'adaptation' and 'resilience' were also prominent, as were words relating to capacity building such as 'training', 'management' and 'action'. The interview findings support the survey results and are incorporated into this report. Meetings with relevant experts also provided information for this report.

Limitations

Although there was reasonable regional representation among survey respondents, there was only one response from the African and South American continents. The survey was in English, with no requests to translate the survey. Other limitations included:

- a short time for responses (August-October 2019)
- a lack of knowledge about coral restoration by some participants
- a paucity of clear policy or plans to provide guidance for respondents
- limited interest in responding among other important tasks
- time management of participants given the survey required several experts
- some only responded for certain reef regions within their country

Many respondents did not answer questions relevant to scale and costs. This likely reflects that coral restoration and adaptation is a relatively new area for many ICRI members and there was insufficient information available to answer these questions. In addition, many coral restoration projects are led by community groups, dive companies and small non-government organisations, and information about their projects may not be captured in government databases or other information repositories used by survey respondents.

What is coral reef restoration and adaptation?

“Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed”

- Society of Ecological Restoration Standards (Gann et al. 2019)



Figure 2: The continuum of management tools designed to aid in the recovery and resilience of ecosystems. Figure from Gann et al. 2019.

Ecological restoration sits within a continuum of management tools designed to aid in the recovery and resilience of ecosystems (Figure 2). Ecological restoration as a tool for conservation on coral reefs started in the 1980s, and primarily involved construction of artificial reefs and the direct transplantation of coral fragments or whole coral colonies (Figure 3). During the 1990s, the field evolved to include substrate stabilisation and asexual propagation of corals, otherwise known as ‘coral gardening’. This technique introduces an intermediate nursery phase between sourcing coral fragments and their subsequent outplanting to recipient reefs. The method has now become synonymous with coral restoration in many places around the world. The early 2000s saw the introduction of techniques that harness the capacity of corals to produce millions of larvae in mass spawning events, in order to reseed depleted reefs. While few completely novel techniques have emerged in recent decades, there has been considerable innovation in improving existing methods. Examples include microfragmentation, a variation of coral gardening where small (<10mm) fragments are cut from massive corals to encourage rapid growth, and the use of various engineered settling structures shaped to encourage coral larvae to settle, allowing rapid deployment on the reef.

While coral restoration in the marine environment has been used as a tool for the past four decades, there has been a resurgence of interest and subsequent publications in the past few years (Figure 4). In particular, there is a growing body of research on coral physiology, ecology, molecular biology and responses to stress (NASEM, 2019a). There is a growing body of research on potential tools to increase coral resilience and assist with coral adaptation and climate protection. This research has been summarised in two comprehensive reviews from the United States (National Academy of Science Review of Interventions to Increase the Resilience of Coral Reefs) and Australia (the Reef Restoration and Adaptation Program - RRAP).

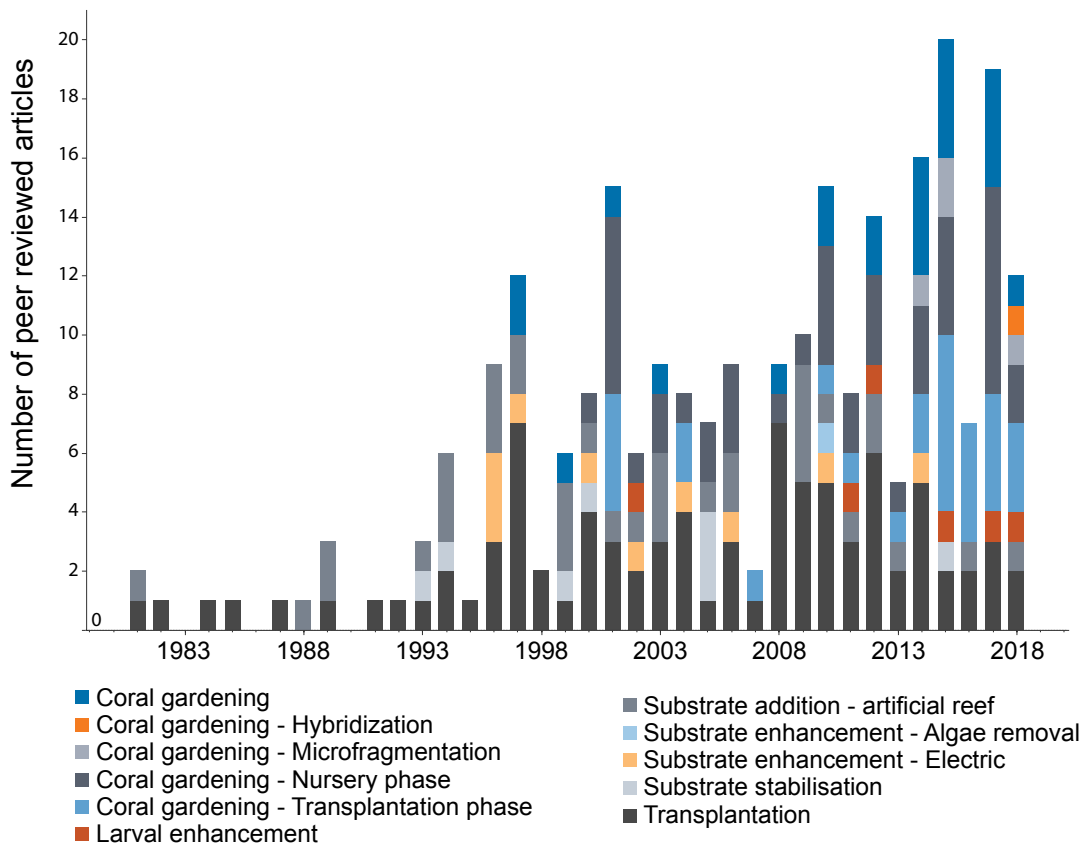


Figure 3: The history of coral restoration from peer reviewed literature. Peer reviewed publications describing active restoration projects, colour coded by restoration type. Figure adapted from Boström-Einarsson et al 2018.

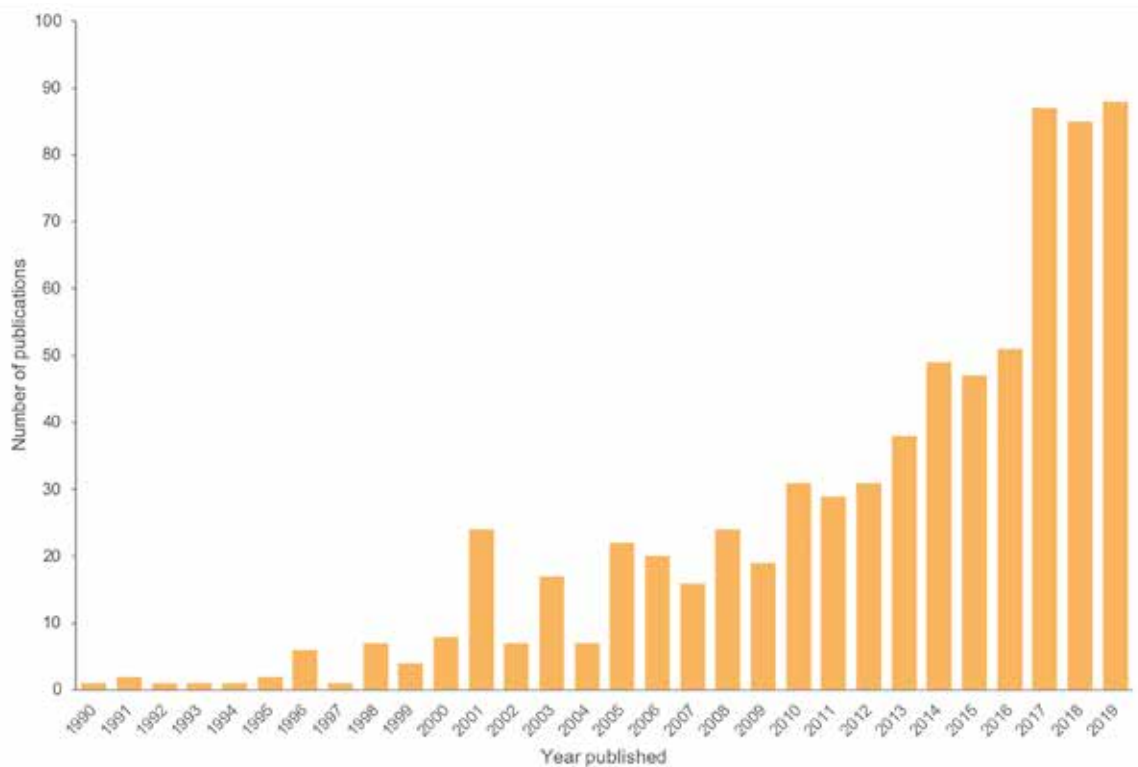


Figure 4: The number of publications per year using keywords [coral + restoration] found in ISI Web of Science. Total n=726, accessed 6 November 2019.

The coral restoration debate

Restoration is commonly used in terrestrial ecosystems, and is an established management tool for mangrove forests, coastal wetlands and shellfish reefs, but has remained controversial for coral reefs. While coral restoration is part of a suite of techniques running concurrently with climate mitigation, critics of coral restoration have argued: (1) coral restoration distracts focus from climate change and other threats to the marine environment; (2) is expensive and there is a low success rate; and (3) any viable impact will be a challenge if restoration can't restore reefs at scale. Proponents of coral restoration counter that interventions can help to protect coral biodiversity in the short-term, while mitigation of large-scale threats such as climate change and water quality take effect. Global temperature is predicted to increase for several more decades even in a zero-carbon emission scenario. Thus, local-scale restoration action could help bridge the temporal gap between large-scale action on climate change and the substantial lag effects predicted for indirect management actions. Given that disturbed reefs are likely to suffer a reduction in genetic diversity due to large-scale disturbances during this period, preserving coral species and genetic diversity through active restoration could 'buy time' for recovery following amelioration or the removal of stressors. Proponents further argue that (1) restoration is necessary for the recovery of endangered and rare coral species such as *Acropora palmata* and *A. cervicornis* in the Caribbean, and (2) restoration increases environmental stewardship and interest in protecting coral reefs by including local communities. Generally ecological restoration should only be undertaken once threats are addressed and reduced. This is challenging when the threats are climate-change related.

Recent reviews of current coral restoration

Initiative Française pour les récifs coralliens (French initiative for coral reefs)

Coral reef restoration is a French priority under the European Marine Strategy Framework Directive, and is linked to France's 'No Net Loss' policy, through which developments leading to any loss of biodiversity or ecosystem services must be offset by restorative actions. The French Ministry of the Environment and the French Ministry of Overseas Regions (through the Initiative Française pour les récifs coralliens, IFRECOR program) recently commissioned a survey scoping 187 projects and a review of 400 scientific articles from the past 50 years of coral reef ecosystem restoration (Leocadie et al. 2019).

A practical toolkit, with a cost-efficiency evaluation about different engineering approaches, was produced to help decision-makers and stakeholders to employ best practices in coral restoration and their associated ecosystems, mangroves and seagrasses (Figure 5, Leocadie et al. 2019). In a related project, IFRECOR engaged Montpellier University, the Florida Environmental Protection Agency, MAREX co. and Blue Finance, to produce a handbook (Pioch et al. 2017) with a method to assess the efficiency of coral restoration called MERCI-Cor (mercicor.com).

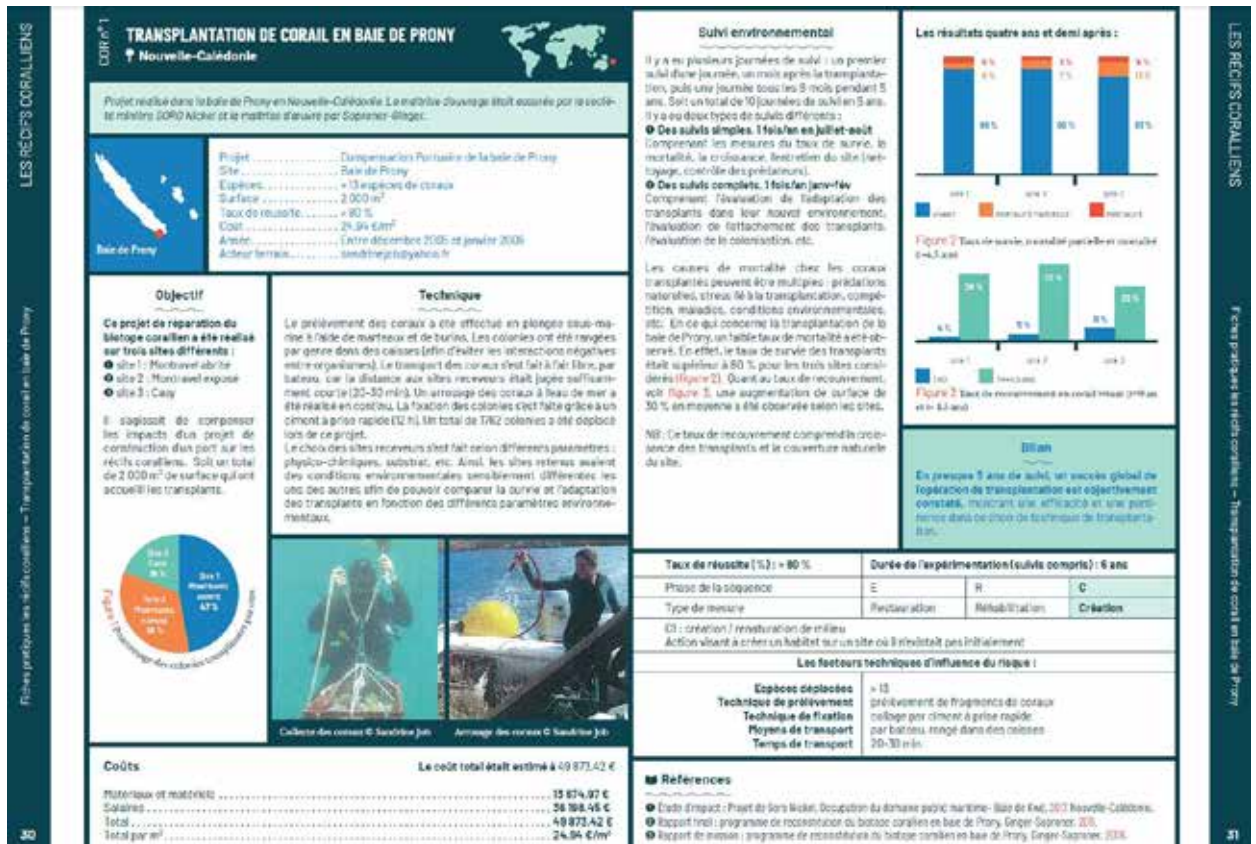


Figure 5: Snapshot of the practical toolkit with coral transplantation in New-Caledonia, Pacific Ocean (Ifreco, Leocadie et al. 2019)

Coral restoration in a changing world - a global synthesis of methods and techniques

A complementary project led through Australia's Reef Restoration and Adaptation Program (RRAP), and the National Environment Science Program (NESP) Tropical Water Quality Hub reviewed current practices in coral restoration around the world. This review included scientific journal articles, government and consultancy reports and an online practitioners' survey to generate 362 case studies. The review described coral restoration projects throughout the tropics, with a surprising diversity of coral species (229) and morphologies (10) used in restoration projects (Boström-Einarsson et al. 2018). Ten categories of coral restoration techniques were captured in the review, including well-established techniques such as artificial reefs, direct transplantation and coral gardening, and emerging techniques such as rubble stabilisation, macroalgae removal, larval enhancement and microfragmentation (Figure 6). While few projects reported on ecological success, there was substantial evidence of the ability to grow corals at smaller scales. The review described common problems (a lack of clear objectives, a lack of appropriate monitoring, inappropriate reporting and poorly designed projects), and provided suggestions and recommendations for future coral restoration projects. The database and an interactive visualisation of the database are available through the RRAP website (gbrrestoration.org/current-practices).

Box 1: Commonly-used techniques for coral restoration

Direct transplantation - transplanting coral colonies or fragments without an intermediate nursery phase

Coral gardening - transplanting coral fragments after an intermediate nursery phase

Larval enhancement - using sexually-derived coral larvae to release or outplant at a restoration site, after an intermediate holding phase which can be on land or in water

Artificial reefs - adding artificial structures for the purposes of coral reef restoration

Substratum stabilisation - stabilising the substratum to facilitate coral recruitment or recovery

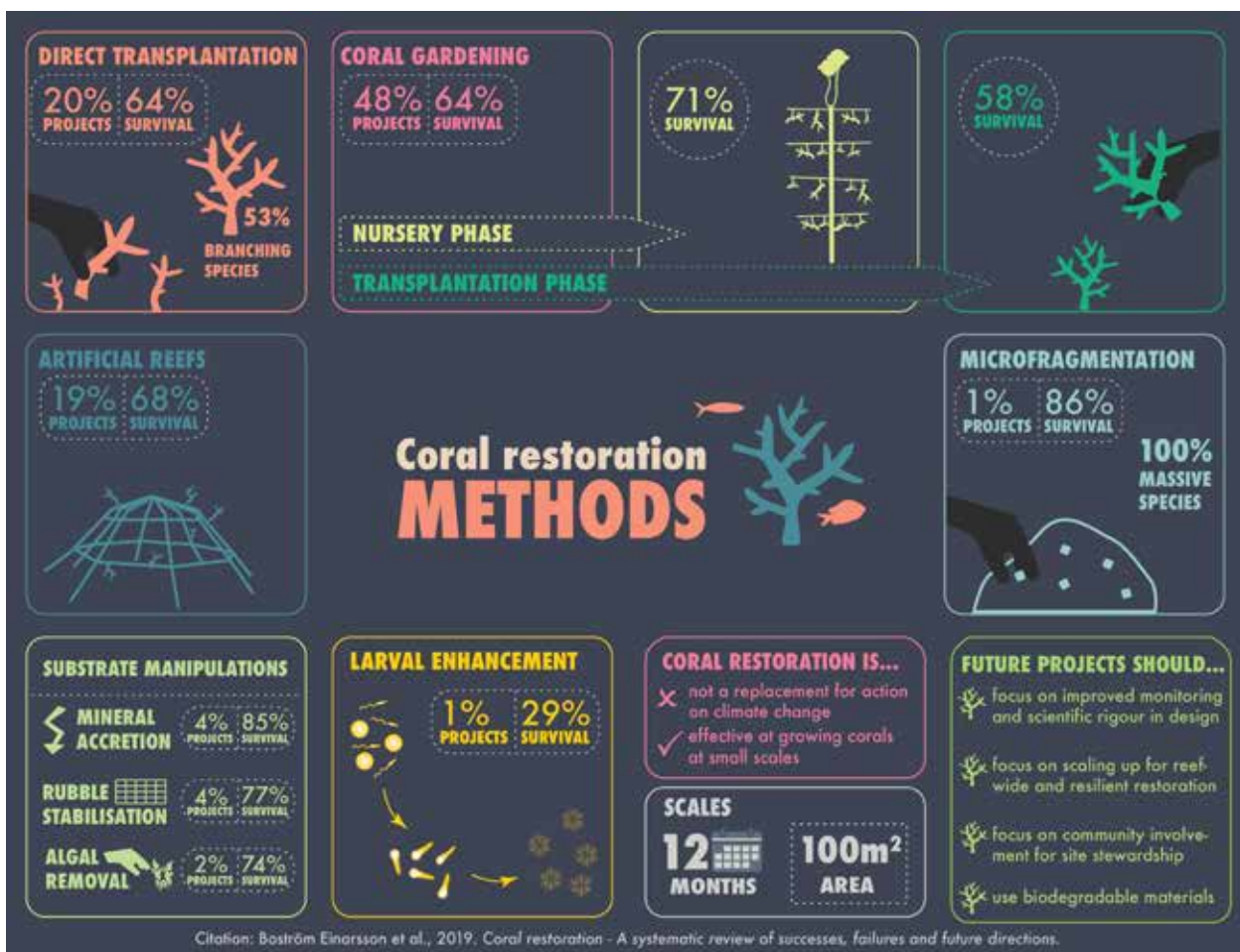


Figure 6: A summary of existing restoration techniques, their success (coral survival) and limitations, from Boström-Einarsson et al 2018.

*Note the mean monitoring period was 12 months, for more information see gbrrrestoration.org/current-practices.

Recent reviews of novel interventions

Interventions to Increase the Resilience of Coral Reefs (NASEM)

The National Academy of Science, Engineering and Medicine (NASEM) summarised 23 interventions in four broad categories:

1. genetic and reproductive interventions
2. physiological interventions
3. coral population and community interventions
4. environmental interventions

Its first report (NASEM, 2019a) described what was known about the benefits, goals, current feasibility, potential scale, risks, limitations, and infrastructure needs for interventions. A second report (NASEM, 2019b) provided a framework for assessing relative risks and benefits of interventions, a decision pathway for research and implementation, and to assess the potential for interventions to meet management objectives for Atlantic and Caribbean reefs. It was commissioned and funded by the National Oceanic and Atmospheric Administration, with additional support from the Paul G. Allen Family Foundation.



Coral spawning is an important time for genetic and reproductive research at the Australian Institute of Marine Science. Photography: Marie Roman.

The Reef Restoration and Adaptation Program (RRAP)

RRAP is a collaboration of Australia's leading experts tasked with creating a suite of innovative measures to help preserve and restore the Great Barrier Reef. In 2018 RRAP reviewed and summarised scientific research on a range of intervention strategies, including evaluation of the state of readiness. Strategies of interest included enhanced corals, translocation of non-native coral stocks or species, manipulation of symbiotic partnerships within the coral holobiont, managed selection, genetic modification, and, to the extent possible, engineering solutions to promote reef persistence, such as shading/cooling during bleaching events. RRAP also looked at the socio-economic and regulatory landscape from coral restoration in Australia (Fidelman et al. 2019). The first stage of the RRAP Research and Development Program is scheduled to begin in early 2020. It will be funded through the AU\$100 million allocated for reef restoration and adaptation science as part of the AU\$443.3 million partnership between the Australian Government's Reef Trust and the Great Barrier Reef Foundation (GBRF). This will be supplemented with AU\$100 million each from philanthropy and research providers.

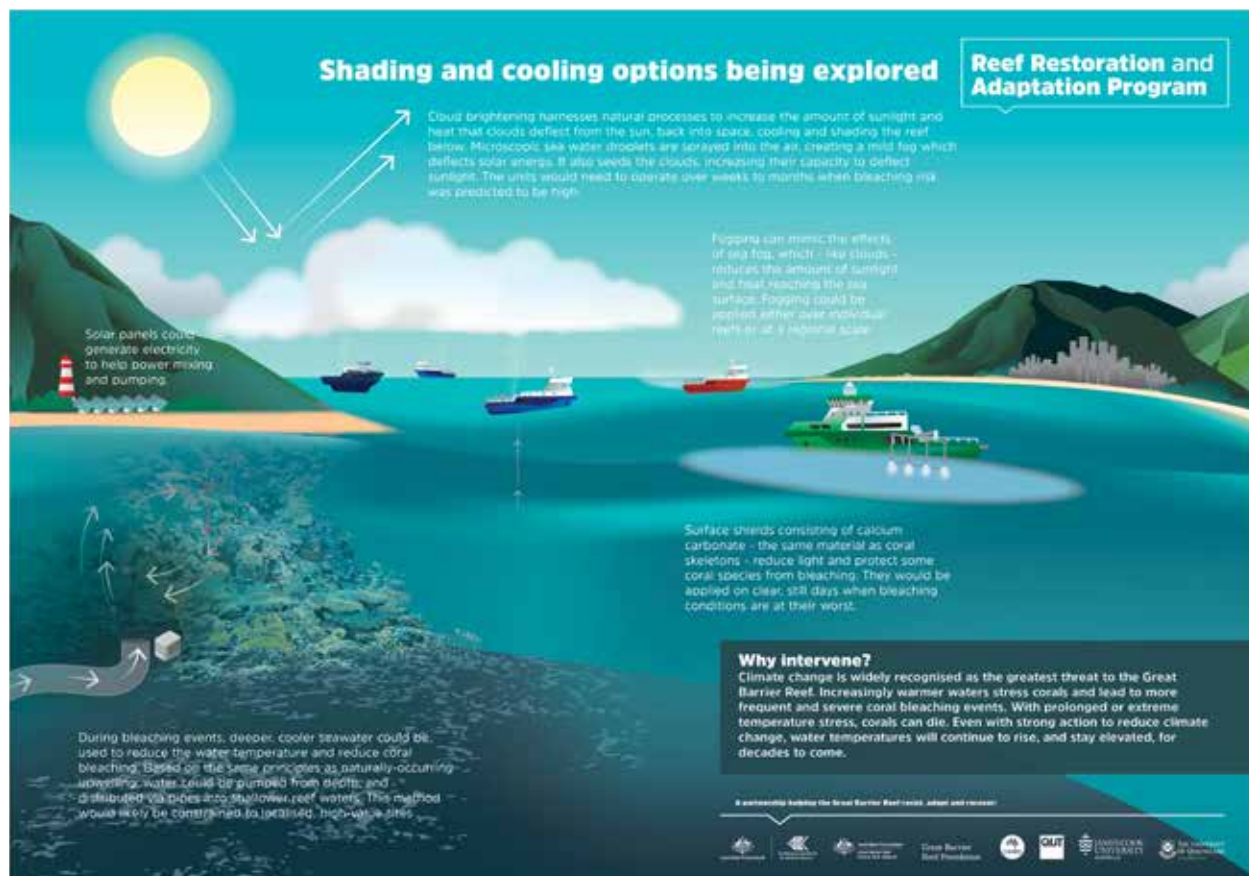


Figure 7: Some of the new shading and cooling interventions being explored in the Reef Restoration and Adaptation Program (RRAP).

Policy and plans relating to restoration

There are several existing and emerging conventions, policies and plans relevant to coral restoration. These sit within three layers: (1) United Nations Conventions; (2) global and regional partnerships; and (3) individual countries and territories (Figure 8).

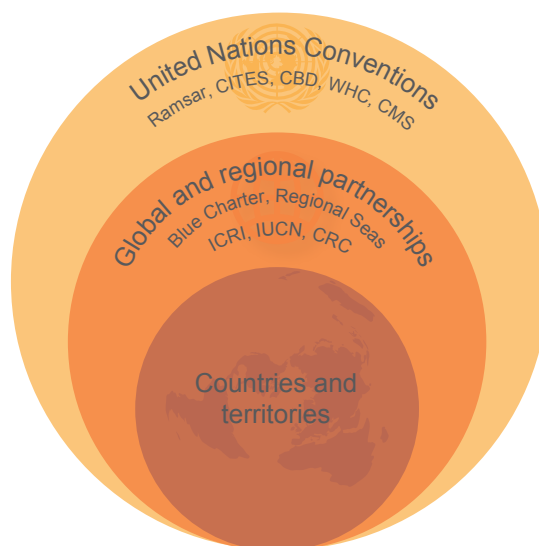
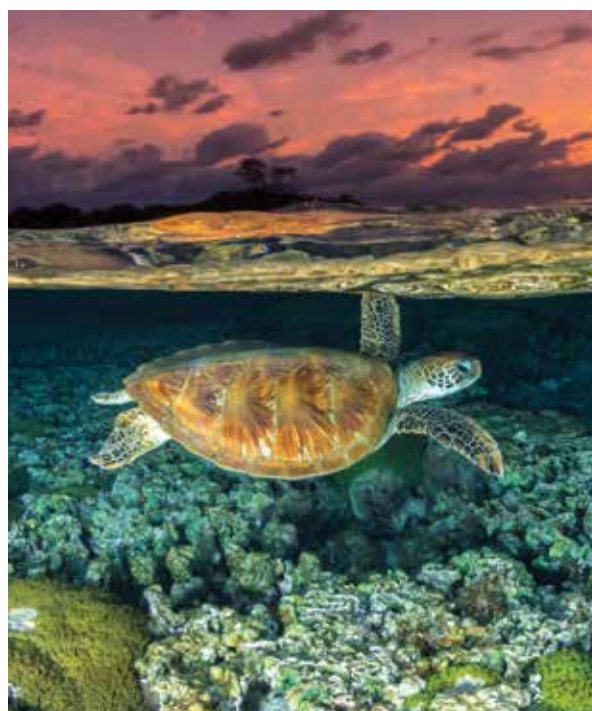


Figure 8: Layers of coral restoration regulatory, policy and resolution governance

United Nations Conventions

The international community has committed to coordinated policy responses to protect coral reef ecosystems. Analyses of policies relating to the protection of coral reefs revealed at least 232 international instruments considered to directly or indirectly support conservation and sustainable management of coral reef ecosystems, and/or address common anthropogenic drivers of change in these systems (UN Environment, 2019).

There are several United Nations (UN) Conventions relevant to restoration including the United Nations Convention on the Law of the Sea (UNCLOS) and the United Nations Framework Convention on Climate Change (UNFCCC) Paris Accord. There are four United Nations Environment Program (UNEP) conventions relating to coral restoration (1) the Conservation of Migratory Species of Wild Animals (aka the Bonn Convention (CMS)), (2) the Convention on Biological Diversity (CBD), (3) the Convention on International Trade in Endangered Species of Wild Fauna and Flora (CITES), and (4) the Regional Seas Conventions and Action Plans. There are also two United Nations Educational, Scientific and Cultural Organization (UNESCO) conventions, the Ramsar Convention on Wetlands and the World Heritage Convention (UNWHC).



Turtle in the Great Barrier Reef at sunset. Copyright Jordan Robins / Coral Reef Image Bank.

Box 2: The United Nations: Decade of Ecosystem Restoration

The UN Resolution has the sole aim of “supporting and scaling up efforts to prevent, halt and reverse the degradation of ecosystems worldwide and raise awareness of the importance of successful ecosystem restoration”. Within the UN, the decade will be led by the UN Environment Programme (UNEP) and the Food and Agriculture Organization. UNEP estimates that restoration of 350 million hectares of degraded land and marine ecosystems between now and 2030 could generate US\$9 trillion in ecosystem services. Restoration would remove an additional 13 to 26 gigatons of greenhouse gases from the atmosphere, providing a cost-effective nature-based solution to climate change. This target builds on the existing Bonn Challenge, launched in 2011 by the German government and IUCN and later endorsed at the 2014 UN Climate Summit.

Coral Reefs and the Decade of Ecosystem Restoration

The degradation of coral reef ecosystems undermines the wellbeing and livelihoods of hundreds of millions of people around the world. A recent report into the business case for the protection, preservation and enhancement of coral reef health, estimates that if reefs continue to decline, their annual value could fall by US\$3.1 billion in Mesoamerica and US\$2.2 billion in the Coral Triangle by 2030 (UN Environment et al. 2019). To address this decline, large and cost-effective investments in coral reef conservation and restoration will be necessary.

This need is reflected in the United Nations Environment Assembly (UNEA) resolution 4/13 on “Sustainable coral reefs management” initially proposed by the governments of Indonesia and Monaco and finally adopted by all member States during the fourth UNEA in Nairobi in March 2019. Following this resolution, UNEP is currently supporting the development of a compilation of best practices for coral reef restoration. Best practice will inform additional ways that UNEP and ICRI can support technical and resource exchange between nations, to build the capacity necessary for successful coral reef restoration in developing countries around the world. In addition, the UN Decade of Ocean Science for Sustainable Development 2021-2030 will complement the Decade of Ecosystem Restoration’ as scientific understanding underpins successful reef restoration.



Global and regional partnerships

Since the early 1990s, there has been a growing response to identifying and addressing drivers putting pressure on coral reefs. Two major global partnerships are the International Coral Reef Initiative (ICRI); and the International Union for Conservation of Nature (IUCN) through The Restoration Initiative (TRI).

The International Coral Reef Initiative

ICRI has adopted a 'Call to Action' and a 'Framework for Action' as its foundational documents. Both documents set the four cornerstones of ICRI: integrated management; science; capacity-building; and review. These were renewed in 2013, and do not mention coral restoration or adaptation. In 2001, ICRI adopted a 'Decision on Reef Restoration'. This decision considered that well-designed reef restoration and enhancement projects had a role to play in managing coral reefs. ICRI called upon members of the global community to support the development of a handbook or guidelines to encourage good practices. This was followed by the 2005 Resolution on Artificial Coral Reef Restoration and Rehabilitation. The resolution was motioned over concerns that artificial reefs and 'electric' reefs (reefs built with a metal structure and a power source) were being promoted as a solution to coral reef damage, but were unproven, expensive techniques that were only feasible at very small spatial scales. The resolution highlighted risks that the promotion of artificial reef restoration may cause damage, and a misdirection of scarce coral conservation funds, and would encourage a view that any reef degradation could be repaired.

International Union for Conservation of Nature

IUCN launched The Restoration Initiative (TRI, 2019) to unite 10 African and Asian countries, and IUCN, the Food and Agriculture Organization of the UN, and UNEP to overcome existing barriers to restoration, restore degraded landscapes, and support the Bonn Challenge. Funded by US\$54 million in grants from the Global Environment Facility (GEF), TRI aims to mobilise an additional \$200 million in partnership funding. This funding appears to be focused on land and wetland restoration rather than marine restoration projects.

Individual countries and territories

While many of the UN conventions, global and regional partnership initiatives influence coral restoration management, the online survey found several countries had, or were planning to develop policy around coral restoration. ICRI countries with existing or draft coral restoration policy and plans include:

- the Netherlands' Coral Reef Action Plan, which has a section on scaling-up coral restoration
- France has policy within the European Marine Strategy Framework Directive, and linked to France's 'No Net Loss' policy.
- the US has the Coral Reef Conservation Program Strategic Plan, and the Florida Keys National Marine Sanctuary Restoration Blueprint
- Indonesia has three relevant policies: the National Action Plan for Coral Reefs 2017-2021; the National Action Plan for Climate Change Adaptation; and a Blue Carbon Initiative 2017-2022.
- Costa Rica has a Coral and Reef Restoration Protocol
- Japan has a Law for the Promotion of Nature Restoration
- Colombia has a National Restoration Plan
- Thailand has a Coral Reef Action Plan
- Australia has guidelines for applications for restoration and adaptation projects and is developing a coral restoration and adaptation policy.

Some nations, including Belize, are developing actions plans under the Blue Charter Action Group for Coral Restoration and Adaption.

A need for new policies was identified by 88% of ICRI countries, noting that just under half saw new policy being incorporated into existing legislation and policy, such as fisheries, education and marine park management, and that there were risks associated with adding new policies within an already complicated policy landscape. One respondent suggested policy was needed to provide a pathway for mechanisms for the payment of marine environmental services.

Coordination and implementation for coral restoration

There is a range of regional and global partnerships and networks that help coordinate coral restoration projects and research, in addition to ICRI and UN members. The following organisations are some of the most active in the field, and were acknowledged in the online surveys and interviews. This is not an exhaustive list of organisations in this space.

Commonwealth Blue Charter Action Group for Coral Reef Protection and Restoration

The Commonwealth Blue Charter is an agreement among the 53 Commonwealth countries to actively cooperate to solve ocean-related problems and meet commitments for sustainable ocean development. Australia, Belize and Mauritius are co-championing the Commonwealth Blue Charter Action Group on Coral Reef Protection and Restoration. This action group will highlight good coral restoration practices and provide a platform to promote collaborative research, workshops and seminars and showcase successful case studies among the Commonwealth.

Coral Restoration Consortium

The Coral Restoration Consortium (CRC) is a community of practice comprising scientists, managers, coral restoration practitioners, and educators. The CRC aims to foster collaboration and technology transfer among participants and facilitate scientific and practical innovation. It has more than 6000 members and is expanding from the core focus area of the Caribbean to have working groups in Australia, the Eastern Tropical Pacific, and Latin America.

The Reef Resilience Network

The Reef Resilience Network aims to build reef management capacity by connecting managers with information, experts, resources, and skill-building opportunities. Led by The Nature Conservancy, the network is supported by dozens of partners, including NOAA's Coral Reef Conservation Program, CRC and RRAP, and includes more than 1500 members, including over 800 reef managers, and 100 global experts. In 2016, the network launched an online coral reef restoration course and is currently developing a manager's guide to coral reef restoration planning and design.

Mesoamerican Reef Fund Reef Restoration Network

The Mesoamerican Reef Fund Reef Restoration Network is the main source of information about marine ecosystem restoration in the region. The network provides a platform for coordinating and developing innovative scientific and technical capacity for its member organisations. It aims to facilitate collaboration and capacity-building to restore the structure and function of coral reefs and associated ecosystems in the region.

International Coral Reef Society

The International Coral Reef Society (ICRS), formerly the International Society for Reef Studies (ISRS), founded in 1980, is the principal association for coral reef scientists, managers and enthusiasts. It promotes the production and dissemination of knowledge about coral reefs. The society has a major conference every four years. Recent conferences have been a focal point for sharing results from coral conservation and restoration studies.

ICRI member perspectives on coral restoration

Techniques currently used by ICRI members

Most ICRI countries (88%) were using coral restoration as a tool to manage their reefs. The most commonly used techniques were coral gardening and direct transplantation (both 64% of countries), followed by artificial structures (41%), reef repair or substrate stabilisation following vessel or extreme weather damage (29%) and larval enhancement (6%). Research was focused on all these techniques, but more countries were researching larval enhancement rather than actively using it as a management tool. Of the non-country members, less than half (45%) were using coral restoration, and just over a quarter (27%) reported research projects only.



Coral gardening, where coral fragments are grown in a coral nursery, was one of the most commonly used coral restoration techniques by ICRI members. Photo by Martin Colognoli for Coral Guardian in Indonesia.



Researcher collecting wild coral spawn for larval enhancement trials in the Philippines. Larval enhancement techniques are being researched in many countries. Photo by Ian McLeod.

Objectives for coral restoration

There were 11 categories of objectives for coral restoration activities reported by ICRI members (Figure 9). The most commonly mentioned were related to the human dimension with engagement of local communities the most common objective. Objectives associated with supporting livelihoods included supporting tourism (including improved aesthetics) and fisheries production were also often listed. That the top three objectives were linked to socio-economic outcomes aligns with recent findings by Hein et al. (2019) who interviewed coral restoration practitioners across four distinct coral restoration programs and found 72% of respondents valued coral restoration efforts for potential socio-cultural and economic benefits. Other objectives were more focused on ecological conservation including creating a self-sustaining reef system and endangered species management. This mirrors findings from a recent survey where 53% of practitioner respondents reported conducting a restoration project to accelerate recovery post-disturbance and to re-establish a functioning ecosystem (Boström-Einarsson 2018).

Research, mitigation in relation to development, shoreline protection and creating artificial reefs to reduce pressure on natural reefs were also listed as objectives (Figure 9). These conservation objectives align with the most common objectives for coral restoration listed in published scientific literature (Hein et al. 2017). The country and non-country responses were similar, except that research was more commonly listed as an objective by country members. Research objectives are linked to motivations of furthering our ecological knowledge and improving restoration techniques, and are most frequently described in projects published in the scientific literature (Bayraktarov et al. 2019). The reduced focus on research objectives here might be due to practitioner-led or management-focused projects prioritising real-world outcomes over academic publishing. Respondents generally ranked coral restoration projects as moderately successful at meeting objectives. No respondents classified projects as very successful and one country respondent said its projects were not at all successful.

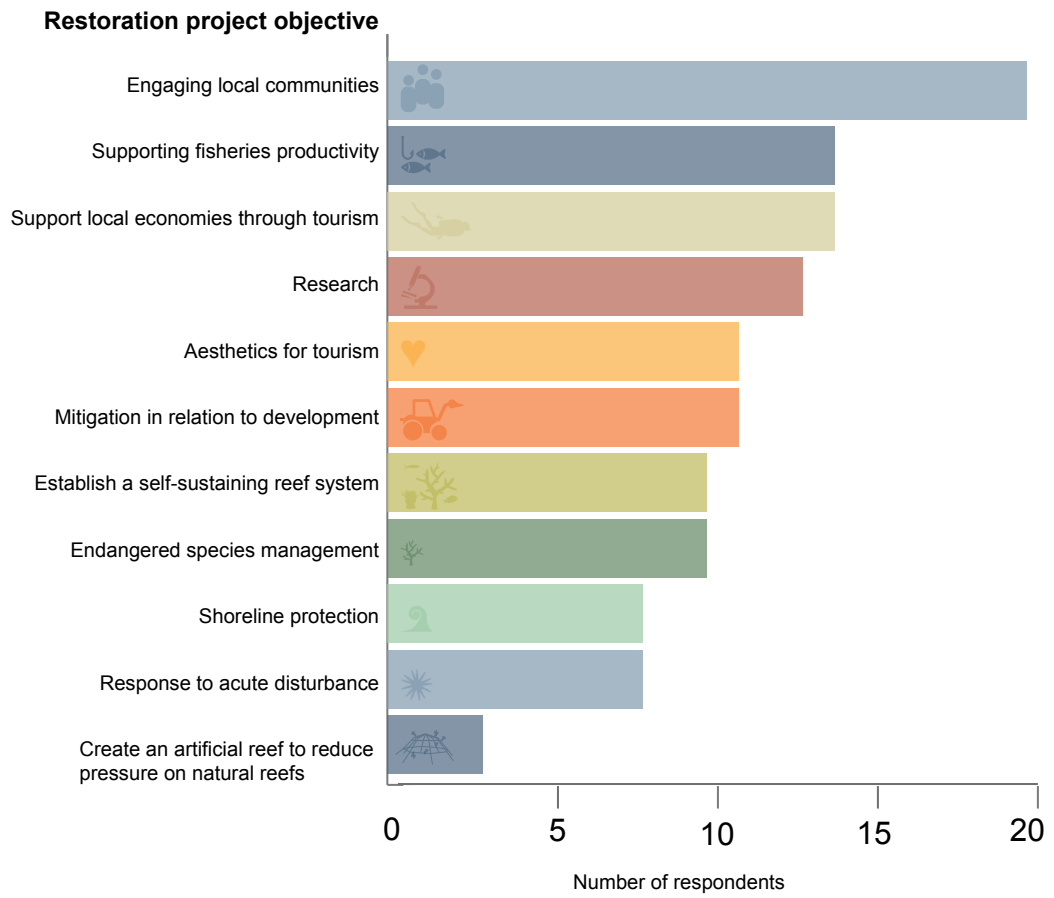


Figure 9: Proportion of restoration project objectives stated by ICRI-member survey respondents



Supporting livelihoods was a common motivation for coral restoration projects. Photo by Ian McLeod.

Emerging research priorities

Fourteen ICRI members (52%) reported research focused on coral adaptation or climate protection. Of these, assisted evolution of corals to cope with projected increases in ocean temperature was the most commonly identified objective for research by ICRI country members (70% of respondents for this question), followed by physically protecting reefs from warming sea temperatures (e.g. through cooling and shading, 12%) and transplantation of corals onto engineered structures (6%). Of the non-country members, one had research focused on assisted evolution and another species, protection measures proven to mitigate climate change.



Coral hybrids growing in tanks as part of an experiment on assisted evolution at the Australian Institute of Marine Science. Photo by Marie Roman.



Exposing corals to stressful conditions can induce physiological responses that toughen them and allow them to better withstand stress. Research at the Australian Institute of Marine Science. Photography by Christian Miller.

Current and future management

ICRI members were asked to rank their top five management actions currently used to support coral reef health and to rank the top five actions they hoped to implement for future management (Figure 10). Improving water quality was identified by ICRI countries as the most important future management action replacing marine protected areas and fisheries management, which moved to second and third place respectively. Coral restoration, reduction in greenhouse gas emissions at the local (country) level, adaptation to projected increases in temperature and ocean acidification, and mitigating damage from extreme weather events and vessel groundings were identified as management actions which ranked as higher priorities in the future. Community and Indigenous management and control from development were ranked as lower priorities in the future.

ICRI member countries

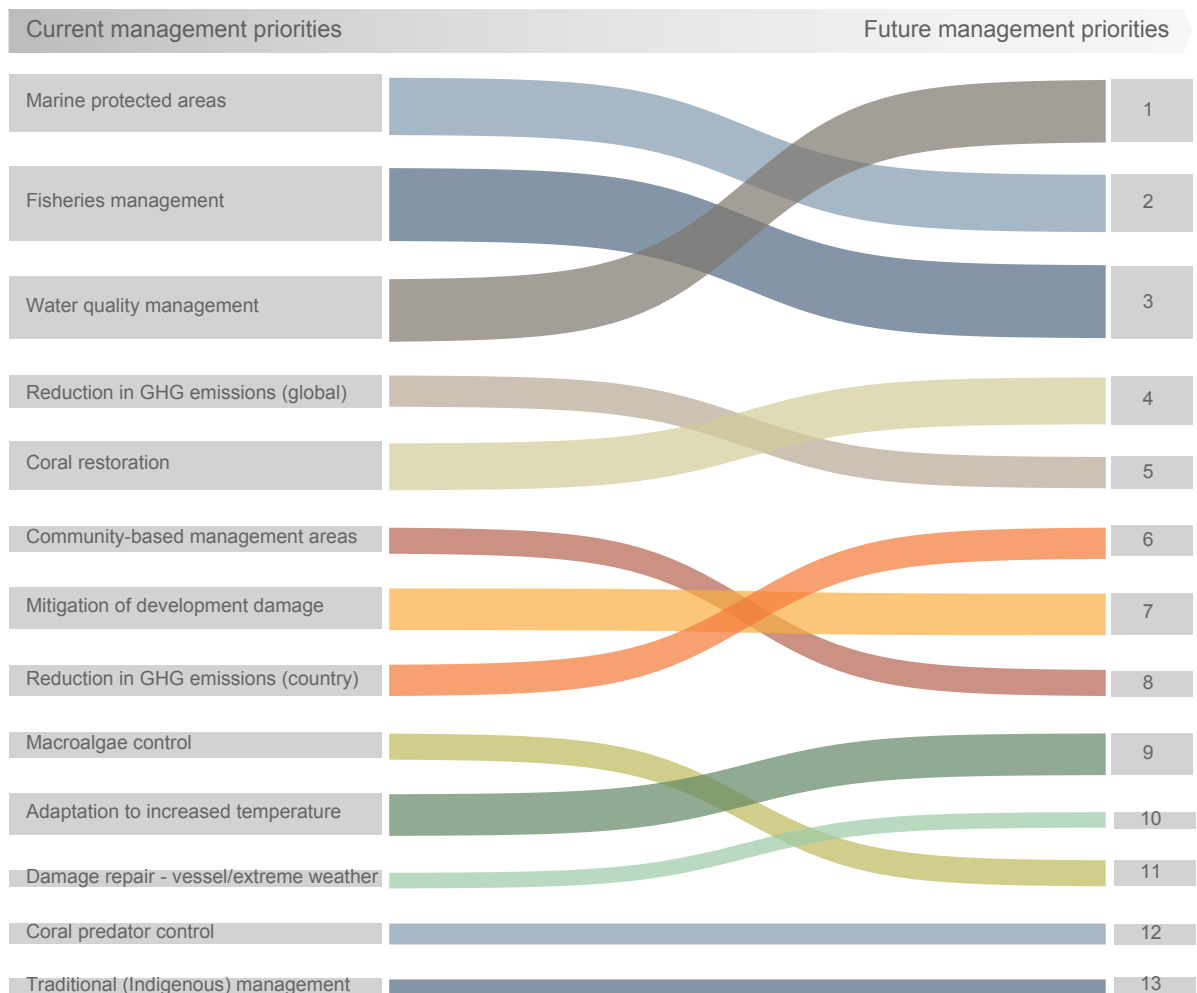


Figure 10: The change from current (left side) to future (right side) management priorities in ICRI country members. The rankings (ordered top to bottom in left and right margins) were calculated based on the average score out of five for each listed management priority, where 5=highest priority and 1=lowest priority. Management actions which were not listed by respondents were marked as a 0. The width of each bar corresponds to the number of countries that gave that management strategy a score >0 in future priorities.

Non-country ICRI members gave markedly different responses (Figure 11). A global reduction in greenhouse gas emissions emerged as the primary future priority, moving marine protected areas and fisheries management lower down the rankings. Community-based management remained the second most important priority for the future. Coral restoration, mitigation of damage from development and control of macroalgae were all identified as lower priorities in the future. Adaptation to increased temperatures, reductions in greenhouse gas emissions at a country level and traditional (Indigenous) management all increased in priority in the future.

ICRI non-country member

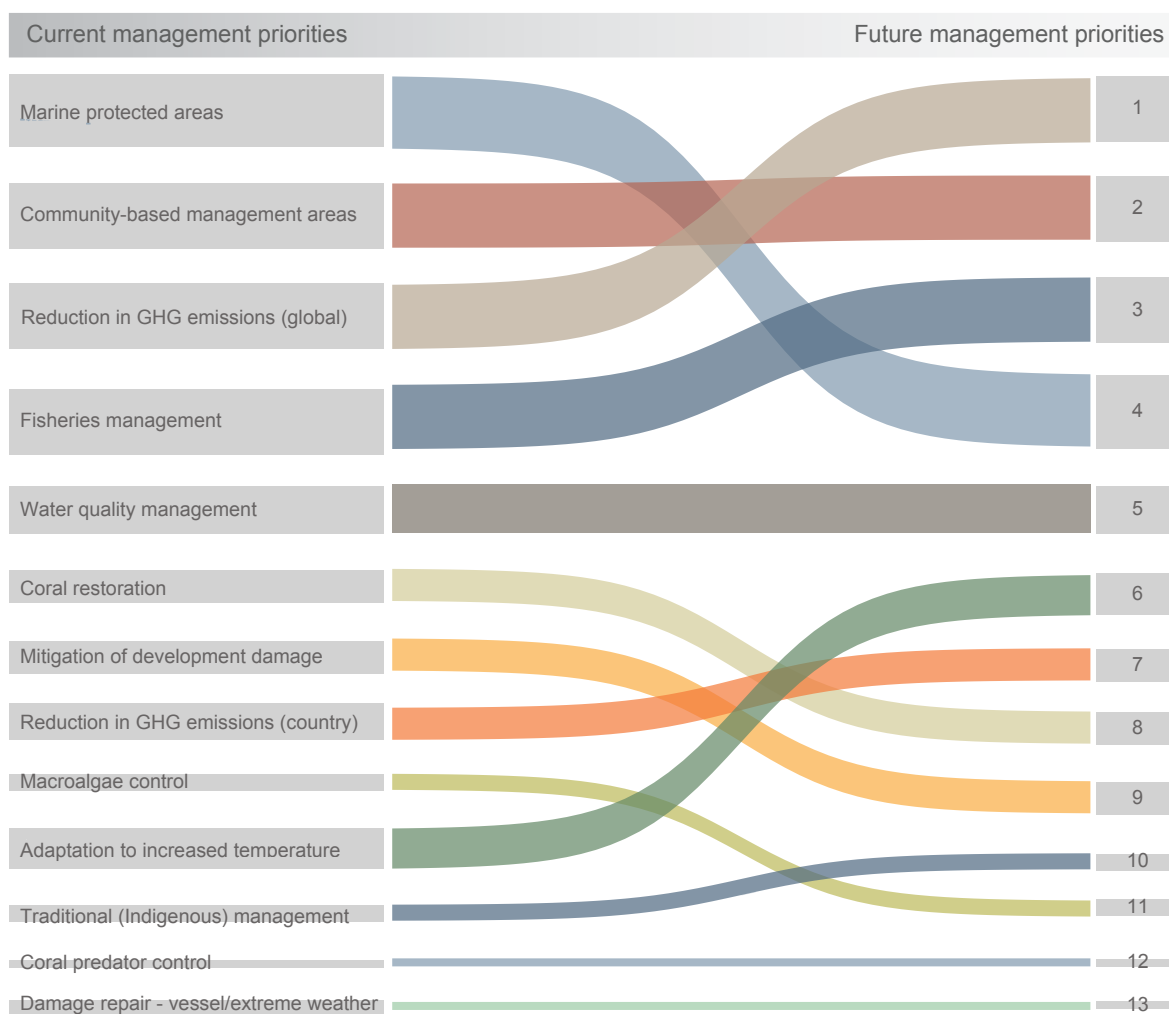


Figure 11: The change from current (left side) to future (right side) management priorities in ICRI non-country members. The rankings (ordered top to bottom in left and right margins) were calculated based on the average score out of five for each listed management priority, where 5=highest priority and 1=lowest priority. Management actions which were not listed by respondents were marked as a 0. The width of each bar corresponds to the number of countries that gave that management strategy a score >0 in future priorities.

Organisations leading and researching reef restoration

Government and NGOs were the groups most commonly leading coral restoration action and research (Figure 12). A non-governmental organisations are leading 39% of coral restoration research, compared with 35% by government. Equally, NGOs are leading 45% of projects, compared with 37% by government members.

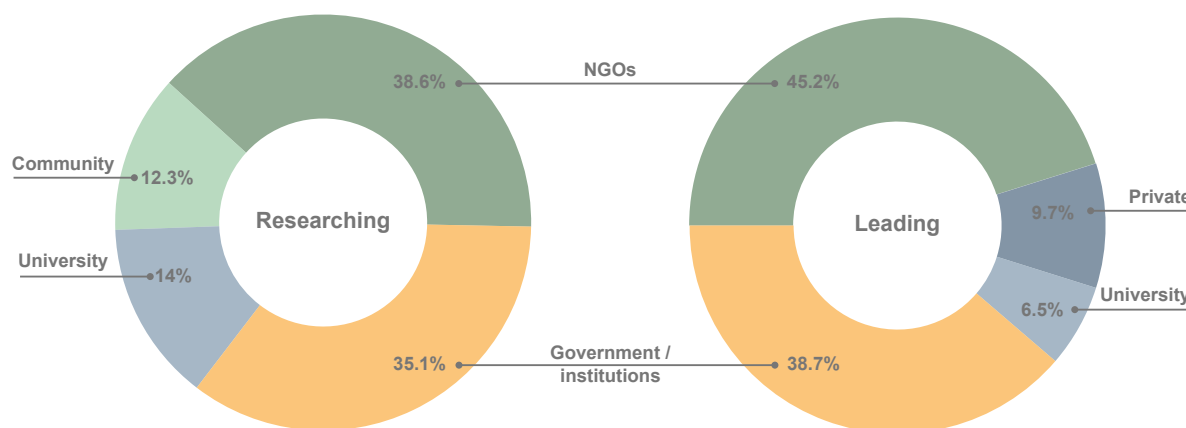


Figure 12: The reported proportion of groups involved in coral restoration research (left) and leading restoration projects (right)

Restoration organisations

Historically, coral reef restoration has been led by enthusiastic individuals who were not necessarily associated with a broader group or organisation. As the field has matured, we have seen the emergence of more defined and formal organisations. Organisations actively involved in coral restoration can be divided into three broad categories: NGOs or philanthropic organisations, private businesses, and research institutions. However, the landscape of practitioner organisations remains complex with substantial overlap between the groups. This section attempts to summarise some of the major players in each category, based on survey answers and interviews, but makes no claim to be an exhaustive list of implementation organisations.

NGOs and philanthropic organisations

Perhaps due to the grassroots nature of how the field developed, and the prevalence of coral reefs in developing countries, a large proportion of coral restoration projects are funded through charitable donations and grants. Close to half (43%) of the groups identified as leading restoration projects by ICRI survey respondents were NGOs.

For example, the Grupo Punta Cana Foundation is a non-profit organisation based in the Dominican Republic. While coral gardening is a core part of the organisation's work, the foundation also conducts a wide range of community work in the Punta Cana region of the Dominican Republic. Fragments of Hope is a similar community-based non-profit organisation based in Belize which, similar to other groups in this category, focusses on fragmentation-based coral gardening techniques. A large and notable example in this category is the Coral Restoration Foundation, which describes itself as the "largest coral restoration organisation in the world". The organisation operates in Florida and has seven large coral nurseries primarily focused on endangered species management of threatened *Acropora* species. In 2015, the foundation Vulcan made a US\$4 million, five-year grant to the Hawaii Institute of Marine Biology and the Australian Institute of Marine Science to identify naturally resilient coral species and replant them to advance regeneration of declining coral reefs.

Private businesses

A large proportion of coral restoration work to date has been driven by privately owned businesses, particularly the tourism industry. Projects and organisations range in size from small nurseries and outplant sites primarily aimed at edu-tourism, to fully-fledged conservation organisations. For example, Reefscapers is a Maldives-based consultancy which started as a small turtle conservation group within the Four Seasons Resort. The

group reports to have outplanted more than 500,000 coral fragments to date, primarily using steel bar frames which elevate the corals from sandy or unstable substrates. While private business may invest in reef restoration as a profit-based venture, others have a corporate sustainability responsibility (CSR) motive. For example, Mars Symbioscience, the CSR department of Mars Inc. has formed a large restoration group, focused on deploying frames with coral fragments. The bulk of the group's work has been focused on Indonesia, however it is currently expanding into Australia and Mexico.

Research institutions

While university-based researchers conduct most formal science-based research concerning methodology and outcomes of coral restoration, they are rarely involved in projects that could be classified as coral restoration, in the true definition of the term. This is not a criticism, as their role as scientists does not require them to also be practitioners. Some independent research organisations like the Mote Marine Lab in Florida Keys straddle the divide between practitioners and scientists. The lab recently developed a microfragmentation technique that speeds the growth and development of corals and allows the fragmentation of massive corals.

Barriers, enablers and capacity

The two most common barriers and enablers identified by ICRI members were within the human dimension (Figure 13). These were: funding (34% identified this as a barrier, 24% as an enabler), and political will (15% identified this as a barrier, 24% as an enabler).

Low numbers of skilled or trained people was identified as a barrier by 15% of respondents as well as scalability and efficacy of existing methods (9%, Figure 13). Research and infrastructure were identified as a barrier by 7% of respondents. Other barriers centre around confidence in research and deployment, restoration not being a management priority, a need for more research, confidence in effectiveness, and drivers of decline yet to be reduced.

More international collaboration and assistance from NGOs was identified as an enabler (12%, Figure 13), followed by more community engagement and trained technical staff (both 7%). Other enablers were planning and guidelines, organisational support, reducing reef stressors prior to restoration and spatial prioritisation.

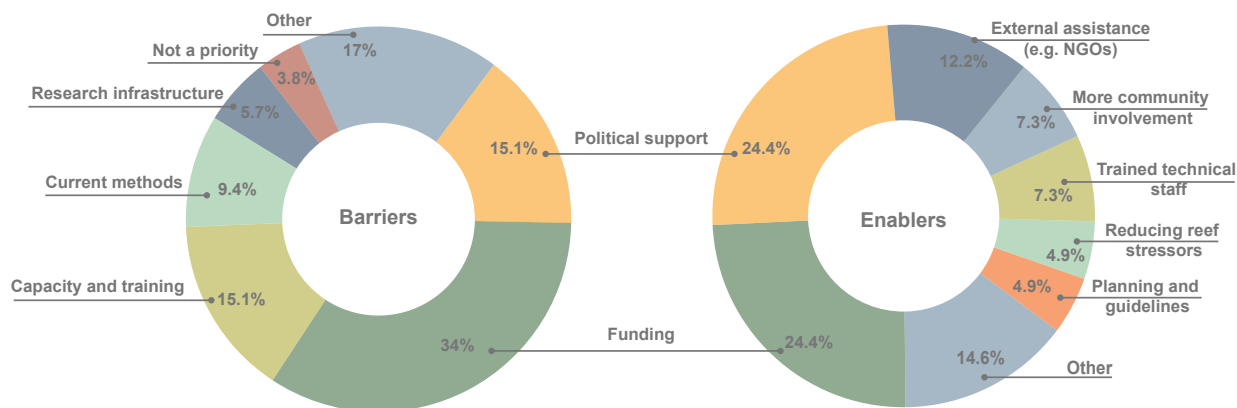


Figure 13: The barriers and enablers to reef restoration reported by ICRI member countries and non-country members. Barriers included: 1) insufficient funding 2) insufficient human capacity and training, 3) lack of political support, supporting policies, and legislative complexity, 4) current methods not effective or scalable, 5) insufficient research infrastructure and, 6) not a management priority. Enablers include: 1) increased funding, 2) political support and supporting policies and legislation, 3) external third party assistance (i.e. NGOs) and international collaboration, 4) more community involvement, 5) trained technical staff, 6) reducing reef stressors prior to restoration and 7) planning and guidelines.

“Reduce local impacts before attempting to restore reefs, as corals are dying now due to those impacts, if these remain, transplanted corals will most likely die too”.

Online survey respondent.



Bleached coral. Photographer P. Marshall. Copyright Commonwealth of Australia (Great Barrier Reef Marine Park Authority).



Bleached coral. Copyright The Ocean Agency / XL Catlin Seaview Survey.

Capacity

The need for increased capacity to implement coral restoration and adaptation actions was a recurring theme from both ICRI country and non-country respondents. Most ICRI members (79%) said they needed more research to understand what they should do, and most (71%) also said they needed a plan of action. Sixty-one percent said they needed more dedicated funding and training. Just under half (46%) said they needed more international collaboration, and more than a third (36%) indicated the need for new methods and more equipment (Figure 14). Country members more commonly listed research, methods and equipment as capacity needs than other ICRI members, who more often identified human capacity and collaboration.

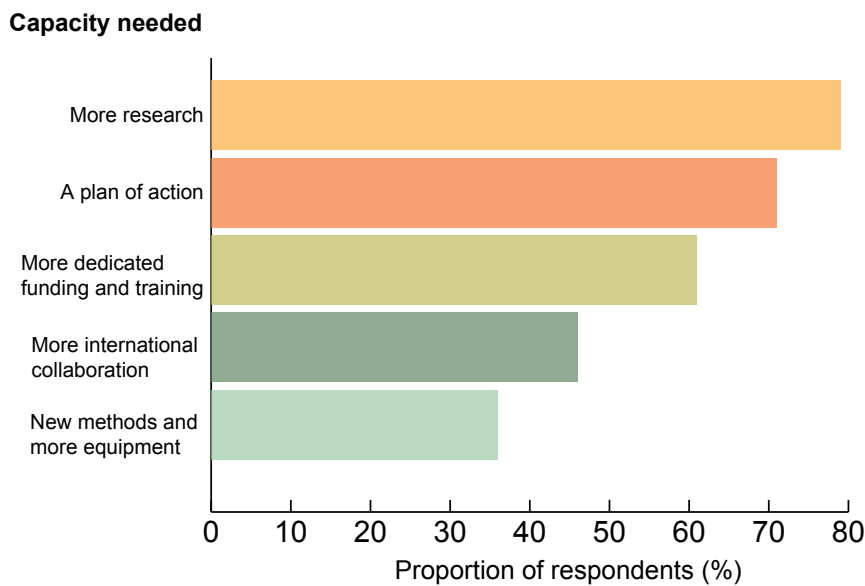


Figure 14: The capacity needed to implement coral restoration and adaptation action. Note that members could select multiple options, so percentages do not add up to 100.

Most ICRI members had a medium level of current technical capacity, where they were able to use specialist methods and technologies that can be taught to non-specialists. Six countries (but no non-country members) said they had no constraints and could use anything from high to low technology. Eight ICRI members said they could only use simple low technology methods. Five countries said they had capacity to use methods requiring high capital investment (above US\$50 million).

Financing

Total funding allocations for coral reefs and associated ecosystems was US\$1.9 billion between 2010 and 2016 (UN Environment et al. 2018). The five-year average was US\$380 million annually, close to 0.1% of the benefits received from coral reefs (estimated at US\$375 billion annually, UN Environment et al. 2018). Most funding was allocated to conservation and marine protected area management, with limited resources for policy development, outreach and monitoring (UN Environment et al. 2018).

The annual national budgets for all coral restoration and adaptation activities for the nine ICRI countries that provided estimates, ranged from US\$30,000 to US\$1 million (mean US\$210,000). For the non-country members, annual budgets for restoration and adaptation ranged from US\$2000 for an NGO to US\$5-10 million a year for a regional intergovernmental organisation. Two other NGOs responded with US\$10,000 to US\$250,000 per year. When asked to estimate the costs required for restoration activities to be feasible in their respective countries, some respondents said there was so little funding available that nothing was really possible. Other countries said if the costs were below US\$1-7 million per hectare, restoration would be feasible.

Coral reefs are more expensive to restore than seagrass, mangroves, salt marshes or oysters (Bayraktarov et al. 2016). Bayraktarov et al. (2019) reviewed published literature about the costs of coral restoration projects (Table 1). The 58 projects that included information about costs varied greatly from US\$6000/ha for a larval enhancement project to US\$143 million/ha for an artificial reef project.

Table 1: The cost of coral restoration methods (per hectare). Adapted from Bayraktarov et al. 2019

Restoration method	Range (USD)	Median (USD)
Direct transplantation	9198 - 8,382,653	218,305
Larval enhancement	6262 - 4,333,826	523,162
Coral gardening	130,000 - 379,139	351,661
Artificial reef	14,076 - 142,667,803	3,341,754
Substrate stabilisation	91,044 - 26,100,000	370,986

While coral reef restoration is expensive, this review (Bayraktarov et al. 2019) may not accurately estimate true costs due to a bias towards projects “motivated by furthering ecological knowledge to improve restoration techniques” (i.e. published research). The costs of running a scientific experiment and actual restoration projects are unlikely to have much in common. In many instances “true cost” may also be masked by the use of volunteers, use of local material, donation of material or infrastructures and in-kind contributions from managers and practitioners. Further, this does not account for economies of scale as restoration transitions into industrial-scale projects.

Note that Bayraktarov et al. (2019) estimated that real costs were likely to be two to four times higher than these reported values. Having said that, the lower costs within these categories are within the cost limits for many ICRI members. This supports the case for improved knowledge-sharing, collaboration and capacity-building. There could be great benefit from focusing on the less expensive and more effective projects and sharing this information as case studies.

While it is important to acknowledge difficulties in reporting and summarising the true costs of existing coral restoration technologies, estimating future costs is fraught with difficulty as well. Future costs are not only unknown but are likely to carry substantial research and development components. Further, while many existing technologies are relatively low-tech, most future methods rely on more advanced technology, which is inherently more expensive to develop, and may require substantial infrastructure. This has been investigated through RRAP and NASEM but remains an important area for future research.



Sombrero Island Reef Philippines. Copyright Jett Britnell / Coral Reef Image Bank.

Scale

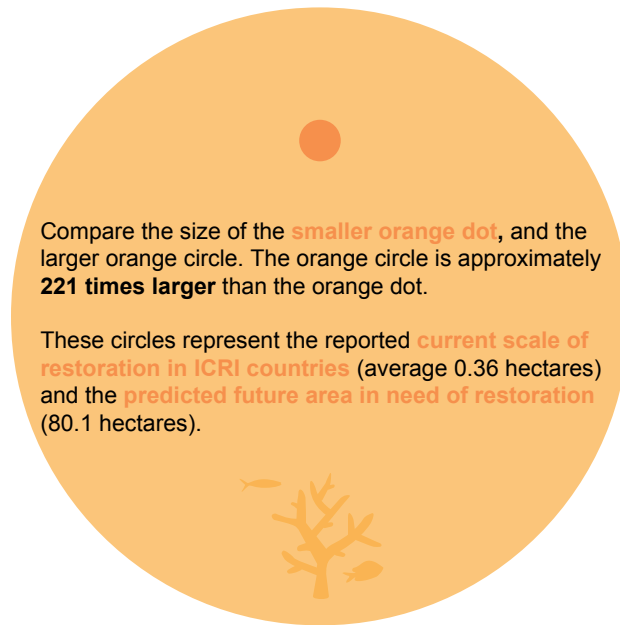


Figure 15: Size comparison between the current reported scale of restoration in ICRI countries (darker orange) compared to predicted future needs (pale orange).

Seven ICRI members provided information about the spatial scale of coral restoration within their countries and followed with estimates of the scale required annually in the future. The current mean total area of restoration projects within countries was just over a third of a hectare (range $> 100\text{m}^2$ - 2.7ha). The average annual scale needed to reach their goals was 80ha (range 100m^2 - 10km^2). This represents a substantial mismatch with a 221-fold increase in scale to meet future restoration goals (Figure 15). However, even the aspirational scale reported is extremely small when compared with the total coral reef area within national borders and the scale of damage. This mismatch between management tools and the scale of the challenges facing coral reefs has been emphasised in recent studies (e.g. Bellwood et al. 2019) and was highlighted by an ICRI member response. When asked what would enable coral restoration and adaptation implementation, the respondent said: “techniques that could deliver effective and affordable restoration at scales of thousands of square kilometres and regulatory and social licence to undertake such techniques”.

Future considerations

Future ICRI restoration and adaptation collaborations

Most respondents (93%) expressed an interest in being involved in future ICRI coral restoration and adaptation work (Figure 16). Most (64%) indicated a willingness to be involved in collaborative research and development activities, receiving training for capacity building (61%), and co-investing in restoration and adaptation research and development (57%). Slightly less than half (46%) indicated a willingness to be active members in joint planning. This reinforces the importance of further collaboration, training and capacity-building and highlights the opportunity for ICRI to show leadership in this space.

Future interest in ICRI restoration and adaptation initiatives?

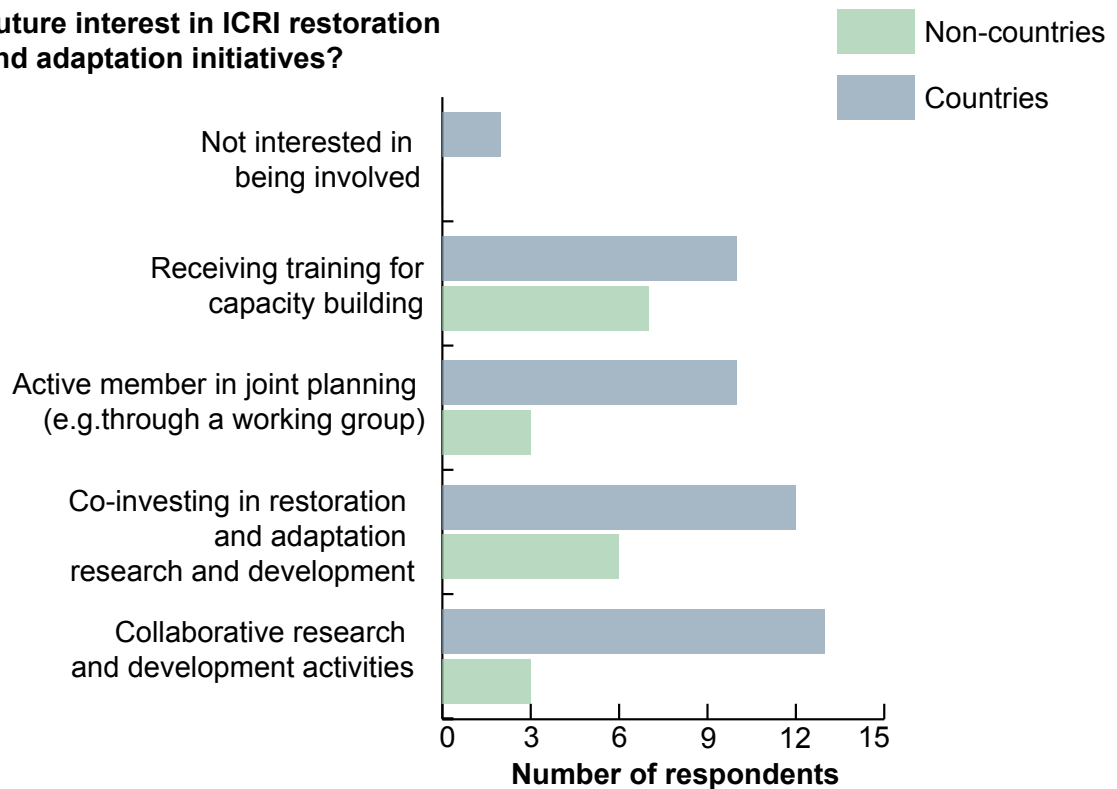


Figure 16: Survey respondents' interest in future ICRI restoration and adaptation activities

Recommendations

This report summarises the findings of an initial scoping study which aimed to identify common interests, facilitate global and regional collaborations, and help identify opportunities for co-investment in research and development. The information was sourced through ICRI members, and drawn from recent reviews, and a series of interviews and meetings with relevant experts and coordinators. The study is a useful starting point to continue a global review and conversation into how active interventions should fit within coral reef management in a changing world.

This interim report recommends:

- **Strong action on climate change and other stressors:** Coral restoration should not be viewed as a replacement for reducing local, regional and global stressors acting on reefs.
- **Invest in research and development:** Substantial research and development is required to scale up and improve all facets of restoration and adaptation.
- **Promote knowledge-sharing and collaboration:** There would be great benefit in global cooperation, collaboration and knowledge-sharing to ensure efficient use of resources.
- **Develop best practice guidelines:** Science-based guidance for restoration practitioners is critically needed, and the UNEP and collaborating organisations have committed to facilitating the production of guidelines in the near future.
- **Develop policy and plans:** New or refined policy and plans relevant to restoration and adaptation are needed.
- **Promote 'blue restoration':** the UN Decade of Ecosystem Restoration represents an opportunity to promote 'blue restoration' including restoring coral reefs. Further, their The UN Decade of Ecosystem Restoration (2021-2030) goal of large-scale restoration, to sequester carbon and reduce anthropogenic climate change, could help mitigate the main threat to coral reefs.

Future plans for the ad hoc committee

In addition to the findings set out in this report, there is also an emerging consensus for stronger collaborations amongst the ICRI members and wider coral restoration field. Nations and partners which have shown interest including the Commonwealth Blue Charter Action Group on Coral Reef Protection and Restoration, UNEP, and the Coral Restoration Consortium to further advance the work of the committee and the ICRI Plan of Action.

Working with ICRI members, reef-bearing nations and relevant partners in 2020, the Committee's future plans will include:

- continuing to assess and document global needs and priorities for current and future reef restoration and adaptation programs
- continue to assess and document global research and development priorities
- provide a coordinating mechanism for international collaboration on coral reef restoration research and development
- advocate for the use of best-practice restoration techniques as part of a broader strategy that involves traditional management and reducing carbon emissions to maintain coral reef functioning and resilience
- facilitate the transfer of new knowledge of restoration techniques to managers and restoration practitioners
- update the global database on coral restoration methods and integrate it with the ICRI website, if resources are available.

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Glossary

Coral restoration - Ecological restoration is the process of assisting the recovery of an ecosystem that has been degraded, damaged, or destroyed.

Coral adaptation - adaptation is a genetic change in the form of allele frequency changes from one generation to the next caused by natural selection on the phenotype. In other words, corals that survive a stress event like coral bleaching, pass on the genetic characteristics that ensure their survival to their offspring, leading to increased thermal tolerance in subsequent generations.

Assisted evolution - the acceleration of naturally occurring evolutionary processes via human intervention to enhance certain traits. It is a holistic term that includes genetic adaptation, transgenerational changes through epigenetic mechanisms, and modifications in the community composition of microbes associated with the target organism.

Coral gardening - Small coral fragments are raised in intermediate nurseries, prior to outplanting on restoration sites. The nursery phase protects corals from damaging conditions during their most vulnerable stages, with the intention of planting them onto damaged reefs once they have reached a size threshold at which their post-transplantation survival is higher.

Direct transplantation - The earliest and most common method of coral restoration involves the direct transplantation of coral fragments, from a donor to a recipient reef.

Artificial structures - The creation of substratum involves structures that are placed on the seabed deliberately, sometimes to mimic characteristics of a natural reef, or for the purpose of increasing potential habitat for reef fauna, fisheries production, recreational diving opportunities, or the prevention of trawling. In many cases, artificial reefs are deployed in conjunction with other methods, such as coral transplantation.

Larval enhancement - Larval enhancement methods aim to exploit the high fecundity of spawning corals to reseed degraded reefs with high numbers of coral larvae. The technique avoids the high mortality-rates immediately post-fertilisation by rearing gametes in enclosures (either aquarium systems ex situ, or in floating in situ pools). After an initial phase of captive rearing (usually <1 week) the larvae are siphoned into protective enclosures on the reef to facilitate settlement on the reef without predators. The enclosures are then removed after 4-5 days, after which no further maintenance or intervention is required.

Substrate stabilisation - The stabilisation of coral rubble, often using mesh or netting over the rubble to prevent further movement. Stabilisation could encourage natural recovery in areas which maintain high natural coral recruitment, as survival rates for coral recruits are low on loose rubble. Stabilisation is often a response to acute disturbances like storms or ship groundings, and is generally a precursor to the transplantation of corals onto the damaged area and/or additional deployment of artificial structures.



