A Structured Approach for Kelp Restoration and Management Decisions

IN CALIFORNIA

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UC SANTA BARBARA
Marine Science Institute

AUTHORS

Mary Gleason
The Nature Conservancy

Jennifer E. Caselle
University of California, Santa Barbara

Walter N. Heady
The Nature Conservancy

Vienna R. Saccomanno
The Nature Conservancy

Julie Zimmerman
The Nature Conservancy

Tristin Anoush McHugh
The Nature Conservancy

Norah Eddy
The Nature Conservancy

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CONTENTS

LIST OF TABLES

LIST OF FIGURES

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EXECUTIVE SUMMARY

Global kelp forests are biodiverse and productive nearshore ecosystems that provide a wide range of ecosystem services. Kelp forests are also at risk from both local stressors and global drivers of kelp loss. Since kelp are ecosystem engineers, the loss of canopy-forming kelp species can have significant impacts on biodiversity and associated values and services of kelp forest ecosystems. For example, in Northern California, the loss of bull kelp forests has been rapid and extensive, causing devasting ecological and economic consequences including the closure of the recreational red abalone fishery. Some drivers of kelp loss and stressors on kelp are manageable (e.g., pollution and overfishing of predators of grazers) while others are not (e.g., warming events and disease epidemics). Climate change, gradual warming of seawater and increases in the frequency of extreme warm-water events are expected to alter both the distribution and abundance of kelp forests. Appropriate responses to kelp declines are hindered by the lack of historical information on natural variation in kelp abundance over time, as well as large spatial variation in the magnitude of responses of kelp to stressors (i.e., is an observed decline of kelp within historical levels of variation at that location, or does it represent a fundamental shift to an undesirable state?). Challenges also include a limited toolbox for kelp restoration, few policy and management levers that are geared toward kelp restoration, and limited understanding of the risks of intervention (or lack of intervention). Kelp restoration is also expensive relative to terrestrial or intertidal restoration, due to the logistical challenges of implementing solutions in subtidal environments.

The dynamic nature of kelp ecosystems, complex and regionally specific drivers of kelp loss, and predicted climate-related changes for California waters make for a complicated decision context for knowing when, where and how to intervene to maintain or actively restore kelp ecosystems. A structured decision making (SDM) framework can help to guide kelp management and restoration decisions and investments toward those interventions that are most likely to achieve desired outcomes. Structured decision making is a values-based approach to making natural resource management decisions. Through a structured process, decision-makers and stakeholders clearly identify the problem that needs to be addressed, the management objectives, and potential management actions or alternatives that can be taken to meet the objectives. By using models or other decision-analysis tools to predict the likelihood of potential actions to achieve objectives, decision-makers can evaluate alternatives, trade-offs, risks, and uncertainty in a transparent manner. An SDM approach also provides opportunities for stakeholders to engage in the decision process and provide a diversity of perspectives and values. Stakeholder engagement can also promote transparency and acceptance of decisions and proposed interventions.

In California, the California Department of Fish and Wildlife (CDFW) is the lead agency for kelp management. This state agency is developing a kelp restoration and management plan, as well as other resources, to guide kelp management decisions and investments in restoration, monitoring and science at this critical time in California. An SDM framework could help to achieve the broader management goals for kelp ecosystems in California by supporting good decision making and investments consistent with the kelp management plan being developed. Structured decision making can improve the chances of good outcomes, or at least advance learning if outcomes are not achieved, for all kinds of decisions—from small decisions made by individual decision-makers at their desks, to much broader and more public decisions in a stakeholder-engagement context. An SDM approach can be applied to project-level decisions about interventions at the scale of a kelp forest, as well as to broader management or monitoring decisions for kelp forests at regional or even statewide scales. By working through a formalized set of steps and addressing key questions, a natural resource problem is framed and organized in a manner that ensures potential solutions are clearly linked to the fundamental objectives that need to be met. This approach can also promote transparency and shared understanding around what problem is being addressed, what are the management objectives, and how decisions are made.

Structured decision making has seven steps. These steps are iterative and can be revisited as new information or ideas emerge (see Figure ES1):

- **STEP 1 | Problem Formulation:** What is the problem we are trying to solve or the programmatic goal we want to achieve?
- **STEP 2 | Set Clear Objectives:** What is the fundamental objective we want to achieve from this activity? What do we need to do in order to accomplish that objective?
- **STEP 3 | Identifying Alternatives:** What are the range of alternatives (solutions) we should consider in order to address the problem and meet the objective(s) identified?
- **STEP 4 | Consequences:** What are the predicted outcomes of alternative actions in terms of the objective(s)?
- **STEP 5 | Evaluating Trade-Offs:** What is the best (optimal) alternative given predicted outcomes, sources of uncertainty, and trade-offs among multiple objectives?
- **STEP 6 | Making a Decision:** What is the best decision to achieve objectives given our understanding of consequences, trade-offs, risks, and uncertainty?
- **STEP 7 | Act, Monitor and Learn:** Can the implementation of the decision be designed as an experiment with targeted monitoring to promote learning and reduce uncertainty or risks in future decisions?

In the context of kelp management and restoration, SDM can provide a framework for bringing together information on the decision context in terms of what is triggering a decision, who needs to be involved, and specific information on the problem that needs to be addressed (such as the status of kelp and the nature of the stressors). From there, objectives are identified, as well as the types of alternatives to consider in order to meet those objectives. These alternatives may exist along a continuum of response strategies, the choice of which might depend on the status of kelp (relative to historic variability) and the manageability of the stressors. An example of that continuum includes strategies ranging from status monitoring, activities to avoid further kelp losses, and active kelp restoration. The SDM approach, with the inclusion of assessments of kelp status and models for kelp dynamics, can help to identify the decision points at which one might move from one strategy to the next or back along the continuum.

Generally, maintaining healthy and resilient kelp forests and avoiding further kelp losses, when possible, is almost certainly cheaper and easier than actively restoring kelp forests. Interventions for active restoration of kelp forests are possible, but require significant investments, further understanding and

Figure ES1. Seven steps in structured decision making, with guidance and tools for the kelp context

testing, and should be grounded in science. Once alternatives are identified that could achieve the objectives, then the next steps in SDM focus on decision analysis of the alternatives being considered in order to predict consequences of different actions, evaluate trade-offs, and assess risk and uncertainty. The final steps involve making and implementing a decision and conducting the monitoring needed to inform learning and adaptive management.

The purpose of this document is to ***provide guidance for how to use a structured decision making (SDM) approach to support informed decisions and investments in kelp management and restoration*** at scales ranging from individual kelp forests to broad regions. The intended audiences of this report are state agencies, NGOs, restoration practitioners, funders and other stakeholders engaged in kelp management, restoration, and conservation efforts in California and beyond. While natural resource managers are commonly in a decision-making role and often lead public SDM processes, this document aims to make the SDM process more transparent and provide enough kelp-specific information for SDM participants to meaningfully contribute to the process. While the guidance and examples are focused on canopy-forming kelp species in California, this SDM framework could be broadly applicable to support management and restoration decisions in kelp ecosystems in temperate regions throughout the world.

1.0 INTRODUCTION

Globally, the degradation and loss of coastal marine habitats has focused attention on the need to reduce drivers of habitat loss, improve resilience to climate changes, and scale up habitat restoration (Abelson et al., 2020; Coleman et al., 2020; Duarte et al., 2020). Across the globe and in California, kelp forests have become increasingly threatened by multiple stressors that are exacerbated by climate change (Krumhansl et al., 2016; Wernberg et al., 2016). Avoiding further losses, improving resilience, and actively restoring kelp (where feasible) is important since kelp forests are responsible for billions of dollars in ecosystem service provisions worldwide. Those ecosystem services include direct harvest; providing habitat for commercially, recreationally, and culturally important fisheries; shoreline protection; recreation; and sources of primary production (Bennett et al., 2016; Carr & Reed, 2016).

Large swaths of California's kelp forests have been lost in recent years and more concerted efforts toward kelp management and restoration are underway by state agencies and a host of other entities. The California Department of Fish and Wildlife (CDFW) and the California Fish and Game Commission (FGC) have management and regulatory authority over the State's kelp resources. The CDFW is developing an ecosystem-based adaptive kelp restoration and management plan, as well as other resources, to guide kelp management decisions and investments in restoration, monitoring and science at this critical time in California. Kelp ecosystems in California are dynamic and drivers of kelp loss are complex, making decisions about when to intervene (or not) difficult. In addition, there are numerous different stakeholders who have strong interests in healthy kelp forests and contributions to make toward improved kelp forest management and restoration.

Given the uncertainties in how best to respond to kelp losses, as well as the complexities in the ecological, social and policy contexts, there are benefits to using a structured approach for decision making to inform learning and guide investments at scales ranging from individual kelp forests to broader regions. Structured decision making is a values-based approach to making natural resource management decisions. Structured decision making is an approach to thoughtfully frame and analyze problems to support decisions that are focused on meeting fundamental objectives (Conroy & Peterson, 2013; Johnson et al., 2015; Keeney, 2004; Moore & Runge, 2012). An SDM approach could help achieve the broader management goals for kelp ecosystems in California by supporting transparent decision making and investments consistent with the kelp management plan being developed. While management of kelp resources in California occurs at the statewide scale, an SDM approach can help guide decisions at multiple scales based on the best available science and understanding of regional variability in kelp ecosystems and drivers.

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1.1 PURPOSE OF THIS DOCUMENT

The purpose of this document is to ***provide guidance for how to use a structured decision making (SDM) approach to support informed decisions and investments in kelp management and restoration*** at scales ranging from individual kelp forests to broad regions. An SDM approach can help to organize a decision process, support stakeholder engagement, ensure that objectives are clear and value-based, and provide transparency on criteria and trade-offs considered during decision making. This document provides guidance on how to use SDM, with explicit examples from the kelp context. Importantly, this document is not the result of an SDM process, and users will need to bring new information and critical thinking to their own decision-problem. The intended audiences of this report are state agencies, NGOs, restoration practitioners, funders and other stakeholders engaged in kelp management, restoration and conservation efforts in California and beyond. While natural resource managers are commonly in a decision-making role and often lead public SDM processes, this document aims to provide guidance for a kelp-focused SDM process, including enough kelp-specific information for SDM participants to meaningfully contribute to the process. While the content and examples are focused on California, this guidance on use of SDM is relevant to addressing ongoing drivers and stressors of kelp loss along the entire west coast of North America and globally.

1.2 BACKGROUND

Kelp ecosystems are some of the most diverse and important ecosystems in the ocean. In California, kelp (and other marine algae) are managed as a resource for both commercial and recreational harvest, largely through a system of administrative kelp bed areas and algae harvest regulations. Additionally, approximately 20–25% of kelp forests were protected in a statewide network of marine protected areas at the time of designation (Gleason et al., 2013). Beyond the direct value of kelp harvest, kelp forests provide critical habitat and food for hundreds of species including seaweeds, invertebrates, fishes and marine mammals; kelp forests also support important fisheries, including finfish, abalone and urchins, that are culturally and economically important in California (Miller et al., 2018).

California encompasses just under 3,500 miles of ocean shoreline. The important drivers of kelp abundance and loss can vary strongly between regions, as does the primary canopy-forming kelp species. For this document, regions are defined roughly as Northern California (Oregon border south to Point Reyes), Central California (Point Reyes to Point Conception) and Southern California (Point Conception to the U.S.-Mexico border). Bull kelp (*Nereocystis luetkeana*) is prevalent in Northern California and giant kelp (*Macrocystis pyrifera*) is prevalent in Southern California; both species are found in Central California with spatio-temporal variability in dominance. The two species have different life histories and demographics, which makes restoration and management options more complex; different suites of options might be necessary for the different species. Of particular importance, bull kelp is an annual species, generally completing its life cycle in a single year, with sometimes multiple populations reproducing year-round in a given location. Giant kelp can live as long as several years (Springer et al., 2010). Other key differences include giant kelp's ability to grow fronds along its whole length (a feature that helps it deal with partial loss and potentially enhances reproduction), while bull kelp only has fronds (and reproductive parts) at the surface.

Large-scale drivers and more localized stressors of kelp forest loss include both physical and biological factors (see Section 3.2 for definitions of drivers and stressors), as well as their interactions, and must be understood for restoration to be effective (Bell et al., 2015; Cavanaugh et al., 2011; Dayton, 1985; Dayton et al., 1992; Filbee-Dexter & Scheibling, 2014; Graham et al., 2008; Layton et al., 2020; Smith et al., 2021; Steneck et al., 2002). In general, kelp requires a hard-bottom substrate or other point of attachment, nutrients and light to grow. Stressors to kelp include overgrazing (often by purple sea urchins, *Strongylocentrotus purpuratus*, which can proliferate when their predators are absent through overfishing or disease or through pulsed recruitment events (Okamoto et al., 2020). Poor water quality, sedimentation, invasive species and prolonged high ocean temperatures are also stressors on kelp. Disturbance in the form of wave events also can control kelp abundance (Jayathilake & Costello, 2020; Young et al., 2016). Larger-scale oceanographic events such as El Niño/La Niña events and marine heat waves that drive temperature and nutrient supply can also strongly affect kelp abundance (Dayton et al., 1992; Dayton et al., 1998; Edwards, 2004). The nature of these drivers and stressors, as well as their effects on kelp, vary substantially across the state, even within regions.

Managers and stakeholders in the state are especially concerned about significant loss of bull kelp forests in Northern California in recent years. This kelp loss is associated with the sequential and combined effects of the loss of a primary urchin predator (the sunflower sea star, *Pycnopodia helianthoides*) to sea star wasting syndrome, lack of urchin predator redundancy (e.g., historical extirpation of sea otters), El Niño, a marine heat wave event, and shifts in foraging behavior and increased recruitment of the purple sea urchin (Harvell et al., 2019; McPherson et al., 2021; Okamoto et al., 2020; Smith et al., 2021; Rogers-Bennett & Catton, 2019). Recent estimates indicate that over 90% of bull kelp in this region has been lost since 2014 (McPherson et al., 2021; Rogers-Bennett & Catton, 2019), and purple sea urchins appear to be keeping many areas in an urchin barren state. As a consequence of kelp loss, the Northern California commercial red sea urchin (*Mesocentrotus franciscanus*) fishery collapsed in 2016, resulting in a federal fishery disaster declaration. The economically and culturally valuable recreational red abalone (*Haliotis rufescens*) fishery has remained closed since 2017. While grazing by herbivores is a key factor in well-documented phase shifts between kelp forests and urchin barrens that are generally devoid of canopy kelp, a variety of other less-manageable stressors affect kelp, including water temperature, nutrients, and wave severity. Responses to the loss of bull kelp in Northern California have been initiated and approaches for managing urchin overgrazing and active kelp restoration are currently being tested. The Northern California coast is a particularly difficult coastline to access, and monitoring and recovery efforts have been limited to a small number of locations. While not as dramatic as in Northern California, some locations in both Central and Southern California have also experienced kelp loss (primarily giant kelp), urchin barren formation, and shifts in dominance of the two kelp species; decisions on whether and how to intervene in these situations need to be made.

1.3 CHALLENGES OF KELP RESTORATION AND MANAGEMENT

The challenges and potential expense of kelp forest restoration at large spatial scales are substantial enough that an emphasis on preventing kelp loss through proactive conservation and management efforts is preferable (Layton et al., 2020). Habitat restoration in general can be difficult and costly, but restoration of kelp forest ecosystems poses a number of unique challenges when compared to other habitats, including habitat accessibility, multiple interacting drivers of loss, the inherent dynamism of the system, and discontinuous phase shifts (i.e. hysteresis), to name a few (Filbee-Dexter & Scheibling, 2014; Johnson et al., 2017; Layton et al., 2020). Importantly, climate impacts such as marine heat waves are predicted to increase in number and severity in the future making restoration and management of kelp that much more challenging (Oliver et al., 2019). The shift to urchin barrens in many locations represents a significant challenge to kelp recovery, for both natural reseeding and active restoration efforts.

Globally, dramatic losses of kelp have happened very quickly and restoration efforts are currently underway in many countries including Australia, Japan, Norway, Canada, and Chile (Eger et al., 2019), as well as in California, providing new approaches and lessons to inform investments in kelp restoration. The toolbox of potential kelp management and restoration activities is also growing and broadly includes monitoring the status of the resource, directly increasing kelp, indirectly increasing kelp through species interactions and improving kelp resilience (see Section 5 for more description of potential alternatives).

Kelp restoration efforts in California have occurred since 1963 (primarily in Southern California), including kelp transplantation and grazer control efforts (Wilson et al., 1977; Wilson & North, 1983). More recently, an urchin removal program is being conducted by Santa Monica Baykeeper (https://www.santamonicabay.org/explore/in-the-ocean/kelp-forest-restoration/). In addition, construction of a large artificial reef occurred in 1999 as environmental impact mitigation from the San Onofre Nuclear Generating Station, and a second section of that reef is being built (https://marinemitigation.msi.ucsb.edu/index.html). Each of these examples has taken place in Southern California with a goal of restoring giant kelp. However, loss of bull kelp in Northern California is unprecedented, and efforts to reduce urchin grazing pressure and restore bull kelp are only now being tested.

The loss of bull kelp and associated closure of fisheries, particularly the red abalone fishery, has prompted a vocal call from a wide range of stakeholders (e.g., scientists, tribal representatives, NGOs and fishermen) to address the issue, and has resulted in increased interest in kelp management and restoration. Several management and planning documents for California kelp resources are in progress or recently finalized:

- A California ecosystem-based adaptive kelp restoration and management plan is under development and being led by CDFW staff. It will bring together the best available science and learnings from recent kelp restoration pilot projects to inform broader management goals and more specific guidance on kelp restoration and management across the state.

- A Giant Kelp and Bull Kelp Enhanced Status Report is being developed by CDFW that will provide an overview of kelp, kelp as a harvested resource, and kelp management and monitoring.

- The FGC and CDFW began a process to review and amend marine algae commercial harvest regulations that is still underway. Several commercial management changes were adopted in 2014, and a review of additional potential draft regulation amendments is in progress. Later stages of amendments to the plan have been complicated by the rapid large-scale loss of kelp in Northern California and the negative effects on kelp-associated fisheries.

- The Greater Farallones National Marine Sanctuary Advisory Council convenes a Kelp Recovery Working Group and developed recommendations to address kelp loss and facilitate management and recovery of bull kelp populations through a *Sonoma-Mendocino Bull Kelp Recovery Plan* (Hohman et al., 2019). This guidance document outlines management strategies to address the extensive loss of bull kelp along the coast in Sonoma and Mendocino counties, laying criteria for restoration site selection and potential interventions to reduce urchin density and enhance kelp abundance in that region.

- The California Ocean Protection Council (OPC), as part of its Strategic Plan 2020–2025, released a draft Kelp Forest Action Plan in 2021, which includes potential restoration and management approaches, and research and monitoring recommendations.

The OPC, CDFW and California SeaGrant identified priorities for research on kelp restoration and through an open call for proposals, a portfolio of projects were selected for funding ("kelp restoration pilot projects" noted above). Once projects were funded, state partners have provided (where needed) coordination, guidance on permitting, consultation on research site locations, etc. Results from these projects are intended to feed into future decision processes. (https://www.opc.ca.gov/webmaster/ftp/pdf/agenda_items/20200619/Item8_KelpRecoveryResearchProgram_ADDENDUM.pdf).

2.0 WHY APPLY A STRUCTURED APPROACH TO DECISIONS?

An SDM framework can assist kelp managers, restoration practitioners and funders in making decisions and investments in a manner that improves the chances of achieving desired outcomes and informs learning and adaptive management over time (see Box 1). This is especially needed now in the face of kelp declines, the nascent status of kelp restoration science and practice, the complexity and dynamics of both kelp ecosystems and regulatory systems, and the uncertainty of climate-change impacts on kelp. An SDM framework for kelp management and restoration decisions can ensure that decision making is informed by available science and aims to recognize both the local/regional drivers of ecosystem dynamics and the benefits of healthy kelp systems for the ecosystem services that they provide. Importantly, an SDM approach can be used to address policy needs, engage stakeholders in a transparent process, incorporate traditional knowledge, and help to ensure that objectives reflect the concerns and values of stakeholders.

Box 1. Why use an SDM approach?

» Organizes the analysis of a problem to reach a decision focused on achieving fundamental objectives.

» Encourages a transparent process for making informed decisions in the face of uncertainty.

» Supports stakeholder engagement, with values expressed as objectives.

» Promotes learning, incorporation of new knowledge, and adaptive management.

2.1 HOW MORE STRUCTURED DECISION MAKING CAN HELP

Through an SDM process, decision-makers and stakeholders clearly identify and define the problem being addressed and the management objectives. Then potential management actions or alternatives are evaluated to decide on the best option(s) to meet the objectives. By using models or analyses to predict how potential management actions will help to meet the objectives, decision-makers can evaluate alternatives, trade-offs, risks and uncertainty in a science-based and transparent manner. Most kelp management or restoration decisions could be improved by stepping through an SDM process, and incorporating models, even very simple conceptual models, of the relationship between the desired objectives and the alternatives being considered. Some more complex decisions, with a high degree of uncertainty or potential risks, may warrant a more robust analysis and a bigger investment of time and resources.

Structured decision making has been used broadly in the marine realm to guide critical decisions ranging from fisheries management (Estévez et al., 2020; Gammage & Jarre, 2020; McGowan et al., 2015), to imperiled species management (Welch et al., 2019), to guiding restoration (Sivapalan & Bowen, 2020), to ecosystem-based management (Espinosa-Romero et al., 2011). Robinson et al. (2020) used an SDM framework to engage diverse stakeholders and evaluate alternatives to managing the overgrazing and urchin barrens resulting from the climate-driven range expansion of the urchins in Tasmania (Robinson et al., 2020). Structured decision making frameworks can help address complex interactions, including stressors or existing management decisions that occur outside of the ecosystem of interest (Carriger et al., 2013; Robinson & Jennings, 2012; Yee et al., 2015). For example, Robinson & Jennings (2012) used an SDM framework to optimize production of juvenile native marine fish that utilize the same flooded estuarine fields previously managed for waterfowl. Similar to the challenges that face kelp management, SDM frameworks have been used to guide decisions among many actions needed in response to the catastrophic loss of coral reefs due to myriad manageable and unmanageable stressors (Anthony et al., 2020).

By involving stakeholders, using the best-available science and local knowledge, and designing interventions as experiments, decision-makers can help to integrate decisions across the science and policy realms (Johnson et al., 2015). Depending on the decision context, SDM can be done simply in a desktop manner with just the decision-maker(s) or be designed as an inclusive and participatory process with a range of stakeholders providing input. Involving stakeholders in SDM processes can promote transparency and potentially broader acceptance of management actions (Wilson & Arvai, 2011). Stakeholders can provide local or traditional knowledge of the kelp ecosystem, share their values that can be incorporated as explicit objectives, and contribute to the process of identifying and evaluating alternatives. Stakeholders can also play a key role in collecting data to support monitoring of implementation (Wilson & Arvai, 2011).

2.2 KNOWING WHETHER AND HOW TO TAKE ACTION TO ADDRESS KELP LOSS

Structured decision making and an experimental approach to interventions (e.g., pilot projects designed to test assumptions) can help to focus early investments on identifying and testing best solutions to kelp losses or other management issues, given the local context and desired outcomes. Understanding when and how to act to restore or recover kelp ecosystems is critical as is incorporating best available- knowledge into the approach. First, it is very important to understand whether observed changes in a kelp forest ecosystem are within the normal range of variability, given the natural dynamics and fluctuations of kelp forests (Johnson et al., 2017; Layton et al., 2020). Then it is critical to understand the drivers and stressors operating in the system and whether they are manageable (Layton et al. 2020). If the changes observed, such as conversion of kelp forests to urchin barrens, are considered alternative stable states and if hysteresis is present (see Box 5), the problem may require significant and sustained interventions over time (e.g., ongoing large-scale urchin removals). In some cases, active kelp restoration (e.g., outplanting of kelp or seeding) to recover the kelp ecosystem may be warranted (Filbee-Dexter & Scheibling, 2014; Johnson et al., 2017; Layton et al., 2020).

Finally, it is important to determine if kelp recovery is even possible, especially in cases where environmental drivers, such as warming ocean waters, are not easily ameliorated. Kelp restoration may also not be possible if the phase shift or underlying stressors cannot be reversed with available resources and technologies; in those cases, investments may be better spent on defending or improving the resilience of remaining stands of kelp (Johnson et al., 2017). Successful restoration of kelp may require some kind of "future-proofing" through outplanting kelp genotypes that are adapted to warm-water, or potentially entirely different species of kelp than in the pre-loss state, in order to restore kelp ecosystem functions (Coleman et al., 2020; Layton et al., 2020).

2.3 THE STRUCTURED DECISION MAKING APPROACH

The "PrOACT" framework for SDM, developed by the U.S. Fish and Wildlife Service and U.S. Geological Service (Conroy & Peterson, 2013; Runge et al., 2017) was adapted here, with the addition of a seventh step focused on monitoring to support learning. Since kelp systems are so dynamic and there are so many uncertainties in the nascent field of kelp restoration and management, many types of decisions may benefit from monitoring and learning about what alternatives are most effective at meeting objectives. Adaptive management is a special class of problems addressed by SDM, when recurrent decisions might be improved over time by learning from previous decisions in order to reduce uncertainty (Runge et al., 2013).

For this document, the SDM approach has seven steps that will be further described in subsequent sections (Figure 1). Steps 1 and 2 establish the decision context, Steps 3 to 5 focus on decision analysis, while Steps 6 and 7 guide decision making and monitoring. The key questions at each step include:

- **STEP 1 | Problem Formulation:** What is the problem we are trying to solve or the programmatic goal we want to achieve?
- **STEP 2 | Set Clear Objectives:** What is the fundamental objective we want to achieve from this activity? What do we need to do in order to accomplish that objective?
- **STEP 3 | Alternatives:** What are the range of alternatives (solutions) we should consider in order to address the problem and meet the objective(s) identified?
- **STEP 4 | Consequences:** What are the predicted outcomes of alternative actions in terms of the objective(s)?
- **STEP 5 | Trade-Offs:** What is the best (optimal) alternative given predicted outcomes, sources of uncertainty, and trade-offs among multiple objectives?
- **STEP 6 | Making a Decision:** What is the best decision to achieve objectives given our understanding of consequences, trade-offs, risks and uncertainty?
- **STEP 7 | Act, Monitor and Learn:** Can the implementation of the decision be designed as an experiment with targeted monitoring to promote learning and reduce uncertainty or risks in future decisions?

Figure 1. Seven steps in a structured decision making process (adapted from Conroy & Peterson, 2013)

3.0 PROBLEM FORMULATION

Defining and framing the problem that requires a decision is the first—and very important—step in a decision analysis (Conroy & Peterson, 2013; Gregory et al., 2012; Runge et al., 2013; Runge et al., 2020). What is the problem you want to address, and is it the "right" problem (e.g., tractable, solvable, represents the values of the stakeholders involved, etc.)? Identifying and articulating the problem correctly will help to establish a clear foundation for identifying measurable objectives (Step 2) and alternatives (Step 3). Often, these steps are iterative, as potential objectives and alternatives are identified, the precise articulation of the problem statement might change somewhat (see Figure 1).

3.1 UNDERSTANDING THE DECISION CONTEXT

Understanding the nature of the decision being made, the broader context in which the decision will be made, and who needs to be involved in developing and implementing solutions are key to a successful outcome (see Box 2). What is triggering the need for a decision and who needs to be involved? Note that the context around a decision may include biological, legal, logistic and/or socioeconomic constraints and opportunities. For kelp ecosystems, decisions could include:

- Deciding what types of monitoring investments will provide the most efficient approach to tracking kelp status over time at broad spatial scales;
- Deciding the status of the kelp forest and whether intervention is warranted;
- Deciding among a suite of actions to take to best help kelp recover from catastrophic declines or concerning levels of loss;
- Deciding whether to permit or fund a particular restoration project and where it should take place;
- Deciding how to regulate kelp harvest, given temporal and spatial trends in kelp abundance; and/or
- Deciding on a process for making decisions and engaging with stakeholders to address a kelp issue.

Understanding the decision context, both limitations and opportunities, will inform the subsequent steps of the SDM process. It is also important to understand the range of stakeholder values and concerns that will need to be addressed through the decision process.

Box 2. Who needs to be involved?

It is important to be clear about who has the authority to make a decision, how stakeholders (and their values) will be involved, and how this decision fits into the context of other decisions. Some initial questions to consider include:

» What is the nature of the problem we are trying to solve? What are we concerned about or hoping to achieve?

» Are the right people involved in problem setting? Who has a stake in the outcome, and who can influence the outcome? What are the stakeholder values that should be considered?

» How can ecological scientists, policy specialists, social scientists and local and traditional knowledge keepers contribute individually and collectively? And what data or information are available to understand this problem?

» Who has authority to make the decision? What are the other roles and responsibilities of participants?

» What is the scope/scale and the timing/frequency of the decision? Are other decisions linked to this one?

3.2 FORMULATING A CLEAR PROBLEM STATEMENT FOR KELP

A clearly defined problem statement is a critically important first step. Generally, the problem needs to be stated in a form broad enough to challenge assumptions, get at the root of the issue, break down perceived constraints, identify and avoid unintended consequences, and generate long-lasting solutions. The problem should be stated as a decision to select a course of action, from all the alternative possibilities, to address a concern or requirement (Runge et al., 2017). For example, how do we best allocate resources to address a specific problem? How do we restore *X* or manage *Y* to achieve a desired outcome? The problem statement should propose an **action** that we **predict** will lead to **outcomes** that should fulfill **objectives** (Conroy & Peterson, 2013). Here, we provide examples of contextual information and questions to pose (Box 3) that could be useful to framing a problem statement and decisions about kelp restoration and management.

Box 3. Key questions to help identify a clear problem statement for kelp decisions

» What species of kelp(s)? What is the status of kelp abundance and trends over time?

» What is the scale of the problem (i.e., how much kelp has been lost over what area? And over what amount of time)?

» What are the primary stressors? Which are manageable and which are not? Over what time scales can they be managed?

» What are the key drivers of kelp in your region? Are they known (i.e., is the relationship with kelp well understood and are there data available)? Are those manageable or not?

» Is there hysteresis in the system? Has the system "tipped," or is it at risk of tipping, into an alternative and less desirable state? (see Box 5)

» What do stakeholders care about? What do they want to protect, restore, or harvest?

» What's possible given legal, regulatory, financial, and logistical constraints?

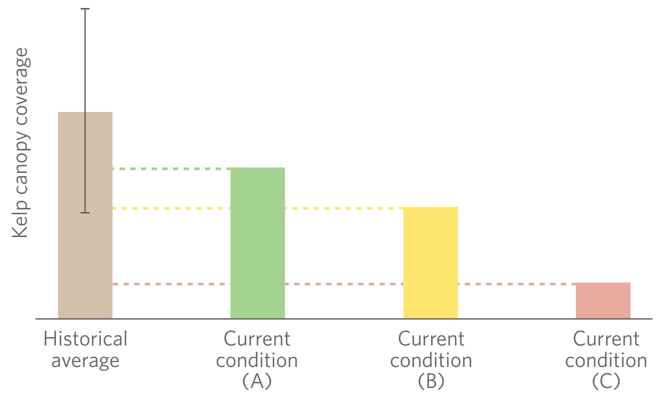


Figure 2. Evaluating current kelp canopy coverage relative to historic coverage. Hypothetical graphical depiction of current kelp canopy coverage (in three different scenarios A, B and C) compared with a historical average kelp coverage as a tool to guide potential response actions, assuming threshold limits have been identified. In this example, standard deviation of historical average is used to reflect the natural range of variability in historical kelp coverage to assess level of concern about current condition; Scenario A is within natural range of variability, Scenario B is falling just below, and Scenario C is well below historical average. Other approaches for assessing current status may be needed, depending on available data and risk tolerance of the decision-makers.

3.2.1 Environmental context

The environmental context, especially information on kelp abundance and drivers/stressors of kelp loss, is key to articulation of a problem statement.

What species of kelp?

California's two species of canopy-forming kelps have different life histories and demographics, which will impact the choice and success of restoration and management options. For example, bull kelp is an annual species and widespread loss can easily result in recruitment failure, making natural recovery less likely (Springer et al., 2010). Thus, recognizing imminent or ongoing decline before catastrophic loss is critical (perhaps more so than for giant kelp), especially if this allows protection of existing stands of bull kelp. Once bull kelp has been widely lost from an area, assisted recovery (i.e., seeding, outplanting, etc.) might be more necessary than for giant kelp, which may have a higher natural recovery rate (Springer et al., 2010).

What are the trends in kelp status over time?

Kelp systems are notoriously dynamic in time and variable in space, with orders of magnitude differences in abundance on scales of tens of kilometers and variation within seasons, within years, among years, and among longer-term cycles such as El Niño (Bell et al., 2020). Prior to implementing restoration efforts, one first must assess the magnitude of the problem in terms of changes in kelp abundance or extent. Are observed kelp losses beyond the range of historic variability? Has the system moved into an alternate state and is that likely to be persistent?

Regular monitoring of kelp status is key to informing the problem formulation step. Existing datasets on spatial extent (or biomass) of kelp canopy provide some recent historic context, but they need to be regularly updated with new surveys to track current temporal and spatial trends. Existing datasets include airplane-based surveys by CDFW, satellite-based datasets (e.g., Kelp Watch), and drone-based surveys (Appendix 1). Understanding the temporal trends in kelp at the spatial scale of interest, and whether recent averages in kelp extent are within the documented range of variability over time, can inform the need for intervention (Figure 2). Whether to intervene (and how) will depend upon the degree of concern about future kelp losses, potential risks of inaction, and the suite of interventions that are feasible; these are all elements that will emerge from an SDM process.

What is the spatial scale of the problem and the decision?
Scale is important to consider when developing a problem statement and will inform both the broader context within which a specific kelp forest exists as well as support the identification of kelp forest sites most appropriate for particular interventions. There are three components of spatial scale that should be considered in decision making:

- What is the scale of the problem (e.g., local, regional, statewide)?;
- What is the appropriate scale of the interventions being considered (this is often smaller than the scale of the problem)?; and
- Is the intervention, if successful, scalable to other areas?

The degree of ecological connectivity of both kelp and the stressors should also be considered (e.g., what are the nearby sources of kelp propagules to promote recovery or sources of urchin recruitment that may hinder recovery?). Challenges and opportunities for the scale and scalability of an intervention may include cost, logistics, regional or local support, and permitting, as well as ecological drivers. Thinking through these aspects of scale will help to hone the "right" problem, objectives and scale of interventions.

What are the drivers and stressors acting on kelp? To what extent can they be alleviated?
Identifying the primary drivers and stressors causing kelp losses is key to successful management and restoration (the terms "drivers" and "stressors" are defined in Box 4). During an SDM process, users may define these terms differently, but understanding the various pressures on a system is important. In many locations, larger-scale drivers of kelp forest decline and more local stressors may include both physical and biological factors, and while some of these may be alleviated through management action, some may not. Even the best plans for restoration will be unlikely to result in persistent kelp forests if the conditions that influenced the declines are still present (e.g., is water temperature still high? Are nutrients still low? Are urchin predators still absent?).

The drivers and stressors that affect kelp abundance are diverse and interactive, and they vary spatially and temporally across California and for the two species of canopy-forming kelp (Table 1). Large-scale drivers of kelp loss (e.g., climate change, disease) may not be manageable (at least at the local scale) but need to be considered as important context for making management decisions. Similarly, stressors may act at different spatial scales and may be manageable or unmanageable at the scale of consideration for the decision. Seasonal variability in stressors should be incorporated, as it can influence what metric to consider (i.e., seasonal maximum rather than mean), how the stressor may temporally influence decisions (i.e., timing of intervention), or overall success of an intervention (will intervention be able to be maintained through future seasonal changes?).

BOX 4. Drivers and stressors of kelp loss

In some regions of California and around the world, the loss of kelp has been rapid and extensive. The forces behind these changes can be described as either "drivers" or "stressors," and the impacts can be referred to as "ecological effects."

Drivers are major external natural and anthropogenic events, processes, and/or forces that have large-scale influences over ecosystem structure and function (Miller et al., 2010; Ogden et al., 2005). In kelp forest systems, examples of drivers include climate change, fishing and sea star wasting syndrome.

Stressors are the biological, physical, and chemical changes that result from drivers and exceed an ecosystem's reference range of variation beyond which a substantive transformation occurs (Henderson & O'Neil, 2004; Miller et al., 2010). In kelp forest systems, examples of stressors include: an unprecedented decline in predator abundance (e.g., sea stars), an overabundance of herbivores (e.g., purple urchin), above-average water temperatures, and a decline in nutrients.

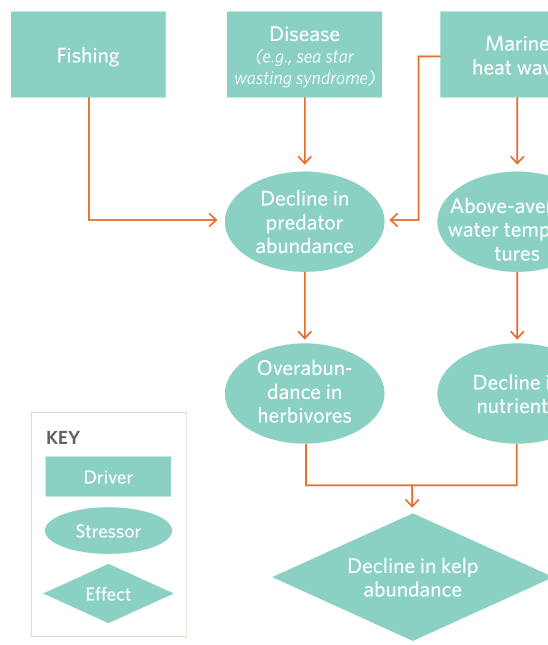


Table 1. Examples of drivers, stressors, and considerations for problem formulation

Drivers/ Stressors	Potential metrics	Scale of consideration	Example considerations for problem formulation
Wave Exposure	Maximum significant wave height	Region- and reef-specific	Wave exposure influences both the kelp type and intervention likelihood of success; can affect choice of locations for interventions.
Water Temperature	Marine heat wave index	Typically a regional consideration. Can be measured regionally via remote sensing or locally with instruments	Water temperature interacts synergistically with many other stressors. While not generally manageable, it will influence the choice and timing of interventions.
Nutrients	Chlorophyll a, Mg, NO_3,	Typically a regional consideration, although point source may affect reefs	Nutrient limitation and nutrient loading influence kelp condition and/or restoration success. Local anthropogenic nutrient loading may be manageable—a reminder to consider onshore sources to address. Large-scale, oceanographically driven nutrient levels are not manageable but should be considered.
Sedimentation	Turbidity, percent fines, embeddedness, or sand depth on reef	Sediment transport and turbidity is likely a regional influence that will interact differently at the reef level	Turbidity and sedimentation of the sea floor may affect kelp condition or restoration success. Localized onshore sources may be manageable.
Pollution	NO_3, heavy metals (e.g., Cu, Pb), glyphosates; kelp photosynthetic efficiency or Chl a, kelp growth	Regional to reef	Pollution can affect kelp condition or restoration success. Local marine or terrestrial sources may be manageable.
Herbivory	Urchin density and distribution	Regional- or reef-specific stressor, influenced by recruitment dynamics of region	Overgrazing is an important stressor, and density of grazers is an indicator of stress and/or potential for natural kelp recovery.
Predation	Presence, richness and density of urchin predators (e.g., sunflower sea star, California spiny lobster, California sheephead, sea otter)	Reef-specific stressor, influenced by predator dynamics	Predator ability to maintain or help recover kelp forests against trophic cascades and phase shifts; the reintroduction or management of predator populations may help with recovering or maintaining kelp forests.
Competition	Native algae or benthic invertebrates; invasive algae or invertebrates	Reef-specific stressor, influenced by presence of competitors within region as source of propagules	If stressed kelp can lose competitively for space, light or nutrients to other native or invasive algae or invertebrates and the system potentially shifts to a different state.
Fishing	Stock condition of species important to kelp forests (e.g. predators)	Reef-specific stressor, influenced by region-wide fishery and conditions of stocks	The role of fishing on predator dynamics and subsequent control of grazing is manageable.
Kelp Harvest	Biomass of kelp harvested	Reef-specific stressor, influenced by region-wide extent of kelp canopy, species of kelp, and amount harvested	The impact of kelp harvest and therefore harvest regulations will depend on the kelp species and harvest methods, and the interaction of many of the other stressors above.

Developing a realistic conceptual model for how different stressors affect kelp and other key species is important for predicting the potential consequence of management actions. In the context of SDM, it will be important to develop a conceptual model that identifies the important top-down (Caselle et al., 2018; Eisaguirre et al., 2020; Estes & Duggins, 1995; Lafferty & Kushner, 2000; Smith et al., 2021; Tegner, 2000) and bottom-up (Foster & Schiel, 2010; Malakhoff & Miller, 2021; McPherson et al. 2021; Schiel, 2013) drivers and stressors that are operating at the scale of interest for the decision. An example of a simple conceptual model (Figure 3) illustrates a range of positive and negative interactions among stressors; actual conceptual models for kelp would vary by region within California. Models need not be conceptual, and they may vary in complexity depending on scientific knowledge of the system; however, the models should be simple enough to be able to inform the problem and the actions. It is important to recognize that multiple stressors might not be additive. For example, despite lower urchin abundance and higher nutrient availability in Central California, giant kelp biomass was lower than in Southern California (Reed et al., 2011). Seemingly paradoxical, high wave disturbance in Central California overwhelms the effects of nutrients and herbivory relative to Southern California (Bell et al., 2015; Reed et al., 2011) and can be the main predictor of kelp persistence in Central California (Young et al., 2016).

Understanding whether hysteresis is present in the system is also key to determining whether kelp restoration is even possible or if the system would require active intervention to reverse the phase shift (see Box 5). In some cases, positive interactions within or among species can help to enhance restoration. For example, enhancing or recovering predator populations may help to reset an ecosystem or prime it for direct restoration (Eger et al., 2020a). Tracking top-down stressors (e.g., herbivory), bottom-up stressors (e.g., nutrients) and disturbance regimes (e.g., waves) over space and time and understanding their interactions, will help inform decisions about whether and where restoration is feasible, and guide the choice of potential methods and sites.

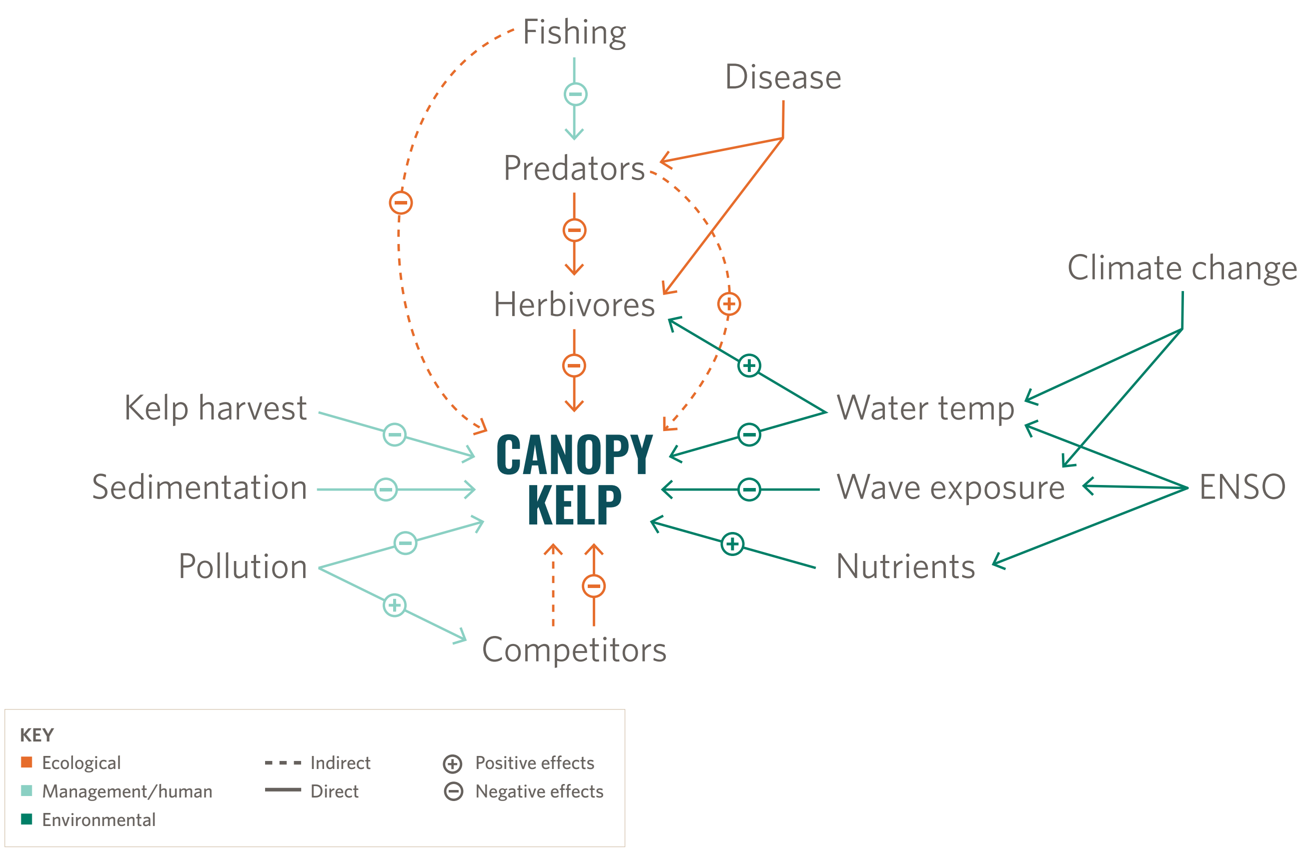
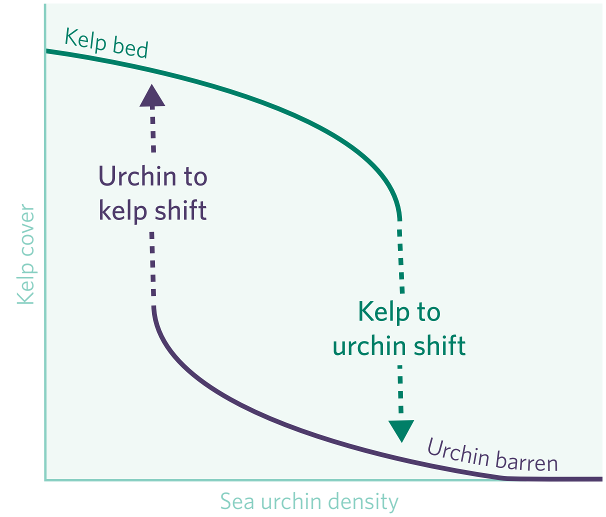


Figure 3. Example conceptual model of key kelp drivers and stressors. This diagram illustrates positive and negative effects, as well as direct and indirect effects. Note this is a generalized model and not specific to any region in California but illustrates the types of information that can help to define alternatives in an SDM. Appendix 2 also provides some examples from the literature on these drivers and stressors.

BOX 5. Is there hysteresis in the system?

Has the system "tipped" or is it close to a tipping point? Hysteresis is well documented in kelp forest systems globally (Ling et al., 2015). Hysteresis describes a shift from one ecosystem state to another state, where the threshold level (e.g., urchin density) for the forward shift (e.g., kelp forest to barrens) is at a different level than the threshold for the reverse shift back to the previous state (e.g., barrens back to kelp forest). This means that once a system has tipped from kelp forest to barrens, the density of urchins required to bring the system back to kelp is far lower than the density that tipped it in the first place. Thus, from a habitat protection standpoint, keeping kelp forests away from the tipping point might be much more cost-effective than bringing a forest back from an urchin barren. While shifts from kelp to barrens can happen rapidly, due to hysteresis, the return to a kelp forest state can take much longer to achieve (Ling et al., 2015). For systems with hysteresis, it is important to assess the likelihood that management interventions will lead to kelp recovery (Johnson et al., 2017).



The process of hysteresis as it relates to kelp ecosystems (after Filbee-Dexter et al. 2014). Note that the sea urchin density at which a system shifts from kelp to barrens is greater than the density required to create the opposite shift.

KELP FOREST **URCHIN BARREN**

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3.2.2 Human context

The scientific, socioeconomic and policy contexts also inform how a problem is articulated and help to frame the decision context to reflect the collective understanding of the problem, values, constraints and opportunities for the solution set.

What data and information do we have to inform this decision, and what are key sources of uncertainty?

California's kelp forests are among the best studied in the world. There is a long history of kelp forest study, and there are several long-term monitoring programs in the state. In addition, there is local and traditional knowledge of resource users and local stewards who can provide additional information. In California, we likely have sufficient data to make articulate, informed problem statements for most kelp issues. Given that, we still lack some forms of scientific information (e.g., interactions among drivers and stressors) and many restoration interventions are untested (especially for bull kelp). Yet decisions to fund and implement projects still need to be made in the face of uncertainty. Identifying data gaps and sources of uncertainty early on will help to inform the evaluation of alternatives and, ultimately, the decision.

What are the regulatory or policy constraints or opportunities?
Strong institutional support for kelp management and restoration can help to provide direction and resources, build stakeholder support, provide incentives, and advance the testing of new approaches (Eger et al., 2020b). Depending on the nature of the problem, the regulatory framework may require stakeholder engagement or public comment. Part of the problem framing is identifying who needs to be involved in the process of making a decision.

The legal, regulatory and policy tools for kelp restoration are still being developed, and there are few successful models of large-scale, persistent kelp restoration from which to learn. Due to the novelty of the problem, there is a lack of policy framework and legal levers to guide clearly defined thresholds of loss, triggers for restoration action, and management goals. These thresholds and triggers for action should be informed by science and stakeholder engagement before being developed into policy and management goals. This current gap creates opportunity to develop new approaches to address kelp restoration needs and to be creative in overcoming existing constraints. For example, while kelp restoration has been used as mitigation for nuclear power plant impacts (e.g., San Onofre Nuclear Generating Station), broader-scale habitat mitigation banking frameworks that exist for terrestrial analogs are not yet developed for kelp forests. Understanding the potential constraints on kelp interventions could also help to identify needed policy changes.

What do stakeholders care about?
Structured decision making is designed to support stakeholder input into complex decisions by encouraging all participants to articulate and justify the values that provide the foundation for the decision process (Runge & Bean, 2020). Decision-makers can frame a decision problem and determine whether the input or buy-in of stakeholders would make for a better decision, and then how stakeholders should be engaged (Box 6). While it is not required for stakeholders to be part of an SDM process, SDM provides a useful structure to engage stakeholders in a transparent decision process. Since SDM is values-based decision making, a good process will get all participants to express their values related to the decision, even if these values (expressed as objectives) are competing. There are also a variety of different roles to be played in a typical SDM process (Table 2).

Stakeholders have keen interests in kelp ecosystems for their intrinsic value and range of services, activities, and economies they support. Social acceptance of, and stakeholder participation in, coastal habitat restoration and management efforts is a key indicator of successful restoration projects (DeAngelis et al., 2020; Eger et al., 2020b). Engaging stakeholders is key to (1) understanding stakeholder values

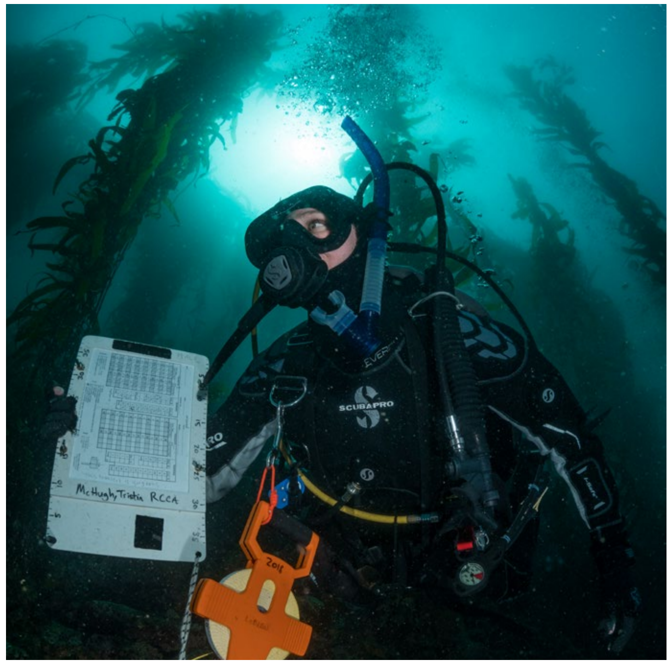

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Table 2. Roles for participants in an SDM process. Adapted from Crawford et al. (2017) with definitions from Gregory et al. (2012) and Conroy and Peterson (2013).

Role	Description
Analyst	Has technical skills (e.g., modeling) to evaluate decision outcomes
Champion	Has political influence with decision-makers, can facilitate buy-in and trust
Decision-maker	Has ultimate authority and power to act within the decision context; is also a stakeholder
Expert	Has expert knowledge about the natural resource issue
Facilitator	Has skills to lead team through the decision process; usually not a stakeholder or decision-maker
Leader	Has knowledge about natural resource issue, stakeholders, and participatory approaches
Regulator	Has authority or legal obligation to constrain decisions and outcomes
Stakeholder	Has ability to affect to be affected by decision; contributes knowledge and perspectives of decision context

to inform problem statement and objectives; (2) bringing diverse perspectives and knowledge (e.g., traditional knowledge) to inform and contribute to the decision process; and (3) building public awareness of the problem and support for the decisions made and solutions implemented (Wilson & Arvai, 2011). Tribal and indigenous communities may offer traditional knowledge, and cultural perspectives and values on stewardship of kelp forests and associated species. Environmental NGOs, fishermen, community groups and others can contribute resources, capacity and expertise to restoration and management efforts, while community science monitoring (e.g., Reef Check California) can contribute valuable monitoring data.

Box 6. Best practices for engaging stakeholders in SDM

- Ensure the process is led by an impartial leader who can lead the group through sound decision making practices.
- Draw on a range of stakeholders with a diversity of viewpoints.
- Encourage the introduction of new evidence and data.
- Encourage the expression and exploration of dissenting views.
- Elicit independent, individual judgements as well as facilitate group discussions and learning.
- Encourage people to consult with others outside the group to share and bring back questions and insights.
- Provide a chance to reflect and discuss "second thoughts."

Note this was adapted from Gregory et al. (2020).

What are the logistical constraints?

To some extent, kelp restoration projects will always depend on feasibility, and site access is a key element. The subtidal nature of most kelp forests makes this habitat more difficult and expensive to access than intertidal marine habitats in which more restoration has occurred (e.g., mangroves or seagrass beds). Access usually requires the use of boats and SCUBA diving, and participation in restoration efforts can be limited. However, in California there is a strong commercial dive fishery (for urchin) and a cadre of recreational SCUBA divers and free divers. Is a site consistently accessible to the people who will be conducting the activities? Is access seasonal and does that match with optimal times for restoration? Stakeholder interest and logistical feasibility have been identified as two key elements of site prioritization for kelp restoration efforts in Northern California (Hohman et al., 2019).

What are the financial constraints?

Restoration in marine habitats is time and resource intensive, and a clear understanding of financial constraints and opportunities will help guide decisions on the scale and methods for interventions. Minimizing costs is almost always an objective in natural resource management decisions and can be expressed as an objective. Sources of funding for kelp restoration could come from federal, state, and private sources and funding may be easier to obtain if an informed decision making approach has been used to articulate the problem, clear objectives, and sound plan for implementation activities to meet those objectives. Every phase of a restoration project requires funding, and failure to provide that funding for any step will potentially undermine the success of the whole project (Eger et al., 2020b). What are the initial costs of a proposed project? Is long-term funding needed for maintenance, and if so, how will it be secured? Is the funding base diversified among the participants? Is funding for monitoring and learning built in? Financial support does not ensure success, but lack of financing and institutional support can lead to failure (Eger et al., 2020b).

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4.0 SETTING CLEAR OBJECTIVES

Once the resource management problem and stakeholder values have been identified and a problem statement framed (Step 1), the next step in the SDM approach is to identify clear objectives (Step 2). The process of identifying objectives based on the problem statement may be iterative and help to further redefine the problem statement.

4.1 IDENTIFYING OBJECTIVES

A clearly articulated problem statement is needed before one can identify appropriate objectives to guide interventions. *Objectives* are specific and quantifiable outcomes that relate directly to the management problem and should also reflect the values of stakeholders and decision-makers (Conroy & Peterson, 2013; Wilson & Arvai, 2011). Objectives are what you care about. They are needed to identify and evaluate alternatives to address the problem, as well as to later evaluate whether the management interventions were successful.

One approach to identifying objectives is to begin by brainstorming, even at the problem-formulation step, with key constituents these questions:

- What are our goals and concerns?
- What do we hope to achieve?
- What are some potential objectives?

By compiling answers to these questions, decision-makers and stakeholders can start to identify potential shared objectives, objectives that may need to be addressed sequentially, and competing objectives that may require trade-offs. By articulating goals and concerns and desired outcomes, potential objectives may arise that are focused on recovering kelp ecosystems, fishery benefits of recovered kelp ecosystems, cost effectiveness, other uses of the resource, or on the process itself (Table 3). Sometimes this process of articulating potential objectives can identify gaps or issues with the problem statement that need to be revisited, so this step man be iterative with Step 1.

4.2 TYPES OF OBJECTIVES

Identifying appropriate objectives can be more difficult than expected as it is also critical to identify and distinguish ***fundamental objectives*** from ***means objectives*** (Conroy & Peterson, 2013).

- **Fundamental objectives** are the things the decision-maker wants or needs to achieve and often reflect the values of the stakeholders involved. If we ask the question "Why is that important?" and the answer is "Because that is what we want to achieve" or "Because that is a legal mandate," then that is probably a fundamental objective. The fundamental objective must be under the authority of the decision-maker, controllable, and not so broad as to be unachievable based on available interventions or the decision-maker's authority.

- **Means objectives** are the methods or means by which fundamental objectives can be achieved, but on their own are not the desired outcome. Asking the question "How do we accomplish that?" can help to identify means objectives. Since means objectives often derive from our conceptual model of how the system works (we need to do *X* in order to achieve *Y*), means objectives can often act as hypotheses for how to achieve the fundamental objective and thus inform potential interventions.

Brainstorming potential objectives and asking those two guiding questions ("Why is that important?" and "How do we accomplish that?") can guide the mapping of an objectives network to clearly distinguish the relationships between fundamental and means objectives (Figure 4).

In some cases, the process for how the problem statement is formulated, objectives established, identification of alternatives, and how decisions are made can be as important as the decision itself. These cases may warrant specific ***process objectives*** that are not focused on solving the problem, but on how stakeholder input is obtained, how decisions will be made, and other process considerations (Wilson & Arvai, 2011). And, depending on the legal and regulatory framework, there can be requirements for stakeholder engagement and/or constraints on objectives and alternatives considered in natural resource decision making. It is important to be clear on the concerns, goals, and values of stakeholders and decision-makers so that there is broad agreement early on ***fundamental objective(s)*** that are achievable, with ***means objectives*** as the way to reach the desired outcome. Other types of objectives (e.g., linked, hidden, stranded) can complicate a decision process (see Box 7).

Table 3. Turning goals and concerns into potential objectives in kelp ecosystems. Identifying what stakeholders care about and hope to achieve can help to identify different types of objectives; these examples from kelp ecosystems are illustrative of this approach (adapted from Runge et al., 2017).

What are goals or concerns of stakeholders?	What do we hope to achieve?	Potential objective	Types of objective
Kelp canopies being lost at accelerated pace	Slow down and reverse loss of kelp	Minimize future loss of kelp extent, relative to historic variability	Fundamental objective
Kelp forests are turning into urchin barrens with low biodiversity	Slow down and reverse conversion of kelp to urchin barrens	Keep urchin populations below hysteresis levels	Fundamental objective
Loss of kelp at large scales may limit the ability of the species to recover naturally	Prevent further kelp losses	Defend remaining patches of kelp by reducing urchin encroachment	Means objective
Loss of kelp at large scales may affect genetic diversity and potential for adaptation	Prevent loss of kelp genetic diversity	Maintain a bank of kelp genetic diversity	Means objective
Loss of sunflower sea stars reduces top-down control of urchin populations	Help sunflower sea star populations so they can help control urchins	Captively breed and grow sea stars for reintroduction	Means objective
Decline in red abalone population and closure of recreational fishery	Recover kelp to improve recreational fishing opportunity	Promote natural or assisted recovery of abalone to be able to reopen abalone fishery	Means objective
Restoring kelp is expensive	Find new restoration techniques that reduce costs and are scalable	Minimize costs of interventions	Fundamental objective
Stakeholders disagree on goals and objectives	More acceptance by stakeholders of the objectives and alternatives being considered	Create an inclusive decision process that allows stakeholder views and values to be considered	Process objective

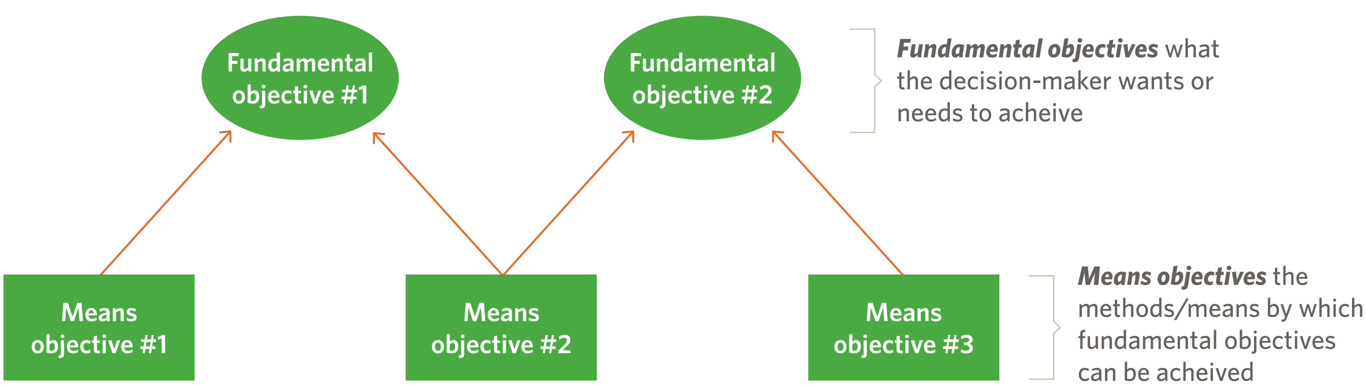

Figure 4. Mapping the relationship between fundamental and means objectives. Adapted from Conroy and Peterson (2013).

In the kelp context, the fundamental objectives at the scale of a kelp forest are likely to fall into these main types, with potential sub-objectives that help to define measurable attributes:

- Objectives focused on maintaining remaining kelp or other important species within the typical range of variability.
  - Maintain abundance of kelp or fishery species or indicator species.
  - Maintain genetic diversity.
- Objectives focused on recovering or restoring kelp or other important interacting species up to a typical range of variability.
- Objectives focused on rebuilding kelp-associated fishery species for harvest (e.g., kelp, red abalone, red sea urchin, finfish).

Means objectives would then focus on the interim steps needed to achieve the fundamental objective(s). Means objectives may be focused on setting harvest limits, reducing urchin abundance, defending remnant patches of kelp, outplanting kelp at priority sites, etc. Both fundamental and means objectives should be quantifiable and measurable in order to be able to evaluate outcomes. Measurable attributes should include:

- A unit of measure (e.g., area of kelp, density of urchins);
- A preferred direction (e.g., decrease or increase; maximize or minimize).

It is important to keep in mind the potential for long-term trends in resource health to affect perceptions of current conditions and to avoid bias associated with "shifting baseline" syndrome (Pauly, 1995), especially given recent declines in kelp cover in some regions. This will help to ensure that objectives are both achievable and oriented toward the appropriate baseline reference condition, as well as potential future environmental conditions for healthy kelp (Coleman et al., 2020; Corlett, 2016).

Once the objectives are articulated, the next step is to identify and map potential interventions or actions onto the objectives to identify candidate alternatives that could help to achieve means and fundamental objectives. The result is a rough depiction of how decision-makers think the system works. At this point, a conceptual model and a hypothesis that clearly link the problem statement and the objective(s) can help to identify appropriate alternatives in the next step of the process. Often there are multiple objectives that may be in conflict with one another or may not all be achievable given constraints. There are a variety of modeling approaches for evaluating multiple objectives in the decision context (see Conroy & Peterson, 2013; Gregory et al., 2012; Runge et al., 2013; Runge et al., 2020).

Box 7. Other types of objectives

These other types of objectives may complicate or affect the likelihood of a successful outcome (Conroy & Peterson, 2013).

» **Linked objectives** occur when means objectives need to be fulfilled sequentially in order to achieve the fundamental objective (e.g., when habitat must first be restored to reintroduce a depleted species). Paying attention to sequencing of actions is key to addressing linked objectives.

» **Hidden objectives** are fundamental objectives that were not defined early on, and arise even after all the fundamental objectives are achieved and stakeholders do not consider the problem to be resolved (e.g., wanting to rebuild an abalone fishery, but the interventions are only focused on restoring kelp and do not fully address the loss of abalone). This can be problematic and cause disappointment in outcomes if not addressed early in the process.

» **Stranded objectives** are fundamental objectives that will not be achieved because they are not linked to means objectives and actions that will achieve those outcomes. This can be the result of the problem being improperly or too narrowly defined or if the problem is not tractable because it lies outside of the decision control of the people involved (e.g., a water-quality objective that may not be able to be met by a resource management agency intervention but may require action by water-quality regulators). The result can be disappointment in the outcomes not meeting all objectives.

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5.0 IDENTIFYING ALTERNATIVES

Once the objectives are determined, Step 3 in the SDM approach involves identifying alternative actions that will meet the fundamental objectives and address the problem that has been identified. It is important to not reverse this process; too often, actions are taken without clearly understanding why and without an explicit link to the objectives (Runge & McDonald-Madden, 2018). One clear distinction between SDM and less-structured approaches is that SDM is values-focused decision making; the objectives should drive all decisions. Our natural tendency in the absence of a structured process is to rely on alternative-focused decision making and to choose between two or more options without considering what we value or hope to achieve.

Alternatives should be discrete actions or combinations of actions. Alternatives should be specific, predicted to achieve one or more objectives, and measurable with a common metric in order to be able to be evaluated one against another, in terms of their predicted performance at meeting the objectives. Generally, alternatives are identified based on prior efforts and an understanding of how the interventions might work, and their limitations and benefits. Given the nascent stage of kelp restoration, many alternatives may be untested or not fully proven. In the face of uncertainty about potential outcomes of different alternatives, pilot projects that test multiple alternatives in a study designed to provide comparative results can be very helpful. However, this should be done in the context of assessing the value of information to determine if the information gained through a pilot may influence future decisions (Smith, 2020). Finally, thinking outside the box can be useful, especially since kelp restoration is a relatively new endeavor. Thinking beyond the current set of activities to identify new and creative alternatives for achieving the fundamental objectives can help to challenge perceived constraints (Runge & McDonald-Madden, 2018).

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5.1 RESPONSE STRATEGIES BASED ON CONCERNS ABOUT KELP STATUS AND STRESSORS

The status of kelp, the nature of the stressors, and fundamental objectives should inform the range of alternatives to consider in an SDM process. The scale at which alternatives will be implemented is usually decided at the problem definition stage. The scale of action resulting from an SDM process or project may not match the scale of the overarching (or "global") problem. For example, kelp loss is widespread at the scale of Northern California, but the scale of a particular restoration project resulting from an SDM process is likely to be smaller. An SDM process may identify specific alternatives that exist along a continuum of response strategies; the choice of which might depend on the status of kelp (relative to historic variability) and the manageability of the stressors. An example of that continuum includes strategies ranging from status monitoring, to activities to avoid further losses, to active kelp restoration. In some SDM literature, monitoring is not included as an "action: or alternative; however, as the State of California evaluates current and potential future kelp loss, kelp status monitoring may constitute an "action" (see Section 9, Step 7), especially when it is tied to a decision to not take other actions (the "do nothing" alternative). Generally, maintaining healthy and resilient kelp forests and avoiding further kelp losses, when possible, is almost certainly cheaper and easier than actively restoring kelp forests. Interventions for active restoration of kelp forests are possible, but require significant investments and further understanding and testing, and should be grounded in science. These elements will enter into an SDM process when evaluating alternatives.

If kelp status is declining, threats to kelp abundance and productivity are evident, and managers and stakeholders are concerned, then direct interventions may be warranted to protect remaining stands of kelp against further losses, protect local spore supply, prevent further conversion to urchin barrens, and retain kelp ecosystem services. This may include reducing grazer abundance near remaining kelp (e.g., reducing urchin abundance), protecting predators of urchins or increasing their abundance (e.g., by reducing fishing pressure), and reducing other stressors (e.g., addressing water-quality issues, pollution, invasive species). Investing in kelp spore banking and genetic studies can help to offset further losses of genetic diversity and support selective breeding of more resilient kelp. Increased levels of management regulation including reduction or cessation of harvest may be warranted.

If current kelp status is of grave concern to managers, stakeholders or scientists, and is determined to be well outside the lower range of known variability with natural recovery appearing unlikely due to hysteresis or other factors, then direct intervention to restore kelp may be warranted. While some of the actions taken may be similar to those described above, they might need to be done with more intensity or larger spatial scales, or for longer periods of time. Restoration efforts should not be initiated until key stressors, at the scale of the intervention, have been abated. In addition, "future proofing" of restored kelp by active outplanting or seeding of strains tolerant to warm water may be among the alternatives needed in the face of changing ocean conditions (Coleman et al., 2020; Corlett, 2016).

5.2 CATEGORIES OF POTENTIAL INTERVENTIONS FOR MANAGING AND RESTORING KELP

Kelp restoration efforts have increased in recent years and there are projects around the world that have piloted a variety of approaches (see Eger et al. 2019). A list of kelp interventions that have been used in California is provided in Appendix 3 characterized into four broad categories. This list is meant as a broad toolbox of some potential alternatives, other alternatives may need to be included in an SDM process:

- **Monitoring the status of the resource:** Monitoring is not usually considered an "action" in SDM (see Step 7), but in cases where it is tied directly to an alternative (such as 'do nothing') then monitoring can trigger a change in a management decision. Here, monitoring is different than *process*, *implementation* or *performance* monitoring described in Step 7, where the monitoring is linked to an intervention following an SDM; in this context, kelp status monitoring may be used to trigger a decision or even trigger an SDM process. Monitoring of kelp forests in much of California is fairly extensive compared with other locations in the world, due to the presence of a large number of agencies and institutions, as well as the importance of kelp forests in the state. Common monitoring techniques in California include *in situ* ecological surveys using SCUBA, aerial surveys with manned and unmanned aircraft, remote sensing, and oceanographic and environmental monitoring (both *in situ* and from remote sensing).

- **Directly increasing kelp:** "Direct" methods of increasing kelp include regulating kelp harvest, culturing and outplanting kelp, and increasing habitat via artificial reefs. California kelp harvest management actions currently include: commercial and recreational regulations, and for commercial harvest there is a requirement of an annual commercial kelp harvest license; kelp bed leasing options that require approval by the FGC and require a kelp harvest plan; allowances for commercial harvest without a kelp-bed lease; a Commission-approved kelp-harvest plan for mechanical harvesters of giant kelp; and reporting of commercial harvest and royalty fees. Perhaps the easiest intervention to understand, yet the most challenging to enact, is the transplantation of kelp as a means to increase spore availability. Kelp might be transplanted from one area to another, or kelp aquaculture may be used to increase stock for outplanting or reduce pressure on wild kelp harvest. Finally, the creation of additional hard structure in the marine environment, through artificial reefs specifically for kelp restoration has been used in California and globally.

- **Indirectly increasing kelp through modification of species interactions:** There may be a number of ways to indirectly increase kelp though altering species interactions such as grazing, predation or competition. Restoring or promoting biological interactions can be a potential restorative tool, such as restoring lost apex predators as a mechanism to safeguard kelp-ecosystem resistance and resilience. For example, regulating fishing on urchin predators may alter kelp density through trophic effects. Restoration of urchin predators that have been lost to the system (e.g., sunflower seastars, otters) or removal of invasive species (e.g., *Sargassum* species) that may outcompete native kelps, can also have follow-on effects on kelp. Directly removing urchins to achieve densities at which kelps may regrow is of current interest in California and the subject of pilot projects. Past and newly developed methods for urchin removal include: manual removal (urchins collected on SCUBA/hookah, sometimes accompanied by amending recreational purple urchin fishing regulations to facilitate increased catch per day) and development of a commercial purple urchin fishery, as well as in-water methods such as hammering, quicklime, suction air lift, and trapping.

- **Improve kelp resilience by modifying surrounding ecosystem:** As noted, it is much easier and cheaper to protect existing kelp than it is to restore it. Improving resilience of existing kelp stands through Marine Protected Areas and/or improvements in water quality (including reducing pollution and sedimentation) should be considered in a list of potential alternatives.

6.0 PREDICTING CONSEQUENCES

After the alternatives are identified, the next step in the process (Step 4) is to predict the consequences of each alternative (that may include combinations of alternatives) to the best extent possible, given data limitations and uncertainty. How would each alternative action help to achieve the fundamental objective(s)?

6.1 EVALUATING POTENTIAL CONSEQUENCES OF ACTIONS

Most every decision in management and restoration requires evaluating a range of alternative actions against the objectives. To evaluate alternatives requires predictions, and to generate predictions, we must have some knowledge of the system dynamics based on evidence or data from past research, as well as insights into future changes or dynamics. A problem-specific conceptual model (such as Figure 3), can help to illustrate how the kelp system "works." For kelp restoration and management, predictions may be best made in a coupled socio-ecological framework, as humans are not divorced from natural systems. For example, many of the stressors of kelp dynamics are directly under the control of humans, while others are human caused but not necessarily controllable (Table 1). While values can drive the early steps of the SDM, such as problem formulation, the evaluation of the consequences of the alternative actions is a science-based process.

Some type of model, or collection of models, can be used to make predictions and compare the potential consequences of different management alternatives. Depending on the information available, this can be based on a simple conceptual model of how the system works, and expert elicitation or more rigorous quantitative models that can support this step (Conroy & Peterson, 2013; Runge & McDonald-Madden, 2018). The key is to ensure that the consequences link the measurable attributes of the objectives with the alternatives. If we select alternative *X*, how will it help to achieve objective *Y*? And how certain are we of that outcome? Often there are multiple objectives, with different measurable attributes that need to be met. Multiple objectives may be in conflict with one another, and they may differ in their importance to stakeholders and decision-makers. Alternative actions may need to be phased to achieve necessary interim outcomes (e.g., to address hysteresis before active restoration).

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6.2 PREDICTING CONSEQUENCES IN KELP CONTEXT

Predicting consequences of alternative actions to address kelp losses can be difficult and may include significant uncertainty given the early state of kelp restoration practice. Simple conceptual models, small pilot projects, and testing more than one alternative can help to improve predictions of consequences. Sources of uncertainty should be identified, as well as potential risks and adverse consequences of actions (and inaction). Investing in science addressing fundamental questions and data collection and learning from other locations can be a key strategy to reduce uncertainty.

A consequence table (Table 4) can be used to organize information on how each alternative links to the fundamental objectives (Runge et al., 2017). This approach requires predicting consequences for each alternative and using consistent metrics within an objective to allow for comparison across alternatives. The information in each cell can be qualitative or quantitative. These predictions should make the most of available information (including expert elicitation) and incorporate uncertainty. A ranking or weighting system can be used to compare alternatives across multiple objectives. Specific examples of consequence tables with the kelp examples are found in the case studies (Section 10).

Table 4. Template for a consequence table that links objectives and alternatives. For each objective, a measurable attribute (and desired direction) allows for comparison of how well each alternative is predicted to meet that objective. The template can include as many objectives and alternatives as necessary (adapted from Runge et al. 2017).

Measurable Attribute (units)	Desired Direction	Alternative 1	Alternative 2	Alternative 3
A common metric that can be used to compare how well each alternative will meet this objective	Increase, decrease, maximize, minimize	Predicted outcome for Alternative 1 to meet Objective 1	Predicted outcome for Alternative 2 to meet Objective 1	Predicted outcome for Alternative 3 to meet Objective 1
EXAMPLE OBJECTIVE: MINIMIZE FURTHER KELP LOSSES				
Kelp canopy loss (e.g. acres, relative to historic average)	Minimize kelp loss	**Alternative 1:** Do nothing Predicted outcome X acres	**Alternative 2:** Diver culling of urchins to levels below hysteresis threshold. Predicted outcome Y acres	**Alternative 3:** Trapping of urchins to levels around hysteresis threshold. Predicted outcome Z acres

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7.0 EVALUATING TRADE-OFFS

Once the potential consequences of the alternatives have been articulated, the next step in the process is to evaluate trade-offs among alternatives, both within and across objectives (Step 5). There are different categories of decisions that might require different analytical approaches to evaluating trade-offs, or whether trade-offs are necessary (see Box 8).

Box 8. Class or type of problem

How many objectives are there? Do they conflict? What is the level of uncertainty? How much risk is there? Below are the most common problem classes:

» **Simple optimization:** There is only one objective, and finding the solution is just a simple matter of searching and comparing. Trade-offs are not needed.

» **Multiple objectives:** There are multiple objectives that may compete, so trade-offs between objectives are needed. Multicriteria decision analysis is a common tool to evaluate trade-offs, and is probably the most common problem class for conservation.

» **Risk:** A decision has to be made in the face of uncertainty; uncertainty can't be reduced, so the best decision will depend on the risk tolerance of the decision maker or organization; decision trees are a common tool. Trade-offs depend on risk tolerance and the risk-reward relationship.

» **Information:** A decision is impeded by uncertainty that can be reduced if we collect enough information; a value of information analysis can determine the resources that should be spent on reducing uncertainty. This is also a very common problem class for conservation. Trade-offs depend on resources that are spent reducing uncertainty versus implementation of alternatives.

» **Portfolio:** The range of alternatives is very large, and the problem usually has two objectives (often cost and an effectiveness or benefit metric); optimization tools can be used to determine the set of alternatives that maximize the objectives. Trade-offs between objectives may be needed.

» **Dynamic:** A series of linked decisions; adaptive management falls in this category. Trade-offs between objectives are often needed.

7.1 EVALUATING TRADE-OFFS

For decision problems with a single primary objective, evaluating across alternatives to determine which single or combination of alternatives best meets that objective is fairly straightforward but depends on the degree of certainty in the predictive outcomes. Simple models, available data and expert judgement can be sufficient to identify the best alternative to meet the objective. More complex quantitative models or investing in additional information can be helpful to improve predictions of consequences to inform the analysis of trade-offs.

However, single objective problems are rare. At the very least, potentially competing objectives of conservation benefit and cost must be considered. Assessing trade-offs across multiple (and potentially competing) objectives is a different kind of decision-problem, and one that is very common in complex resource management contexts. In these cases, it may be necessary to reduce gains for one objective in order to better meet another, perhaps more important or necessary, objective. It is difficult for decision makers to evaluate trade-offs across more than a couple of objectives without assistance; for complex decisions, we often resort to rules of thumb or other cognitive shortcuts. In these cases, there are sets of tools that can assist decision makers to evaluate trade-offs in a transparent manner and incorporate input from a team or stakeholders.

There are two general classes of methods for solving problems with multiple objectives: Multi-criteria Decision Analysis (MCDA) and Multi-objective programming (Converse, 2020). MCDA is used in cases where we have a defined set of alternatives and need to evaluate trade-offs among the objectives, providing tools that can assist decision-makers to identify a preferred alternative or smaller set of alternatives based on the range of consequences for each objective across the alternatives. There are several classes of methods within MCDA, including the analytic hierarchy process, outranking methods and methods based on multi-attribute value or utility. Out of this set of tools, the Simple Multi-Attribute Rating Technique (SMART; see Goodwin & Wright, 2004; Runge et al., 2015) with swing weighting is commonly used in natural resource management.

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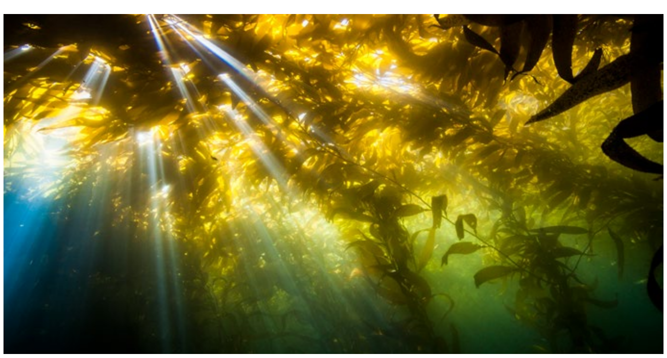
7.2 IDENTIFYING THE BEST ALTERNATIVE IN A KELP CONTEXT

The best alternative, or combination of alternatives, is selected by carefully evaluating the predicted outcomes, sources of uncertainty, and potential risks associated with the alternatives. Given the emergent status of kelp restoration and management efforts in California, predicted outcomes may have a high degree of uncertainty and may need to be designed as pilot projects to inform bigger investments. In many cases, the best alternative may be a combination of alternative actions that are designed and implemented as an experiment to promote learning. Given the limited resources available for kelp interventions, it is important to leverage information from previous studies and to identify the most important next steps and gaps that need to be filled. Understanding the type of decision being made (Box 8) and asking some key questions (Box 9) can help guide the evaluation of trade-offs. Some examples of predicting consequences and evaluating trade-offs are included in the kelp case studies (section 10).



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Box 9. Some key questions when evaluating trade-offs

- Are all the objectives equal or are some more important than others? (e.g., Maximizing kelp extent may be most important, but still needs to be evaluated for cost-effectiveness or other objectives).
- Do some objectives need to be achieved before others? (e.g., Linked objectives such as reducing urchin density before restoring kelp.)
- How does the 'no-action' alternative compare to alternatives to take action? (e.g., What is the risk of doing nothing? Will further kelp losses be an acceptable outcome?)
- Are all the alternatives (including combinations of alternatives) being evaluated complete solutions? (e.g., Will a combination of urchin removals and predator restoration be more effective than either action on its own?)
- Are the logistical, financial, or regulatory constraints captured as objectives to inform trade-offs? (e.g., Cost effectiveness is almost always an objective that needs to be evaluated.)
- What are the risks and uncertainties associated with each alternative, including no-action? (e.g., How certain are we of predicted outcomes from kelp outplanting techniques? How risky is it if we are wrong?)

8.0 MAKING DECISIONS

The evaluation of tradeoffs leads to the identification of alternatives that are predicted to be successful at achieving the desired objectives; however, those outcomes are not assured given uncertainty in predicted future outcomes, environmental stochasticity, and other unforeseen events. Making informed decisions (Step 6) does not guarantee good outcomes, but it should improve the chances of success and should inform learning (Bottrill et al., 2008; Conroy & Peterson, 2013).

8.1 MAKING DECISIONS IN THE FACE OF RISKS AND UNCERTAINTY

Making decisions inherently involves tackling uncertainty and determining an acceptable level of risk. Uncertainty can be incorporated in the decision process through the evaluation of alternative models for how the system may respond and use of statistical distributions to represent error and environmental variability. While uncertainty should be accounted for, uncertainty does not necessarily have to be resolved in order to make informed decisions (Conroy & Peterson, 2013).

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Understanding what new information is pivotal and when that new information can significantly improve the predictions needed to make a decision will help inform when to invest in research or monitoring, instead of more direct restoration interventions. Sometimes collecting more data and adding new information to the decision process can help to reduce uncertainty, but it should not be used to delay taking action unless this investment in new information will substantially change the decision or improve the outcome of the decision (Moore & Runge, 2012). Using time and resources to fill information gaps will likely delay action and may not improve the conservation outcome. Taking action at small scales and through pilot projects can help to fill gaps in information needed to reduce uncertainty and inform the restoration or management process.

Decisions can be made to take action even in the face of high uncertainty, if potential risks are deemed acceptable. The risk perceptions and risk tolerance of the decision maker is an important factor; risks can be evaluated, communicated, and sometimes mitigated.

8.2 ENABLING CONDITIONS TO SUPPORT DECISIONS AND INVESTMENTS IN KELP INTERVENTIONS

Resource-management decisions are always made in the context of a broad array of stakeholder, regulatory, logistical and financial considerations. Decision making can be considered as hierarchical, whereby higher-level decisions might be focused on strategies at broader spatial and temporal scales, perhaps building upon a high-level management plan (e.g., a kelp management plan). Once a strategy has been developed, another decision process could focus on project implementation and explicitly consider more local enabling conditions.

Enabling conditions enter the SDM process at multiple stages including problem setting (Section 3), alternatives (Section 5) and making decisions (this section). In the kelp context, making a decision on the best alternatives will depend, to some extent, on enabling conditions and constraints such as the:

- Spatial location of the kelp forest (e.g., inside a protected area, in a kelp harvest lease area, etc.) and associated regulatory context;
- Other resource management considerations (e.g., fishery management regulations, permitting, etc.);

- Capacity and interest by partner organizations and funders;
- Importance of the site and the problem to stakeholders;
- Socio-economic impacts of kelp losses in this area;
- Logistical or feasibility of actions (e.g., accessibility, scale); and
- Available financial and technical resources.

While these constraints should be built into the process and considered at earlier stages, the selected alternative at the decision step should address the underlying constraints and opportunities. The SDM approach can help to elucidate constraints and, through a careful process, identify ways to challenge and potentially overcome existing constraints by bringing a broad array of stakeholders and policy makers together around what needs to happen.

8.3 MAKING DECISIONS IN AN ADAPTIVE MANAGEMENT CONTEXT

An adaptive approach to decisions and investments is needed in the face of the uncertainty and environmental change characteristic of kelp forest ecosystems. Adaptive management is an ongoing cycle of learning that is comprised of a structured, iterative process of robust decision making in the face of uncertainty (Walters, 2002). Kelp management or restoration activities should be designed with explicit hypotheses of how actions will lead to desired outcomes, as well as how monitoring of changes in kelp resource conditions over time can inform understanding of the effectiveness of management or restoration actions. Understanding when new information will add significant value—and would inform better decisions—can help to guide investments in science and monitoring (Runge, 2020; Runge & McDonald-Madden, 2018; Runge et al., 2011).

9.0 ACT, MONITOR AND LEARN

Taking action by implementing the preferred alternative and incorporating monitoring and learning is the last and most essential step of the SDM approach (Step 7), without which one cannot effectively do adaptive management (Conroy & Peterson, 2013). Robust monitoring of several types (see Box 10), as well as designing programs to facilitate the gathering of new information, are important elements of adaptive management. Gathering and incorporating new data or knowledge can happen at any step of the SDM process, and when incorporated meaningfully, it can allow for mid-project course corrections and adaptive management to reduce uncertainty and increase efficiency. Monitoring supports flexible decision making and can allow for modifying existing activities or creating new activities if new scientific information indicates that projects are not meeting their goals.

Pre- and post-implementation monitoring is needed to know whether project objectives are being achieved. Monitoring should be conducted on all types of projects. Project objectives could be, for example, related to the delivery of ecosystem services from the restored kelp area, or may relate to the programmatic or social aspects of the project design, such as community participation or resource manager acceptance. Regardless of the type of objective, monitoring and assessment will allow for refinement or course correction as a project moves forward.

Monitoring is also essential for reducing uncertainties in decision making, especially through pilot projects that test assumptions or methodologies before bigger investments are made. For example, a current uncertainty in California is the spatial scales at which herbivore removal can be sustained. Designing pilot urchin removal projects to test this can reduce uncertainty in future project design, while simultaneously working to restore a site. Another example is around the uncertainty in the spatial connectivity of kelp patches and natural recovery rates. Reducing uncertainty in that domain might inform whether to take a direct restoration approach, such as outplanting versus a passive "watch" approach assuming natural recovery.

9.1 DESIGNING MONITORING

Developing a monitoring plan early in a project will help to identify resources needed, timelines for data collection, and potential risks (Conservation Measures Partnership, 2020). Monitoring a kelp restoration project should include ecosystem monitoring (e.g., biological, nutrients, water temperature, etc.) to align with project goals and objectives, with indicators to inform outcomes and follow-on actions. A key aspect is that the monitoring program needs to be linked explicitly to the project objectives or goals to inform learning and adaptive management. Monitoring of criteria explicitly identified in stakeholder processes is necessary to gain support for adaptive changes in approach. Building on existing programs can be a cost-effective way to monitor, as long as the collected data address the objectives.

Decisions about who will do the monitoring are also important to make early in the process. For many habitat restoration programs, success has come from the involvement of stakeholders or interested community members. While the subtidal nature of kelp habitat may limit participation, there may still be opportunities for engagement between the community, scientists and managers. Thought should be given to how, when and what form this involvement will take (e.g., co-created to collaborative to cooperative science (Shirk et al., 2012). In California, there are a number of ecosystem-monitoring programs for kelp habitat that range from *in situ* SCUBA surveys to remote-sensing tools (see Appendix 1). Finally, development of a set of minimum universal metrics or indicators (e.g., performance criteria) that can be shared across programs both within California and globally, will enhance the impact of a project. Examples of potential ecological and environmental metrics are provided in Table 1. Other project-specific metrics might also be needed. Systematic monitoring and effective communication of results within programs will inform restoration management and improve outcomes of future projects.

The specific design of kelp-ecosystem monitoring and evaluation for restoration is based upon a wide variety of considerations, including:

- Clearly articulated and realistic goals and objectives: What question(s) is the kelp monitoring program intended to answer?
- Hypotheses and predicted responses of resources and ecosystems to interventions: What are the stressors and drivers, and what is the conceptual model of how kelp forests function currently and historically?
- Objective-based indicators of system response: What variables or indicators will be measured (e.g., density or biomass of urchins, kelp or abalone, temperature, nutrients)?

- Informed estimates of the spatial and temporal scales of system response: What temporal and spatial scales do kelp ecosystem processes operate and populations and communities respond?

- Identifying sources of uncertainty, sampling bias and variance in response variables: What are the prior patterns of kelp variation? What still needs to be learned?

- Identification of appropriate reference or control sites (e.g., non-restoration sites): Where will kelp restoration be done? Are there “appropriate” control sites? Can these sites be monitored?

- Appropriate analytical models (e.g., BACI— before-after-control-impact): Does the analysis provide statistical power, the ability to detect real outcomes against the background of natural environmental variation, measurement error and uncertainty?

- Balancing sampling requirements with financial and environmental constraints: Can monitoring be funded and implemented for as long as needed?

9.2 KELP INTERVENTIONS AS “EXPERIMENTS” OR “ADAPTIVE MANAGEMENT”

Given that kelp restoration is an emerging discipline and oceanographic conditions are quite stochastic, kelp restoration projects should be thought of and designed as experiments. Properly designed restoration projects can test techniques, cost-effectiveness, spatial and temporal scales, and durability (e.g., when does kelp become self-sustaining?). If possible, data should be gathered before, during and at appropriate time scales following intervention, which will allow for a before-after-control-impact (BACI) analysis. The length of time for post-intervention monitoring will depend on the questions and could be short-term (to test the effectiveness or measure the costs of implementation) or long-term (to track community succession or fisheries rebuilding). By taking an experimental approach, a restoration project can inform future projects—and become adaptive management. At a minimum, monitoring and assessment need to happen in a way that will allow for measurement of success of the project but ideally, both the restoration action and the monitoring will be designed in a way to allow comparison among similar projects (e.g., across California and internationally).

Box 10. Types of monitoring

Note some metrics might be shared across different types of monitoring.

» **Process monitoring:** Was the process efficient? Did the process impact the success of the intervention? Was the process fair and equitable?

» **Implementation monitoring:** Did the intervention (or restoration) work? (E.g., were urchins removed over *X* acres or to *Y* density? Did kelp outplants survive?)

» **Performance monitoring:** Did the intervention achieve the fundamental objective and have the desired habitat effect on populations, communities or ecosystems? (E.g., did the restoration result in *X* area of kelp biomass? Did the restoration result in kelp recruitment or increase fish recruitment? Did the restoration restore abalone populations?)

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10.0 HYPOTHETICAL CASE STUDIES

Hypothetical case studies that reflect real kelp management issues in California are used as examples to help illustrate the steps in an SDM approach. Note these are merely examples and do not reflect actual SDM processes, stakeholder values, agency priorities or existing projects. The hope is to provide a template or model upon which kelp SDM pilots could be built to address real decision problems. These examples include:

- **Hypothetical Case Study 1:** A relatively simple multiple-objective problem to evaluate trade-offs between two objectives focused on kelp monitoring (Box 11).
- **Hypothetical Case Study 2:** A more complex multiple-objective problem to evaluate trade-offs among objectives to identify the best alternative for urchin removals to defend kelp forests (Box 12).
- **Hypothetical Case Study 3:** A linked-objectives problem, where achievement of the fundamental objective depends on sequential achievement of other objectives in kelp restoration (Box 13).

Box 11.

Hypothetical Case Study 1

This is a relatively simple multiple-objective problem to evaluate trade-offs between two objectives focused on kelp monitoring.

DECISION CONTEXT

A consortium of partners, in collaboration with the state regulatory agency, are trying to decide how to best design a monitoring approach to assess kelp extent statewide, at least annually, to support kelp restoration and management efforts. This monitoring also needs to be as cost-effective as possible. Based on this decision process, the partners will decide to make investments in testing and demonstrating kelp monitoring approaches to assess the extent of canopy kelp across one region, with potential to scale statewide.

Background: Year-over-year fluctuations in kelp biomass coupled with a recent marine heat wave present concerns; as water temperatures continue to rise, the resilience of kelp forests along a significant stretch of coastline may be threatened. The coastline is generally accessible and well-researched. Though otters and sunflower sea stars are locally extinct in the region, other urchin predators are present. Nutrient and pollution inputs are localized but managed.

Scale of the problem: Region-wide

Species of canopy kelp: Giant kelp (perennial)

Kelp loss drivers/stressors:

- Warming waters due to climate change; episodic marine heat waves [*unmanageable*]
- Wave exposure is mild to moderate [*unmanageable*]
- Reduction of predator control of urchin [*manageable*]
- Site specific increase of urchin numbers [*manageable*]
- Nutrients and pollution and sediment contribute to kelp forest health [*manageable*]

Values: Kelp forests support substantial fisheries and tourism industries and contribute significantly to the regional economy and cultural value; managers need to track kelp abundance over time in order to make management and restoration decisions.

STRUCTURED DECISION MAKING APPROACH

STEP 1 | Problem Statement: How can we monitor and assess the extent of kelp region-wide to inform management; and collect this information consistently and within a limited budget?

STEP 2 | Objective Setting: What do we hope to achieve?

- *Fundamental Objective 1:* Maximize spatial extent of kelp monitored and optimize spatial and temporal resolution to support management decisions and actions.
- *Fundamental Objective 2:* Minimize costs.

STEP 3 | Alternatives: What can we do? These are examples of potential alternatives or combinations of alternatives to meet objectives:

A. Occupied aircraft surveys

B. Satellite imagery

C. Unoccupied aircraft (drones)

D. Combination of satellite imagery and unoccupied aircraft (drones).

Box 11.

STEP 4 | Consequences: How will alternative actions achieve desired objectives? These are potential alternatives that could meet objectives. (Note: the predicted outcomes presented here are hypothetical to illustrate trade-offs.)

Measurable Attribute	Direction	Alternative A: Occupied aircraft	Alternative B: Satellite imagery	Alternative C: Unoccupied aircraft (drones)	Alternative D: Combination of satellite and drones
OBJECTIVE 1: MAXIMIZE KELP EXTENT THAT IS MONITORED					
Extent of kelp monitored on a seasonal to annual basis (geo-referenced kelp extent in m^2)	Maximize	Annual, region-wide extent at high resolution. *Notes: High logistical constraints and moderate risk that survey could not be completed due to air quality, weather or ocean conditions.*	Open-access imagery collected monthly, region-wide, at medium resolution. *Notes: Low risk; covers region well except nearshore margin and sparse kelp forests due to sensor limitations.*	Conducted at small spatial scales; could cover much of region with multi-week deployment in one season at highest resolution. *Notes: Hard to conduct surveys at large spatial scales; limited to near-shore; limited by weather conditions, but quickly deployed; labor intensive.*	Could cover region at medium resolution and cover priority sites (or to fill gaps) at highest resolution. *Notes: Use drones to fill coastal margin gaps that satellite imagery misses.*
OBJECTIVE 2: MINIMIZE COST					
Total annual cost (dollars)	Minimize	$$$$ (high)	$ (low)	$$$ (medium-high)	$$ (medium)

STEP 5 | Trade-Offs: What are the trade-offs among objectives and alternatives?

A. *Occupied aircraft:* The high spatial resolution data from occupied aircrafts may be beneficial for many purposes but is above the necessary threshold to meet Objective 1; there are significant risks of not being fully implementable each year (due to flying conditions). Due to high cost of data collection, would not meet Objective 2.

B. *Satellites:* Open access, medium resolution satellite imagery (such as Landsat) could provide cost-effective regionwide coverage at high temporal scales, with some spatial limitations at coastal margins; thus not fully meeting Objective 1, but at a cost less than occupied aircraft.

C. *Unoccupied aircraft/drones:* provide the highest-resolution data; however, they are limited to nearshore areas and may not capture kelp further offshore due to connectivity constraints with a ground controller. Drones are nimble, able to be deployed at specific sites with flexible timing to meet specific needs or address gaps. Drone surveys are labor-intensive and data processing is expensive at large scales; drones alone would likely not meet Objective 1 and/or Objective 2.

D. *Combination of satellite imagery and drones:* would enable tracking kelp trends region-wide with medium resolution combined with higher resolution drone data used strategically to fill gaps in satellite coverage and for focal sites or areas of concern. This combination would meet Objective 1 and Objective 2.

STEP 6 | Decision: What should we do to best achieve our objectives? Moderate spatial and temporal resolution of satellite imagery will meet Objective 1 at large spatial scales and at a lower cost than occupied aircrafts or drones. Drones can be used to survey sites where understanding kelp abundance at small spatial scales and higher temporal resolution may be critical. Labor and risk are minimized with satellites and drones combined; costs are moderate. Alternative D most reliably meets Objectives 1 and 2; however, this will require investment in labor and expertise to deploy resources and manage both data streams.

STEP 7 | Act, Monitor and Learn: Can we design interventions and monitoring to advance learning? Use existing data to compare resolution, spatial extent and utility of both satellite imagery and drone data to design monitoring protocols that will meet management needs. Pilot Alternative D for two years with appropriate monitoring of outcomes to determine whether objectives can be met, and at what cost. Adapt as needed.

Box 12.

Hypothetical Case Study 2

This is a more complex multiple-objective problem to evaluate trade-offs among objectives to identify the best alternative for urchin removals to defend kelp forests.

DECISION CONTEXT

State managers are trying to decide whether and how to intervene to address patchy losses of kelp and concerns about growing abundance of urchins and urchin barrens in a subregion. A decision on whether and how to intervene will allow managers to provide resources, permits, and support to implement specific projects aimed at management objectives.

Background: The region contains both giant kelp and bull kelp. In response to recent marine heat wave and generally warming waters, reefs within the region have experienced increased spatio-temporal variability of kelp canopy extent, switches in dominance between kelp species, and in some cases, phase shifts to urchin barrens. Sunflower sea stars are locally extinct, but otters are present with healthy populations. This is a populous area that supports an active group of stakeholders interested in kelp forests, a major driver of the economy in the region.

Scale of the problem: Mosaic of urchin barrens, degraded kelp forests, and healthy kelp forests of both species throughout a subregion.

Species of canopy kelp: Bull kelp (annual), giant kelp (perennial)

Kelp loss drivers/stressors:

- Warming waters and episodic marine heat waves due to climate change [*unmanageable*]
- Wave exposure is variable within the region and known to drive kelp species dominance [*unmanageable*]
- Reduction of predator control of urchins [*manageable*]
- Patchy explosion of urchin numbers [*manageable*]
- Kelp removed by grazing urchin fronts [*manageable*]

Values: Local tourism sector is concerned about kelp loss, as is an active recreational dive community. Loss of kelp forests would mean regional economic impacts and a loss of identity, as well as impacts to ecological connectivity, genetic diversity, ecosystem function and resilience.

STRUCTURED DECISION MAKING APPROACH

STEP 1 | Problem Statement: How can we maintain kelp forest extent above thresholds (e.g., within historic variability) within the subregion in the face of urchin grazing pressure?

STEP 2 | Objective Setting: What do we hope to achieve?

- *Fundamental Objective 1:* Constrain the expansion of urchin barrens and promote persistence of remaining kelp within the subregion to protect spore supply (measurable attributes: urchin density, m^2 or # of persistent kelp forests).
  - Means Objective 1a: Reduce urchin grazing pressure on kelp by reducing mean urchin density below hysteresis threshold (2 urchin/m^2).
  - Means Objective 1b: Defend priority kelp forests to promote persistence of kelp (m^2 kelp or # of kelp forests persisting).

Box 12.

- *Fundamental Objective 2:* Maximize recreational diver opportunities to engage on this problem (measurable attributes: # of divers engaged or diver days).
  - Means Objective 2: Involve local recreational dive and community science monitoring groups in the project.
- *Fundamental Objective 3:* Minimize costs (measurable attribute: dollars).

STEP 3 | Alternatives: What can we do? These are examples of potential alternatives or combinations of alternatives to meet objectives.

A. Volunteer divers conducting urchin removals; random locations (uncoordinated effort)

B. Paid professional divers conducting urchin removals; directed to priority kelp forests

C. Paid urchin trap fishing; directed to priority kelp forests

D. Combine volunteer-diver urchin removal and monitoring with paid urchin trap fishing; both directed to priority kelp forests

STEP 4 | Consequences: How will alternative actions achieve desired objectives? (Note: These predicted outcomes are hypothetical and qualitative to illustrate trade-offs.)

Measurable Attribute*	Desired Direction	Alternative A: Volunteer diver removal; random locations at site	Alternative B: Paid diver removal; directed to priority locations	Alternative C: Paid urchin trap fishing; directed to priority locations	Alternative D: Trap fishing, followed by directed volunteer removals and monitoring
MEANS OBJECTIVE 1A: REDUCE URCHIN GRAZING PRESSURE					
Urchin density (urchins/ m^2)	Minimize	Moderate effectiveness at achieving hysteresis threshold. *Note: relatively low accountability***	High effectiveness at achieving hysteresis threshold. *Note: high accountability***	Unknown but potentially high effectiveness at achieving hysteresis threshold. *Note: unknown accountability***	Moderate to high effectiveness at achieving hysteresis threshold. *Note: moderate to high Accountability***
MEANS OBJECTIVE 1B: EXTENT OF PERSISTENT KELP					
Amount of kelp persisting in priority kelp forests (m^2 kelp)	Maximize (max = 10 sites)	Estimate 2 sites or approximately "X" m^2 kelp (Low effectiveness)	Estimate 6 sites or approximately "3X" m^2 kelp (Moderate effectiveness)	Estimate 8 sites or approximately "4X" m^2 kelp (Moderate-high effectiveness)	Estimate 8–10 sites or approximately "4-5X" m^2/kelp (Moderate to high effectiveness)
FUNDAMENTAL OBJECTIVE 2: ENGAGE RECREATIONAL DIVE GROUPS					
Number of divers engaged (diver days)	Maximize	High engagement (X divers/days)	No engagement	No engagement	High engagement (X divers/days)
FUNDAMENTAL OBJECTIVE 3: MINIMIZE COST					
Total cost (dollars)	Minimize	$ (low)	$$$ (high)	$$ (medium)	$$-$$$ (medium-high)

*This is just an example, a real SDM analysis would be based on pilot efforts and actual estimates of relative costs and amounts of urchins that each method could remove.

**We define accountability in this context as the ability to control and measure the actions taken. This will affect risk of the action as well as the ability to learn from the action.

Box 12.

STEP 5 | Trade-Offs: What are the trade-offs among objectives and alternatives?

A. Volunteer divers removing urchins randomly are hard to coordinate in large-scale efforts. Benefits include free labor and enhancement of community awareness, involvement and support of programmatic objectives. Effectiveness and accountability are likely lower than other methods.

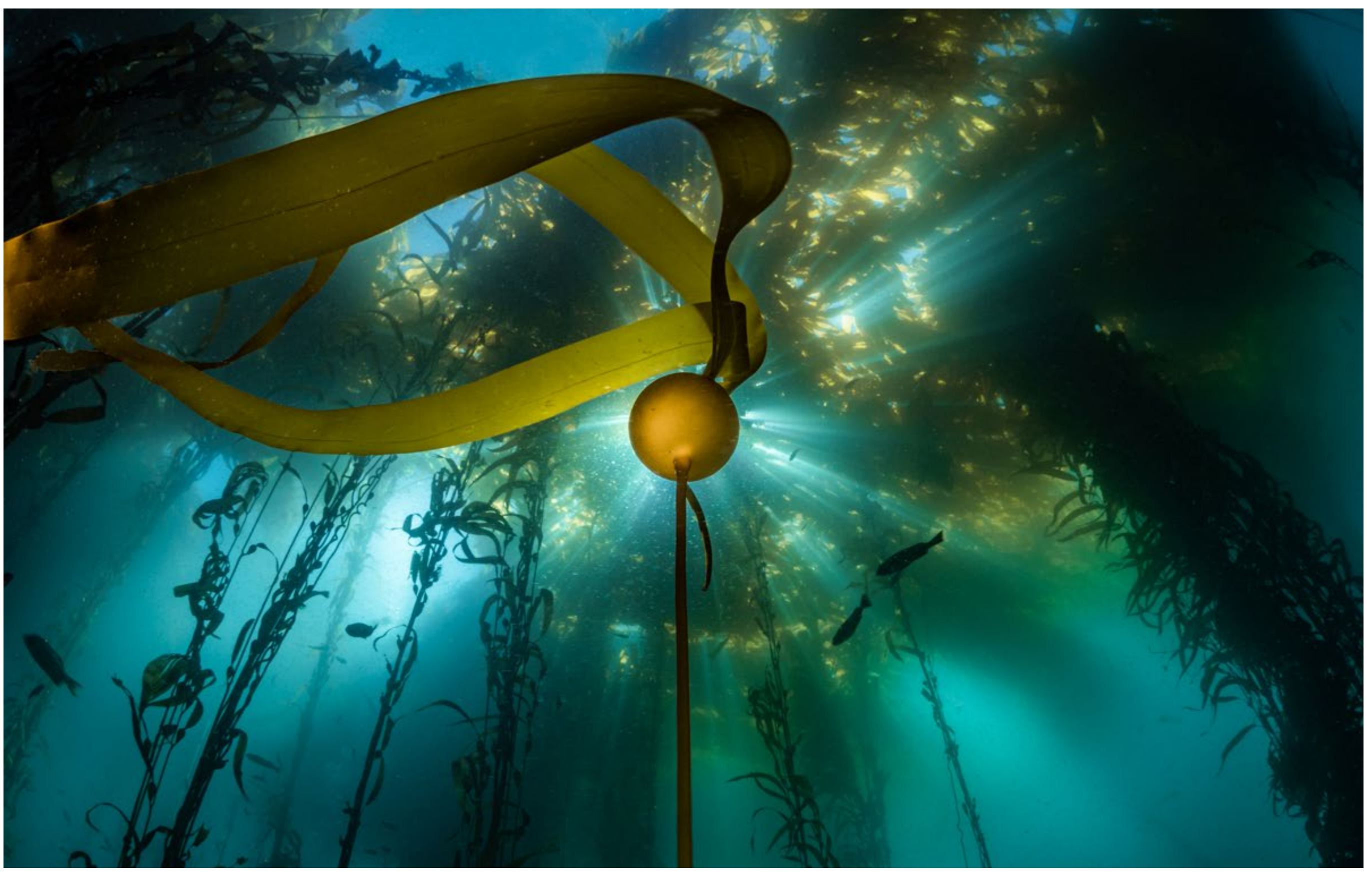
B. Paid diver removal directed to priority locations is highly effective, with high accountability; however, it is also very expensive and does not involve community science.

C. Paid urchin trap fishing, directed to priority locations, is still very experimental but may be effective and cost-efficient. However, without some sort of in-water monitoring of urchin density remaining after trapping, the accountability is quite low, and this alternative does not involve community science.

D. Directed experimental trap fishing around priority kelp forests followed by volunteer diver removal and monitoring of urchin density could provide a cost-effective first-line defense, with high accountability and significant community involvement.

STEP 6 | Decision: What should we do to best achieve our objectives? Targeted urchin removals in and around priority kelp forests will be most effective at meeting Objective 1. Given the cost and effectiveness of the alternatives, Alternative (d) could most effectively meet all three Objectives by combining the effectiveness of trapping with in-water divers for additional removals and monitoring. It is also important to note that there are regulatory and permitting constraints that would have to be addressed to implement this decision.

STEP 7 | Act, Monitor and Learn: Can we design interventions and monitoring to advance learning? Conduct Alternative D in a pilot project with rigorous scientific design, and with associated implementation and performance monitoring, to understand the efficacy of each approach and impact on urchin density, kelp extent, and community engagement.



Box 13.

Hypothetical Case Study 3

This is a linked objectives problem, where achievement of the fundamental objective depends on sequential achievement of other objectives in kelp restoration.

DECISION CONTEXT

Catastrophic kelp loss across a region and closure of the abalone fishery have raised concerns of managers and stakeholders who want to see the return of healthy kelp forests and the fisheries they support. The resource manager needs to decide on a course of action to promote the recovery of kelp forests and other associated resources (e.g., abalone). Given high uncertainty, the manager plans to start with a pilot project at a priority site. An SDM process could be initiated with stakeholders to frame the problem and identify the many steps needed to recover or restore kelp and associated species over time.

Background: All but 5% of bull kelp across a region has disappeared due to warming waters, loss of urchin predators, and explosion of purple urchin populations. Much of the coast throughout this region is rough and inaccessible. Plagued by warm water events and tipped into hysteresis by an outbreak of urchin, Swimmer's Cove, once filled with bull kelp and a valuable commercial and recreational fishing area has transitioned to an urchin barren. There is limited kelp spore supply within a reasonable distance, limiting natural recovery of kelp.

Scale of the problem: Region-wide. Decision scale is at the individual pilot site, Swimmer's Cove.

Species of kelp: Bull kelp (annual)

Kelp drivers/stressors:

- Warming waters and episodic marine heat waves due to climate change [*unmanageable*]
- Wave exposure is variable within the cove [*unmanageable*]
- Reduction of predator control of urchin [*manageable*]
- Explosion of urchin numbers [*manageable*]

Values: Recovery of kelp and reopening of recreational fishery (abalone) and commercial fisheries. Tourism and recreation fuel local economy. Kelp forests, and key organisms such as abalone and fish, in Swimmer's Cove provide a core sense of identity for local community.

STRUCTURED DECISION MAKING APPROACH

STEP 1 | Problem Statement: How can we restore a significant patch (at least 3 acres) of self-sustaining kelp in Swimmer's Cove despite catastrophic losses and overabundance of purple urchin? And can we eventually restore and maintain enough kelp to provide habitat for important species (e.g., fish and abalone)?

STEP 2 | Objective Setting:

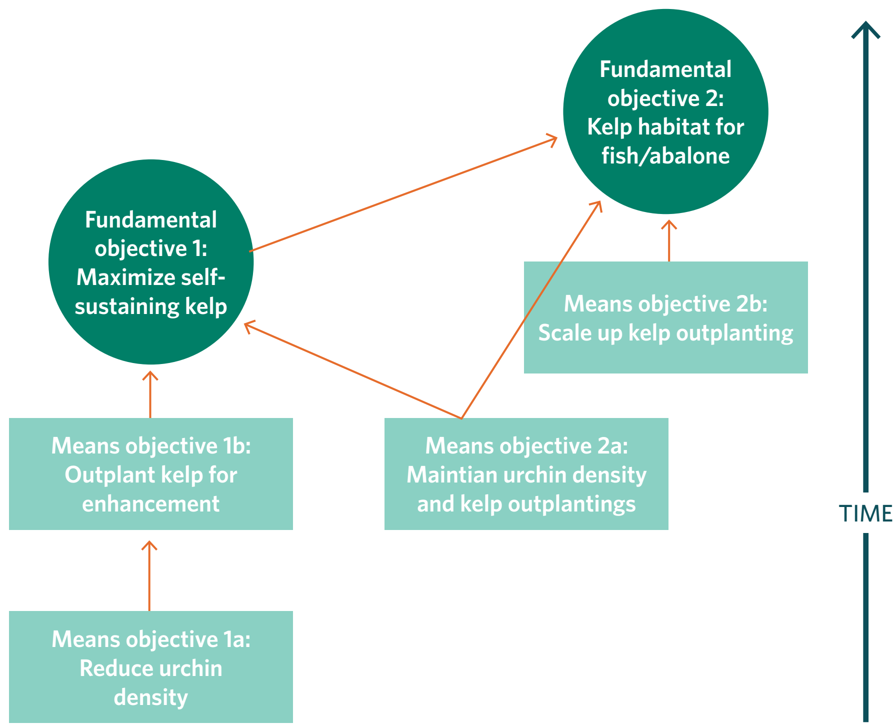
- *Fundamental Objective 1:* Maximize amount of self-sustaining kelp in three-acre test plot (measurable attribute: acres).
  - Means Objective 1a: Minimize urchin abundance (must be below hysteresis threshold) to prepare site for restoration and facilitate natural recovery.
  - Means Objective 1b: Outplant kelp sporophytes or spores to enhance natural recovery.

Box 13.

- *Fundamental Objective 2:* Maximize kelp habitat in the cove to support important fish species and abalone (measurable attributes: acres of kelp, presence of key species).
  - Means Objective 2a: Maintain urchin density and kelp enhancement, as needed.
  - Means Objective 2b: Scale up outplanting of kelp sporophytes or spores, using best method from Means Objective 1b, to maximize kelp habitat.

Fundamental Objective 3: Minimize costs (measurable attribute: dollars)

This is an example of linked objectives that require sequencing of decisions and actions, as shown in the figure below. Mapping out linked objectives can help to inform sequential decisions and ensure stakeholders understand all the steps needed to achieve the fundamental objectives. In this case, Fundamental Objective 1 must be completed before Fundamental Objective 2 may be achieved. Means Objective 1a needs to be completed before effort begins on Means Objective 1b. Means Objective 2a supports both Fundamental Objectives 1 and 2.



STEP 3 | Alternatives for Means Objective 1b: The alternatives and predicted consequences to meet Means Objective 1a may be similar to Hypothetical Case Study 2 and need to be achieved before Means Objective 1b. This example consequence table focuses on achieving Means Objective 1b—enhancing kelp to support a self-sustaining patch. (Note: An analysis of alternatives to meet Means Objectives 2a and 2b would follow, but is not included here).

Examples of Alternatives to meet Means Objective 1b: These methods are relatively untested, so predictions of consequences have high uncertainty. Additionally, there are regulatory and permitting constraints that would have to be addressed for each method.

A. Green gravel seeded with kelp sporophytes

B. Bags of kelp spores tied to seafloor

C. Outplant sporophytes from nursery stock

D. Combination of green gravel and spore bags

Box 13.

STEP 4 | Consequences: How will alternative actions achieve Means Objective 1b (Outplant kelp)? (Note: these predicted outcomes are hypothetical to illustrate trade-offs.)

Measurable Attribute* (units)	Desired Direction	Alternative A: Green gravel	Alternative B: Bags of spores	Alternative C. Out plant sporophytes	Alternative D. Combo of green gravel and spore bags
MEANS OBJECTIVE 1B: SELF-SUSTAINING KELP FOREST					
Kelp extent (acres)	Maximize	Easy to seed multiple acres; but survivorship rate unknown	Easy to seed multiple acres; but survivorship rate unknown	Could cover up to 3 acres at low density; survivorship rate unknown	Combination of green gravel and spore bags to cover multiple acres; survivorship rates unknown
FUNDAMENTAL OBJECTIVE 3: COSTS					
Total cost (dollars)	Minimize	Moderate-low cost	Low cost	High cost	Low-moderate cost

*This is just an example. A real SDM analysis would likely be based on pilot efforts and estimates of relative costs and effectiveness of each methods.

STEP 5 | Trade-Offs: What are the trade-offs among objectives and alternatives?

A. *Green gravel:* Demonstrated elsewhere to have many benefits including being cost-effective; able to cover large areas of reef simply by being dropped from boat, without divers. Relatively low nursery effort. The effectiveness is uncertain in this setting; a concern is that small sporophytes on gravel will be washed away or damaged by wave action and turbulence.

B. *Bags of spores:* The simplest approach, bags of kelp blades with sori could be dropped from boats without divers, or anchored by divers to prevent being washed away. No nursery effort needed, and negligible impact to source sporophytes. Needs appropriate season and substrate for gametophytes to recruit. Effectiveness uncertain.

C. *Outplant nursery grown sporophytes:* The most complex and expensive approach, with nursery and field effort needed. Estimated lowest number of sporophytes per dollar spent—but each sporophyte would likely have a higher probability of success due to larger starting size and careful anchoring.

D. *Combination of green gravel and spore bags:* This could be tested at the same location under pilot experimental scenario to evaluate effectiveness of cheapest options. Keeps costs low to moderate, and allows assessment of the effectiveness of two scalable techniques for bull kelp.

STEP 6 | Decision: What should we do to best achieve Means Objective 1b? Given the dire state of kelp in the region, there is a need for improving information to scale up kelp restoration; therefore, set up the kelp enhancement as an experiment to improve understanding and demonstrate the value of new information to inform subsequent efforts. Given the cost objective, test the most cost-effective and scalable methods first. For this example, that would include testing green gravel and spore bags in urchin-cleared plots (Alternative D). It is also important to note that there are regulatory and permitting constraints that would have to be addressed to implement this decision. Upon completion of the pilot project, adapt and expand upon most cost-effective alternative(s) to increase patch size and number of restored patches to promote connectivity and natural recovery of fish and abalone habitat in later phases (Fundamental Objective 2).

STEP 7 | Act, Monitor and Learn: Can we design interventions and monitoring to advance learning? Implementation monitoring (e.g., success and cost effectiveness of the two methods) and performance monitoring (e.g., urchin density, kelp plant and patch size, as well as habitat use of restored patches by fish and abalone) are both needed. Lessons learned can then be applied to other sites in an ecologically connected network of patches of restored kelp to act in a source-sink metapopulation.

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11.0 CONCLUSION

Incorporating SDM approaches into kelp restoration and management can help to promote transparency in decision making, and support learning and adaptive management. Even a semi-formal use of the steps in SDM can improve decision making of all types, by different kinds of decision makers and at different scales. A variety of SDM resources and trainings are available to go deeper into decision science and practice (see Box 14). A more structured approach to decision making is especially useful when the stakes are high, there are many stakeholders involved, there is a large amount of uncertainty, or there is a lack of clarity on the best interventions. To a large extent, those conditions describe California and many other locations—where the natural dynamics of kelp, complexity of kelp drivers and stressors, and concerning losses pose a big challenge to management and recovery of these important ecosystems.

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Box 14. Additional Resources to Support Structured Decision Making

In addition to overview books and publications (such as Conroy and Peterson 2013, Gregory et al. 2012, Runge et al. 2020, Runge et al. 2013) there are other SDM training and guidance resources available:

- U.S. National Fish and Wildlife Service, National Conservation Training Center. *"An Overview of Structured Decision Making"* (Runge et al., 2017) and other training courses at https://training.fws.gov/
- www.structureddecisionmaking.org A website that lays out key steps, tools and case studies, based in part on the book *Structured Decision making: a practical guide to environmental management choices* by Robin Gregory et al., Wiley Press.
- *Structured decision making: Using decision research to improve stakeholder participation and results.* Robyn S. Wilson and Joseph L. Arvai. Oregon State SeaGrant program. https://seagrant.oregonstate.edu/sites/seagrant.oregonstate.edu/files/sgpubs/onlinepubs/h11001.pdf
- Decision Point (http://decision-point.com.au/), an online magazine on conservation decision science. Example article: *Navigating the field of decision analysis*. Michael C. Runge and Eve McDonald-Madden, April 2018. http://decision-point.com.au/article/navigating-the-field-of-decision-analysis/

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Appendix 1: California Kelp Abundance Data Sources

Understanding and tracking changes in the distribution and abundance of canopy-forming kelp is necessary and foundational for kelp management and restoration. Kelp abundance data support structured decision making, including in the problem formulation stage and in monitoring to understand the effects of different decisions and interventions. Remote sensing (RS)—coupled with in-water surveys to ground truth RS data—is a promising option for monitoring kelps that form floating canopies. The selection of an RS dataset should be based on both the characteristics of the region of interest, as well as the problem statement and associated management objectives established in the SDM process. There are several promising RS data streams that can be used to assess trends in the spatial extent, area, range and persistence of kelp canopy. These RS platforms can be split into three core categories, differentiated mainly by the spatial and temporal resolution of their data: satellite, occupied aircraft and unoccupied aircraft vehicles. *In situ* surveys (usually using SCUBA) can not only serve to ground truth RS data streams but also can be used to monitor canopy kelps as well as other biological and physical aspects of kelp-forest communities.

IN SITU KELP MONITORING

Ecological surveys of kelp forests generally cover less geographical area than RS surveys but can track many factors of the kelp-forest community, including subcanopy kelp and other species. Standard surveys usually include some form of belt transects or quadrats, and replication can vary depending on the program. Two programs that monitor subtidal rocky reefs at the statewide scale in California include the Partnership for Interdisciplinary Studies of Coastal Oceans (PISCO) and Reef Check California. PISCO is an academic consortium, and ReefCheck is a citizen-science program. Both programs track the abundance of kelp and other species in the kelp forest community. There are a large number of other kelp-forest monitoring programs that work at specific, smaller geographies, primarily in Southern California (e.g., Channel Islands National Park Service Kelp Forest Monitoring, Santa Barbara Channel Long-term Ecological Research; Vantuna Research Group).

REMOTE-SENSING DATA STREAMS

Satellite:

Satellite platforms are generally capable of monitoring large areas and have more extensive temporal resolution due to repeat global coverage. With numerous satellites currently spaceborne, pixel resolution of collected imagery varies from sub-meter to approximately 100 meters. Satellites with moderate resolution (10–30 m) have been shown to provide data that allow for the accurate estimation of the biomass of large kelp beds (e.g., 10s m – 100s km; Cavanaugh et al., 2011), but detecting thin stands of kelp—such as those found in degraded kelp forest ecosystems or along coastal margins—is generally less accurate with these data (Hamilton et al., 2020). Therefore, the use of satellite data to monitor kelp should be designed to address specific objectives. If using satellite data are appropriate, selection of a data stream should be based on spatial resolution, temporal coverage and cost to meet the stated management objectives. Examples of satellite platforms and their ranges of information quality can be found in table A1.

Table A1. Examples of satellite platforms for monitoring kelp canopy

	Landsat (NASA/ USGS)	Sentinel-2 (ESA)	Planet
Spatial resolution	30 m	10 m	3–4 m
Temporal resolution	16 days	5 days	Daily
Image cost	None	None	Yes—licensing required

Occupied aircraft:
Occupied aircraft platforms (i.e., airplanes) are generally capable of monitoring moderate-size areas with less extensive temporal resolution, relative to satellite platforms. However, these aircraft-based surveys generally provide higher spatial resolution images (~0.25–3 m) and have more flexibility when it comes to timing data acquisition to align with proper field conditions (e.g., tides, weather, kelp biomass, etc.). Higher operational costs, as well as limited appropriate flight conditions, tend to hinder the reliability of this RS platform. For example, the California Department of Fish and Wildlife began occupied aircraft surveys of California's coastline in 1989; while these surveys were intended to be annual events, lack of funding or unsuitable flight conditions resulted in semi-annual flights between 2002 and 2020. There has not been a comprehensive coastal occupied-aircraft survey of kelp in California since 2016.

Unoccupied aircraft vehicles (UAVs, or drones):
Drones are generally used to monitor kelp canopy over local scales and provide data at a very high resolution (2–3 cm, depending on the sensor and flight altitude). This RS platform arguably has the greatest flexibility when it comes to timing data acquisition to align with proper field conditions, as well as the desired frequency of data acquisition. Drones do have a lower wind-speed tolerance relative to occupied aircraft and are further limited by battery life. When operated from shore, drones have a limited distance they can survey to maintain connection with the controller; operating drones from vessels at sea is possible but challenging.

RS data for informing management decisions:
Because many kelp species have highly dynamic life histories and experience natural inter-annual variability in canopy coverage, RS data can be used to inform the status of a given kelp bed relative to either a long-term average (i.e., 30 years) or a running average. The ability to quantify changes in canopy coverage—especially in response to a catastrophic event(s)—relative to a historical dataset allows managers to understand whether or not the system is functioning within the range of natural variability. Understanding patterns of natural variability and how current kelp status compares provides critical information from the outset for an SDM process, because it can inform the intervention strategies best suited to meet the needs of the system in question.

USER-FRIENDLY OPTION TO INTERFACE WITH RS DATA

KelpWatch (https://kelp.codefornature.org/) is an open-source tool that allows users to track changes in kelp canopy coverage in California waters since 1984. By applying machine-learning algorithms to Landsat imagery, users are able to quantify and visualize how kelp canopy has changed in select regions, time frames and seasons of interest. Users can animate the changes in kelp coverage over time to understand dynamics in the distribution and abundance of local kelp forests, and download the data to determine the current status of canopy coverage in the context of the curated historical average and associated standard deviation.

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Appendix 2. Effects of stressors and drivers on California kelps

Note this list is not exhaustive and literature examples are focused on California. For a comprehensive review of kelp drivers see Dayton et al. 1985, Steneck et al 2002, and Graham et al. 2007

Stressor	Direct and Indirect Impacts of Stressor on Kelp	Example Reference(s)	Potential Influence on restoration/ management decisions (Active or Passive)
Wave exposure	**Direct:** Wave disturbance effects kelp abundance, recovery from loss and recruitment through direct removal/dislodgement. Giant kelp more susceptible than bull kelp to dislodgement.	Reed et al. 2011, Byrnes et al. 2011, Graham et al 1997, Young et al. 2016	**Active:** Consider disturbance regimes when actively seeding or transplanting kelp or removing urchins. **Passive:** Consider prioritization of new MPAs, relocation of existing MPAs, and/or create restoration sites at low disturbance locations.
	Indirect: Wave exposure can covary with net primary productivity, affecting kelp growth and abundance.		
	Indirect: Wave exposure can effect urchin grazing behavior (reduction of grazing in high wave environments).	Harrold & Reed 1985, Cowen et al 1982, Ebeling et al. 1985	
	Indirect: Frequency but not severity of wave disturbances alters community structure (increasing understory algae and epilithic sessile inverts) which can increase competition with kelp.	Castorani et al. 2018	
	Direct: Wave disturbance (winter wave height) positively correlated with bull kelp abundance.	Hamilton et al. 2020	
Water temperature	**Direct:** Anamolously warm SST (such as marine heatwaves) can lead to decreased kelp abundance.	Tegner & Dayton, 1991; Tegner et al., 1997; Edwards, 2004, Cavanaugh et al., 2019; Beas-Luna et al., 2020; Rogers-Bennett & Catton, 2019	**Active:** Consider locating active restoration sites in areas predicted to warm less (i.e., refugia) and focus may need to be on removing tropical/warm-affinity herbivores. **Active:** Consider selective breeding and outplanting of warm-water tolerant kelp genotypes **Passive**: Consider ecosystem management tools such as MPAs located in refugia.
	Indirect: High temperatures indicated in disease event negatively affecting urchin predators.	Harvell et al. 2019	
	Indirect: High temperatures potentially related to increase (Nor CA) or decrease (So CA) in recruitment of purple urchins.	Rogers-Bennett & Catton, 2019; Okamato et al. 2020	
Nutrients	**Direct:** High nutrients resulting from strong upwelling increase kelp growth during winter/windy months; nutrient limitation (especially nitrate) during low upwelling periods results in lower abundance and growth.	Zimmerman & Kremer 1984, Cavanaugh et al. 2011; Reed et al. 2008	**Active:** Consider natural seasonal variation in nutrient levels when undertaking active restoration such as seeding, tranplanting or nutrient manipulations.

Stressor	Direct and Indirect Impacts of Stressor on Kelp	Example Reference(s)	Potential Influence on restoration/ management decisions (Active or Passive)
Sediment	**Direct:** Sediment loads can negatively impact sporophytes, as well as reduce kelp recruitment.	Dayton et al. 1984	**Active:** Consider sediment loads when choosing active restoration sites. **Passive:** Explore the possibility of reducing excess sediment loads through land-use practices or other regulations; consider multi-agency collaboration.
Pollution	**Direct:** Sewage can over-nutrify kelp in normal years but can add needed nutrients in low nutrient years (e.g., El Niño).	Tegner et al. 1995	**Active:** Consider pollution loads when choosing active restoration sites. **Passive:** Explore the possibility of reducing pollution through regulations; consider multi-agency collaboration.
	Direct: Exposure to pollutants, such as copper and petroleum, decreases germling growth rates and gametophyte development.	Antrim et al. 1995	
Herbivory—urchin	**Direct:** High urchin abundance can lead to high levels of kelp consumption—reducing kelp abundance and potentially reinforcing the maintenance of urchin-barren state.	Steneck et al. 2002, Dunn and Hovel 2019, Rogers-Bennett & Catton 2020	**Active:** Consider hysteresis thresholds when physically removing urchins to promote shifts from barrens to forests; or when preventing urchin populations from reaching phase shift threshold. **Active:** Consider focusing removal efforts on larger urchins and/or starved/barren urchins. **Passive:** Consider allowing persistence of diseased urchins in barrens. **Passive:** Promote intermediate levels of meso-herbivores for induction of chemical defenses.
	Direct: Larger urchins consume more kelp, have greater reproductive ouput and may achieve a size refuge from predation [urchin size].	Selden et al. 2017, Ebert 2008, Eidaguirre et al. 2020	
	Direct: Starved/barren urchins are less likely to be consumed by predators leading to higher abundance [urchin condition].	Eurich et al. 2014, Smith et al In press	
	Indirect: Disease can control starved/barren urchins through density-dependent mortality [urchin condition].	Lafferty 2004	
Predation	**Indirect:** Large urchin predator populations and large body sizes can directly reduce urchin populations and indirectly, result in a reduction in grazing pressure on kelps (note that importance varies substantially in space).	Eisaguirre et al. 2020, Hamilton & Caselle 2015, Lafferty 2004, Cowen 1983; Duggins 1983; Tegner & Levin 1983; Estes & Duggins 1995; but see Foster & Schiel 2010	**Active:** Consider predator reintroductions or tranlocations (e.g., sunflower star, otters, California sheephead or California spiny lobsters). **Passive:** Consider protection and conservation of urchin predator abundance and size class structure through fisheries management and MPAs. **Passive:** Consider protection of trophic redundancy within urchin predator guild through managment and regulation.
	Indirect: The presence of predators can cause behavioral changes in urchin foraging, with urchins less likely to actively graze in the open when predators are abundant.	Tegner &Levin 1983, Matassa 2010, Duggins 1983 (Alaska)	

Stressor	Direct and Indirect Impacts of Stressor on Kelp	Example Reference(s)	Potential Influence on restoration/ management decisions (Active or Passive)
Fishing	**Indirect:** Reduction in fishing pressure or hunting (through management and MPAs) can lead to higher abundances of urchin predators such as fish, lobsters or otters.	Eisaguirre et al. 2020, Hamilton & Caselle 2015, Nichols et al. 2015, Cowen 1983	**Active:** support fisheries management that accounts for interactions among species affecting kelp; or consider role of MPAs in protecting top predators from fishing pressure.
	Indirect: Ecosystem management tools such as MPAs can conserve multiple predators consuming urchins in the same community (redundancy).	Halpern et al. 2006	
Competition—space/light	**Direct:** Increase in space holders or other direct competitors can cause decrease in kelp settlement and/or early survival.	Rassweiler 2008, Reed et al. 1990, Arkema et al. 2009	**Active:** Consider reduction in space or light competitors of kelp before active restoration. **Passive:** Promote/maintain space competitors that create herbivore grazing refuges. **Passive:** Consider community dynamics that support high kelp densities. **Active:** Consider kelp density when doing active restoration Remove urchins in order to promote kelp recolonization and invasive competition.
	Indirect: Increase in space competitors (e.g. *Corynactis californnica*) can lead to a decrease in herbivory through urchin avoidance.	Levenbach 2008	
Competition—invasive species	**Direct:** Invasive algae may outcompete native kelps in some situations.	Caselle et al. 2018, Ambrose & Nelson, 1982, Dayton et al. 1998	
Kelp Harvest	**Direct:** kelp canopy harvest increases light penetration to benthos. May have little effect on survival, biomass or growth of kelp plant.	Kimura & Foster 1984, Dayton et al. 1998	**Active:** Conduct regional based science to update best harvest practices with changing ocean conditions. **Active:** Consider using the best best available science with an ecosystem perspective, including links between consumers (e.g. abalone), grazers, and predators, when managing kelp harvest.
	Indirect: increase in abundance of understory algaes.	Arkema et al. 2009	

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Appendix 3. Kelp Monitoring, Management and Direct Interventions in California

This table lists types of "interventions" or actions that have been utilized to protect, monitor or restore kelp forests. Specific focus is placed on the California coast, although other/international examples are also included for discussion and learning. Four broad categories are used to organize the interventions: Monitoring of Kelp Abundance and Health; Directly Increase Kelp Abundance; Indirectly Increase Kelp Abundance; and Improve Kelp Resilience.

Broad category	Sub category or example	Description	Location tested/implemented with reference	Cost	Durability	Notes on scalability
Monitoring of Kelp Abundance and Health	Long-term surveys or networks	Long-term subtidal or intertidal surveys, including PISCO, LTER network, or BOEM-sponsored MARINe, allow understanding of phases or ecological trends in kelp communities (surveys may become increasingly valuable with climate change).	Statewide: PISCO (http://www.piscoweb.org/kelp-forest-sampling-protocols) MARINe (https://www.marine.gov/) KEEN (http://www.kelpecosystems.org/)—inlcudes links to related networks inlcuding LTER, NEON, etc. Reef Check CA (http://reefcheck.org/california/ca-overview)	Mid-cost to maintain. Long term data collection programs should be prioritized, especially given climate change.	Highly durable when prioritized, valuable for understanding long-term trends.	Many strong programs at scale already exist, a challenge lies in maintaining funding.
	Aerial Kelp Surveys (giant and bull kelp)	Aerial surveys usually invovle occupied aircraft. Several studies on giant kelp and bull kelp. (a) Annual CDFW aerial kelp surveys: 1989, 1999, 2002-2006, 2008-2016. Surveys depict surface and (in some years) subsurface kelp canopy as GIS shapefiles and are in MarineBios, a CDFW Data Viewer. Majority of surveys are conducted by CDFW, other agency data compiled if CDFW data not available. (b) Aerial giant kelp surveys performed by MBC for ocean dischargers to abide by regulations of the San Diego Regional Water Quality Control Board and LA Regional Water Control Board. Although the surveys are conducted on a quarterly basis, the max extent of kelp for the year is recorded. Surveys ongoing, began in 1982/83 for San Diego to southern Orange County, extended to Ventura County in 2002.	Kelp beds offshore of the mainland and surrounding the Channel Islands. Surveys were not conducted in all regions and years due to budget constraints or weather. Datasets are available by CDFW as GIS shapefiles and in CDFW MarineBios (2018). MBC surveys from San Diego to Ventura counties (SCCWRP 2018).	High cost. Costs unknown for MBC surveys but likely high and paid for by the ocean dischargers.	No secure funding source for CDFW surveys and subject to environmental constraints such as wildfires. MBC surveys highly durable, motivated by compliance with water-quality regulations.	CDFW survey is coastwide (when funding allows). MBC survey is site specific (see description).
	Remote sensing (such as Landstat and other satellites)	Various studies focus on detection of canopy forming kelps. Giant kelp studies include: (a) KelpWatch online application maps kelp canopy cover using Landsat 5,7, and 8. (b) development and testing methods to estimate giant kelp canopy area and biomass using SPOT satellite imagery (10 m spatial resolution). Study included temporal changes to biomass. (c) Santa Barbara Coastal Long Term Ecological Research (SBC LTER) time series of kelp biomass using Landstat 5, 7 and 8 for 1984–2016—ongoing. 30 m spatial resolution. Available for download. (d) use of Hyperspectral Infrared Imager (HyspIRI) for giant kelp biomass and physiological condition (60 m spatial resolution).	Remote-sensing studies include Cavanuagh et al. (2010), Bell et al. (2015), Hamilton et al. (2021) and and references therein. KelpWatch online application covers San Diego to the California border with Oregon. UCLA exploring use of Planet Labs satellites in Northern CA (3 m spatial resolution). Further study needed on sensing of submerged kelp (Uhl et al. 2016).	A range of costs to freely available. Some satallite images may be available at no or little cost to various organizations (such as academia or government), however, cost increases with higher-resolution images. Cost for software, hardware, and staff. KelpWatch (Landsat data) is freely available to the public.	Long-term data infrastructure needed to collect and process images. High potential for increased survey efficiency using developing tools; ongoing studies in progress regarding comparisons/tradeoffs with ground-based and very high-resolution surveys.	Studies focus on giant kelp. Research is being conducted on applicability to bull kelp.
	Drone (unoccupied aerial vehicle, or UAV) surveys	Drones are generally used to monitor kelp canopy over local scales at very high resolution (2–3 cm, depending on the sensor and flight altitude). This platform arguably has the greatest flexibility when it comes to timing data acquisition to align with proper field conditions, as well as the desired frequency of data acquisition.	Mendocino and Sonoma Counties, Palos Verdes and Santa Barbara. TNC led drone surveys of kelp canopy in 2019 and 2020 in Mendocino and Sonoma County priority kelp sites; these campaigns represent the largest marine drone surveys ever conducted in the State of CA. Measurements on canopy based on state-of-the-art methods (Cavanaugh 2020).	Moderate cost. Local surveys can be conducted with off-the-shelf drones (e.g., DJI Phantom with the standard camera). Flight time + post-processing can be time intensive depending on quantity of data acquired.	Moderately durable. Depends on funding, technical expertise for data acqusition and post-processing. Drones have a lower wind-speed tolerance relative to occupied aircraft and are further limited by battery life.	Regionally scaleable; not spatially scaleable (i.e. donres have flight limitations the make them a near-shore monitoring tool).
	Oceanographic monitoring	Monitoring of oceanographic conditions can be tied to kelp health (wave/storm, ocean chemistry) to inform conservation and management activities or predict possible impacts.	Integrated ocean observing systems, such as CeNCOOS (https://www.cencoos.org/) and SCOOS (https://sccoos.org/). CeNCOOS incorporates CDFW aerial kelp survey data into their system.	Cost of data infrastructure and maintenance over long term to link relevant oceanographic conditions monitoring information to kelp forest restoration/management.	Similar to long-term kelp monitoring programs, long-term oceanographic-conditions monitoring can be highly durable when prioritized, and is valuable for understanding long-term trends.	Many strong programs at scale already exist; a challenge lies in maintaining funding.

Broad category	Sub category or example	Description	Location tested/implemented with reference	Cost	Durability	Notes on scalability
Directly Increase Kelp Abundance	Regulate harvest of giant and bull kelp	Kelp harvest management strategies and regulations differ between bull (annual) and giant kelp (perennial) due to differences in life history characteristics. Harvest is managed so that populations are able to viably reproduce. California kelp harvest management actions include: commerical and recreational regulations, requirement of an annual commercial kelp harvest license, a kelp bed leasing program and allowances for commercial harvest without a kelp bed lease, reporting of commerical harvest, and royalty fees.	California-coast kelp harvest managed through CDFW, CA Fish and Game Commission commerical (including a leasing program) and recreational regulations (Springer et al. 2010, CDFW 2014). These include Title 14, California Code of Regulations Sections 165 and 165.5, 2018 California Fish and Game Code Sections 6650-6751, and California Saltwater Sport Fishing Regulations 30.00-30.10. The CDFW and the Fish and Game Commission are currently on Phase Two of a three-phase process to review and amend the regulations for the commercial harvest of kelp and other marine algae. Phase One was adopted in 2014 with a focus on updating kelp bed boundaries, requiring a kelp-harvest plan for all leases and for all mechanical harvest, and editorial changes. Phase Two, the current review, focus is on management policies including harvest methods and seasons for kelp and other marine algae. Phase Three will follow and will address license fees and royalty rates. Current regulation changes CDFW are focused on a regional approach to kelp management. The following are the likely to be proposed regs—remove limits for giant kelp, removed proposed closures in Humbodlt Bay and Crescent Harbor (protections for herring spawn). Bull kelp is put forward as a priority for review.	Mid-high cost of management and permit program. Consider development of science-based regulations, adaptively updated to reflect/respond to changing ocean conditions.	Regulations highly durable, yet adaptive management is dependent on other oceanographic, ecological, political and socioeconomic factors.	Highly scalable, given adequate resources for development of science-based regulations, permitting staff and enforcement.
	Outplanting kelp	Transplanting kelp as a means to increase spore availability.	Southern CA. (Wilson and North 1983; CDFW Kelp CEQA 2001).	Unknown.	Provides or increases kelp spores in areas devoid of kelp or with reduced kelp, and increases kelp biomass to lessen urchin impact. If this method is utilized, urchin control must also be in place.	Highly dependent on regional conditions, so scalability must be critically reserached and considered.
	Culturing kelp	Kelp aquaculture may be used to increase stock for outplanting or reduce pressure on wild kelp harvest.	OPC/CA Seagrant funded project (https://caseagrant.ucsd.edu/news/new-research-to-address-kelp-forest-crisis-in-california): Assessment of practical methods for re-establishment of Northern California bull-kelp populations at an ecologically relevant scale. Development of cost-efficient methods for reestablishing Northern California bull-kelp populations at ecologically relevant spatial scales following sea urchin removals. The researchers plan to test various culture methods for growing bull kelp for restoration purposes; conduct controlled field experiments to determine the most successful method for outplanting bull-kelp recruits to areas following sea-urchin removal; and then monitor the bull-kelp outplant growth, survival and reproduction at field sites. Experimental bull-kelp farm in Humbodlt Bay to test potential upside of culturing kelp in a farm setting—outcomes TBD (work done by TNC and Greenwave).	Start-up costs may be high, specifically in regards to time and expertise in navigating the permit process.	Durability unknown and highly case dependent; influenced by other economic and ecological factors.	
	Artificial reefs	Provision of additional hard structure in the marine evironment specifically for kelp restoration.	Many examples throughout the world. Best example in California- San Onofre Nuclear Generating Systems Mitigation Monitoring Project (SONGSMMP)—construction of an artificial reef to mitigate losses of kelp forest habitat from a turbidity plume caused by the plant's outfall (Ambrose 1994, Ambrose and Swarbrick 1989).	Extremely high if built to scale, initial contruction and follow-up monitoring.	Potentially high. Once built, artificial reefs are likely to remain in the marine environment for a very long time. However, there are also many examples of artificial reefs that did not persist or did not perform as designed over time. Careful design and placement of artificial reefs necessary. Design and location must take into account the oceanographic and geomorphologic context in which the reef will be placed in, paying particular attention to avoid excessive scour or sinking of reef materials.	May not be desirable to add too much man-made structure due to other considerations and impacts. Permit process complex and lengthy.

Broad category	Sub category or example	Description	Location tested/implemented with reference	Cost	Durability	Notes on scalability
Indirectly Increase Kelp Abundance	Regulate fishing pressure/ harvest for non-urchin species that have direct or indirect interactions with kelp (e.g., abalone, lobster, predatory fishes). (For urchins, see below)	Fishing regulations (harvest control through rules such as temporal or spatial management, effort or catch limits) provide mechanisms by which to manage ecosystem interactions.	Overfishing has been shown to reduce kelp bed resilience, especially in the face of climate change (Ling et al. 2009). Tegner & Dayton (2000) review fishery-kelp interactions across case studies including California, NW Atlantic, Australia, South America, and South Africa.	Consider development of science-based regulations, adaptively updated to reflect/respond to changing ocean conditions; mid-high cost of permit management.	Highly dependent on other oceanographic, ecological, political, and socioeconomic factors (ie consider, for example: changing ocean conditions on larval distribution, sea otter management policies, recreational effort).	Important to work closely with fisheries scientists and managers to fully understand fishery-kelp linkages, as well as utilize limited management resources efficiently.
	Restoration or recovery of natural preda-tors of grazers (e.g., seastars, lobsters, sheephead, otters)	Protection and active restoration or recovery of important predators to keep urchins and other grazers in check to promote kelp recruitment and growth.	MPAs with management objectives to restore size and abundance of key predators (Caselle et al 2017). Single-species recovery or restoration efforts (e.g. lobster, sea otters). OPC Funded Project: A multi-pronged approach to kelp recovery along California's north coast—seek to explore the potential of an urchin predator, the sunflower sea star, to aid control of urchin populations.	Varies. MPA management and monitoring and implementation of species-recovery plans can be expensive.	Highly dependent on other oceanographic, ecological, political and socioeconomic factors.	Potential impacts on fisheries.
	Invasive species removals	Invasive algae and other species can compete with native kelps, causing declines. Removal of invasive species can include physcial (mechanical), chemical or biological methods.	California example of Caulerpa taxifolia (Anderson 2005) and Ascophyllum nodosum (Miller et al. 2004).	Reasonable if invasion caught early and removed from small areas. Requires follow-on monitoring to gauge success.	Complete removal likely to be durable if source of vectors are also controlled. Complete eradication is preferable rather than control because it is likely to be more self-sustaining. The few documented cases of total eradication of a marine invasive algae occurred when the invasion was caught early, the invasion scale was small or in an isolated area, the response was rapid and well-coordinated by cooperating government agencies, and the biological and ecological characteristics of the invader were well understood	Physical removal is unlikely to result in complete eradication unless the invasion is limited to a relatively small area.
	Feeding urchins	Study in 1991 by Kelco fed urchins in barrens, allowed for kelp recruitment.	Southern CA (CDFW Kelp CEQA 2001)	Unknown.	Unknown.	Unknown.

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Broad category	Sub category or example	Description	Location tested/implemented with reference	Cost	Durability	Notes on scalability
Indirectly Increase Kelp Abundance (continued)	**Remove urchins to facilitate kelp regrowth using a variety of potential methods—see below:**					
	Manually remove urchins	Urchin removal to lower urchin density, break up urchin barrens, and facilitate kelp regrowth, especially in areas of grazer overpopulation.	Project goal to "reduce the density of purple sea urchins to two per square meter within the boundaries of sea urchin barrens off the Palos Verdes Peninsula," California. The Bay Foundation (2018). OPC Funded Project in partnership with ReefCheck and CDFW: urchin removal study in Noyo Harbor and Monterey Bay.	High cost in removals.	Durability unknown and likeley to depend on environmental conditions, scale of intitial removals.	Unlikely to ever remove urchins at spatial scales of kelp loss. Research needed on scales of removals that promote natural recolonization and spread of kelp.
	Amend recreational purple urchin regulations	During its April 2018 meeting, the Fish and Game Commission adopted an emergency action to increase the recreational daily bag limit for purple urchin from 35 individuals per day to 20 gallons with no possession limit for subtidal take in Sonoma and Mendocino County only. This was further increased in 2020 to 40 gallons per day in Humboldt, Mendocino and Sonoma Counties. There is no bag limit for take of purple sea urchins in Caspar Cove, in Mendocino County in the area east of a straight line drawn between 39 22.045' N. lat. 123 49.462' W. long. and 39 21.695' N. lat. 123 49.423' W. long. for the purpose of restoring kelp. Purple sea urchins may only be taken by hand or with manually operated handheld tools.	Humboldt, Sonoma and Mendocino Counties, subtidal only.	Cost of regulatory action, management, enforcement.	Unknown. Dependent upon demand. May have negligible impacts to purple urchin population.	Highly scalable.
	Develop commercial purple urchin fishery	Wilson and North (1983) state the development of a commercial fishery for purple and white urchins "should be enouraged as a complete solution to the control problem." Current commercial regulations allow for take of all urchins (with additional regulations for red urchins), however purple urchins have not been targeted by the fishery.	Southern California (Wilson and North, 1983) Commercial Regulations include Title 14, California Code of Regulations Sections 120.7, 123 and 190, California Fish and Game Code 9054 and 9055. More information in the 2018 California Commercial Fishing Digest (http://www.eregulations.com/california/fishing/saltwater/).	Economics/drivers of new fishery not yet known. Management and enforcement costs of new fishery.	Unknown. Dependent upon demand.	Economic drivers of new fishery not yet known.
	Hammering	Divers use geology hammers to smash urchins.	Southern CA and currently offshore of Palos Verdes (Wilson and North 1983; CDFW Kelp CEQA 2001; The Bay Foundation); Limited in-situ 'smashing' in Caspar Cove, Mendocino per CDFW.	High cost. Most effective with a trained, dedicated group of divers.	Urchin-specific. Wilson and North stated average urchins culled just over 3,000 per hour for trained divers.	Due to labor intensive, must be site specific. Concerns about potential impacts of spreading gametes and disturbing the environment.
	Quicklime	Quicklime reaction with water and placement on urchins or water column results in urchin death within a few days or weeks . Results have been effective to restore giant kelp, however, also results in killing sea stars, cucumbers, abalone, key hole limpets.	Southern CA, Nova Scotia (Wilson and North, 1983; Bernstein and Welsford 1982; CDFW Kelp CEQA 2001).	Unknown at this time but pilots in Norway indicate high costs.	Has been effective in reducing urchin population. Impact to non-target species may need to be reduced.	Quick lime also results in loss of urchin predators and competitors, sport and commercially important species, and species currently reduced.

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Broad category	Sub category or example	Description	Location tested/implemented with reference	Cost	Durability	Notes on scalability
Indirectly Increase Kelp Abundance (continued)	Suction dredging	(a) Developed and historically used by the Kelco Co. in southern CA. A diver rakes urchins to the suction dredge entrance, urchins are crushed as they go through the pump and the remains are discharged into the water. (b) Similar techinique currently being tested, difference is urchins are brought delivered to boat for collection of live urchins.	(a) Southern CA (Wilson and North 1983; CDFW Kelp CEQA 2001) (b) Northern CA; Technology in development by C-Robotics of Norway; Air-Vac developed by California commercial fisherman John Holcombe.	High cost.	Urchin specific. (a) Reports of impacting 6,000 urchins per hour.	Due to labor intensive, must be site specific.
	Marauder Robotics	Currently in the fundraising and development stage. Marauder Robotics goal is to develop an autonomous underwater drone that can distinguish species and target purple urchins, and can be deployed a week at a time. Prototype development in 2019–20 and testing in 2021.	Untested but see similar system for Crown of Thorns Starfish on GBR (COTSbot) (in development since 2014, www.balancedoceans.com).	unknown. Marauder Robotics states their system will cost significantly less than diver removal (estimates they provide for divers $375 k/acre whereas their robotic $40 k/acre.	Unknown.	Unknown.
	Trapping	Currently being piloted in the North coast. Goal is to collect large numbers of urchins with set traps and reduce bycatch.	Soon to be tested in the North coast of CA (TNC); Jim Penny in Monterey.	Unknown at this tine but pilot tests will allow costs to be calculated.	Unknown.	Unknown but potential for scaling is high.
Improve Kelp Resilience	Marine protected areas (MPAs)	MPAs, depending on their objectives and allowed activities, can restore ecosystem health, provide direct protection for kelp from harvest, and/or protect and rebuild size and abundance of natural predators of kelp grazers.	Varies by region, but approximately 22% of kelp area protected in MPAs in California, with 13% in no-take reserves (Gleason et al. 2013). Some CA MPAs also protect key predators of kelp grazers (Caselle et al.2017, Eisaguirre et al. 2020).	Relatively high cost of MPA network planning, implementation, monitoring, and enforcement.	To achieve kelp conservation objectives, MPA networks must be monitored and adaptively evaluated/managed, especially given changing ocean conditions.	Moderately-scalable: process of MPA network is lengthy due to science-based site selection combined with thorough stakeholder engagement and involvement.
	Water quality improvements (land-sea connections)	Remove land based threats to kelp from poor water quality and sedimentation via better land use practices, policy changes or engineering solutions (wetland reconstruction).	Southern california water quality improvements thought to greatly improve kelp in southern California (Foster and Schiel 2010).	Important to coordinate with city managers, local to state policy makers, and others often outside direct realm of kelp science.	Permanent improvements to water qaulity and discharge likely to improve likelihood of kelp regrowth depending on other environmental factors (SST etc).	Advocating for water-quality improvement policies may have multiple benefits (win-win).

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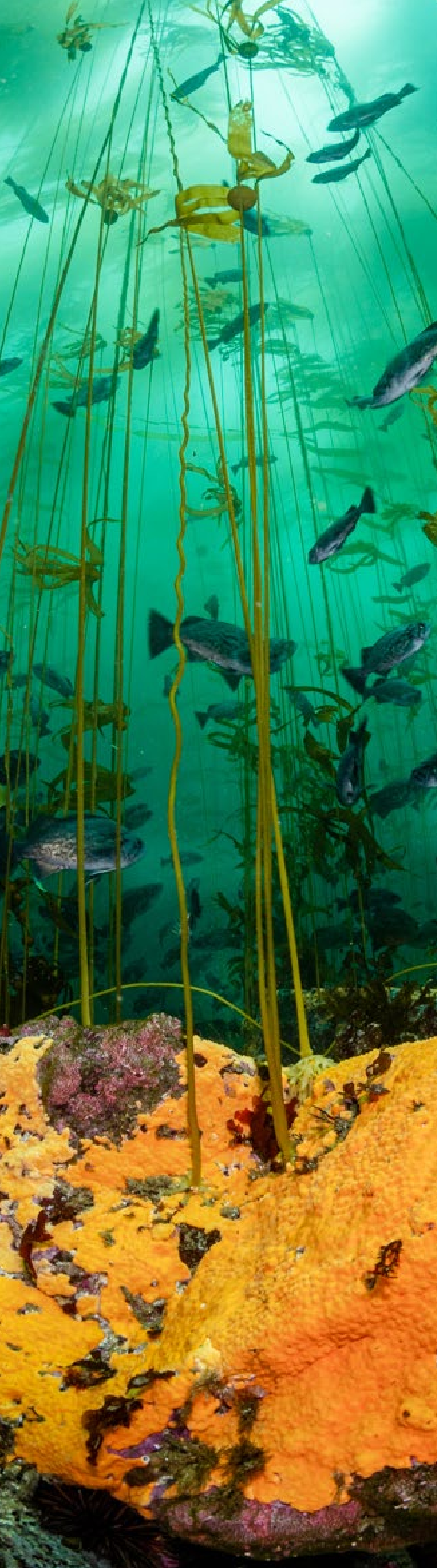

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