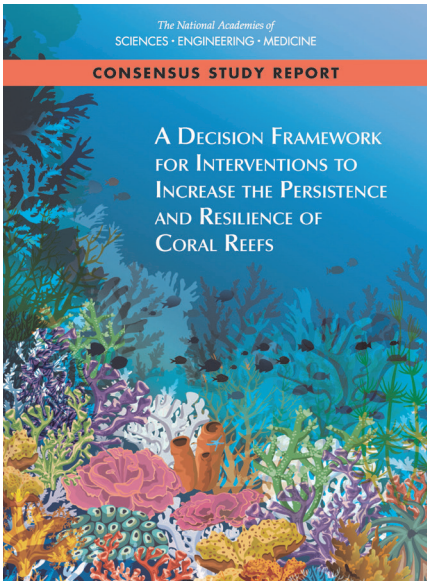
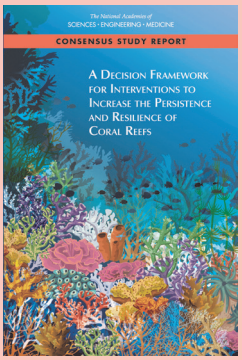
Consensus Study Report
HIGHLIGHTS
June 2019

# A Decision Framework for Interventions to Increase the Persistence and Resilience of Coral




Coral reef managers are faced with a crisis: deteriorating environmental conditions are reducing the health and functioning of coral reef ecosystems worldwide. Established approaches for managing coral reefs are neither sufficient, nor designed, to preserve corals in a changing climate. Recent episodes of above-average water temperatures have increased coral bleaching events and are associated with a rise in disease outbreaks. Dissolved carbon dioxide is lowering the pH of seawater, which is slowly impairing the ability of corals to grow or maintain their skeletons via calcification. These growing threats compound the persistent local stresses coral reefs have experienced for decades from pollution, overfishing, and habitat destruction.

A growing body of research on "coral interventions" aims to increase the ability of coral reefs to persist in rapidly degrading environmental conditions. New coral interventions include activities that affect the genetics, reproduction, physiology, ecology, or local environment of corals or coral populations with the goal of enhancing their persistence and resilience in degraded, or soon to be degraded, environmental conditions. These changes may benefit coral reefs, the species that live on them, and the human communities that depend on them.




A prior report, released in November 2018, examined what is known about 23 novel coral reef ecosystems interventions

This report, the final of two by a committee of the National Academies, is designed to help guide coral reef managers in their response to this growing crisis. A first report, released in November 2018, reviewed the state of science on potential interventions; it identifies what is known about the benefits and goals, current feasibility, potential scale, risks, limitations, and infrastructure needs for 23 novel approaches. This final report provides a decisions framework to help managers assess and implement interventions that are suitable for their region and goals.

## SELECTING INTERVENTIONS FOR DECISION ANALYSIS

Managers and decision makers are faced with the task of evaluating the benefits and risks of a growing number of interventions, separately and in combination. A number of factors help narrow down the field of options. Primarily, readiness or the timeframe for achieving readiness for implementation will determine which interventions are practical on short- or long-term timeframes. For example, testing corals for heat resistance and growing them in nurseries is available to support managed selection, managed breeding, and managed relocation. In contrast, using genetic engineering to increase resilience, or marine cloud brightening to reduce light and cool reef surface waters are not yet feasible, and the risks and benefits of these are not well defined. Even for those interventions that may be technically ready, further research would be valuable to lessen risks or improve benefits and their scale.

The interventions have different risks, benefits, and feasibilities in different regions. Biophysical attributes of a reef or region that influence the choice of intervention include the current degree of reef degradation, disease prevalence, bleaching history, and future projections of bleaching events, water quality, herbivory, recruitment, connectivity, spatial extent of the reef, potential for cold shocks, and temperature variability. Moreover, these dependencies are likely to differ when considering where to test versus where to deploy or scale up interventions.

Equally important is the social context in which interventions are deployed. Resources are needed to deploy interventions, and existing infrastructure may already exist to make some more feasible, such as restoration programs that currently propagate corals in nurseries and outplant corals in large numbers. The size of a management jurisdiction, or the ability to partner across jurisdictions, will drive the acceptable scale of implementation or downstream impacts of chosen interventions. Finally, an intervention must be an acceptable course of action to the local stakeholders, and these preferences can be made clear in a structured decision approach.

## A STRUCTURED, ADAPTIVE APPROACH TO DECISION MAKING

The evaluation of coral interventions is part of a broader decision context that includes climate mitigation and managing other stressors (e.g., water quality, overfishing, habitat destruction) to achieve overall coral reef conservation objectives based on community values. Within this context, there are likely to be multiple and potentially conflicting stakeholder objectives. Additionally, there will be uncertainty about system dynamics, future conditions, and the risks and benefits of a particular decision. An adaptive management approach provides an explicit process for planning, implementing, monitoring, evaluating, and adjusting specific management strategies when outcomes are uncertain (See Figure 1). The steps of this adaptive process, focused on evaluating coral interventions, are outlined below.

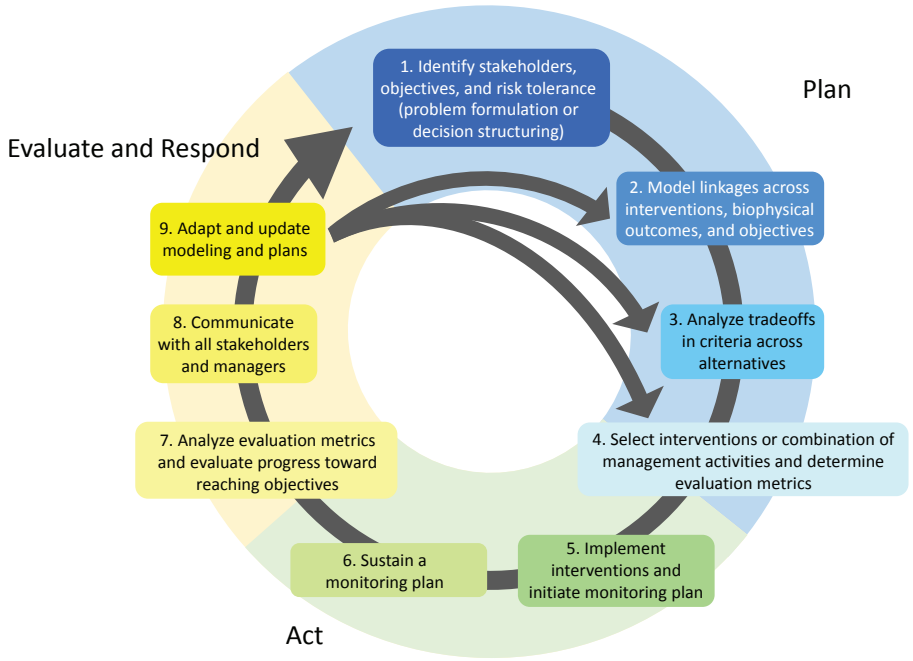



**FIGURE 1** The adaptive management cycle shown as three major phases (Plan, Act, and Evaluate and Respond) composed of nine steps. SOURCE: adapted from Delta Stewardship Council, 2013.

### Step 1: Identify the decision context

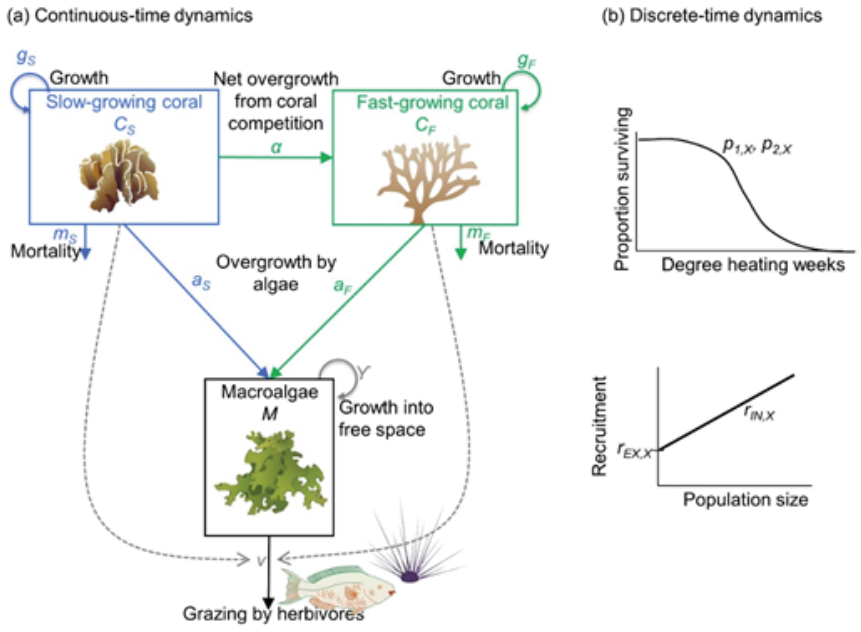
An iterative adaptive management process begins with a planning and problem formulation stage to establish the decision context: identifying long- and short-term goals, objectives, possible biophysical outcomes, and their relationship to evaluation metrics and decision criteria. Although decision makers have primary responsibility for problem formulation, stakeholder involvement is crucial to establish shared goals and objectives.

### Step 2: Model linkages across interventions, biophysical outcomes, and objectives

Evaluation of expected intervention risks and benefits requires modeling, as quantitatively as possible, the biophysical (and as appropriate social and economic) consequences of implementing different interventions or set of interventions. Model design and input parameters should be tailored to specific locations at relevant spatial and temporal scales. The model design should also be able to capture the expected mechanisms of the interventions of interest. For illustrative purposes, the report's authoring committee constructed a biophysical coral community model to capture the basic ecological dynamics of the reef system, and model the impacts of interventions on coral cover (Figure 1).

### Step 3: Analyze tradeoffs in criteria across alternatives

Reef managers are likely to consider a range of management alternatives, including using one or more interventions in concert with conventional restoration activities as well as a baseline of no action. These combinations, along with uncertainty in knowledge about the reef system and future climate, will yield a range of modeled outcomes across alternatives with tradeoffs in their abilities to meet management objectives




**A BIOPHYSICAL MODEL OF A CORAL REEF COMMUNITY.** As described in Step 2 of the decision framework processes, evaluating expected intervention risks and benefits requires modeling. As an example, the committee constructed this biophysical coral community model to capture the basic ecological dynamics of the reef system. The committee uses a simple model appropriate for qualitative, comparative interpretation; any model constructed for a decision-making process in a particular location would use a more realistic and locally-tailored modeling framework appropriate for more quantitatively precise predictions. As a proxy for a range of coral responses and community states, the model predicts the proportion of area covered by macroalgae and two types of coral: slow-growing coral (such as a foliose or massive coral) and fast-growing coral (such as a branching coral).

and minimize risk. For example, some intervention strategies may support the growth of a small subset of coral species that provide fish habitat but not the solid reef structure that is needed to provide coastal protection from storm waves. If fish habitat and strong reef structure are both key objectives for different stakeholder groups, then tradeoffs need to be made to reconcile different priorities or value preferences. A number of tools are available for analyzing these tradeoffs to guide a preferred course of action. These include multi-criteria decision analysis, decision trees, system dynamics models, and Bayesian networks. Most importantly, analyzing tradeoffs requires a deliberative approach with stakeholder values at the center.

### Step 4: Select interventions or combination of management activities and determine evaluation metrics

Once decision-makers understand the potential performance of the suite of intervention strategies relative to the multiple objectives, and tradeoff analyses have generated an agreed subset of preferred strategies, one or more strategies can be selected for implementation. Measurable evaluation metrics are developed across decision criteria that link to the objectives established in Step 1.

### Steps 5 and 6: Implement interventions, and initiate and sustain a monitoring plan

A targeted monitoring program, conducted prior to, during, and after implementation, based on specific biophysical outcomes is needed to provide the data necessary to quantify the evaluation metrics. Effective and targeted monitoring is critical to assess intervention performance compared to objectives, and to reduce critical uncertainty in models.

### Steps 7, 8, and 9: Evaluate, communicate, and adapt

Evaluation of monitoring data can identify progress made toward meeting management objectives (including partial success or failure), or reveal the need for more information. The results of the evaluation can be used to communicate progress in meeting objectives to stakeholders and decision makers. The adaptive management framework allows for monitoring data to inform iterative improvements to model design and input parameters to inform strategy adjustment.

## ADVANCEMENTS THROUGH RESEARCH

Despite the rapid pace of research on coral biology and conservation that is occurring on a global scale, there are many gaps and unresolved issues that need to be addressed in the short and long term. Priority research would improve understanding of the risks and benefits associated with a potential intervention and reduce critical uncertainty to better inform decision making. Advancing research would also bring more interventions into a state of technical readiness and improve abilities to manage their risks and benefits. The report identifies priority research needs in four areas:

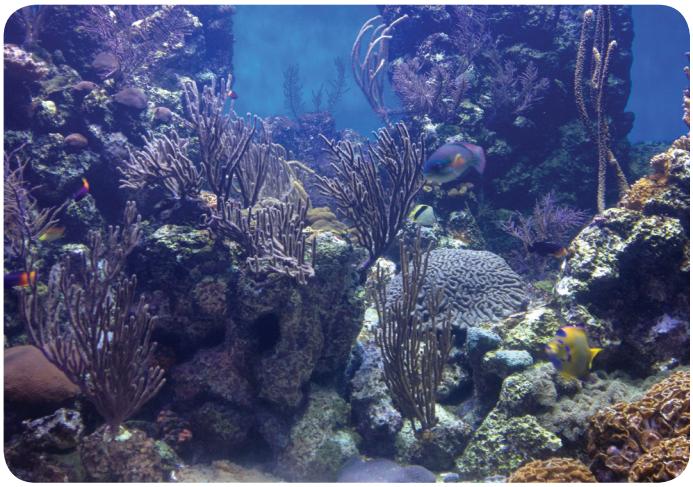
1. **Research on Fundamental Coral Reef Biology.** Effective intervention approaches for reefs require an improved understanding of which factors underpin coral health and how these lead to reef resilience at scale.
2. **Site-Specific Research and Assessment.** Development of appropriate ecological models and identification of relevant management objectives and alternatives requires site-specific information.

3. **Research to Improve Specific Interventions.** Research is needed to stage interventions from laboratory experiments to full-scale management strategies. Additionally, research can help inform the safety, efficacy, and cost-efficiency of interventions.
4. **Research to Inform Risk Assessments and Modeling.** The adaptive management cycle requires monitoring and evaluating the results of a management action based on an established monitoring program in order to iteratively gain knowledge and improve information to support decision making.

## A CASE STUDY: THE TROPICAL WESTERN ATLANTIC AND CARIBBEAN

The authoring committee considered how application of the proposed decision making framework might be influenced by the regional setting of coral reefs in the tropical western Atlantic and Caribbean. Coral reefs in this region show widely variable conditions, but many areas have experienced uniquely devastating losses in recent history. Assessing the conditions of Atlantic/Caribbean reefs helps clarify the attributes most relevant to selecting interventions, and influences analyses aimed at deciding which interventions to test and deploy. These attributes include generally poor reef conditions, intrinsic vulnerability, high interconnectedness, low diversity of coral and algal symbionts, high environmental variability across the region, and persistent and destructive disease outbreaks. These attributes also include a relatively widespread and growing network of coral restoration practitioners, located in a small (compared to the Indo-West Pacific) but politically complex region.

The committee identifies the most relevant or promising intervention strategies for the Atlantic/Caribbean region based on the regional context dependencies and technical readiness across interventions. For example, the presence of persistent disease suggests that (1) identifying corals that are both heat and disease-resistant is a priority, (2) there will be increased risks of coral relocations, (3) there is value in exploring interventions that treat disease, and (4) there is a need for quarantine and disinfection as part of intervention strategies.



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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 Decision Framework for Interventions to Increase the Persistence and Resilience of Coral Reefs* (2019). The study was sponsored by National Oceanic and Atmospheric Administration and the Paul G. Allen Family Foundation. 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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