

Adaptation Design Tool

Corals & Climate Adaptation Planning



NOAA Technical Memorandum CRCP 27



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ADAPTATION DESIGN TOOL

CORALS & CLIMATE ADAPTATION PLANNING PROJECT

Introduction

The Adaptation Design Tool of the Corals & Climate Adaptation Planning (CCAP) project was developed to help coral reef managers incorporate climate-smart design into their plans, programs, and projects at any stage of planning and implementation. The CCAP Adaptation Design Tool (henceforth referred to as the Design Tool) can be used to incorporate climate change adaptation into programs using existing planned actions as a starting point, and also to consider development of additional climate-smart strategies as needed. Most managers will be working from existing plans responsive to previously established management objectives, with climate change already taken into account to varying degrees.

The Design Tool was initially developed for Step 4 of the Climate-Smart Cycle of Stein et al. (2014; Figure 1). The Climate-Smart Cycle shows “typical” steps in management planning where climate change information can be used to improve management effectiveness in light of climate change. This includes consideration of the implications of climate change for defining goals and objectives, assessing vulnerabilities to interacting climate and non-climate stressors, identifying, selecting and implementing climate-smart management responses, and monitoring effectiveness. The cycle is iterative in the sense that readjustments can be made at any step—leading to potential changes in other steps in response—as new and improved information becomes available.

For Step 4, “Identify adaptation options”, the Design Tool provides a systematic approach to help managers: (1) integrate climate-smart design considerations (inner circle of Figure 1) into their existing management actions; and (2) build out an expanded set of actions based on options (middle circle in Figure 1) found under general adaptation strategies (outer circle in Figure 1) from the literature (see CCAP Compendium; Appendix 1). Use of the Design Tool also yields valuable supplementary information on data gaps and research needs, and on potential interactions among actions (synergies, sequencing issues) that are relevant for evaluating logical groupings of actions for implementation (Step 5 of the cycle). Finally, the

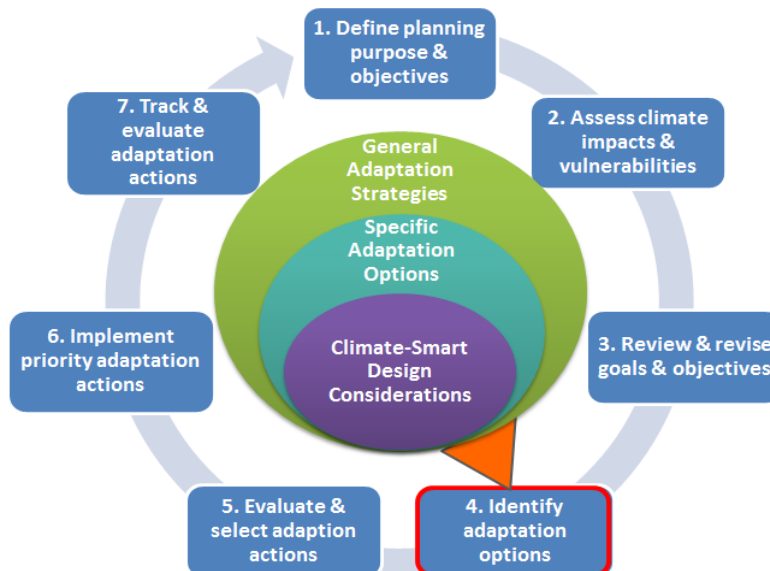


FIGURE 1. CLIMATE-SMART CONSERVATION CYCLE (STEIN ET AL. 2014) WITH ADAPTATION DESIGN FRAMEWORK

Design Tool can be applied in greater depth once priority actions have been selected, in order to develop designs to the level of specificity needed for actual implementation (Step 6 of the cycle). While

this guide describes how to use the Design Tool for Step 4 of the cycle (initial brainstorming of design), the process for using it in Step 6 (detailed design for implementation) is the same.

In order to use the tool for Step 4 (Figure 1), you will need your list of potential management actions based on your goals and objectives, and any available information on vulnerability and resilience potential for your reef. Your goals and objectives can be the original ones associated with your management plan (if one exists), or can be modified based on realizations gained from the assembly of climate change vulnerability information (in Step 2). In either case, you will have a preliminary list of candidate management actions under consideration for your plan. The Design Tool then supports you in generating descriptions of climate-smart versions of the actions designed to inform evaluation and selection (Step 5 of the cycle). The Design Tool is best applied to management actions that are place-based and specific enough to enable consideration of particular design aspects; for maximum effectiveness this may require that general strategies or grouped activities be converted into separate actions. In order for the output of the Design Tool to support robust evaluation, there needs to be sufficient information on climate-smart design such that managers can both judge whether an action is adaptable in the face of climate change and assess typical selection criteria such as feasibility, urgency, and cost-effectiveness in a comparative manner. The Design Tool is crafted to help managers accomplish this, using a modest level of effort to arrive at sufficient design information for evaluation, without getting bogged down in too much detail.

In Step 4, the Design Tool focuses on the development of “Climate-Smart Design Considerations”. These involve two categories of questions (Box 1) related to how climate change is likely to impact both the stressors being managed by an action and the effectiveness of the action itself. Using the answers to these questions, managers can consider how the design or implementation patterns of their management actions could be modified for greatest effectiveness in the face of climate change. This may be accompanied by consideration of additional adaptation options for potential inclusion in a management plan, based on ideas from the literature (see Appendix 1). Box 1 shows an example of a management action, described in basic terms compared to a more climate-smart description based on using the tool. Such descriptions can position managers to more effectively evaluate which actions have the greatest potential for success under climate change, both individually and in combination with each other.

The Design Tool is comprised of two main activities as illustrated in Figure 2. Together these activities aim to make the actions in an existing plan climate-smart and, if appropriate, expand the list of actions included for evaluation and selection. They also can help identify those actions that likely cannot be adapted to function adequately in the face of climate change (and thus may need to be replaced). The activities are:

ACTIVITY 1: Develop information to address Climate-Smart Design Considerations and apply it to adapt existing actions to account for climate change effects.

ACTIVITY 2: Identify additional, general adaptation options that may be needed to more comprehensively address climate change impacts, tailor them as place-based actions, and add them as a second iteration of Activity 1.

BOX 1. CLIMATE-SMART DESIGN CONSIDERATIONS

For any management action to be considered Climate-Smart, two categories of Climate-Smart Design Considerations must be applied:

Category 1 Design Considerations

How will climate change directly or indirectly affect how the stressor of concern impacts the system?

Category 2 Design Considerations

How will climate change affect the functionality of the management action (through its effects on the stressor and/or its effects on the action directly), and as a result how will the action need to be adjusted (in terms of location, timing, or engineering design)?

EXAMPLE:

Action: *Install terraces adjacent to dirt roads in agricultural areas to reduce sediment loads from runoff.*

Category 1: *How will increasingly severe storms affect the volume, pattern and timing of runoff into terraces?*

Category 2: *How can the terraces be designed (number, durability, dimensions) and located (placed in the landscape) to account for these effects?*

Climate-Smart Action: *Install terraces resistant to extreme events, adjacent to roads that are targeted as contributing the largest percent of sediment outflows to the reef; design terraces of sufficient dimension, number, and step-series appropriate to location; increase maintenance frequency to shorter time intervals and after heavy rainfall events.*

The culmination of these two activities is an expanded list of climate-smart actions that can be advanced to the evaluation and selection step (Step 5; Figure 1) for potential inclusion in a new or revised – and now more climate-smart – management plan. This list is comprised of better-crafted actions with respect to climate change implications for timing, placement (siting), engineering, and other physical aspects of design. In addition, these activities generate supplementary information that informs subsequent planning steps of evaluation and selection, as well as implementation. This information can also prompt you to return to earlier planning steps to incorporate additional information.

Supplementary Output 1 aggregates information on key data and information gaps and research needs that can be used to improve vulnerability and resilience assessments and the design of management actions. Supplementary Output 2 compiles information on possible interactions and timing issues among the list of climate-smart actions in order to identify logical groupings relevant to implementation.

Additional instructions for each activity and output type are provided in the sections that follow.

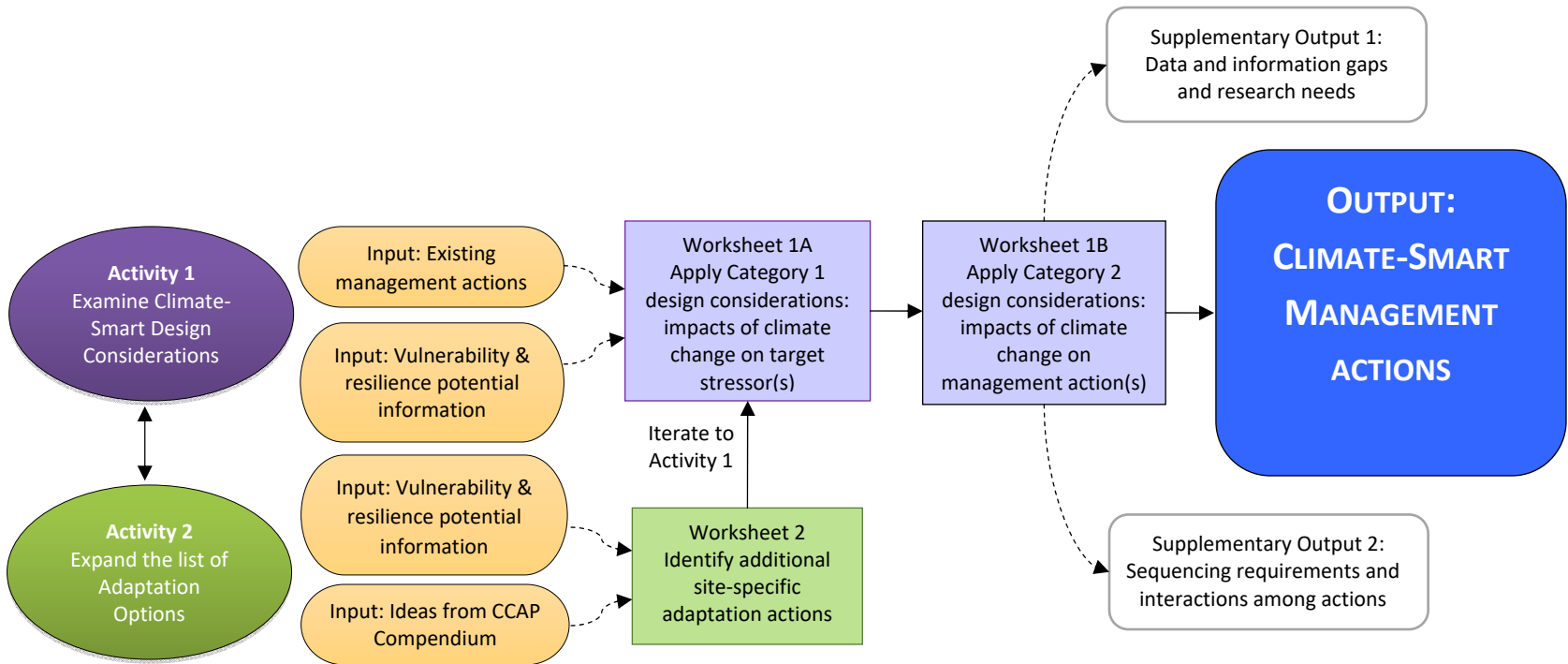


FIGURE 2. FLOW CHART OF ACTIVITIES IN THE CCAP ADAPTATION DESIGN TOOL

Using the Design Tool

As a manager, you can use this tool in different ways depending on your available resources and preferred starting point. For example:

- If you would like to begin by making your existing management plan more climate-smart, start with Activity 1 (application of Climate-Smart Design Considerations).
- If you are primarily interested in identifying gaps in your existing management plan to address key climate vulnerabilities – or if you do not have an existing plan – you can start with Activity 2 (reviewing the CCAP Compendium in Appendix 1 to identify climate-smart management options).

Before starting, review this guide and the examples provided to get a sense of the process and the reference information you will need to gather. Do not get bogged down if you do not have all the information you would like, as important insights can be gained through the general thought process, and you can always add more detail as additional information becomes available.

What actions should be put through the Design Tool?

Ideally, you want to put as many management actions through the tool as possible, and include the participation of a range of experts (see next section) who are familiar with the actions and the stressors that the actions address. However, if you have very limited time and/or resources for management plan revision, it is possible to limit the initial level of effort by identifying the management actions that will most benefit from being put through the Design Tool. Possible criteria to consider in selecting subsets of management actions to put through the Design Tool include:

- **Stressor Sensitivity.** Is the planned management action addressing a stressor that is likely to be significantly affected by climate change?
- **Action Sensitivity.** Does the action have the potential to be re-designed based on use of the Design Tool (e.g. engineering design, siting, when it is applied, etc.)? Does it lend itself to changes in when/where/how the action would be implemented?
- **Exigency.** Has the planned management action already been identified by decision makers as a priority for imminent implementation?

Under time or resource constraints, these criteria can be useful in selecting a subset of management actions that would benefit most from being put through the tool first, so that the initial commitment of effort can be controlled. There are, however, some cautions. Even if some actions seem relatively insensitive to climate change based on current information, managers must be attentive and reconsider this judgement as new information comes to light. In the end, all actions that are ultimately selected for implementation ideally should be put through this tool, to gather more in-depth information needed for detailed implementation planning.

Who should be involved in using the Design Tool?

The Design Tool is intended for use by a group of participants with a range of expertise relevant to the management actions. A group size of 3-10 people is considered optimal. Using the tool is not intended

to circumvent engagement with broader stakeholders, but rather to provide you with a systematic and transparent process that yields information that can be presented and explained in subsequent stakeholder communications. It is recommended that, if circumstances allow, a site manager or individual knowledgeable of the site, management plan and supporting technical information use the Design Tool to conduct a preliminary, or 'rough cut', climate-smart analysis of existing management actions prior to consultation with the expert team. Interns, research fellows, or other individuals familiar with the site could support this process. Such a preliminary analysis can serve several important functions, including: (1) help staff become familiar with the tool, (2) highlight information and data needed as inputs to the use of the tool, such as a vulnerability assessment, and (3) increase the efficiency of subsequent, more in-depth efforts by a larger team of experts.

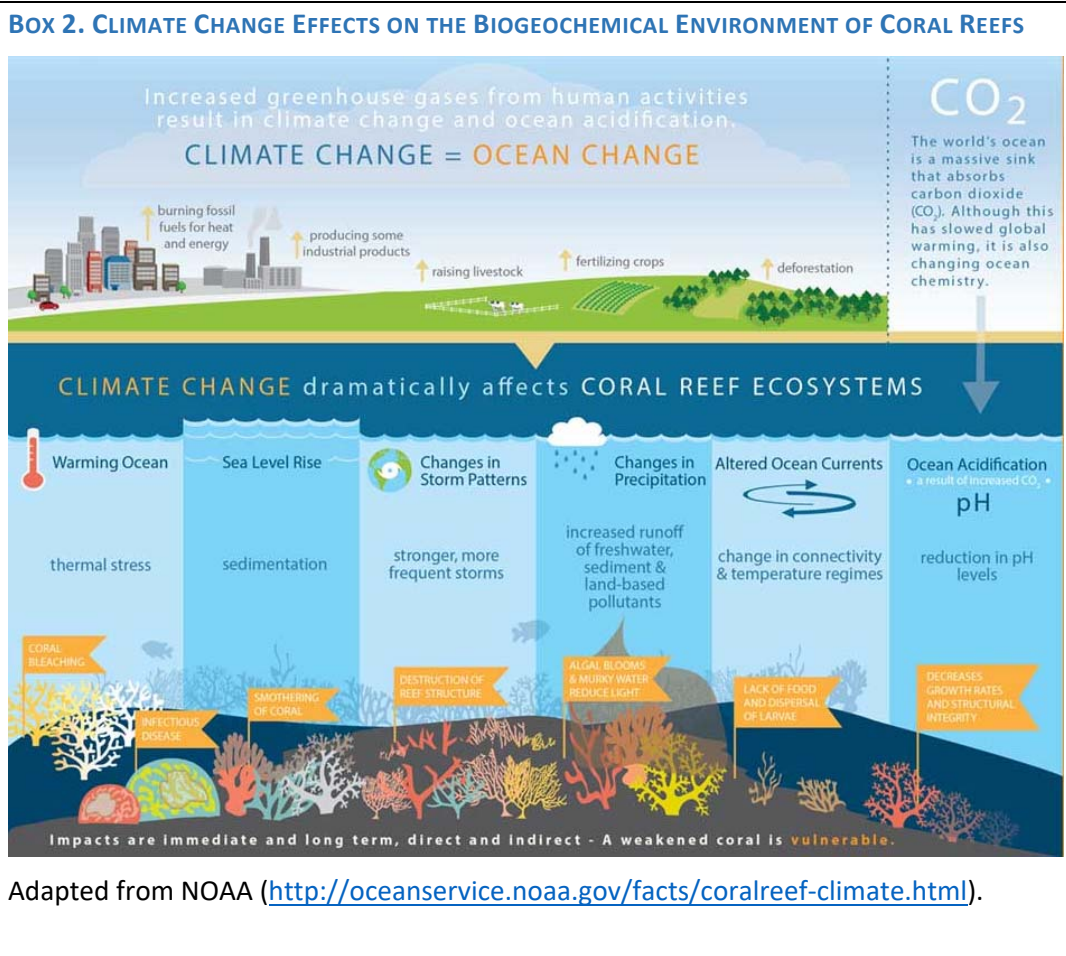
What is the time commitment for using the Design Tool?

The time required to use the tool depends on your number of existing management actions and the availability of information on vulnerability and resilience potential as well as the availability of experts; but it can also be adjusted depending on timing or staffing constraints. To increase efficiency, your site manager or technical staff can select a subset of actions (see discussion above on criteria) and use the Design Tool to conduct a preliminary 'rough cut' climate-smart analysis; then subsequent expert consultations will be more focused. Holding an orientation call with participants to introduce the Design tool will also maximize productivity of any in-person workshop. After this preliminary preparation, a 2-day workshop with appropriate experts typically would be sufficient to complete the worksheets for approximately 6-12 actions. This process is meant to generate information of sufficient detail to inform evaluation and selection of priority actions for your plan. To subsequently use the Design Tool for implementation planning, the selected actions could then be put through a second round, or 'deep cut', of the tool, to generate detailed specifications on location, timing and/or structural design. Time requirements in this case will depend on the ease with which experts can be identified and convened and the number of actions to be assessed. It may be possible to further increase efficiency by convening expert groups based on thematic groupings of actions, and/or meeting through video conferencing or through separate consultation calls with individual experts.

Activity 1: Examine Climate-Smart Design Considerations

Rationale

Climate change will impact coral reefs in many ways (see examples in Box 2). Both the direct effects of climate change and the interactions of climate change with other stressors are of increasing importance for management, conservation, and restoration efforts. This highlights the need to design management actions to incorporate adaptation to such effects. Through the use of the following two worksheets (1A and 1B) you can complete Activity 1 and incorporate climate change effects into existing plans.



Worksheet 1A

The first category of Climate-Smart Design Considerations addresses how climate change is expected to affect the non-climate stressors to which coral reefs are subjected. To examine these considerations, Worksheet 1A guides managers through a series of information-gathering steps. The worksheet's column headings, reflecting these steps, are defined below, with an example for each column provided; a more detailed description of the process for using the worksheet follows after. The full (blank) worksheet for the activity can be found in Appendix 2.

WORKSHEET 1A: COLUMN DEFINITIONS. PRINT THIS PAGE FOR REFERENCE AS YOU WORK WITH WORKSHEET 1A.

A1	A2	A3	A4	A5	A6	A7
Action number	Existing management Action	Target stressor(s)	Climate change effects on stressors (direction, magnitude, mechanism, uncertainty)	Timing of climate change effects	Implications of A4 & A5 for effectiveness metrics & how to measure them	Notes
Provide a sequential ID number for each action.	List each site-specific action from your management plan and/or from Activity 2. (Color code actions from Activity 2 as “new” actions being added to the original list of “existing” actions.)	Identify the stressor(s) (e.g., pollutant, fishing pressure, etc.) that the management action targets. (An individual action may address more than one stressor.)	Describe expected climate change impacts on the target stressors. This includes information on the direction, magnitude, and mechanism of change along with level of uncertainty. This will support consideration of how actions would have to be modified (e.g., scaled, placed, timed, engineered) to remain effective. Supporting materials needed include vulnerability and resilience information, climate projections, etc.	Indicate the anticipated timing of when climate change will affect the target stressor(s). This informs when the action is needed, sequencing with other actions, and the time frame under which effectiveness should be evaluated. Mid-century is a management-relevant time frame commonly used; however, this also could include seasonal outlooks/forecasts, or shorter-term events like El Niño.	Identify metric(s) to be used to assess technical performance (i.e. effectiveness) of the action. If possible, suggest targets for quantitative or qualitative changes in the stressor/ metric that would be used to measure effectiveness. Describe how monitoring (e.g., frequency, location, duration, etc.) might need to be modified given climate change effects on the stressor.	Make notes on reasoning, concerns, or information gaps essential for: <ol style="list-style-type: none"> 1) Providing a transparent record of the thought process; 2) Keeping track of emerging insights into sequencing needs or interactions with other actions; 3) Identifying causal chains to social or ecological effects on the stressor that may cause feedback loops; 4) Recognizing the actions possible consequences for other human or ecological systems outside of the reef; 5) Describing uncertainties/knowledge gaps that need to be filled as new information becomes available.

WORKSHEET 1A: EXAMPLE.

A1	A2	A3	A4	A5	A6	A7
Action number	Existing management action	Target stressor(s)	Climate change effects on stressor(s): (direction, magnitude, mechanism, uncertainty)	Timing of climate change effects	Implications of A4 & A5 for effectiveness metrics and how to measure them	Notes
1	Plant cover crops on high elevation farms	Sediment and nutrient loads reaching reefs following storms	<p>Direction: As storm severity increases, runoff from land increases, bringing greater sediment and nutrient loads.</p> <p>Magnitude: Storms are expected to become more intense, delivering sediment and nutrient loads in high-pulse events.</p> <p>Mechanism: Stronger storms will dislodge more dirt in high-elevation, high-slope farms, especially where soil is drier due to higher temperatures.</p> <p>Uncertainty: There is high uncertainty regarding how storm frequency will change, but low uncertainty regarding the projection that storm severity will increase.</p>	Increasingly severe storms releasing more sediment and nutrients may already be occurring. Storm severity is expected to continue to intensify over the coming decades. If there are thresholds for sediment and nutrient effects on reefs, increasingly severe storms may trigger that threshold sooner.	<p>Success metric: Sediment/nutrient loading, measured as a concentration (e.g., mg/l) or a total load (kg).</p> <p>Target(s) for success metric: Sediment/nutrient loading reduction of (e.g.) 40% compared to baseline (existing) condition.</p> <p>Implications for how to measure success metrics: As storms become stronger, it will become more important to have long-term sampling that captures the extreme episodes. Sampling will likely need to be able to record a broader range of loads.</p>	<p>How much will the intensity of 10- vs. 25- vs. 50- vs. 100-year storms change by 2050?</p> <p>How will the timing and/or spatial pattern of pulse events change?</p> <p>How much reduction in sediment and nutrient loads can be expected per acre of cover crop?</p> <p>How much will sediment input from other sources such as roads contribute along with sources from agricultural fields and how should that be accounted for?</p> <p>Where are the best places to plant cover crops (particular farms and locations in farms)?</p>

Worksheet 1A Process

For this worksheet, you will need to assemble your reference materials (listed at right) as well as your list of existing or planned management actions to be put through the tool. See below for specific information on filling out this worksheet:

Columns A1 and A2: Action Groupings

Some prioritization and/or grouping of related management actions may increase efficiency in using the tool. For example, reef management plans often include an upland/watershed component with multiple actions to address local land-based threats to coral reefs. For Worksheet 1A, it is useful to group the suite of existing or planned actions that address the same threats (such as sediment and nutrient runoff) because they will draw on similar information and may have more interactions with each other.

Columns A3 and A4

To begin, it is important to be specific in identifying the stressor(s) being addressed by each action (Column A3), and thereafter to capture the climate effects on the stressor(s) that are relevant to the action (Column A4).

Also, when describing expected climate change effects on the stressor(s) relevant to a management action (A4), the uncertainty associated with those assessments (i.e. uncertainty about climate change effects on the stressor(s)) must also be considered. This information is important to carry forward to the next planning step (Step 5 - Evaluation and Selection). Given that uncertainty can be difficult to quantify, a relatively simple approach, such as a categorical (high/low) judgement is recommended. More information on this approach can be found in Appendix 4 (Expanded Considerations, Resources, and Lessons Learned).

Columns A5 and A6

The timing of expected climate change effects (Column A5) informs when the action is needed, how it should be sequenced with other actions, and the time frame under which future effectiveness should be evaluated. Management actions should be matched with measurable outcome targets and appropriate metrics or indicators of changes in the target stressor(s) (Column A6), which can later be used to measure effectiveness of the action. Potential changes in how to measure the success metrics should also be described here.

Column A7

The notes column (A7) plays an important role in documenting the reasoning for decisions as well as supplementary information on research gaps and potential interactions among actions (optional worksheets for collecting these “supplementary outputs” are provided in Appendix 3). This information will be useful in subsequent steps of evaluation, selection, and implementation, and for revisiting and refining previous steps in the adaptive management cycle. Other drivers of global change, such as

MATERIALS NEEDED:

- *Worksheet 1A*
- *Reference materials:*
 - *List of management actions and stressors*
 - *Climate change projections*
 - *Vulnerability information*
 - *Resilience potential information*
 - *Available maps of vulnerability, resilience, and climate change information*
 - *Available maps of land-based stressors and/or land use change*
 - *Available maps of reef areas, management areas, action implementation sites*

population growth, tourism, infrastructure/development, and land use change, are typically addressed in vulnerability assessments; however, when particularly relevant to an action, information about them can also be captured in the worksheet notes columns for later use.

Worksheet 1B

The second category of Climate-Smart Design Considerations combines the results of Worksheet 1A with additional information to address how climate change is likely to alter the functionality or durability of the management actions, and how those actions would have to be modified in order to remain effective. To examine these considerations, Worksheet 1B guides coral reef managers through a second series of information-gathering steps. The worksheet's column headings, reflecting these steps, are described below, with a practical example for each column provided; a more detailed description of the process for using the worksheet follows after. The full (blank) worksheet for the activity can be found in Appendix 3.

WORKSHEET 1B: COLUMN DEFINITIONS. PRINT THIS PAGE FOR REFERENCE AS YOU WORK WITH WORKSHEET 1B.

B1	B2	B3	B4	B5	B6	B7	B8
Action number	Existing Management Action	Changes in effectiveness of management action due to: climate impacts on target stressor	Changes in effectiveness of management action due to: climate impacts on management action	Time frame or constraint for using the action (e.g., urgency, longer or shorter term)	What changes are needed to adapt the action (place, time, and engineering design)	Climate-Smart Management Action	Notes
Transfer action numbers from Worksheet 1A.	Transfer management actions from Worksheet 1A (including any management actions identified as a result of Activity 2).	Describe how climate impacts on the stressor (from Worksheet 1A) will change the effectiveness of the management action over its implementation and functional lifetime. Will the action be able to handle changes in the target stressor?	For actions that involve physical structures or elements, describe how climate change may directly impact the management action in ways that will change the effectiveness of the management action over its implementation and functional lifetime. Could the action be physically destroyed by climate change impacts?	Identify temporal considerations, including: (1) urgency due to anticipated time frame of climate change effects on the action and (2) short-term and long-term needs for planning and implementation of the action (including lead-time for design, permitting, construction, or other enabling conditions).	Describe the changes needed to adapt the design of the action in terms of place, time and engineering design. Be sure to review and take into account the information from all previous columns including the Notes columns.	Revise the original management action (from Column B2) to incorporate the climate-smart design considerations. Be as specific as possible.	Make notes to: <ol style="list-style-type: none"> 1) Provide a transparent record of the thought process; 2) Identify knowledge gaps and research needs for better understanding climate impacts and design needs/changes in effectiveness of the action; 3) Record social or economic considerations for making adaptation design changes to the action; 4) Describe any other concerns or uncertainties relevant to adaptation design of the action.

WORKSHEET 1B: EXAMPLE.

B1	B2	B3	B4	B5	B6	B7	B8
Action number	Existing Management Action	Changes in effectiveness of management action due to: climate impacts on target stressor	Changes in effectiveness of management action due to: climate impacts on management action	Time frame or constraint for using the action (e.g., urgency, longer or shorter term)	What changes are needed to adapt the action (place, time, and engineering design)	Climate-Smart Management Action	Notes
1	Plant cover crops on high elevation farms	Cover crops will likely become less effective without modification. Cover crops may not be able to retain enough soil under more extreme storms. Soil itself may become more erosion-prone if it becomes drier and more compacted during periods of drought (smaller soil pores leading to less infiltration leading to more surface flow).	Some cover crops commonly planted in this region will become less hardy and could die due to increasing temperatures and reductions in summer precipitation. Selection of cover crop species will have to be modified.	This can be implemented immediately. It will need to be re-implemented (with appropriate modifications, if needed) during each fallow period. It has the potential to quickly affect sediment and nutrient loads.	Cover crops need to be selected for both drought and high-flow resistance. It might be possible to plant different cover crops depending on the forecast for the fallow period (wet versus dry). If only certain fields or portions of fields can be planted with cover crops, it might be best to do ones near rivers/streams and on steeper slopes (where flow is more likely to loosen sediment). Plant the cover crops as soon as is feasible after the previous crop has been harvested so that fields are uncovered for less time.	Annually plant cover crops that are drought- and flood-resistant as soon as possible after commercial crop has been harvested. Preferentially plant cover crops near streams/rivers/ channels, on steeper slopes, and on more erosion-prone soils.	Additional cover crop species that will be hardy to future climate conditions need to be researched/identified. Potential changes in the seasonal timing of planting of cover crops need to be analyzed, especially if new species are used.

Worksheet 1B Process

For this worksheet, you will need to assemble your reference materials (listed at right). See below for specific information on filling out columns:

Columns B1 and B2

To start, simply carry over your management actions addressed in Worksheet 1A (Columns A1 and A2) into Columns B1 and B2.

Columns B3 and B4

Columns B3 and B4 capture information on different ways in which climate change can alter the effectiveness of the management action.

Column B3 examines whether the action will remain effective given expected climate-mediated changes in the target stressor(s) (which were identified in Worksheet 1A). In the example provided in the worksheet above, the use of cover crops may be planned to retain excess sediment in storm runoff; however, increasing storm frequency and severity due to climate change may increase the amount of runoff and associated sediment loads, potentially overwhelming the capacity of the planned cover crop area.

Column B4 asks how climate change may directly impact the management action itself, potentially damaging or destroying its effectiveness or its ability to persist after placement. In this example, increased temperatures and decreased precipitation may negatively impact some crop species used as cover, decreasing their effectiveness to retain sediments (perhaps due to lesser biomass or root production), or even killing them. Both of these categories of information inform the redesign of management actions to accommodate such climate-induced impacts, as well as judgements as to whether certain actions can be redesigned or perhaps should not be carried forward.

Columns B5 and B6

Column B5 is used to examine various timing considerations related to using the action. These can include, but are not limited to: (1) the urgency of—versus the ability to defer—implementation based on the time frame over which the stressors and related climate change influences are expected to occur; (2) the time and sequencing requirements of project engineering, permitting, construction, and other logistical factors that contribute to determining when (e.g., how quickly) a project should be considered for implementation in order to be effective; and (3) issues related to timing of maintenance or replacement schedules given the effects of climate change on the action.

Column B6 then synthesizes the information from all previous worksheet columns. The result is a summary statement of what needs to be done to adapt the design of the action in terms of place, time and engineering design, based on what has been learned from the previous columns.

MATERIALS NEEDED:

- *Worksheet 1B*
- *Reference materials:*
 - *Worksheet 1A*
 - *Your management plan with any design specifications and timing for each action*
 - *Climate change projections and maps*
 - *Available maps of land-based stressors and/or land use change.*
 - *Available maps of reef areas, management areas, action implementation sites*

Column B7: The Main Tool Output

The ultimate output of the tool is Column B7 (Climate-Smart Management Actions), which consists of your 'existing' actions that have been put through the tool, plus any 'new' actions brainstormed in Activity 2 (see below) that will have been added to the list and also put through the same design process. It should be noted that it is the collective information from all columns across both worksheets 1A and 1B that progressively leads to understanding what needs to be done to make each action climate-smart. These improved descriptions of 'climate-smarter' versions of your management actions are meant to support a more rigorous evaluation and selection process for finalizing actions for your plan that will be as robust as possible in a changing climate.

Column B8

The notes column (B8) is intended to: document reasoning, capture supplementary information on research gaps and on potential interactions with other actions (e.g., sequencing, synergies), and other information that can be used in subsequent steps for evaluation, selection, and plan formulation, or revisit and revise previous steps in the adaptive management cycle. It can also capture potential unintended consequences of an action (e.g., proliferation of disease-carrying mosquitoes in constructed wetlands intended for nutrient and sediment retention after runoff). Finally, the notes column should document the level of uncertainty about the expected climate change impacts on the effectiveness of the action (B3). This information, combined with the Worksheet 1A assessment of the uncertainty about climate change effects on the stressor targeted by the action, is important to carry forward to the next planning step (Step 5 - Evaluation and Selection). Given that uncertainty can be difficult to quantify, a relatively simple approach, such as a categorical (high/low) judgement is recommended. More information on this potential approach can be found in Appendix 4 (Expanded Considerations, Resources, and Lessons Learned).

Supplementary Outputs

After completing worksheets 1 and 2 of the Design Tool, it is recommended that managers review information in the Notes columns of worksheets 1A and 1B, from which they can compile supplementary information on: (1) information gaps and research needs required to improve future iterations of planning (Supplementary Output 1; see Appendix 3); and (2) insights into the potential for important interactions among actions that will be relevant during evaluation and final selection of groupings of actions (Supplementary Output 2; see Appendix 3). These supplementary outputs support the iterative nature of the tool, where continued improvement of the climate-smart management actions is possible as new science becomes available.

Activity 2: Expand the List of Adaptation Options

Rationale

This activity is designed to help identify actions that could be added to a management plan. The purpose is to identify any key vulnerabilities that are not sufficiently addressed in your existing plan and to craft additional actions to fill those gaps. Or, if you do not have an existing plan and are building one for the first time, it is equally effective for brainstorming a starting list of actions from scratch. The CCAP

Compendium (Box 3; Appendix 1) informs this activity by providing general adaptation strategies, adaptation options, and climate-smart design considerations for coral reefs compiled from an intensive review of the literature (West et al., 2016). Activity 2 involves reviewing each ecologically-based, general adaptation strategy and considering actions appropriate for management of your particular reef. These are then run through Activity 1 in order to apply climate-smart design.

Box 3. CCAP Compendium of General Adaptation Strategies, Adaptation Options, and Climate-Smart Design Considerations

The CCAP Compendium (Appendix 1) provides examples of management adaptation options for coral reef ecosystems compiled from the literature. These are organized using a structure for brainstorming and “binning” adaptation options according to categories of ecologically-oriented general strategies familiar to managers, but specifically viewed through the climate change lens.¹ These include:

General Strategy	Definition
A. Reduce Non-Climate Stresses	Minimize localized human stressors that hinder the ability of species or ecosystems to withstand or adjust to climatic events
B. Ensure Connectivity	Protect habitats that facilitate movement of organisms (and gene flow) among resource patches
C. Support Evolutionary Potential	Protect a variety of species, populations and ecosystems in multiple places to bet-hedge against losses from climate disturbances, and where possible manage these systems to assist positive evolutionary change
D. Protect Key Ecosystem Features	Focus management on structural characteristics, organisms, or areas that represent important “underpinnings” or “keystones” of the current or future system of interest
E. Restore Structure & Function	Rebuild, modify or transform ecosystems that have been lost or compromised, in order to restore desired structures and functions
F. Protect Refugia	Protect areas less affected by climate change as sources of “seed” for recovery or as destinations for climate-sensitive migrants
G. Relocate Organisms	Engage in human-facilitated transplanting of organisms from one location to another in order to bypass a barrier (e.g., conflicting current)

Within each general strategy, the Compendium provides a variety of ideas for management adaptation options for coral reefs, along with examples of climate-smart design considerations. In conjunction with available vulnerability information, these can provide a starting point for identifying any gaps in your current plan and crafting specific place-based actions to add to your list.

Worksheet 2

Worksheet 2 provides a table for compiling your site-specific actions using the Compendium as a reference. The column headings for this activity are described below, with an example for each column provided; a more detailed description of the process for using the worksheet follows after. The full (blank) worksheet for the activity can be found in Appendix 2.

¹ The use of general strategy ‘bins’ is just one framework for brainstorming adaptation options presented in the Climate-Smart Guide (Stein et al. 2014); see the Guide for an overview of alternative frameworks that could also be used.

WORKSHEET 2: COLUMN DEFINITIONS. PRINT THIS PAGE FOR REFERENCE AS YOU WORK WITH WORKSHEET 2.

1	2	3	4	5
General Adaptation Strategy	Definition	Potential New Site-Specific Action	Key Vulnerabilities Addressed	Notes
General Adaptation Strategies.	Definition of general strategies, placed in the context of future as well as current conditions, including climate-related impacts (provided in Box 3).	Craft new, potential place-based actions (i.e. general options from the Compendium, made into actions specific to your location) to address gaps in your existing/planned activities. Transfer these actions to column 2 of Worksheet 1A as additions in order to run them through Activity 1; color code these actions to distinguish them as “new” actions being added to the original list of “existing” actions.	Describe what key vulnerabilities are being addressed by this action (that may not have been sufficiently addressed in your plan thus far). This documents the logic for why the action is needed/how it addresses the impacts of particular climate stressor-interactions as identified in the vulnerability information.	Make notes on any issues that might prompt you to go back to earlier planning steps (revise goals & objectives, further assess vulnerabilities); e.g., if a new action extends the management plan beyond the scope of the existing goals & objectives.

WORKSHEET 2: EXAMPLE.

1	2	3	4	5
General Adaptation Strategy	Definition	Potential New Site-Specific Action	Key Vulnerabilities Addressed	Notes
Protect key ecosystem features	Focus management on structural characteristics (e.g., geophysical stage), organisms, or areas (e.g., spawning sites) that represent important “underpinnings” or “keystones” of the current or future system of interest)	<ul style="list-style-type: none"> Expand or duplicate the herbivore replenishment areas in reefs in the 5 watersheds and adjacent source areas in Olowalu, North Kihei Protect some of the most durable reef areas (reefs that have survived multiple stressors) as being resilient to multiple stressors 	Coral bleaching impacted reefs in 2014 – 2015	Attention to adjacent source areas in addition to the managed reefs associated with the 5 watersheds may extend the area of managed reefs, may require review of goals & objectives.

Worksheet 2 Process

You will need to look at three resources (listed at right) to use Worksheet 2: (1) the results of Activity 1 (Worksheet 1B) if completed; (2) your vulnerability information (to identify gaps); and (3) the CCAP Compendium (for ideas to fill gaps).

This activity is a brainstorming exercise that is supported by the seven ecologically-oriented, general strategies from Box 3, listed sequentially in the first column of the worksheet, with their definitions (for reference) listed in Column 2. You then need to know which actions that already exist in your management plan address key vulnerabilities and stressor impacts identified in your vulnerability and resilience potential reference information. It is also helpful to know which existing actions fall into each strategy, again to identify strategies that may not be well represented. An optional matrix worksheet (Appendix 3) can aid in examining this.

The focus questions in Box 4 can be used to walk through the process for completing Worksheet 2.

MATERIALS NEEDED:

- *Worksheet 2*
- *Reference materials:*
 - *Worksheet 1B*
 - *Vulnerability & resilience potential information*
 - *CCAP Compendium (Appendix 1)*

Box 4. FOCUS QUESTIONS FOR WORKSHEET 2

1. From the perspective of your vulnerability assessment information, what vulnerabilities are adequately addressed by your climate-smart actions generated from Worksheet 1B?
 - a. What vulnerabilities are not addressed?
 - b. What actions might be needed to address vulnerability gaps?
2. From the perspective of the CCAP Compendium, to what extent are your existing or planned management actions adequately covering/representing the seven strategies?
 - a. What strategies/adaptation options from the Compendium might be beneficial additions to your overall approach to reef management?
 - b. Which strategies/adaptation options would address your vulnerability gaps?

Iteration: Apply Climate-Smart Design Considerations to New Actions from Activity 2

Any new actions added through Activity 2 can now be taken through the Activity 1 worksheets in order to develop the same set of climate stressor and time frame information needed in order to design them as climate-smart actions. The ultimate output is therefore the combined list of Climate-Smart Management Actions found in Column B7 of Worksheet 1A.

Conclusion

Completion of these worksheets will produce a potentially large list of climate-smart management actions. The goal is to be as comprehensive as possible in running actions through the climate-smart design process, in order to allow for many possibilities in response to climate change. Effective combinations of actions can then be considered for implementation through the next step of the Climate-Smart Conservation Cycle (Step 5 - Evaluation and Selection). Ideally, the listed options will have

sufficient detail for thorough evaluation using whatever selection method you desire. In addition, the compiled notes on data and information gaps and research needs captured in the Notes columns (Supplementary Output 1; Appendix 3) can inform the direction of future data collection, which can be targeted to refine actions, identify new actions, and improve comparisons of actions with each other.

Considering multiple combinations of management actions during evaluation and selection (Step 5) is important because some actions may need to be implemented in conjunction with others, or in sequence with others over different time frames. Information from the Notes columns is critical for identifying such interaction and timing concerns (Supplementary Output 2; Appendix 3).

As you learn more through application of the Design Tool, the iterative nature of the Climate-Smart Planning Cycle encourages you to go back to previous steps and refine or expand the outputs at each step. This can include going back to develop more information on vulnerability and resilience potential, or to refine or expand the goals and objectives to remain compatible with a potentially expanded geographic, jurisdictional, or budgetary frame of management. It also feeds into the next steps in the cycle. As actions are put through the Design Tool, information is developed that may not be specifically applicable to climate-smart redesign of the action, but which becomes important moving forward to the evaluation/selection and implementation steps (Steps 5 and 6). For more supporting information on the steps in this process, please see Expanded Considerations, Resources, and Lessons Learned in Appendix 4.

In the meantime, it is profitable to move forward with what you know. Too often, the complex issues and detailed information needed to integrate climate change considerations into natural resource planning and adaptation become barriers to the urgently needed movement toward climate change adaptation. While the iterative nature of the process means that applying this tool does not mean that you are 'done', one strength of this tool is that it allows you to make your actions climate-smart according to existing information. This puts you in a strong position with an improved, climate-smart management plan that contains clearly articulated actions that take into account the effects of climate change. At the same time, an added benefit is that the tool also provides a conceptual framework that supports (and encourages) you to return to make subsequent climate-smart design improvements (or additions) to your management actions as new information, new ideas, and innovative approaches come to light. It is a structure that lends itself to transparent documentation of reasoning, and the pursuit of continuous improvements through time. The Design Tool allows you to do what you can now, incorporate new information as it becomes available, and make better and better decisions into the future as our knowledge grows.

References

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- West, J.M., Courtney, C.A., Hamilton, A.T., Parker, B.A., Julius, S.H., Hoffman, J., Koltes, K.H. and MacGowan, P. 2016. Climate-smart design for ecosystem management: A test application for coral reefs. Environmental Management. DOI: 10.1007/s00267-016-0774-3

Appendix 1: CCAP Compendium

CCAP COMPENDIUM: GENERAL ADAPTATION STRATEGIES, ADAPTATION OPTIONS, AND CLIMATE-SMART DESIGN CONSIDERATIONS.

(Reprinted from “Climate-smart design for ecosystem management: A test application for coral reefs”, by West et al., 2016, Environmental Management, DOI: 10.1007/s00267-016-0774-3. Adapted with permission.)²

General Adaptation Strategies[1] and Adaptation Options ³	Climate-Smart Design Considerations
A. REDUCE NON-CLIMATE STRESSES <i>Minimize localized human stressors (e.g., pollution, fishing pressure) that hinder the ability of species or ecosystems to withstand or adjust to climatic events</i>	
i. Restrict future coastal development and shoreline modification, including hard coastal engineering and land reclamation [2, 3]	<ul style="list-style-type: none"> • <i>How will sea-level rise and changes in the intensity and frequency of large storms affect coastal hydrology and erosion?</i> • <i>Given this information, how can the design, location and timing of development be planned or modified in order to minimize negative impacts to adjacent reefs?</i>
ii. Remove existing structures that harden the shorelines to allow inland migration of sand and vegetation [2, 3]	<ul style="list-style-type: none"> • <i>How will sea-level rise and changes in the intensity and frequency of large storms affect coastal hydrology and erosion?</i> • <i>Given the above information, which structures should be the highest priority for removal in order to allow more natural migration of sand and vegetation?</i>
iii. Minimize land-based pollution due to excessive loadings of suspended sediments and nutrients from agriculture, deforestation, urbanization, and other land uses [2, 4-10]	<ul style="list-style-type: none"> • <i>How will climate change-related shifts in precipitation patterns, including storm frequency and intensity, and in hydrology affect the runoff of sediments and nutrients from different land use types to coastal waters?</i> • <i>How and in what locations could the protection or restoration of forests and/or wetlands, the management of agricultural areas and/or roads, or the installation of land-based pollution controls be focused to minimize runoff to coastal waters?</i> • <i>How will any such pollution control installations have to be designed (including size, structural characteristics) and located to both accommodate projected sediment or nutrient runoff loads and</i>

² The Compendium (reprinted from West et al., 2016) maintains the seven general adaptation strategies from West & Julius (2014) as a relevant and useful framework for identifying adaptation options for coral reef ecosystems. The example adaptation options and climate-smart design considerations in the Compendium are meant to be illustrative rather than comprehensive and to stimulate thinking of site-relevant possibilities. As new research and practices emerge, the range of examples will continue to grow and the Compendium will need to be reviewed and updated over time.

³ Numbers in brackets in the first column identify references from which specific adaptation options were obtained.

General Adaptation Strategies[1] and Adaptation Options ³	Climate-Smart Design Considerations
	<i>also withstand the direct physical climate change impacts of larger, more intense storms, greater erosion, etc.?</i>
iv. Minimize marine-based pollution from solid waste, sewage, plastics, nets, and releases of hazardous materials from oil and gas installations, cruise ships, and shipping, etc. [2, 3, 11]	<ul style="list-style-type: none"> • <i>How will changes in the intensity and frequency of large storms affect the frequency, severity and location of spills, groundings, and other pollution inputs from marine-based installations and activities?</i> • <i>How can safety requirements, installation and equipment design, timing and location of activities, etc., be adjusted to counteract these effects?</i>
v. Prevent direct habitat destruction from anchoring, ship groundings, and destructive fishing activities [6, 8, 12]	<ul style="list-style-type: none"> • <i>How will climate change effects, such as changes in currents and tidal patterns, or changes in water depths from sea-level rise, affect recreational and commercial boating and shipping patterns and fishing activities?</i> • <i>What are the cumulative impacts of climate change and destructive activities in marine managed areas?</i> • <i>Given this information, how should regulations or spatial and temporal restrictions be added or modified, and in what locations should enforcement be concentrated?</i>
vi. Prevent overfishing of coral reef-associated fish and invertebrate species, especially herbivores [5-7, 9, 13-18]	<ul style="list-style-type: none"> • <i>How will climate change effects on oceanographic conditions (e.g. increased sea surface temperature, changes in upwelling patterns from stratification of surface waters, changes in ocean circulation, and ocean acidification) directly affect the distribution, abundance, and recruitment patterns of fish and invertebrate populations, especially herbivorous species needed to manage algal overgrowth?</i> • <i>Will these or other impacts of climate change (e.g., increased runoff from more frequent/intense storms) also interact with other stressors (e.g., land-based pollutants) to further impact coral reef herbivores?</i> • <i>How would these climate change impacts interact with and/or exacerbate impacts from current levels of fishing effort and gear operation?</i> • <i>How can this information on the locations and extent of changes in fisheries production be factored into measures to reduce fishing effort and increase fish biomass on coral reefs?</i>
vii. Protect at least 20% (ideally 30%) of each habitat type within permanent no-take areas [8, 12, 19]	<ul style="list-style-type: none"> • <i>How will climate change affect the extent, distribution, quality, and/or accessibility of various habitat types?</i> • <i>How should this information affect the selection of habitats (location, size, shape) as long-term no-</i>

General Adaptation Strategies[1] and Adaptation Options ³	Climate-Smart Design Considerations
	<i>take areas?</i>
B. PROTECT KEY ECOSYSTEM FEATURES <i>Focus management on structural characteristics (e.g., geophysical stage), organisms, or areas (e.g., spawning sites) that represent important “underpinnings” or “keystones” of the current or future system of interest</i>	
i. Protect special or unique sites [8]	<ul style="list-style-type: none"> • <i>What is the vulnerability of special or unique sites to the direct effects of climate change?</i> • <i>Are there interactions between climate change and other stressors to special or unique sites that further affect their vulnerability?</i> • <i>Given this information, how do protections of these sites need to be adjusted in terms of prioritization among sites, stressors on which to focus, and design of management techniques?</i>
ii. Protect ecologically significant areas such as nursery grounds, spawning grounds, critical habitat for threatened and endangered species, and areas of high species diversity [11, 20]	<ul style="list-style-type: none"> • <i>How will climate change affect the location and viability of ecologically significant areas (e.g. low lying sandy islets for sea turtle nesting; mangrove areas as fisheries nursery grounds)?</i> • <i>How might practices and protections have to be adjusted or initiated to ensure the persistence of ecologically significant areas under climate change?</i>
iii. Manage functional species and groups necessary for maintaining the health of reefs and other ecosystems [7, 20-22]	<ul style="list-style-type: none"> • <i>What is the vulnerability of functional species and groups (e.g. herbivores, apex predators) to the interaction of climate change with other human and natural stressors, and in what locations are they most vulnerable?</i> • <i>What management options can be employed, and in which locations, to minimize impacts on the most vulnerable species and groups?</i>
iv. Include linked ecological units in managed areas to help maintain ecosystem functions and resilience [20, 23]	<ul style="list-style-type: none"> • <i>How will climate change affect supporting functions provided by coral reef-associated habitats (e.g., adjacent mangroves and seagrasses)?</i> • <i>What locations and which types of ecological units are most affected?</i> • <i>What are the implications of this information for selection of areas for protection and management?</i>
v. Use temporal restrictions such as seasonal, closures and temporary zoning to protect spawning aggregations and manage fishing effort to support faster recovery during times of severe stress, such as a bleaching event or after extreme events. [8, 11, 24]	<ul style="list-style-type: none"> • <i>How will climate-related events, such as El Niño, impact the seasonality and location of spawning aggregations?</i> • <i>How will timing of closures to protect spawning aggregations need to be adjusted to account for these effects, in order to support fisheries production and faster recovery after events?</i>
vi. Design managed areas with dynamic boundaries and buffers to protect breeding	<ul style="list-style-type: none"> • <i>How will migratory and pelagic species ranges change in response to climate change, and what is the variability spatially around those changes?</i>

General Adaptation Strategies[1] and Adaptation Options ³	Climate-Smart Design Considerations
and foraging habits of highly migratory and pelagic species and allow shifting of species ranges [8]	<ul style="list-style-type: none"> • <i>How will climate change affect the condition, extent, and location of breeding and foraging habitats for those species?</i> • <i>Given this information, what should be the extent, location and configuration of boundaries and buffers to provide sufficient protection of breeding and foraging habitat, and how do they need to be adjusted over time to account for shifts in species ranges?</i>
C. ENSURE CONNECTIVITY <i>Protect and restore habitats that facilitate movement of organisms (and gene flow) among resource patches</i>	
i. Identify and manage networks of resilient reefs connected by currents [8, 17, 22, 25]	<ul style="list-style-type: none"> • <i>Which areas have historically demonstrated resistance to/or recovery after exposure to climate change impacts?</i> • <i>Which areas are projected to have less exposure to climate change impacts (e.g. increased sea surface temperatures, decreased ocean pH) and could therefore serve as refugia?</i> • <i>How will climate change affect currents that provide connectivity between resilient areas?</i> • <i>Which areas have demonstrated resistance and/or recovery to climate change impacts?</i> • <i>What are the implications of this information for design of managed area networks to maximize connectivity and maintain it into the future?</i>
ii. Include a mixture of habitats and habitat edges (e.g., mangroves, seagrass) within systems of managed areas connected by currents [8, 9, 26]	<ul style="list-style-type: none"> • <i>How will climate change affect adjacent habitats that are critical for various life history stages of reef species?</i> • <i>Which areas are most likely to retain high heterogeneity (rugosity, microhabitats) that may contribute to increased resilience to climate change?</i> • <i>How will projected changes in currents affect connectivity among the areas important for larval dispersal? What are the implications of this information for design of managed area networks?</i>
iii. Apply minimum size and include a variety of shapes to systems of managed areas [8]	<ul style="list-style-type: none"> • <i>How will climate change affect currents that provide ecological connectivity among areas being considered for inclusion in a managed area system?</i> • <i>What are the implications of changes in current patterns for the optimal shape and size of the areas selected?</i>
iv. Consider managing areas upstream within the dominant current flow to improve downstream habitats and populations [8]	<ul style="list-style-type: none"> • <i>How will projected changes in surface circulation affect ecological connectivity?</i> • <i>What are the implications of this information for identification of areas of the marine environment that support source populations of key species?</i>

General Adaptation Strategies[1] and Adaptation Options ³	Climate-Smart Design Considerations
v. Separate no-take areas by 1 to 20 km apart (with a mode of ~1 to 10 km)[8]	<ul style="list-style-type: none"> • <i>How will projected changes in surface circulation affect ecological connectivity among no-take areas?</i> • <i>What are the implications of this information for determination of the maximum distance between no-take areas?</i>
vi. Identify ecological connections and apply that information to protect source populations in resistant areas that can provide recruitment and support recovery in other areas [6-9, 17, 20, 22, 27-30]	<ul style="list-style-type: none"> • <i>How will projected changes in surface circulation affect ecological connections among ecosystems?</i> • <i>What habitat characteristics, or exchanges among systems, contribute to resistance to climate change within the managed area and how might those change?</i> • <i>What implications does this information have for determining which source populations and areas that are resistant to climate impacts are priority for protection and management?</i>
D. RESTORE STRUCTURE AND FUNCTION <i>Rebuild, modify or transform ecosystems that have been lost or compromised, in order to restore desired structures (e.g., habitat complexity) and functions (e.g., nutrient cycling)</i>	
i. Enhance natural recovery processes following extreme events through active restoration [31, 32]	<ul style="list-style-type: none"> • <i>How will climate change affect the timing, frequency and intensity of extreme events such as prolonged, high sea surface temperatures and damage from storm events?</i> • <i>What species, habitats and locations will be most affected and least affected by extreme events, and what are the projected times of recovery for the most and least affected after the different types of events?</i> • <i>What are the implications of this information for targeting and designing restoration activities to maximize recovery following extreme events?</i>
ii. Re-establish source populations of corals with the highest sensitivity and lowest adaptive capacity in ecologically suitable areas with the lowest exposure to non-climate stressors and climate impacts [33-35]	<ul style="list-style-type: none"> • <i>How will the impacts of climate change vary for different species due to differences in sensitivity, exposure, and adaptive capacity?</i> • <i>What areas currently have suitable habitat that remain so in the future, or are currently on the margin of habitat suitability (e.g., due to temperature regime) that could become more suitable because of low exposure to non-climate stressors and climate impacts?</i> • <i>Given the above information, which populations are vulnerable and should be re-established, when, and in what locations to ensure their viability under climate change?</i>
iii. Restore herbivore populations of fish and invertebrates to increase coral resilience to bleaching and disease [11, 12, 15, 17, 21, 36-38]	<ul style="list-style-type: none"> • <i>How will climate change affect the growth and recruitment of important reef herbivores?</i> • <i>Which areas important to herbivores have demonstrated resistance and/or recovery to climate change impacts?</i>

General Adaptation Strategies[1] and Adaptation Options ³	Climate-Smart Design Considerations
38]	<ul style="list-style-type: none"> Given the different functional roles of reef herbivores and the different exposures reefs will face, what species or functional groups and locations should be the focus of management efforts?
iv. Prevent and manage biofouling and invasive species to preserve the integrity of marine communities in managed areas [11, 19, 39]	<ul style="list-style-type: none"> How will climate-related changes in ocean currents, nutrient runoff, marine debris, and other factors affect the transport and growth of non-indigenous species? What areas will be the biggest sources of non-indigenous species and what areas down-current are most important to protect? Given the information above, which areas should be targeted for protection from or removal of non-indigenous species?
v. Control outbreaks of coral predators such as Crown-of-Thorns Starfish and <i>Drupella</i> snails [11]	<ul style="list-style-type: none"> How will climate change affect populations of crown-of-thorns starfish and <i>Drupella</i> snails? What coral species and reefs will be most affected by outbreaks of these predators under climate change? Given the information above, which predators should be targeted for control and in what areas?
vi. Restore mangroves for multiple benefits including expansion of nursery habitat, improved water quality, release of tannins and other dissolved organic compounds that may reduce photo-oxidative stress in corals, and carbon sequestration (“blue carbon”) [20, 23, 39, 40]	<ul style="list-style-type: none"> How will climate change, in combination with land use change, affect the extent of mangrove habitat and environmental conditions needed for successful mangrove restoration? At what locations will conditions most favor successful mangrove restoration? What are the implications of this information for selection and prioritization of sites for mangrove restoration, including where land use policies could be put in place to allow landward migration of mangroves in response to sea-level rise?
vii. Develop artificial reef complexity using electrochemical or geochemical modification of seawater or other methods [37, 41]	<ul style="list-style-type: none"> How will the effects of ocean acidification on coral skeleton growth vary among species and locations? What are the implications of this information for placement and engineering design (size, configuration, strength of current) of electrochemical or geochemical modifications?
E. PROTECT REFUGIA <i>Protect areas less affected by climate change as sources of “seed” for recovery (in the present) or as destinations for climate-sensitive migrants (in the future)</i>	
i. Identify and protect current and future areas that appear to be resistant to climate change effects or that recover from climate-induced disturbances [6, 11, 14, 15, 20, 22, 42, 43]	<ul style="list-style-type: none"> What areas will be less exposed or sensitive to climate impacts, or will recover quickly from a disturbance once it occurs (examples include areas with structurally complex reefs in deeper water, reefs with high density of juvenile corals and/or herbivorous fishes, reefs where nutrient and/or sediment loads are low, areas with localized upwelling or other cool-water anomalies that protects corals from bleaching during large-scale temperature anomalies, areas with heat-resistant coral species, areas with cooler water runoff from land, areas where reef complexes are well flushed by oceanic water, areas with carbonate rich environments including raised limestone reefs and islands,

General Adaptation Strategies[1] and Adaptation Options ³	Climate-Smart Design Considerations
	<p><i>extensive reef flats, patch reef/coral head complexes, and reefs near carbonate sediment deposits)?</i></p> <ul style="list-style-type: none"> • <i>How will climate change affect the location of current and future refugia (e.g., changes in upwelling, circulation and residence time of water in reef ecosystems) that can be targeted for protection and use as destinations for future recruitment and/or relocation of coral reef species? Are there risk tradeoffs (e.g. areas with upwelling may see less heat stress, but can sometimes see cold-related die-offs)?</i>
<p>ii. Establish dynamic managed areas with flexible boundaries that can be defined by large-scale oceanographic features such as oceanic fronts where changes in types and abundances of organisms often occur [20]</p>	<ul style="list-style-type: none"> • <i>How will the dynamics of large-scale oceanographic features be affected spatially and temporally by climate change effects such as increasing sea surface temperatures, sea-level rise, and storm events, and what is the variability around those spatial and temporal alterations?</i> • <i>How will this information alter the way these moving managed areas should be defined or sited?</i> • <i>Given this information, what type and degree of flexibility in management strategies will be necessary (spatially and temporally) in order to effectively manage areas as oceanic features shift?</i>
<p>iii. Protect habitats similar to those that thrived during the middle Holocene, when coral reefs flourished closer to the poles, to allow for range migration [39, 44]</p>	<ul style="list-style-type: none"> • <i>What are the characteristics of the types of habitats that existed during the middle Holocene, and where are habitats with those characteristics projected to be in the future under climate change?</i> • <i>Given this information, what habitat types should be protected, and in which areas, as sites for range migrations in the future?</i>
<p>iv. Use artificial shading or water mixing when corals are exposed to thermal stress, to protect coral sites of specific importance from bleaching [39]</p>	<ul style="list-style-type: none"> • <i>How is climate change expected to affect the location, magnitude and duration of temperature anomaly events with respect to coral sites of specific importance?</i> • <i>How can this information be used to select which reefs of specific importance might become particularly vulnerable to thermal stress in the future, and to determine when artificial shading or water mixing should be use, and what amount of light reduction or mixing will be needed to sufficiently counteract the interaction of temperature and UVR that induces bleaching?</i>
<p>v. Designate large managed areas in ways that increase the likelihood that they will contain some areas of natural refugia that escape temperature anomalies [8, 45]</p>	<ul style="list-style-type: none"> • <i>What are the locations and scales of areas with less exposure to climate impacts now or in the future, (e.g., currents or other features that protect areas from temperature anomalies or if a refuge shifts spatially, a large managed area could contain all anticipated locations such as poleward of the typical range)?</i> • <i>Given this information, what large/complex coral reefs should be protected and how large should managed areas be, and at what locations, to maximize the likelihood that they will contain some areas of natural refugia?</i>
<p>vi. Identify and protect seagrass beds to provide a short-term local pH buffering effect for adjacent coral reefs [1]</p>	<ul style="list-style-type: none"> • <i>How will climate change impact seagrass beds adjacent to coral reefs?</i> • <i>What are the locations and scales of seagrass habitat that can provide buffering capacity to adjacent reefs and calcifying organisms?</i>
<p>F. RELOCATE ORGANISMS <i>Engage in human-facilitated transplanting of organisms from nurseries or from one location to another in order to by-pass a barrier (e.g. environmental, genetic)</i></p>	

General Adaptation Strategies[1] and Adaptation Options ³	Climate-Smart Design Considerations
i. Relocate corals to overcome environmental barriers or negative chemical cues to recruitment [46-55]	<ul style="list-style-type: none"> • <i>How will climate change contribute to environmental conditions (negative chemical cues from degraded reefs, disruption of connecting currents) that restrict recruitment from source reefs?</i> • <i>What are the implications of this information for selection of source and sink reefs for transplantation of coral fragments?</i>
ii. Establish coral nurseries and fish hatcheries for out-planting and restocking of species whose recruitment is negatively affected by climate change [33, 34, 41]	<ul style="list-style-type: none"> • <i>How will climate change contribute to environmental conditions (negative chemical cues from degraded reefs, disruption of connecting currents) that restrict recruitment from source reefs?</i> • <i>For which corals and fish will this pose the greatest problem by impeding recruitment to historically-connected sites?</i> • <i>Which of these organisms can be grown/hatched in nurseries for use in “assisted migration” to impeded sites?</i>
G. SUPPORT EVOLUTIONARY POTENTIAL <i>Protect a variety of species, populations and ecosystems in multiple places to bet-hedge against losses from climate disturbances, and where possible manage these systems to assist positive evolutionary change</i>	
i. Protect species and populations with genetic, physiological, or ecological traits characteristic of low sensitivity and high adaptive capacity to climate impacts [22, 35, 56, 57]	<ul style="list-style-type: none"> • <i>How is climate change expected to affect the frequency, duration and magnitude of temperature anomaly events and other climate-related stressors?</i> • <i>Which species, assemblages or communities are likely to be most resistant to the negative effects of climate stressors and/or have greater recovery capacities after events?</i> • <i>Are the same species, assemblages, or communities resistant or resilient to different stressors (e.g. to both heat and acidification)?</i> • <i>What are the implications of this information for selection of sites for special protection?</i>
ii. Create “designer” reefs using human-assisted evolution with species that have beneficial genetic variants for and/or are acclimatized to higher sea surface temperatures and ocean acidification [49-55, 58, 59]	<ul style="list-style-type: none"> • <i>Which symbionts are most stress-tolerant?</i> • <i>Which coral species have the greatest genetic resistance and/or greatest ability to acclimatize to climate impacts?</i> • <i>How can this information be used to create and/or select species for special protections or for use in restoration of degraded reefs?</i>
iii. Protect species, population and genetic diversity within and across habitats [8]	<ul style="list-style-type: none"> • <i>What are the factors that influence species, population and genetic diversity within different habitats, and how will climate change affect those factors?</i> • <i>Based on this information, how can protections within different habitats be designed to maximize characteristics that promote the greatest possible diversity? What about selection of different managed areas within the broader landscape?</i>
iv. Replicate habitat types in multiple managed areas to spread risks associated with climate	<ul style="list-style-type: none"> • <i>How will climate change affect the spatial scale and pattern of temperature anomaly events (and conversely, temperature refugia) and other extreme events? What about acidification or other</i>

General Adaptation Strategies[1] and Adaptation Options ³	Climate-Smart Design Considerations
change [9, 20]	<p><i>stressors?</i></p> <ul style="list-style-type: none"> • <i>How can this information be used to select a suite of managed areas that best spread risks across space and time? That maintain genetic, population, and species diversity?</i>
v. Ensure that the full breadth of habitat types is managed (e.g., fringing reef, fore reef, back reef, patch reef) [20]	<ul style="list-style-type: none"> • <i>How do different habitat types vary in their vulnerability to climate change across space and time?</i> • <i>Do areas with low vulnerability for one habitat type tend to have low vulnerability for other habitat types, or is there no relationship?</i> • <i>What are the implications of this information for how the spatial pattern of protection may have to be adjusted to ensure that the full breadth of habitats is protected?</i>
vi. Maximize habitat heterogeneity within managed areas and consider protecting large areas to preserve biodiversity, connectivity, ecological functions and evolutionary potential [20]	<ul style="list-style-type: none"> • <i>How will climate change affect the spatial scale and pattern of temperature anomaly events (and conversely, temperature refugia) and other extreme events)? What about acidification or other stressors?</i> • <i>What are the scales and locations of areas with high habitat heterogeneity and biodiversity, and which of these areas are expected to be the least sensitive or exposed to climate change, or have high adaptive capacity?</i> • <i>What are the implications of this information for the design and size of managed areas to maintain habitat heterogeneity, connectivity and ecological functions into the future?</i> • <i>Are there tradeoffs between selecting for areas where past exposure to climate stress has led to lower sensitivity to future climate stress and areas with lower past exposure to climate stress but potentially higher sensitivity?</i>

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Appendix 2: Activity Worksheets (1A, 1B, 2)

WORKSHEET 1A: EXAMINE CATEGORY 1 CLIMATE-SMART DESIGN CONSIDERATIONS: *CLIMATE CHANGE EFFECTS ON TARGET STRESSORS.*

A1	A2	A3	A4	A5	A6	A7
Action number	Existing management action	Target stressor(s)	Climate change effects on stressor(s): (direction, magnitude, mechanism, uncertainty)	Timing of climate change effects	Implications for effectiveness metrics and how to measure them	Notes

WORKSHEET 1B: EXAMINE CATEGORY 2 CLIMATE-SMART DESIGN CONSIDERATIONS: *IMPACTS OF CLIMATE CHANGE ON MANAGEMENT ACTIONS.*

B1	B2	B3	B4	B5	B6	B7	B8
Action number	Existing management action	Changes in effectiveness of management action due to: climate impacts on target stressor	Changes in effectiveness of management action due to: climate impacts on management action	Time frame or constraint for using the action and implementation (e.g., urgency, longer or shorter term)	What changes are needed to adapt the action (place, time, and engineering design)	Climate-Smart Management Action	Notes

WORKSHEET 2: EXPAND THE LIST OF ADAPTATION OPTIONS.

1	2	3	4	5
General Adaptation Strategy	Definition	Potential New Site-Specific Action	Key Vulnerabilities Addressed	Notes
A. Reduce non-climate stresses	<i>Minimize localized human stressors (e.g., pollution, fishing pressure, coastal development) that hinder the ability of species or ecosystems to withstand or adjust to climatic events</i>			
B. Ensure connectivity	<i>Protect habitats that facilitate movement of organisms (and gene flow) among resource patches</i>			
C. Support evolutionary potential	<i>Protect a variety of species, populations and ecosystems in multiple places to bet-hedge against losses from climate disturbances, and where possible manage these systems to assist positive evolutionary change</i>			
D. Protect key ecosystem features	<i>Focus management on structural characteristics (e.g., geophysical stage), organisms, or areas (e.g., spawning sites) that represent important “underpinnings” or “keystones” of the current or future system of interest)</i>			
E. Restore structure and function	<i>Rebuild, modify or transform ecosystems that have been lost or compromised, in order to restore desired structures (e.g., habitat complexity) and functions (e.g., nutrient cycling)</i>			
F. Protect refugia	<i>Protect areas less affected by climate change (i.e., currently-protective habitats or future protective habitats) as sources of “seed” for recovery or as destinations for climate-sensitive migrants</i>			
G. Relocate organisms	<i>Engage in human-facilitated transplanting of organisms from one location to another in order to bypass a barrier (e.g., conflicting current)</i>			
H. Other				

Appendix 3: Optional Worksheets (SO1, SO2, Matrix)

Supplementary Output 1: Aggregating Information on Key Data and Information Gaps and Research Needs

Rationale

Documentation of data gaps and research needs will help inform subsequent management plan revisions to improve vulnerability/resilience potential information and design activities. The categories used in the worksheet (below) represent a range of topics specifically relevant to the technical inputs needed to address the climate-smart design questions laid out in Worksheets 1A and 1B. They are intended to help organize the information captured in the notes sections of Worksheets 1A and 1B in a way that facilitates assessment of the scope of missing information and its importance to ongoing climate-smart adaptation decisions.

SUPPLEMENTARY OUTPUT 1: COLUMN DEFINITIONS.

1 Action number	2 Existing Management Action (Original)	3 Understanding of watershed processes (historical and current)	4 Understanding patterns of climate change drivers	5 Understanding climate change effects on stressors of concern	6 Understanding stressor effects on biota	7 Understanding climate change effects on effectiveness of management action
Transfer action numbers from Column 1 of Activity 1.	Transfer the original management actions from Column 2 of Worksheet 1B.	As many stressors come from adjacent watersheds, data and research on processes and rates that drive stressor dynamics are often needed to understand their interactions with climate change, and should be captured here.	Needs for climate change effects at spatial or time scales more relevant for effective evaluation of adaptation; or for climate change parameters that are more specifically related to types of watershed or coral reef processes being managed; should be captured here.	Capture here any data, information, or research needed to understand or document the processes that determine the interactions between climate change and the watershed or <i>in situ</i> stressors that impact managed coral reefs.	Information on coral species, associated reef species, watershed and/or adjacent ecosystem biota, needed to understand processes or responses to climate change, stressors, and their interactions should be captured here.	Information specific to the methods, processes, design, scale, or other aspects of management action methods/approaches that determine their effectiveness should be captured here.

SUPPLEMENTARY OUTPUT 1: EXAMPLE. (Drawn from consultation exercise with experts in Guanica Bay, Puerto Rico.)

1	2	1	2	3	4	5
Action number	Existing Management Action (Original)	Understanding of watershed processes (historical and current)	Understanding patterns of climate change drivers	Understanding climate change effects on stressors of concern	Understanding stressor effects on biota	Understanding climate change effects on effectiveness of management action
9	Switch from sun-grown to shade-grown coffee	Need to understand about defoliation and triggers (need to study guava, Guama, capa, mocha, etc.) to determine possible impacts of coffee shade trees on coffee plants How drought-tolerant are the shade grown coffee plants?	Is there information on the projected increase in wind speeds in general? Will there be changes in circulation patterns that would impact sediment delivery to Puerto Rico's coral reefs?	Need to do a geospatial analysis of the flooding in Lajas Valley to document aerial extent	Need to better understand the sensitivity of reef species to various stressors. Conduct a gap analysis to identify where improvements might be made to the Guánica Dry Forest and the upper watershed forests, as well as connections between the forests (upper and lower).	How wide do buffers need to be in the Caribbean sub-tropics? How much larger a buffer is needed to accommodate the larger rain events and flooding?

Supplementary Output 1 Process

In Activity 1, it is common to start recognizing various information gaps and research needs throughout the climate-smart design process, and you have been encouraged to document these ideas in the Notes columns of previous worksheets. Supplementary Output 1 helps you capture and re-organize this information from the Notes columns of Worksheets 1A and 1B into logical categories that are relevant to the range of climate-smart questions that must be addressed in order to redesign adaptation actions in the face of anticipated climate change effects. This information can be carried forward to inform research efforts in terms of priority information that needs to be further developed to be useful for climate-smart management. The Supplementary Output 1 Worksheet (above) is structured to support this thought process.

MATERIALS NEEDED:

- *Supplementary Output 1 Worksheet*
- *Worksheets 1A & 1B*
- *Reference materials:*
 - *Vulnerability & resilience potential information*

Supplementary Output 2: Analyze Sequencing and Interactions Among Actions

Rationale

Documentation of interactions helps with recognizing natural groupings of actions that work best together. It also aids in identifying actions that could conflict with (or negate) each other, or could be redundant but perhaps represent alternatives. We recognize that in many contexts, redundancy can be considered beneficial, e.g., when providing backup in case of failure of one component of a system. In resource management, this is often called ‘replication’ and is used to distribute desired effects over a broader area or to achieve a larger net capacity of action. However, in the context of this activity, we are specifically defining redundancy to refer to alternative approaches where one action renders the other superfluous with no added benefit.

Box 5 details four major types of interactions as defined for the purposes of this activity. Chronological sequencing can be another form of relationship among actions; sometimes an action may require a particular temporal relationship (e.g., a particular order of implementation) with other actions in order to be effective. Sequencing also captures the idea of planning when an action will be needed in light of the timing of climate change effects on the target stressor. Finally, information on timing needs and constraints for implementation (e.g., time frames needed for engineering and design, permitting, and other implementation activities) can also inform when implementation of an action should be initiated in the sequence of a management plan.

BOX 5. TYPES OF INTERACTIONS AND SEQUENCING AMONG ACTIONS

There can be many interpretations of and ways to describe interactions among management actions. For the purpose of the Design Tool, we use the following terminology:

Interdependency: Includes actions that must be implemented together in order to be effective; this can be because multiple separate actions to reduce a stressor are needed to produce a sufficient cumulative result, or because one action has a functional dependency on another.

Redundancy: Includes actions that accomplish the same purpose, so that only one or the other needs to be implemented; these could be considered alternatives, where doing one would render the other ‘superfluous’.

Conflict: Includes actions that would interfere with each other, or generate negative synergies or ‘trade-offs’ such that together the net gains would be less than the sum of the gains from either action alone.

Positive (+) Synergy: Includes actions that together produce more gains than the sum of either action working alone, i.e. producing greater-than-cumulative net benefits.

Sequencing: Includes timing considerations among actions, such as one action being a prerequisite to another, or the need to begin two actions concurrently due to short- and long-term effectiveness.

SUPPLEMENTARY OUTPUT 2: COLUMN DEFINITIONS.

1	2	3	4	5	6
Action number	Existing Management Action (Original)	Climate-Smart Management Action	Interactions (interdependency, redundancy conflict, + synergy*	Sequencing (overlap requirements, prerequisites, temporal implementation)	Notes
Transfer action numbers from Column 1 of Activity 1.	Transfer the original management actions from Column 2 of Worksheet 1B	Transfer the climate-smart management actions from Column 8 of Worksheet 1B.	Interdependency: Redundancy: Conflict: + Synergy:	Detail any sequencing considerations such as lead-time and/or overlap requirements and other prerequisites for the action.	Capture any other action- or site-specific information that will be important for further adaptation of the action, and for moving toward evaluation and implementation.

* Identify potential interactions of this action with other actions listed in the table. Include a brief description of the nature of the relationship: interdependency, redundancy, conflict, + synergy. Conflicts should be flagged, but actions are not eliminated at this stage.

SUPPLEMENTARY OUTPUT 2: EXAMPLE. (Drawn from consultation exercise with experts in Guanica Bay, Puerto Rico.)

1	2	3	4	5	6
Action number	Existing Management Action (Original)	Climate-Smart Management Action	Interactions (interdependency, redundancy conflict, + synergy)	Sequencing (overlap requirements, prerequisites, temporal implementation)	Notes
9	Switch from sun-grown to shade-grown coffee	Plant shade-tolerant coffee with heat-tolerant shade plants. Plant understory/secondary canopy plants that will effectively use or provide nutrients (e.g., n-fixation) and stabilize soil during more intense storms.	<p>Interdependency: with farm inventory</p> <p>Redundancy: cover crops in coffee farms</p> <p>Conflict:</p> <p>+ Synergy: with treatments and standards for dirt roads</p>	Continue to implement, but need to conduct a farm inventory to assist in prioritization of future conversions; continue to develop treatments and standards for dirt roads on coffee farms (concurrent action)	Conduct a farm inventory for the upper watershed to determine additional farms for conversion to shade grown coffee and also identify farms with active erosion issues; include crops grown, BMPs, fertilizer/pesticide/herbicide application rates and production

Supplementary Output 2 Process

As noted in Activity 1, it is common to start recognizing various dependencies, trade-offs, and spatial and temporal relationships between actions throughout the climate-smart design process; you have been encouraged to document these ideas in the timing and notes columns of previous worksheets. Supplementary Output 2 helps you capture this information and explore these relationships more fully, to begin identifying groupings of actions that should be considered together as you move into your evaluation and selection process. The Supplementary Output 2 Worksheet above is structured to support this thought process.

Visualizing groupings

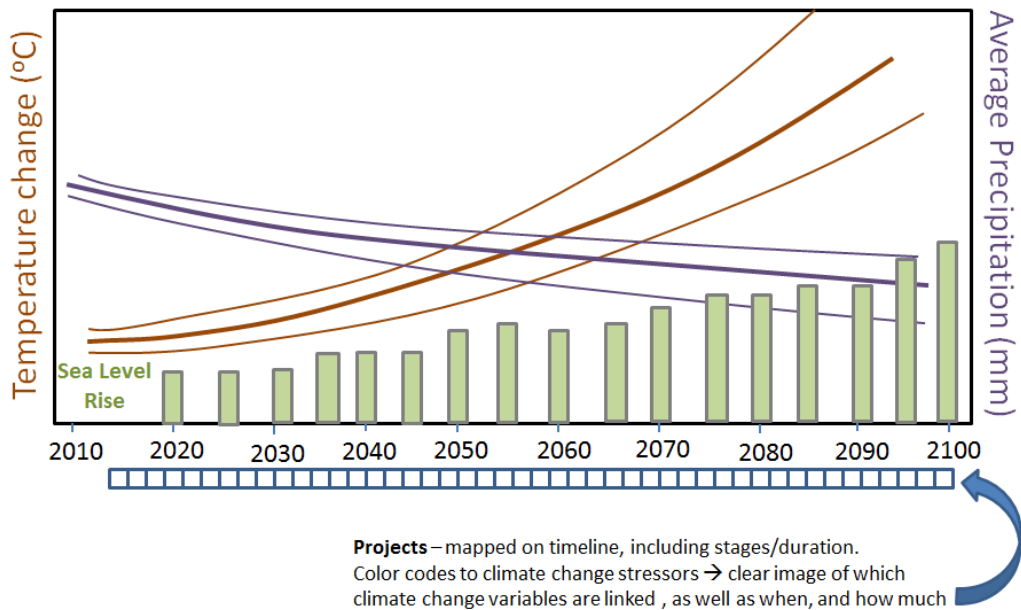
The outputs of Supplementary Output 2 are climate-smart actions coupled with information on key relationships among actions. This forms the basis for moving into your evaluation and selection process (Step 5 of the Climate-Smart Cycle; Figure 3), in order to decide on any updates to your plan (or craft your new plan). In preparation for this step, it can be useful to begin visualizing these groupings in ways that will help with evaluation. This could be as simple as re-ordering your spreadsheet to group actions together, using color coding in the spreadsheet, adding a column on spatial location, etc. Or, you could use index cards to physically lay out groupings, with the help of maps to think about spatial design. Or, you could use an integrative conceptual model such as that shown in Box 6 below, which aims to visualize multi-action sequencing based on timing of climate impacts.

MATERIALS NEEDED:

- *Supplementary Output 2 Worksheet*
- *Worksheets 1A & 1B*
- *Reference materials:*
 - *Your management plan with specific design specifications and timing for each action*
 - *Climate projections and maps*
 - *Maps of reef areas, management areas, action implementation sites*

BOX 6. VISUAL AIDS FOR SEQUENCING CLIMATE-SMART ACTIONS

The CCAP Adaptation Design Tool is intended to promote planning that recognizes and achieves alignment between the timing of the various risks being addressed, including climate change and its interactions with conventional stressors, and the timing of the needed responses. One temporal planning concept is illustrated in the figure below⁴. This could be implemented by mapping the projected patterns of pertinent climate change stressors over time (temperature, precipitation, and sea-level rise are shown as examples). Actions would then be laid out on the same timeline according to when they would need to be functional in order to effectively address their target stressors. Implementing such timeline planning would require working backwards as well as forwards. That is, for most types of actions, planning would have to start with defining the future time when the project would be needed (the endpoint), and working backwards to plan when implementation of enabling steps would have to be initiated. This gives a temporal sequencing of actions that highlights the near/intermediate (3- to 5-year) term as well as the long (50- to 100-year) term.



⁴ Adapted from original drawn by Tova Callendar, July 2014.

Optional Matrix Worksheet and Process

The optional matrix worksheet below is intended to help with brainstorming potential additional management actions by identifying where gaps may exist in the array of strategies/actions included in an existing management plan. It is important to note that the seven strategy “bins” are merely a framework for exploring ideas and are not meant to be exhaustive or mutually exclusive; that is, individual actions may fulfill more than one strategy, and there may be the potential to add more strategies in the future. The intent is to examine options for addressing vulnerabilities from multiple angles, based on gaps that are exposed by showing which actions fill each strategy in a matrix.

OPTIONAL WORKSHEET: MATRIX OF POSSIBLE MANAGEMENT ACTIONS BY CLIMATE-SMART GENERAL ADAPTATION STRATEGY

Management Action	Reduce Non-Climatic Stressors	Ensure Connectivity	Support Evolutionary Potential	Protect Key Ecosystem Features	Restore Structure and Function	Protect Refugia	Relocate Organisms
Protect mangroves		X			X	X	
Protect sea grass beds				X	X		
Establish coral nurseries			X		X		

Appendix 4: Expanded Considerations, Resources, and Lessons Learned

Now that you are familiar with the tool and this guide, it is time to expand the ‘how to’ with some of the considerations, resources and lessons-learned that give context to the Design Tool process. This includes: 1) documenting information to ensure transparency; 2) how the tool lends itself to the iterative nature of adaptation planning; 3) information resources for vulnerability and resilience assessments; 4) suggestions for how to consider uncertainties in the design process; and 5) concluding thoughts on moving forward into evaluation and selection of a final list of actions for your plan.

Documenting a Transparent Process

The Design Tool enables transparency in decision making. It does so by providing a consistent structure for recording the decision making process and the supporting information on which it is based. Transparency is important, not only to help others understand and be able to replicate the structured thought process for themselves, but also to clarify, legitimize, and help build trust and support for moving forward with the resulting decisions. Along with the information recorded in the worksheets, consider documenting: names and affiliations of participants in any workshops or calls; dates that worksheets are filled out and/or edited; reference and resource materials used to fill out the worksheets; and notes explaining any decisions to use certain resources and not others. This is important given the iterative nature of the planning process and the common reality of staff turnover through time—with a clear record of where, when and how the tool was last used to generate “current” decisions, any staff can quickly review/orient themselves and identify any new information that has since become available and could be used to update those results. In this way, the Design Tool can serve as a “living” repository of information that is continuously improved through time in support of iterative planning. This topic is discussed in more detail below.

Iterative Application of the Design Tool and Cycle

As new information emerges over time and with ongoing management, monitoring, and adaptation results, adaptation actions and portfolios may need to be re-evaluated to develop and retain a climate-smart management plan. For example, after implementation of adaptation actions (Step 6 in the Climate-Smart Planning Cycle), monitoring is used to track and evaluate action performance (Step 7), supporting the ability to use adaptive management and ongoing revision of adaptation approaches.

In addition, as shown in the Figure 2 flow chart, Climate-Smart Conservation Cycle Steps 1 and 2 (Assess climate vulnerabilities/resilience potential and Revise goals) provide the key inputs used to apply the tool. Most users of this tool will be starting with an existing plan, for which goals and objectives have been defined, with varying degrees of consideration of climate change. It is essential to continuously work toward clearly stated goals and objectives that are realistic in light of how climate change is expected to influence the coral reef system and the management actions under consideration. As the Design Tool assessment of climate influences on site-specific stressors and management actions proceeds, there may emerge a need to return to Step 3 (Figure 1) to revise some goals and objectives. Sometimes this occurs after first returning to the vulnerability assessment step (Step 2) to acquire more information. The need to expand vulnerability and resilience information may often come to light as a result of data gaps identified during exploration of Climate-Smart Design Considerations with the tool (captured in Supplemental Output 1, Appendix 6). In each case, refining information from earlier steps

would support additional iterations with the tool, for continued improvements in design of climate-smart actions.

Finally, the iterative nature of the Design Tool also lends itself to inclusion of other drivers of global change besides climate change, such as population growth and development trajectories that are often presented in vulnerability assessments. While climate-smart strategies and design principles focus on climate, these other global changes often have important interactions and feedbacks with climate change effects, as well as critical influences on the adaptation methods and locations that are feasible and effective. The Design Tool refocuses resource management planning to incorporate consideration of future conditions, thereby encouraging a process into which these other important global changes can also be integrated.

Vulnerability and Resilience Information

It is essential to gather vulnerability and resilience potential information in advance of using the Design tool, in order to use it effectively. Where possible, involving workshop participants in the information-gathering process can build relationships and strengthen the knowledge base in preparation for collective use of the Design Tool. While methods for conducting vulnerability and resilience assessments are outside the scope of this guide, there are numerous sources of guidelines for how to assess climate change vulnerability and resilience, and many options for how to display vulnerability information. For example, the U.S. Coral Triangle Initiative Support Program (2013) provides information on how to conduct vulnerability assessments and present the results (see <http://www.coraltriangleinitiative.org/library/fact-sheet-local-early-action-planning-leap-climate-change-adaptation-natural-resources>). Another useful example of the display of vulnerability information can be found in the Mid-Atlantic Integrated Assessment report (U.S. Environmental Protection Agency (EPA) 2001), where color-coded arrows of different sizes were used to illustrate the relative magnitudes of positive and negative climate change (and other stressor) impacts. Additional resources regarding the assessment and display of vulnerability and resilience information can be found at the National Climate Assessment website (<http://nca2014.globalchange.gov/>).

Whatever display format is chosen, a key concept for its use with the Design Tool and the climate-smart process in general is that vulnerability outputs must inform the worksheets. To meaningfully support redesign (adaptation) of individual management actions, the information must be specific enough to support interpretation of likely climate change influences on stressors of concern at management-relevant spatial and temporal scales, and include summaries of direction, magnitude, and timing of anticipated changes. We recognize that the most readily available climate change information is often summarized at broader (regional) spatial scales, and for longer (e.g., end of century) time frames, potentially making it a challenge to find and summarize finer scales of climate change information relevant to the range of anthropogenic stressors and resource processes that must be considered. Filling such information needs can become time consuming or expensive, which in some cases may not be practical. We encourage users to not get bogged down by lack of complete information; whatever climate vulnerability or resilience information is available can be tailored to support application of the tool at a rough or coarse level and will still produce useful insights. Such insights will include not only a first-cut idea of the potential for actions to be effectively adapted for the climate context, but also clear

indicators of where additional efforts are most needed to generate more refined climate vulnerability information.

Information from reef resilience assessment has been mentioned in conjunction with climate vulnerability information. In the context of applying climate-smart principles, the utilization of resilience potential is not a requirement, but is useful if available. Information on relative resilience among locations within a managed area can be especially useful for spatial planning, or for prioritization of some types of actions (e.g., for help in identifying where to implement particular actions, such as placement of mooring buoys, or more enforcement, etc.). Whether resilience potential would be helpful in a particular management context could be addressed by asking the question “Do I need a resilience assessment to site or prioritize actions?” Information on how to assess the relative resilience of coral reefs can be found on the TNC Reef Resilience Toolkit website (<http://blog.nature.org/science/2013/12/12/reef-resilience-toolkit/>).

Uncertainty

As mentioned above in the instructions for using Worksheets 1A and 1B, it is important to include consideration of the uncertainty associated with assessments of climate change effects on target stressors (for Worksheet 1A) and of climate change effects on the effectiveness of the action itself (for Worksheet 1B). Rigorous estimates of uncertainty can often be difficult and/or expensive to obtain, and may be beyond the scope of a typical management plan revision. One approach to consider is to develop qualitative categorical estimates of each type of uncertainty. This could be accomplished using two (low/high) or three (low/medium/high) uncertainty categories. If only two categories (low and high) are used, the result is a matrix (shown below) with 4 possible outcomes - ‘HH’ (high uncertainty associated with both types of estimates), ‘LL’ (low uncertainty associated with both types), and ‘HL’ or ‘LH’ (high uncertainty associated with one estimate but low uncertainty associated with the other). Results of this assessment of relative uncertainties can be compared among actions, as an important component along with other evaluation/selection criteria.

Uncertainty of Strategy / Action Effectiveness	High	Low uncertainty stressor + High uncertainty of strategy/action	High uncertainty of stressor + High uncertainty of strategy/action
	Low	Low uncertainty of stressor + Low uncertainty of strategy/action	High uncertainty of stressor + Low uncertainty of strategy/action
		Low	High
Uncertainty of Stressor/Climate Projection			

Moving into Evaluation and Selection

As you work through the Design Tool, many factors may emerge that relate to criteria typically used in the Evaluation and Selection phase of the planning cycle (Step 5; Figure 1). These can include factors such as feasibility, cost, effectiveness, flexibility, urgency, social barriers, or the political will for

implementing various actions (Figure 4). Using the Supplementary Outputs to capture this information will be a valuable aid in moving forward to this next step.



FIGURE 4. EVALUATION AND SELECTION CRITERIA THAT REFLECT CLIMATE-SMART CHARACTERISTICS.

References

- U.S. Coral Triangle Initiative Support Program. 2013. "Climate Change Adaptation for Coral Triangle Communities: Guide for Vulnerability Assessment and Local Early Action Planning (LEAP Guide)." *Prepared with support from the United States Agency for International Development.*
- U.S. Environmental Protection Agency (EPA). 2001. How Will Climate Change Affect the Mid-Atlantic Region? Philadelphia, PA: EPA/903/F-00/002. Region 3.

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