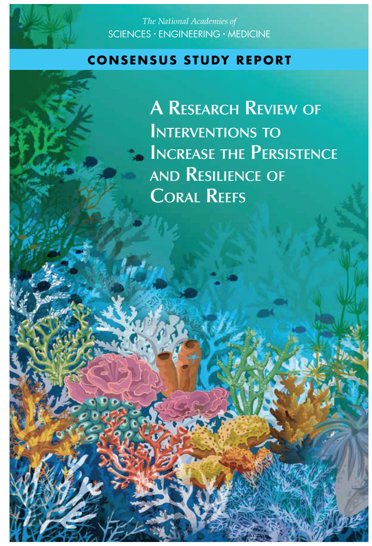
Consensus Study Report

HIGHLIGHTS

November 2018

A Research Review of Interventions to Increase the Persistence and Resilience of Coral Reefs



Coral reefs are declining in all major tropical ocean basins. Since the 1980s, reef cover has been reduced, on average, approximately 30-50% globally. Those losses are the result of a host of problems including habitat destruction, pollution, overfishing, disease, and climate change. Greenhouse gas emissions and the associated increases in ocean temperature and carbon dioxide (CO_2) concentrations have been implicated in increased reports of coral bleaching, disease outbreaks, and ocean acidification. Coral reef declines have profound implications for the hundreds of millions of people who depend on reefs for food or livelihoods, the thousands of communities that depend on reefs for coastal protection, the people whose cultural practices are tied to reef resources, and the fisheries and tourism economies that depend on healthy reefs.

While it will be essential for reef managers to continue addressing local and regional stressors, those efforts alone will not be sufficient because of the additional stress of ongoing climate change. Recent mass bleaching events showed that remote coral reefs, with minimal impact from human activities, bleached as severely as reefs exposed to multiple stressors such as pollution and overfishing. Reduction and mitigation of carbon emissions will be required for successful, global management of marine ecosystems.

Even if efforts to reduce emissions accelerate, committed warming from the current accumulation of greenhouse gases is expected to expose the majority of the world's reefs to harmful thermal stress events, with annual exposure to severe bleaching conditions, by 2050. Coral reefs have existed for hundreds of millions of years, adapting and changing as the Earth's climate has changed. However, given the unprecedented losses in reefs caused by relatively fast changes in the Earth's climate, many coral populations may not have the capacity to adapt at a sufficiently rapid rate.

Reef managers and scientists increasingly recognize that new approaches will be needed to address changing environmental conditions. Novel genetic, ecological, and environmental interventions designed to increase persistence and resilience of coral in a deteriorating environment have been proposed, with a rapid increase in research in this area. *A Research Review of Interventions to Increase the Persistence and Resilience of Coral Reefs* reviews the state of science on these interventions and their current feasibility. Itis a benchmark that reflects current research and efforts in the field.

Source: coralreefimagebank.org

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STRESSORS ON CORAL

Impacts of Human-Induced Climate Change

Increasing changes in the global climate and ocean chemistry threaten the persistence of coral reefs. By far the most attention has been paid to the global effects of ocean warming on coral health. The link between temperature and corals derives largely from the bleaching response of corals to higher than normal temperatures (Box 1). Recent increases in ocean temperature have led to a significant increase in exposure of corals to high temperature events (Figure 1) and have caused severe coral loss globally.

A second global stressor related to climate change is the gradual acidification of the oceans. CO_2 from fossil fuel combustion forms carbonic acid when it dissolves in the ocean. This causes a decrease in pH and a decline in the carbonate concentration, resulting in a lower aragonite saturation state (Ω_a). Aragonite is the type of calcium carbonate that corals secrete to form their skeletons; as saturation state decreases, aragonite becomes more soluble. Long-term exposure to a lower Ω_a reduces calcification and growth rates, with a reduction in calcification of 15-22% per unit decrease in the Ω_a of seawater.

Disease Linked to Climate Change

Increased reports of coral disease outbreaks have been associated with warming events as well as local stressors. Disease outbreaks within coral ecosystems often occur when thermal thresholds are surpassed. For example, increased sea surface temperatures have been linked to the spread of white-band disease, which contributed to the region-wide declines of the dominant Caribbean reef building coral of the *Acropora* genus. Because disease agents often infect the frame-building corals, outbreaks cause loss of reef habitat that also affects other components of the coral reef ecosystem. Environmental stress affects basic biological and physiological properties of coral, thus influencing the balance between opportunistic pathogens and the coral's ability to resist infection. Currently, understanding of the interactions at the cellular level between the disease agents, the coral immune system, and environmental factors is poor and prevents attribution of disease causation.

Impacts of Local Stressors

Despite the impact of bleaching on coral cover, historically the majority of coral losses have been ascribed to non-climate related coral reef changes, such as local habitat destruction, overgrowth by algae after overfishing, pollution, sedimentation, and invasive species. There have been many studies, and decades of effort, to measure the impact and mitigate the effect of human activities on reef ecosystems.

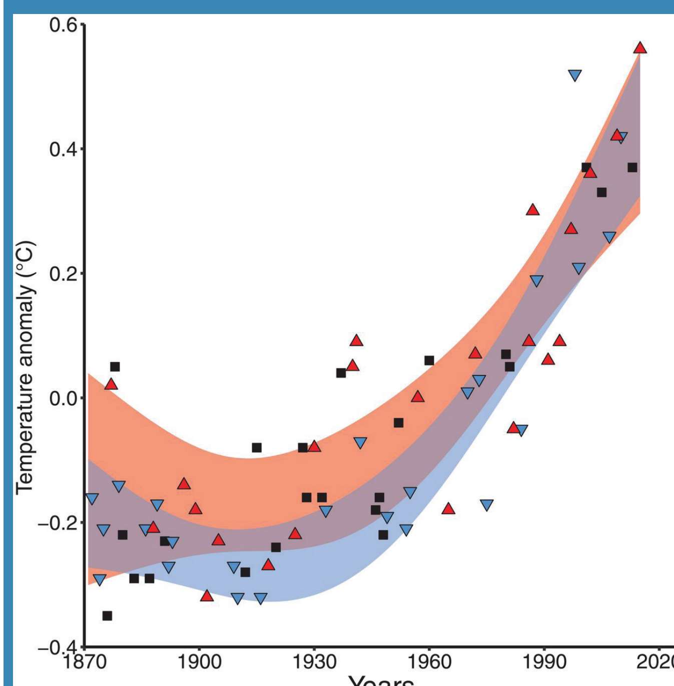
Fishing can impact coral health through many mechanisms. Removal of herbivorous fish, which prevent fast-growing algae from over-growing coral reefs, can result in a phase shift from coral-dominated to algal-dominated reefs. Many human activities lead to the loss of coral reef habitats. This may include damage from fishing methods, such as blast fishing and trawling, as well as damage associated with tourism and the aquarium trade. Construction of facilities (e.g., ports and airports) can directly lead to the removal and loss of reefs,

Box 1. Coral Bleaching

The phenomenon of coral bleaching is visible when colonies turn from their normal tan, gray, or green color to a stark white. These corals are not dead. Instead, individual polyps that make up the coral colony have ejected their internal single-celled algal symbionts (from the dinoflagellate family Symbiodiniaceae) as a response to environmental stress, leaving largely transparent tissues covering their white skeletons. Bleaching reactions are most commonly driven by temperature extremes, tending to occur at temperatures 1-2°C above the normal maximum summer temperatures. Because corals depend on their algal symbiont's photosynthesis for much or most of their food, bleached corals are deprived of the energy they need for normal growth and reproduction. Colonies without abundant external food supplies or energy reserves typically die after bleaching, but others recover and repopulate with symbionts.

Source: coralreefimagebank.org

Figure 1. Ocean temperatures have increased dramatically since 1930. Sea surface temperature anomalies within 100 coral habitats are compared to the 1961-1990 average. Red triangles denote El Niño years whereas La Niña and non-ENSO years are blue triangles and black squares, respectively. 95% confidence intervals are shown for El Niño and La Niña conditions (red and blue shading, respectively). SOURCE: Hughes et al., 2018



while indirect reef destruction occurs due to increases in sedimentation associated with coastal development, pollution, and other environmental alterations. Pollution from human sewage systems, farm runoff, golf courses, urban development, waste deposition, oil and gas leakage, livestock pens, and many other human activities, even use of sunscreens, can damage coral.

CORAL REEF RESILIENCE

This report identifies interventions that have the potential to make coral reefs more resilient to a changing environment at multiple ecological scales (see Box 2). Resilience refers to the overall ability of individuals, populations, or communities to respond positively after disturbance, restoring some part of their original state. As a concept, resilience can be applied to different levels of ecosystems. For example, individual organisms can show physiological resilience via survival, sustained growth, and/or reproduction (fitness). Populations can show resilience through the ability to recruit new individuals after a disturbance. Communities can show resilience in ecosystem traits such as productivity, diversity, trophic linkages, or sustained biomass through shifts in species composition. A key goal for any intervention is that corals become more resilient in the field than they would have been without it.

Box 2. Summary Of Interventions To Increase Persistence And Resilience

A growing body of research on coral ecology, molecular biology, and response to stress has revealed the complex nature of corals and their associated microbiome (including symbiotic algal, prokaryotic, fungal, and viral components). Some of this knowledge is poised to provide practical interventions in the short-term, whereas other discoveries are facilitating research that may soon open the doors to additional interventions.

GENETIC AND REPRODUCTIVE INTERVENTIONS

Managed selection is the detection of corals with above average stress tolerance, and their use in subsequent interventions.

Managed breeding is the maintenance and restoration of diverse coral reef populations through artificial propagation to achieve increased population sizes and fitness. It may be implemented as supportive breeding within a population, outcrossing between populations, and hybridization between species.

Gamete and larval capture and seeding seeks to enhance the natural processes of sexual reproduction in corals by using natural spawning events to supply gametes for future use or larvae for settlement and lab growth.

Coral cryopreservation is the process by which gametes, embryos, or other living materials are frozen in such a way that they remain viable after being thawed.

Genetic manipulation refers to the direct alteration of the genome of an organism, which may be the coral, algal symbiont, or other member of its microbiome.

PHYSIOLOGICAL INTERVENTIONS

Pre-exposure is the deliberate exposure of an organism to conditions that might confer some degree of additional tolerance to subsequent re-exposure of the organism (and potentially, its progeny) to the same or similar conditions.

Algal symbiont manipulation refers to mechanisms by which algal symbiont communities are changed in favor of types that enhance the stress tolerance of the coral host.

Microbiome manipulation is the control or shifting in the abundance of the fungal, prokaryotic (bacteria and archaea), and viral components of the coral microbiome.

Antibiotics can be highly effective in the prevention and treatment of bacterial (and some protozoan) diseases.

Phage therapy is the isolation, identification, and application of viruses that specifically target and infect bacteria.

Antioxidants may be used to deplete the reactive oxygen species (ROS) that are produced as a result of exposure of coral to high incident light levels.

Nutritional supplementation of essential nutrients can compensate for lost energy from algal symbiont dysfunction during periodic episodes of major stress events.

CORAL POPULATION AND COMMUNITY INTERVENTIONS

Managed relocation is the movement of species, populations, genotypes, or phenotypes from a source area to locations outside of their historical distribution, sometimes with different environmental parameters. It can occur at a variety of scales: within their range (assisted gene flow), just outside their range (assisted migration), or across ocean basins (introduction to new areas).

ENVIRONMENTAL INTERVENTIONS

Shading of coral reefs consists of interventions in the atmosphere and in the water that reduce the exposure of coral reefs to high solar irradiance, both to lower peak sea surface temperatures during warm summer months and reduce light stress.

Cool water mixing onto coral reefs is a way to reduce thermal stress by replacing or diluting warm water.

Abiotic ocean acidification interventions at the local reef scale act directly on the carbonate chemistry of the seawater flowing over reefs by shifting it towards a higher pH and higher aragonite saturation state.

Seagrass meadows and macroalgal beds can act as ocean acidification interventions by drawing down CO2 concentrations and elevating the saturated aragonite saturation state in shallow-water environments on or adjacent to coral reefs.

While a focus on stress-tolerant genotypes or species is inherent to many of the interventions described in this report as a way to maintain overall coral cover, maintenance of diversity of genotypes or species is another consideration for supporting the goal of increasing resilience of coral reefs and their associated ecosystem services. Diversity can increase population-level adaptive capacity and community-level resilience to disturbance. Having a diversity of genotypes or species might increase the likelihood of reef persistence when exposed to multiple stressors, especially under an uncertain future about the degree of change across stressors.

The report also includes consideration of interventions that could promote persistence of coral reefs though they may not improve resilience, particularly those that reduce exposure to environmental stress, as an important part of the toolkit of responses to deteriorating environmental conditions.

Source: coralreefimagebank.org

CONSIDERATIONS FOR IMPLEMENTING INTERVENTIONS

The interventions discussed in this report have not been implemented beyond experimental scales in the field, if at all, making their efficacy and impacts uncertain. Adaptive management can help account for and resolve key uncertainties in management practices with uncertain results, and thus is important for assessing the readiness of interventions for implementation at meaningful scales and their ability to meet conservation goals. Careful planning and monitoring of interventions, including the development of model-based expectations, can ensure that projects maximize learning.

These interventions carry varying degrees and likelihoods of their benefits and risks. They alter the environment with consequences that cannot be foreseen completely, given the state of knowledge. A subsequent report will provide a framework for evaluating the relative risks and benefits of implementing these interventions and provide a decision pathway to guide progress of interventions from the research phase to implementation when appropriate. Such a framework can be used to identify intervention strategies for which the consequences and costs may be justified. Although it is outside of the scope of this study to consider the social, policy, legal, and ethical considerations of implementing interventions, these will be important to decision-makers as well.

COMMITTEE ON INTERVENTIONS TO INCREASE THE RESILIENCE OF CORAL REEFS

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For More Information . . . This Consensus Study Report Highlights was prepared by the National Academies of Sciences, Engineering, and Medicine based on the Consensus Study Report *A Research Review of Interventions to Increase the Persistence and Resilience of Coral Reefs* (2018). The study was sponsored by the National Oceanic and Atmospheric Administration and Paul G. Allen Philanthropies. Any opinions, findings, conclusions, or recommendations expressed in this publication do not necessarily reflect the views of any organization or agency that provided support for the project. Copies of the Consensus Study Report are available from the National Academies Press, (800) 624-6242; http://www.nap.edu or via the Ocean Studies Board web page at http://www.nationalacademies.org/osb.

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