Science Guidance for Coastal and Ocean Restoration in California into a Changing Future

Coordinating Authors

Monica LeFlore
California Ocean
Science Trust

Dr. Tanner Waters
California Ocean
Science Trust

Working Group Authors

Dr. Richard F. Ambrose
University of California,
Los Angeles

Dr. Marissa Baskett
University of California,
Davis

Dr. Kathryn Beheshti
University of California,
Santa Barbara

Dr. Peter Raimondi
University of California,
Santa Cruz

ABOUT THIS REPORT

This report was collaboratively developed by the California Ocean Science Trust (OST) and a four-member science working group, in close coordination with the California Ocean Protection Council (OPC). OPC is a Cabinet-level state body whose mission is to protect California's ocean and coast by advancing innovative, science-based policy and management, making strategic investments, and catalyzing action through partnerships and collaboration. The report authors received targeted input from additional state regulatory agencies, non-governmental restoration project managers, and research scientists. This document presents scientific concepts, considerations, and recommendations for coastal and ocean restoration decision-making in California that the working group identified as best practices.

The need for a report of this scope was identified through policy discussions between OPC and State natural resource management agencies. The State expressed interest in a resource to guide and inform conversations about statewide coastal and ocean restoration target-setting, including when and where restoration action may be appropriate, designing effective restoration monitoring programs, and enhancing climate resilience for long-term restoration success. In response, the collaborators of this report convened to identify priority topics that would both effectively respond to State interests and provide forward-looking, best-available science on restoration in the face of climate change.
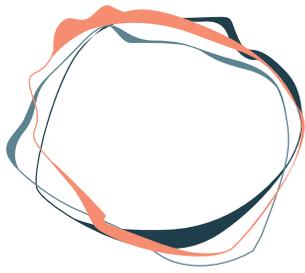
ABOUT CALIFORNIA OCEAN SCIENCE TRUST

OST strengthens the bridge between scientific research and sound ocean management. Created by state legislation, we support and bring world-class science and innovation together with state and federal policymakers to accelerate progress toward a healthy and resilient coast and oceans.

ACKNOWLEDGMENTS

Table of Contents

EXECUTIVE SUMMARY

The purpose of *Science Guidance for Coastal and Ocean Restoration in California into a Changing Future* is to support California policymakers, managers, practitioners, communities, and stewards as they navigate coastal and ocean restoration under changing climate conditions. Restoration is challenging as it requires an iterative science-based approach, navigating uncertainty, and making values-based decisions. Climate change is accentuating these challenges by creating additional uncertainty into the future.

This document outlines the decision points in statewide- and project-level restoration planning and management to provide scientific and applied best practices to help navigate those decisions. This report can be applied to voluntary restoration (i.e. restoration not conducted for mitigation purposes) and, when aligned with regulatory requirements, to restoration required for mitigation. *Science Guidance for Coastal and Ocean Restoration in California into a Changing Future* includes sections on coordinated statewide approaches to coastal and ocean restoration, restoration goal setting, decision-making process design, project planning, restoration techniques, and monitoring and evaluating restoration projects. This report offers the following key messages to this end:

1. Minimizing the need for restoration by preventing sources of degradation and managing for more resistant and resilient habitats should be prioritized.

While restoration is a useful tool for ecosystem and species (together referred to as "systems" in this document) recovery, and will be even more necessary under climate change, it is not a substitute for conservation. The proactive protection and management of California's natural resources is the most effective approach for maintaining ecological function, particularly because restoration is resource-intensive and success is highly variable. The likelihood of success in restoration will become more uncertain as the unknowns of climate change continue to shift our understanding of systems and their responses to climate impacts. Conservation and restoration will need to be undertaken in coordination, constituting a paired approach in which conservation is prioritized and restoration is employed when conservation alone is not sufficient or possible.

2. Climate change necessitates expanding the definition of restoration—and setting a targeted vision for what success looks like.

Historically, restoration has focused on supporting recovery-in-place wherein restoration is used to recover lost systems and processes where they previously occurred. While recovery-in-place will continue to be an important component of restoration practice, shifting ocean and coastal conditions will call on restoration to proactively adapt systems to new environmental realities. To identify the most appropriate restoration action, implementing a decision-making framework can be instructive. Structured decision-making frameworks provide guidance on identifying, comparing, and evaluating the numerous complex and value-driven priorities with the given uncertainties of restoration in a fair and transparent manner. The Resist-Accept-Direct ("RAD") decision-making framework provides users with a guide to decide whether to resist change in a system, accept the change that a system is facing, or direct a system to a new, preferred condition.

3. Restoration success should be measured against accomplishing project goals, as well as the return of ecosystem functioning that is comparable to reference sites, rather than the recovery of a single function.

Restoration can be motivated by a variety of interests, such as the recovery of a particular species, ecosystem function, or ecosystem service. During restoration planning, these motivations often become a project's restoration goals, against which a project's success can be measured. However, projects sometimes identify a unilateral goal (e.g., increasing carbon sequestration or protection from sea-level rise) as the purpose for undertaking a restoration action. This report asserts that goals such as these are insufficient to claim full restoration, and the overarching definition of project success should also include the return of ecosystem functioning (e.g. biodiversity, species richness, resilience) comparable to that of a reference site.

4. Statewide restoration priorities can effectively inspire coordinated restoration action by catalyzing strategic goal-setting and investments while balancing achievability and ambition.

The State plays a crucial role in guiding coordinated statewide restoration efforts by establishing restoration priorities and goals, funding opportunities, regulatory and permitting pathways, management frameworks for marine resources, and other mechanisms. Beyond California's borders, the State also contributes to global initiatives and conservation frameworks, elevating the importance and impact that restoration in California can have worldwide. Using science-based information regarding focal

systems' extent, stressors, restoration potential, current protections, and prognosis under climate change when identifying restoration priorities and actions can yield more effective restoration outcomes. Efforts based on scientific information to coordinate statewide restoration can determine target restoration acreage for particular systems, identify an appropriate number of restoration projects to fund based on system type and region, and more. Statewide actions and priorities should be grounded in science-informed need for a system while incorporating a level of ambition beyond that need to help motivate innovation and incentivize urgent action.

5. Restoration site suitability depends on historical and projected future extent, the feasibility of addressing drivers of degradation, project goals, and human communities' priorities for restoring a degraded habitat.

Historical records, including tribal knowledge (when tribes deem it appropriate to share such knowledge) and local knowledge (e.g. from fishers, harvesters, and community members), can inform where ecosystems and species were able to persist without current stressors, which presents a starting point for understanding candidate restoration sites. Considering how climate change is predicted to affect potential restoration areas may serve as an additional filter for identifying candidate sites. Determining whether causes of degradation have been or can be feasibly addressed further narrows down potential sites. Beyond these minimum criteria for site suitability, potential sites will have differing capacity to achieve project goals, so sites should be selected with clear project goals in mind. If selection from multiple remaining sites is still required, considering additional social dimensions such as community buy-in, the risk tolerance of affected communities and funders, feasibility and logistics, cost effectiveness, and permit viability, can help with final site selection.

6. Restoration must meaningfully incorporate and be inclusive of the social considerations of tribes and other local communities connected to a project.

Although the primary purpose of this document is to convey natural science principles for restoration, restoration decision-making is inherently interwoven with social values. Restoration can strengthen place-based identities, restore tribal access, revitalize cultural practices, and support the implementation of Indigenous and local ecological knowledge. Project goals should therefore incorporate the values, priorities, and lived experiences of tribes and local communities. Doing so contributes to a more successful restoration effort by aligning project outcomes with community needs and building community capacity needed for long-term support for a restoration project.

7. Restoration techniques include methods to address stressors and assist system recovery.

Restoration interventions are organized into two categories in this document: a) stressor management, which consist of interventions that remove or mitigate stressors, and b) assisted recovery, which refers to interventions to reintroduce or promote recovery of key species and ecosystem processes. A non-exhaustive list of interventions is presented in the appendix for seven coastal and marine systems in California: sandy beaches and dunes, tidal wetlands, oyster beds, rocky intertidal, seagrasses, kelp forests, and mid-depth subtidal rocky bottom. By presenting restoration methods for these species and ecosystems, organized into techniques for stressor management and assisted recovery, this report can serve as a starting point for identifying potential appropriate restoration methods and understanding the state of restoration practice for different systems.

8. Climate change will require developing and employing innovative restoration and management techniques.

As the impacts of global climate change accelerate, restoration is shifting towards proactive, climate-adaptive approaches that anticipate the need for larger-scale restorations and more climate-resilient systems. These approaches to restoration include a) protecting natural adaptive processes, b) decelerating environmental stressors, and c) enhancing the capacity of systems to adapt to change. Protecting natural adaptive processes includes restoring locations and processes that enable natural buffering against climate impacts, such as restoring habitat connectivity, safeguarding climate refugia, and scaling current restoration technologies. While decelerating environmental stressors is already a main component of restoration, future efforts to manage stressors may require greater intensity, broader scale, or more technologically-advanced methods to respond to projected climate futures. Enhancing the capacity of a system to change means accelerating climate resistance and resilience within an ecosystem, which includes an array of genetic, physiological, microbial, and community interventions. Because many of these techniques are novel and carry uncertainty, continued research, risk evaluation, and pilot testing may be needed for further development.

9. Monitoring sites before, during, and after implementation enables adaptive management and increases the likelihood of project success.

Monitoring is critical across all phases of restoration, from pre- through post-intervention, to assess restoration efficacy, enable learning for improved management

through time, and to understand whether project or permit goals have been satisfied. Pre-restoration monitoring at both project and reference sites is essential to determine whether restoration is appropriate given the ecosystem's current status and trend and to establish system baselines that inform site suitability. During a project, monitoring is used to compare baseline metrics to in-progress metrics to indicate whether interventions are aligning with expectations or need to be adapted. Post-restoration monitoring is used to determine the success of a project by measuring if a project has accomplished its goals or if adaptive management is needed to realign a project's trajectory so that it can achieve its goals.

10. Making monitoring data publicly available and easily usable is critical for advancing our understanding of restoration and for tracking statewide restoration goals and targets.

The ability to share and access long-term restoration monitoring data is important to advance restoration techniques and increase the scale and impact of future restoration efforts. Unfortunately, monitoring data is not often publicly available or, when it is, it is not often in a standardized, usable format. The creation and use of a centralized, statewide database for restoration monitoring data is a critical next step to accelerating our understanding of restoration in the state. Data sharing should be governed by FAIR (Findable, Accessible, Interoperable, Reusable) data principles and CARE (Collective Benefit, Authority to Control, Responsibility, and Ethics) Indigenous data sovereignty principles.

By sharing these guiding scientific principles, the authors aim to encourage increased coordination and efficiency in restoration planning and implementation, and therefore accelerate successful restoration under climate change in support of a healthy California ocean and coast. This report serves as a resource for enhancing restoration outcomes across the state by integrating climate change principles directly into project planning. Leveraging scientific advancements and piloting climate-ready interventions in California can ensure that future investments foster resilient, equitable ocean and coastal ecosystems that are capable of thriving in a changing environment.

1. Introduction

The purpose of *Science Guidance for Coastal and Ocean Restoration in California into a Changing Future* is to support policymakers (state and federal legislators and agency leaders), funders (public or private entities that fund restoration work), managers (local, state, tribal and federal government staff responsible for day-to-day management of coastal and ocean jurisdictions), permitting staff, practitioners (groups or individuals conducting on-the-ground restoration projects), and coastal communities in decision-making on coastal and ocean restoration planning, design, implementation, and monitoring. By providing a common framework for restoration grounded in best available science and knowledge, this report seeks to support a coordinated approach that accelerates restoration progress in coastal California. This science guidance applies to voluntary restoration (i.e. restoration undertaken that is not required to comply with a permit, regulation, or legal mandate) and to regulatory restoration for mitigation when aligned with permitting requirements.

This document is not a detailed guide to the specific procedures and regulations governing mitigation and is not intended to replace or contradict agency documents that prescribe how restoration must be conducted to fulfill mitigation or permit requirements. However, most large-scale restoration that has occurred in California, particularly for wetlands and kelp forests, has been conducted through permittee-required mitigation and thus offers valuable lessons for coastal and ocean restoration statewide. Unless otherwise specified, the guidance in this report applies to the restoration-for-mitigation context as well as for voluntary restoration. The intent of this report is to serve as a scientific resource for those interested in pursuing ocean and coastal restoration, not to set state policy.

Figure 1 summarizes the restoration decision-making framework that structures this document. The report begins with identifying whether restoration is feasible and, for voluntary restoration, whether interventions are necessary and appropriate. Next, it outlines considerations for statewide action and coordination on restoration and identification of project-specific goals, prioritization of site selection, and development of project metrics to track progress. The document concludes by describing how the framework is applied in practice, including choosing restoration interventions, approaches to monitoring, and data sharing.

Science information is the foundation for restoration decision-making, but it is not the only set of principles informing and guiding restoration in California. Although the primary motivation for this document is to convey scientific principles for coastal and ocean restoration into the future, the document's focus on scientific applications for restoration practice is not intended to imply that other fields of knowledge and information are less important in restoration decision-making. For example, one gap in information and perspective in this document is Indigenous restoration practices, knowledge, and priorities. Tribal stewardship and management of ocean and coastal territories includes restoration activities, and future efforts may further explore how science and traditional knowledge can complement one another to yield a healthier California coast and ocean.

To develop this report, OST convened a series of virtual meetings with the working group and OPC to discuss the report's content and scope. The working group members served as scientific and technical advisors for the report's content, while OPC provided policy context and State perspective. After each meeting, OST compiled discussion notes into report content, which underwent revisions by the working group considering feedback from OPC. Before the report was finalized, it was reviewed by additional
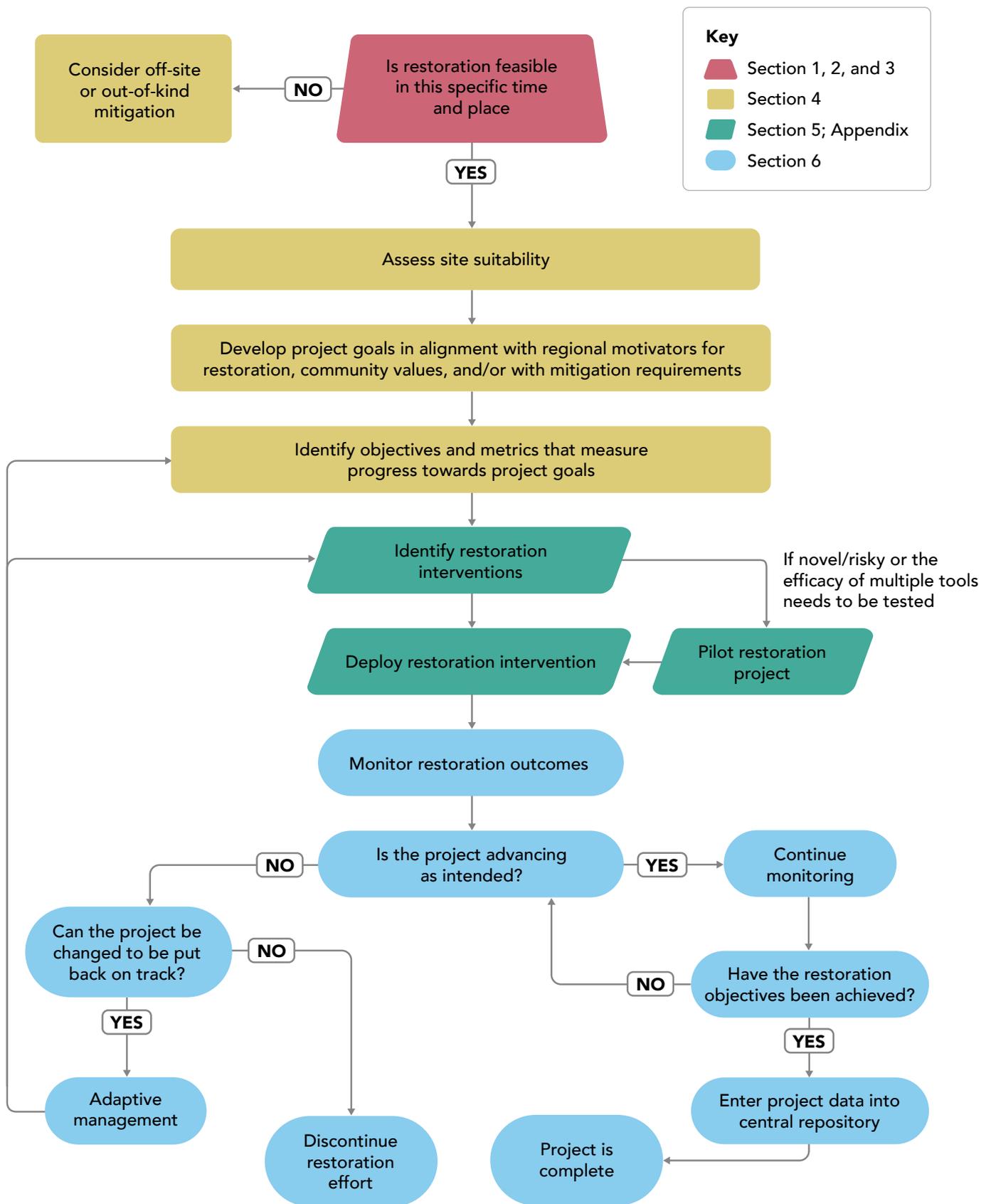
Figure 1. Flow chart of the restoration planning framework depicting the decision points that this document helps inform, with relevant document sections identified. Decision points may vary depending on the system and scale of restoration. Not included in this figure is a more detailed flowchart, Figure 2 (Section 2.3), which can further inform decisions on whether or not to restore.

California State agencies (California State Coastal Conservancy, California Coastal Commission, California Department of Fish and Wildlife, California State Lands Commission, and State Water Boards) to ensure that its content is presented in the appropriate context within existing State policies and regulations. The report was simultaneously reviewed by an external peer review committee led by OST to ensure technical accuracy and rigor.

2. Navigating Restoration in a Changing World

2.1 An Evolving Definition of Restoration

The definition of restoration is continually evolving as scientists and practitioners expand our understanding of how ecosystems function, respond, and recover from disturbances, and as restoration is increasingly recognized as an inherently social and scientific concept [1]. The conventional definition of restoration presented by the Society for Ecological Restoration is the process of reestablishing the function and value of ecosystems that have been degraded, damaged, or destroyed [2]. Beyond this scientific framing, the term restoration also holds regulatory and legal meaning. For example, California's Fish and Game Code § 1671, The Restoration Management Permit Act, defines a "qualifying restoration project" to be "a management or propagation project that has the primary purpose of restoring native fish, wildlife, plants, or their habitat". Federally,

the Natural Resource Damage Assessment, authorized through the Comprehensive Environmental Response, Compensation, and Liability Act of 1980 and the Clean Water Act, defines restoration as "actions undertaken to return an injured resource to its baseline condition, as measured in terms of the injured resource's physical, chemical, or biological properties or the services it previously provided." While additional statutory definitions exist, there is a general lack of statutory clarity over the definition of restoration [3]. As a result, these statutes are generally broadly defined and remain misaligned with the evolving scientific understanding of restoration [3].

Consistent with these definitions, restoration has historically focused on supporting recovery in place, or in-situ restoration, and involves removing stressors, creating or improving habitat, and restoring ecological processes so that a species or ecosystem (referred to collectively in this document as "systems") will be self-sustaining in the long term [4]. Restoration practices have historically relied on past system conditions as a template for desired restoration outcomes, yet, what constitutes a "past" or "normal" state is inherently subjective depending on the period for which an ecosystem's baseline is set (e.g. pre-colonial vs the 1980s). Differing baselines for past system conditions have significant implications for restoration planning and evaluation. Therefore, while bringing back healthy systems where they once thrived will likely remain a focus of restoration where feasible [5], this practice may overlook that past conditions may no longer be attainable.

With climate change and other global environmental change come shifting conditions that may inhibit the ability for past ecosystem assemblages to thrive where they once were, and new opportunities for systems to exist in places where they previously did not. As such, historical ecosystem states are not necessarily the most ideal, or even possible, outcomes for restoration under future climate conditions [5]. The restoration of a system's function might, in some cases, have to move beyond the conventional idea of in-situ recovery [5,6]. In this expanded view, restoration encompasses both the recovery of historical systems and the proactive adaptation of ecosystems to new environmental realities. For degraded systems, this includes enhancing their capacity to absorb or recover from climate disturbances [7,8]. In areas where recovery-in-place is not feasible, restoration may instead warrant guiding a local ecosystem toward a new assemblage or recreating lost habitat elsewhere. In all cases, the focus shifts from restoring past conditions to ensuring that the existing ecosystem functions effectively.

Restoration can be triggered by a diversity of motivators. In some cases, a local community may wish to see the return or restored health of a particular system. In other cases, an agency may provide funding for restoration projects that advance a statewide goal or that prioritize the recovery or enhancement of particular ecosystem services or functions. Although restoration may be inspired by the aforementioned or other specific motivators, this report asserts that for a project to be considered restoration, it must also seek to restore overall ecosystem function. If a project's sole purpose is to restore one aspect of ecosystem health without the complementary goal of restoring the system's function as a whole, there may be negative consequences for non-focal aspects of the system's health.

2.2 Resist-Accept-Direct Framework

Due to shifting environmental conditions outside the control of local authorities, resource managers may choose to adopt the Resist-Accept-Direct ("RAD") decision-making framework to inform restoration action as part of a larger spectrum of environmental management [9,10]. According to the RAD framework, restoration may be used to help *resist* change by restoring ecosystem composition, structure, processes, or function according to past conditions. Resisting ecosystem change can include bolstering the system's resilience by reducing local recurring stressors and restoring ecosystem components that enable greater resistance, recovery rate, and recovery likelihood (i.e., ecological resilience) [11–13]. If restoration to achieve natural recovery of the desired state is not possible, the framework offers *acceptance* as an alternative in which managers allow ecosystem composition, structure, processes, or function to change autonomously without restoration intervention [14]. Beyond these options, managers can actively intervene to help *direct* a system's transition to a new composition, structure, or function that is more likely to persist under future climate change [15].

The goal of the RAD framework is to enable clarity of goals, and identification of relevant management interventions to achieve those goals, when global environmental change challenges the feasibility of the traditional restoration goal of restoring to historic baselines [9,10]. Determining which approach (resist, accept, direct) may best achieve desired outcomes depends on a range of considerations including the degree of climate impact (current and anticipated, including the degree of uncertainty around anticipated future outcomes), feasibility (in terms of ecological, societal, and financial considerations), and societal acceptability [9,10]. Depending on the

information available (e.g., availability of downscaled climate models, mechanistic understanding of thresholds in system dynamics), navigating RAD may involve more qualitative approaches such as scenario planning or more quantitative approaches such as cost-benefit analysis [9]. Taken together, the considerations and information availability guide RAD's deliberative approach for evaluating the three pathways, with the chosen approach justified when it best serves the ecological and social objectives of the restoration. Therefore, acceptance of change is not a default to inaction but a deliberate outcome that is chosen once the full range of possible responses are considered. This choice, however, isn't static, as the relevant approach may also vary in space or time with changing environmental conditions, where multiple approaches can be considered together as a portfolio. Effective implementation rests in flexibility to adjust management over time [9,10]. Adoption of the RAD framework in projects by the National Park Service and USGS [9,16], and its use in evaluating management decisions in California coastal systems [17], exemplifies the utility of RAD in an array of contexts.

Use of the RAD Framework within the National Wildlife Refuge System and National Parks Service

The National Wildlife Refuge System and National Parks Service manages millions of acres of land across the United States. As such, managers of these systems experience a wide range of climate impacts which have provided real-world examples of different RAD decisions.

Resist: The Billy Frank Jr. Nisqually National Wildlife Refuge in Washington is an estuary whose tidal inundation was blocked by a dike in order to convert the area into farmland. These wetlands continued to degrade with the introduction of invasive grasses and impacted hydrologic flow. Managers decided to resist changes through invasive species removal and tidal flow restoration to restore the refuge to its pre-farmland conditions [18]

Accept: The Chassahowitzka National Wildlife Refuge is a system of estuaries, marshes, and islands in Florida that are being impacted by the effects of sea level rise. Rising seas are creating more brackish conditions for the ecosystems in the refuge. Managers have chosen to accept the changes in salinity and vegetation as they have decided that resisting these changes are not feasible [18].

Direct: In Glacier National Park, warming water temperatures and the proliferation of an invasive trout species are impacting the survival of the endangered bull trout (*Salvelinus confluentus*). Managers have decided that resisting these changes is not possible and that accepting these changes would lead to the further loss of the native trout species. As such, managers have decided to direct changes to the ecology of the upper creek above an impassable waterfall so as to create a new habitat area to help restore the threatened population of fish [19].

Mixed Approaches: The Blackwater National Wildlife Refuge in Maryland sits at sea level in tidal Maryland and is threatened by sea level rise. Managers have implemented a mix of resist, through invasive species removal and added elevation that bolsters against the effects of sea level rise on native vegetation, and direct, through excavation that enables tidal saltmarsh expansion [9].

Although directing a system to a new state is typically viewed as a last resort, accelerating climate change may make such interventions unavoidable in the future [20]. Recognizing this possibility early enables decision-makers to start collecting relevant ecological and social information now, which can inform choices in the future. Directing a system's transition to a new state, or creating a habitat where it currently does not exist, must be approached with the understanding that there are trade-offs associated with converting one habitat type into another. When the purpose of restoration is to recover lost ecosystem function, considering the social and ecological values of an ecosystem, even in a differing state, can support decisions about whether a shift in habitat composition is most appropriate.

Regardless of the management choice made under the RAD framework, restoration should only be deployed if it enables or accelerates recovery compared to what would normally occur. This determination depends on the feasibility of natural recovery, the timescale required for natural recovery, the expected scale of restored ecosystem function, availability of tools, regulatory frameworks, social desire, and adequate financing. Comparing potential restoration futures to a no-action alternative is helpful for informing whether restoration investments are worthwhile.

2.3 Identifying When to Restore

While there are many social, logistical, and economic considerations, understanding a system's natural spatio-temporal dynamics will help inform whether restoration intervention is worthwhile, at a given time and place. The productivity and persistence of many marine systems fluctuate in response to cyclical oceanographic conditions. Having sufficient and diverse historical data and modeling for future conditions can indicate whether a location may or may not be an ideal candidate for intervention. As an example, utilizing best available science can evaluate whether: (a) a location has a low likelihood of maintaining required conditions in the future and therefore may not be a candidate for intervention; (b) a system is lost or degraded beyond the potential for natural recovery on management-relevant time scales, and therefore may be a candidate for restoration intervention, or (c) whether that system is in a cyclical, predictable period of lower productivity or extent, and may likely recover within a reasonable time frame without intervention. Figure 2 provides a generalized framework that can be applied across a range of habitats to inform decisions on whether or not to restore.

While restoration is a helpful tool for supporting healthy ocean and coastal systems, and will likely be even more needed in the future, the field of restoration ecology broadly acknowledges that conservation, or proactive protection and prevention of degradation, is preferred over restoration necessitated in response to significant degradation [21]. Minimizing the need for restoration by preventing sources of degradation in the first place and managing for more resistant and resilient habitats should be prioritized. Conserving suitable areas today, whether they are lost, degraded, or healthy, can support managed systems in the future. One such example includes mitigation for environmental impacts of continued operation of Diablo Canyon Power Plant in San Luis Obispo County. As part of the Power Plant's certification to continue operations through 2030, the operator will protect 4,500 acres of land adjacent to San Luis Obispo through conservation easements [22]. Doing so enables opportunities for future management action, including restoration, in new areas that may not be priority or viable restoration sites today [4].

Conservation is preferred over restoration because restoration is a time- and resource-intensive endeavor with high variability of success. However, in urbanized and modified systems, many communities will need to pair conservation with restoration and subsequently conserve restored areas to support ecosystem function recovery.
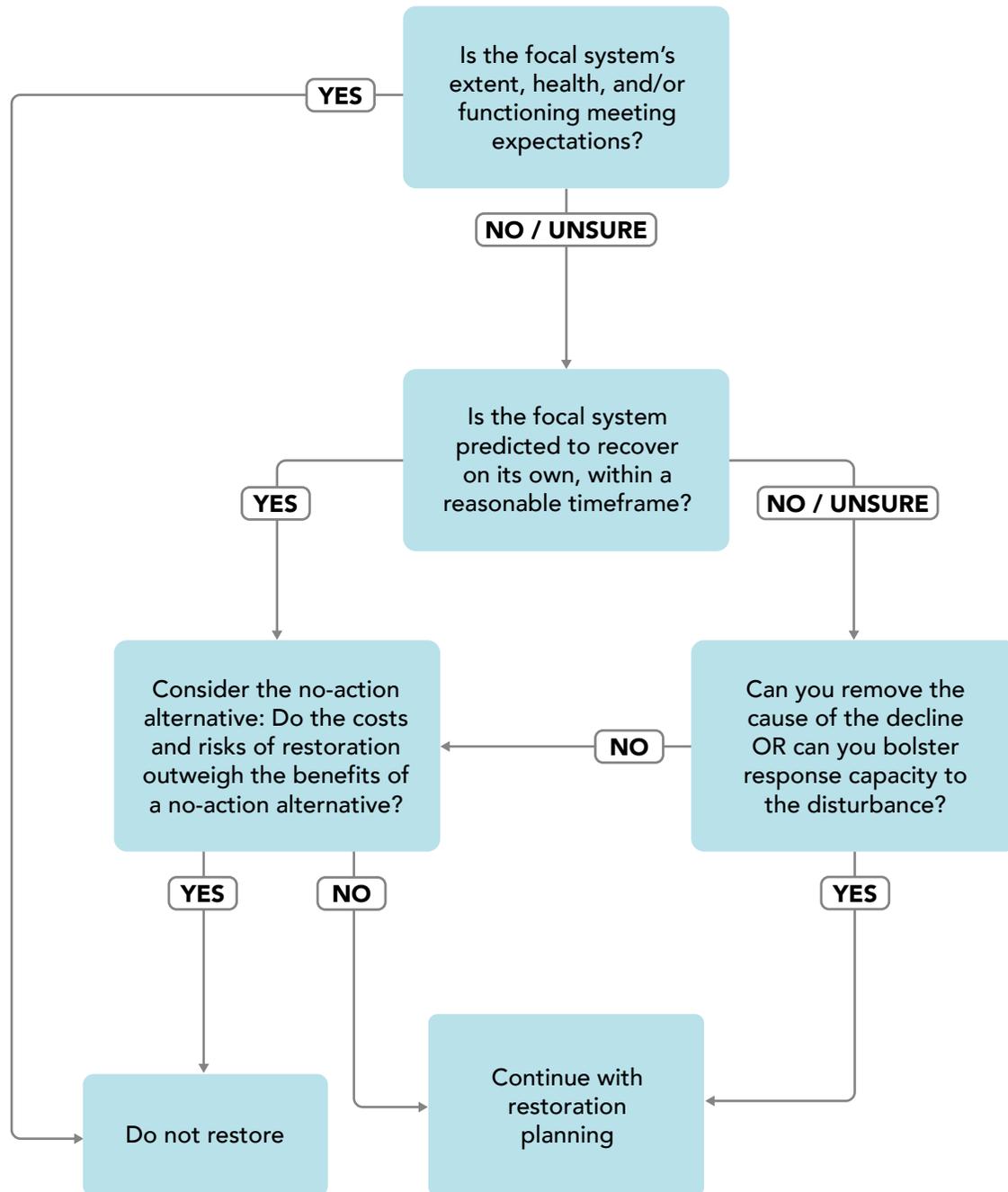
Figure 2. A generalized decision tree that can be applied across habitats to inform whether restoration is appropriate. The first decision point, which requires determining whether or not a target system's health is outside of its historical norm, can be based on a variety of habitat-specific factors. In most cases, determining thresholds for health abnormality requires collaboration and deliberation by subject matter experts. There is immense value in identifying habitat-specific restoration thresholds, and these efforts are encouraged to ensure thresholds are collaboratively developed, spatially/temporally appropriate and include multiple knowledge streams to guide decision making. One such example includes the ongoing development of the Kelp Restoration and Management Plan.

Restoration's uncertain return on investment is made even less sure under the influence of climate change, which introduces additional challenges, such as novel stressors, compounding disturbances, and uncertain recovery trajectories. Although restoration yields variable outcomes, some systems are so damaged, and some species are at such low abundances, that opting to conserve rather than restore is no longer a viable option. In some cases, restoration action may need to be taken regardless of cost because conservation may not be sufficient to support severely degraded systems into the future.

Restoration success rates can be increased by iteratively incorporating lessons learned from previous projects and on-site experimental studies. Knowledge sharing through the perpetuation of lessons learned supports more informed, and therefore more successful, restoration going forward. The development of new methods, techniques, and strategies offers opportunities for practitioners to remain optimistic as the pace, scale, and effectiveness of restoration continue to improve. Given this understanding of the difficulties of restoration, especially under climate change, this document is structured to help inform a coordinated, climate-informed approach to ocean and coastal restoration in California.

3. Considerations for Coordinated Statewide Ocean and Coastal Restoration

3.1 The Value of Coordinated Statewide Restoration Efforts

California's 1,100-mile coastline supports a high diversity of plant and animal species, both above and below the ocean's surface. The health of ocean and coastal ecosystems vary across the state, falling along the spectrum of healthy to degraded, often fluctuating along that spectrum according to seasonal, annual, or semi-decadal cycles. These ecosystems are subject to multiple management jurisdictions. Several State agencies such as the California Department of Fish and Wildlife, California Coastal Commission, California State Coastal Conservancy, and California

State Lands Commission have overlapping and complementary management responsibilities in ocean and coastal areas, as do federal agencies like the National Oceanic and Atmospheric Administration's Office of National Marine Sanctuaries and Office of Coastal Management, the Bureau of Land Management, and the Bureau of Ocean Energy Management. California's coastal and ocean ecosystems have also been stewarded and managed by Indigenous peoples since time immemorial. Tribes continue to lead in protecting and restoring marine ecosystems, both through centuries-long stewardship and, more recently, through tribally-led research and monitoring programs such as the Tribal Marine Stewards Network. As California works to more meaningfully engage with tribes in natural resource management, the state is increasingly supporting tribal stewardship through actions such as co-governance and co-management agreements (e.g. Assembly Bill 1284, which authorizes the California Natural Resources Agency to enter into such agreements with federally-recognized tribes) and land back initiatives (e.g. the Wiyot Tribe's leadership and stewardship of *Mouralherwaqh*, a 46-acre stretch of ancestral lands acquired by the Tribe through funding from the California Ocean Protection Council). Jurisdictional and ecosystem diversity combine to yield a complex landscape for tribal and local governments, natural resource managers, policymakers, researchers, community members, and restoration practitioners to navigate.

Supporting a healthy California coast and ocean requires coordination across tribal, local, state, and federal governments, guided by the expertise and knowledge of scientists, practitioners, and local communities working on ecosystem restoration and management. Aligning efforts and goals across resource managers and permitting agencies is essential to making the most of limited financial resources and for minimizing barriers to conducting restoration in California. Statewide coordination on restoration actions and priorities for the California coast under climate change can bolster ecosystem health, support biodiversity, facilitate species range shifts, and contribute to climate refugia, as discussed in Section 4 of this document.

Establishing shared priorities[1] and agency-specific actions to accelerate coastal and ocean restoration supports both individual agency mandates and cross-jurisdictional coordination. Restoration priorities for California have historically been set by its executive branch via agency strategic plans [23,24] and by its legislative branch via

---

1   Although statewide restoration actions and priorities may also fit the definition of a restoration goal, this document reserves the term "goal" for the project-specific context discussed in Section 4, so it is not used in the context of statewide restoration priorities and actions to avoid confusion.

new legislation like Assembly Bill 1581, the Restoration Management Permit Act passed in 2024, and Assembly Bill 1757, passed in 2022 to establish nature-based climate targets. Past and current restoration priorities have been presented in multiple ways, including restoring a desired acreage of habitat; supporting an identified number of projects; assessing current systems' health, extent, and management practices; and more. Examples of recent or current statewide restoration actions and priorities include

- **By 2027, in partnership with the California Department of Fish and Wildlife, complete the statewide Kelp Restoration and Management Plan and restore at least 2,000 acres of kelp forest by 2030"** Target 3.3.2 from OPC's 2026-2030 Strategic Plan.

- **"Restore at least 7000 acres of coastal wetlands, 100 acres of native oyster beds, and 200 acres of eelgrass meadows by 2030."** Target 3.3.3 from OPC's 2026-2030 Strategic Plan.

- **"Support 85 habitat restoration or enhancement projects"** Target 3.2.1 from the California State Coastal Conservancy's 2023-2027 Strategic Plan.

- **"By 2030, fund at least three land acquisition projects that increase** opportunities **for coastal habitat restoration and upland migration in the face of sea level rise."** Target 3.3.5 from OPC's 2026-2030 Strategic Plan.

Coordinated statewide actions and priorities can be helpful for incentivizing progress and investment by creating a sense of urgency and collective action. Statewide actions and priorities can provide

a common outcome that multiple agencies, governments, and non-governmental organizations can rally behind, empowering those entities to identify their individual roles and responsibilities in contributing to success. This sense of community and individual responsibility in service of a unified vision can be a powerful tool for progress in multiple applications, restoration included. However, if statewide priorities and actions are not developed and executed with consideration of the best-available science and needs and values of the people they affect, they can be counterproductive due to misallocation of resources and loss of public trust. Statewide priorities can also be counterproductive if they set unrealistic targets or create unfunded mandates.

3.2 Science Information Needs for Identifying Statewide Restoration Actions and Priorities

To identify whether restoration can contribute to the State's vision for a healthier California coast, it is necessary to understand the current extent and health of focal systems, potential for restoration, and likelihood of restoration success. To the best of their ability, policymakers should seek to answer the questions in Table 1 to understand how an individual site and the focal system as a whole contribute to statewide priorities.

The process of establishing state-level restoration priorities and identifying actions often occurs from the top down because of the need for consistency across agencies or coordination of funding. A top-down approach means that policymakers identifying statewide restoration needs would be informed by a broad California-wide picture of restoration potential, area-based management measures, needs, jurisdictions, and causes of degradation. However, informing statewide actions and priorities through a bottom-up approach can ensure that local considerations, knowledge, and values are reflected in statewide targets. Questions in Table 1 highlight how similar considerations can be asked at the local scale and the statewide scale. Recognizing the similarities in these considerations and differences in approaching their answers can help bridge the difference between statewide and local priorities. Setting state priorities that balance statewide interests with local needs can yield clear, coordinated, and actionable plans.

Table 1. Information needs for bottom-up (project-specific) and top-down (statewide) approaches for identifying scientifically sound statewide restoration priorities and actions. When answers to the questions below are unknown or of low confidence, section 5.3 (risk considerations) and section 6.2 (adaptive management), can support implementing protective measures rather than delaying action due to incomplete information.

Science Need	Local Scale Questions	Statewide Scale Questions	Questions for Both Scales
Projected impact of a no-action alternative	Are adjacent systems sufficient to maintain local ecosystem functions if a no-action alternative is pursued?	Is the current statewide distribution and status of the system sufficient to support natural recovery?	If restoration interventions are not taken, what is the prognosis for the target system? How might changing ocean conditions impact this trajectory?
Stressors	What are the site-specific, or immediately adjacent, stressors that are leading to the degradation of the system?	What are the broadly prevailing stressors degrading the system that require statewide management?	Could the stressors be reasonably removed, improved, or mitigated? How will a changing climate affect the frequency and magnitude of the stressors?

Science Need	Local Scale Questions	Statewide Scale Questions	Questions for Both Scales
Extent and Distribution	How large is the system? Where does the system currently exist?	What is the combined area of the systems? What is the regional distribution of the system across California?	How much larger were the systems historically? Where has the system historically existed? What is the amount of variation- spatially and temporally? Where might the system reasonably exist in the future?
Restoration potential	Are site-level environmental and social conditions supportive of restoring the system?	Is there sufficient statewide policy, funding, and permitting support to enable restoration of the system at the statewide scale?	What is the general condition of the system? Is there available area to be restored, or is restoration potential inherently space-limited?

Science Need	Local Scale Questions	Statewide Scale Questions	Questions for Both Scales
Availability and efficacy of restoration techniques	Have restoration techniques for the focal system been piloted and/or scaled in the area in which restoration is being considered? If so, how successful have techniques been and what can be learned from previous projects? If not, are there parallel regions that techniques could be borrowed from? Are there new or more experimental techniques available?	How extensive has restoration of the focal system been statewide? Do techniques vary from region to region?	Are some regions demonstrating higher restoration efficacy than others, and if so, can causes or influencing factors be identified?
Current protections	What site-level measures are protecting the system?	What State policy frameworks and regulations are protecting the system?	Are current protections sufficient to support the recovery and preservation of the system?
Future impacts	What are the projected changes in site suitability under future climate conditions?	Where is the system projected to exist under future climate conditions? How will this impact the system's health and function across California?	How can future projections of climate inform whether restoration interventions should resist, accept, or direct the system to change?

3.3 Criteria for Statewide Restoration Priorities and Actions

Although specific statewide restoration actions and priorities are unique to each system and to the various agencies with jurisdiction or permitting authority relevant to the system in question, there are several broadly-applicable criteria that policymakers may want to consider when they determine statewide restoration priorities. A scientifically sound statewide restoration priority or action needs to be ambitious, achievable, trackable, have a specified timeline, and be flexible in recognition of context dependencies and climate change considerations.

Achievability in this context means obtaining the desired benefits for the predicted cost, taking into account current restoration methods, potential area to be restored, financial resources, and likelihood of success. Although it is critical to be aware of the scale and speed at which restoration is currently underway for a focal system, statewide priorities may also choose to identify ambitious actions that require innovation and collaboration. A priority or action must also be achievable from a permitting perspective. Whether the priority is conducting a defined number of projects, restoring a system to a desired acreage amount, or innovating new restoration techniques, permitting pathways must exist or be able to be revised to allow progress to achieve the priority. Effective and efficient permitting takes into account the resources needed to secure permits, available restoration areas, possible restoration techniques, and the likelihood of success. When testing new methods of restoration, appropriate scaling of pilot projects should be employed to minimize the risk of unintended consequences while still allowing for innovation, prior to applying at full scale.

Actions must also be trackable through metrics that describe a project's contribution to state priorities, such as the number of projects supported, the number of acres restored, and the percent of projects that were successful, as discussed in Section 3.5. Understanding whether progress is aligning with priorities and actions to which the State has committed provides opportunities to adjust course as needed. This is also why tying actions to a specific date is important; projecting whether current efforts will lead to completion of an action or progress toward a priority by the specified date allows for timely reassessments of approach and resource allocation, if needed. Being able to track and measure progress hinges on sufficient investment and resources allocated toward restoration monitoring, which is discussed in more detail in Section 6.

Policymakers should also consider the difference in value that a restoration action may have if it is carried out in the near future versus the longer term. Although there may not be regulatory or legal consequences for missing mandated or adopted deadlines for restoration action, the cost of delaying restoration may be incurred by coastal human communities that are dependent on the services provided by healthy coastal ecosystems [25]. One study estimates that every dollar invested in coastal restoration provides $15 in economic benefits, meaning every year of delay represents lost value to communities [26]. Setting and sticking to specified dates for restoration action can ensure that investments yield outcomes that are as impactful and valuable as possible.

3.4 Setting Goals for How Much of the California Coast to Restore

Restoration actions at the State level can include establishing restoration grant programs, creating clearer permitting pathways for restoration, supporting Tribal stewardship of coastal lands and waters, and more. Another way that state agencies and the legislature can, and often have, promulgated restoration priorities is by setting statewide acreage-based targets for restoration of specific systems. Because acreage-based targets (e.g., restore 1,700 acres of coastal wetlands by 2030) [27] and percent protection targets (e.g. conserve 30% of California's lands and coastal waters by 2030, or the "30 x 30" initiative) are commonly used, this section focuses on that type of state action by presenting considerations for how to arrive at a scientifically-informed target extent.

Effective acreage-based restoration targets should be grounded in the possibilities and opportunities available within the state, yet ambitious enough to address present and future needs, and signal that restoration action is a priority. A useful start for determining acreage-based restoration targets is identifying how much area is ecologically feasible to restore.

Ecologists often begin to understand an ecosystem's potential for restoration by developing a picture of its previous known extent prior to anthropogenic stressors. This often comes in the form of a system's oldest known extent (an examination of the system's historical ecology). Identifying a system's extent prior to the effects of industrialization or other primary degrading stressor can indicate where the system thrived before prevailing causes of degradation, and therefore where the system may be able to flourish in the future if the causes of degradation are addressed. In other cases, a more recent

known extent of a healthy and functioning system may be used to understand current restoration potential. While both are helpful starting points, considering current and future sources of degradation, and whether those stressors can be feasibly addressed, provides bounds for developing a realistic restoration target. Historical data, long-term time series, and accurate, current maps can help ecologists and resource managers begin to develop this picture [28]. Traditional Knowledges held by California Native American tribes, who have stewarded the coast and ocean of what is now known as California for millennia, can complement non-indigenous science and provide a richer picture of long-term ecosystem health, cyclical trends, and other information. Land-based restorations have included partnerships with California Native American tribes to inform knowledge of past ecosystem health and extent, which have the potential to serve as blueprints for future application in a coastal context. One such land-based example was a partnership between researchers and the Karuk Tribe Department of Natural Resources, which resulted in a simulation model of cultural burning practices within Karuk Aboriginal Territory in northern California. The partnership leveraged inter-views, historical maps, ethnographies, ecological studies, contemporary maps, and generational knowledge to create an understanding of the extent and frequency of cultural burning practices across the study landscape, which can now inform ecosystem and fire management plans [29].

In addition to the challenge of obtaining or understanding past conditions, another challenge when creating restoration targets for a system is identifying *current* extent, statewide site suitability, and possible restoration potential. These assessments require significant data that may not be available for focal systems. Restoration practices are more developed for some systems in California than others since some systems have been the subject of restoration practice for multiple decades (e.g., wetlands), while others have only recently garnered restoration attention (e.g., kelp). For data-poor systems, in lieu of an acre-age-based restoration target, decision makers interested in progressing toward restoration may instead identify a restoration priority focused on developing system health and extent maps, or supporting projects that fill knowledge gaps in restoration research. State-level actions to these ends will help California continue to build its restoration capacity.

Once viable restoration extent and/or system health goals have been determined, managers and policymakers may narrow down total potential extent based on financial, social, and ecological factors. Target extent can be identified as the total amount of statewide area for which there are projected net positive ecological, economical, and societal values gained through restoration compared to the predicted outcomes of a no-action

alternative. Identifying the potential benefits that restoration may bring can be informed by restoration goals that are explored further in Section 4.

As warming ocean temperatures, sea level rise, ocean acidification, hypoxia, and other climate stressors become more intense, efforts to develop restoration targets should be guided by an understanding that current habitat extent and successful restoration interventions are likely to evolve over time. Periodic reevaluation of restoration targets can ensure continuous alignment with observed and projected climate conditions. This may include adjusting acreage goals, redefining target habitats, or identifying new areas to prioritize as understanding of sustainable long-term management actions changes. Given the dynamic nature of climate change, the State may want to maintain flexibility in adapting both restoration targets, and methods for how to achieve said targets.

Understanding that restoration rarely, if ever, achieves a perfect match to the intended restored extent can also be helpful when considering targets. Varying levels of recovery should be expected for restoration efforts, both at site-specific and regional scales. The uncertainty that exists in regard to restoration success is evident in mitigation ratios, which often require restoration of 2-4 times the area that has been lost or degraded, as only a fraction of a restored area yields successfully restored systems [30]. Policymakers will want to consider whether statewide acreage-based targets should reflect the actual extent of desired recovery or reflect a larger scale than needed to account for uncertainty and variability of restoration success.

3.5 Defining Restoration Success

Policymakers and managers will need to define what is considered a successful project in order to track progress towards state priorities. Ultimately, as described in Section 2.1, restoration success is defined by a system that is self-sustaining with natural processes that maintain a desired state or condition. However, given the increasing influence of global stressors unable to be mitigated at the local level, a restoration that isn't self-sustaining does not mean that it is not worthwhile. For some restoration interventions, actions may be taken to "buy time" to preserve environmentally, economically, or culturally valuable resources while global stressors are being addressed. Restoration interventions can also provide systems experiencing rapid ecological change with benefits even when long-term project goals are not ultimately realized. For example, many species (e.g., migratory birds, anadromous fishes, and other taxa dependent on pulsed resource availability) rely on ephemeral habitat features and short-lived surges in resources such as food provisioning

or predator refugia that can arise during early or temporary phases of restoration. These transient gains can significantly influence survival, reproductive success, and broader population dynamics, providing critical energetic subsidies at moments of acute need. However, the protracted timelines associated with permitting, environmental review, and interagency coordination may delay action to the point that opportunities to deliver these ecologically meaningful but time-sensitive benefits are forfeited. As a result, organisms that might otherwise capitalize on temporary habitat improvements are left without support precisely when climatic stressors, phenological mismatches, and habitat degradation amplify their vulnerability. Recognizing the value of such interim benefits argues for more agile, iterative restoration models capable of delivering ecological relief on operationally-relevant timescales, rather than restricting investment only to projects expected to achieve long-term permanence.

For State funded or permitted restoration actions, success will need to be evaluated at two levels: state-level success and project-level success. State-level success for restoration projects is determined by a project's contribution to broader state priorities, such as successfully completing a certain number of projects or contributing to acreage-based targets. Project-level success is determined by whether the project accomplished specific predetermined goals as described in Section 4. Together, this creates a nested framework that links individual project outcomes and statewide restoration impacts. For example, a project that restores 50 acres of rocky reef by introducing hard substrate to an area where previously exposed rocky reef had been permanently buried by sediment (e.g. via a landslide) to support kelp recovery would succeed on both levels if kelp returns and the reef habitat is restored with the required species and structure to support all the previous functions of a productive rocky reef ecosystem. If the reef is restored but kelp does not return, the project has contributed to the state-level rocky reef acreage target but failed in its project-level goal. If the reef isn't restored and kelp does not return, then neither level of success is achieved. Distinguishing between types of success allows policymakers and managers to track progress while incorporating the variability of restoration projects outcomes.

Defining success also requires an understanding of how the scale of a restoration influences the outcome of a project. Different spatial scales achieve different outcomes, and successful restoration uses both small-scale and large-scale approaches. Small-scale projects can serve as testbeds for piloting new techniques, fostering community involvement, and catalyzing natural recovery, such as by acting as source populations for adjacent areas. Small-scale restorations are particularly impactful in urban or

resource-limited settings where they can deliver a disproportionate number of benefits, such as improved water quality or shoreline protection, relative to their size. Large-scale projects, on the other hand, have a greater likelihood of providing full recovery of ecosystem functions. However, determining what constitutes a 'small' or 'large' scale project is dependent on the system (such as the dispersal distance of the species) and on the extent of degradation that motivated the restoration. Ideally, the scale of the intervention should match the scale of the problem. If that is not feasible, clear goals should be articulated to understand the objectives of a small-scale project and how it can be scaled if techniques show promise and resources can support expansion. By linking scale to success metrics, practitioners and policymakers can better evaluate progress.

Finally, restoration success must be interpreted through the lens of climate change. As environmental changes persist and intensify, policymakers will increasingly face complex questions about what constitutes success. For example, should a system be considered restored if it achieves the desired function but requires chronic intervention to persist? Similarly, if a project using the RAD framework initially aimed to resist change, but post-intervention monitoring reveals that this system can't be sustained, does deciding to accept the change or direct it to a new assemblage mean the project was successful? Integrating the RAD framework into restoration planning allows for the flexibility required but risks shifting the goalpost of what is considered a success.

Restoration in Action: Small-Scale Restoration with Large-Scale Impact

Restoration of *Zostera marina*, a native species of seagrass, in California's Elkhorn Slough constituted small-scale experimental restoration, but resulted in large-scale impact. The restoration transplanted seagrass into 117 0.25m² plots over two years within the Slough, with the goal of tracking the survival and health of the transplanted seagrass, its rate of expansion, and whether the restored seagrass ecosystem would function similarly to naturally existing beds. Over time, transplanted seagrass beds expanded without further restoration intervention by ~8,500%, from a total initial transplanted area of 29m² to 2,513m² of restored seagrass within three years [31]. This highlights the notion that small-scale restoration can have an outsize, large-scale impact, and emphasizes the value of small-scale restoration that has the potential to catalyze further natural recovery.

3.6 Translating Statewide Restoration Priorities Into Regional Opportunities

After statewide priorities have been identified, realizing them may require translation into regional opportunities. Focal systems such as kelp, eelgrass, wetlands, sandy beaches and dunes, oyster beds, and rocky reefs have variable restoration potential and need across the state. For example, a statewide acreage-based target of restoring a specified number of acres of an ecosystem type does not mean that California's South, Central, North Coast, and Channel Islands regions must contribute equally to achievement of that target. Instead, prioritization can draw on regional contexts, historical extent, the condition of existing habitat where restoration is most likely to be effective, and areas of degradation or loss. Similarly, restoration practices in one region may be further developed than practices for another region due to differences in ocean conditions, species composition, or accessibility. For example, a statewide funding opportunity to innovate scalable practices may concentrate requests for proposals in regions with less established practices and therefore higher funding needs.

4. Restoration Goal Setting and Project Planning

Motivators for restoration serve as the foundation for project goals. Project goals constitute the broad, overarching vision for why restoration is proposed and may encompass multiple objectives. In the context of mitigation, goals may be pre-defined according to regulatory requirements. For voluntary restoration, project goals are based on the reasons why restoration intervention is determined to be necessary, advantageous, or valued.

4.1 Developing Project-Specific Goals

Restoration goals form the foundation for all project decisions, from site and intervention selection to monitoring and evaluating success. As such, goal setting should be a deliberate and holistic process that happens at the beginning of a restoration project. Project goals reflect the primary motivators for restoration, such as replacing lost or degraded marine and coastal resources,

reestablishing ecosystem services, advancing community priorities, progressing toward statewide restoration targets, and more. Project goals are often inclusive of multiple types of motivators and considerations, which may require different approaches, and therefore need to be developed in an inclusive manner. It is advisable for practitioners to consult with the relevant state agencies (e.g., California Department of Fish and Wildlife, State Coastal Conservancy, and the California Coastal Commission) early in the planning process when goals are being scoped.

While statewide goals may motivate restoration as they are usually tied to available resources and permitting, they are often not the only goal that practitioners must consider. Due to the complexity of competing and varied interests that arise, a structured decision-making approach can guide the process of goal development, project design, and implementation [33–35]. Structured decision-making is an iterative approach to analyzing decisions by defining the scope of decision-making, identifying possible goals, comparing restoration actions, and evaluating how those actions may achieve the identified goals. In practice, the goal-setting stage of a structured decision-making approach is an invaluable time to engage with connected communities, stakeholders, tribes, agencies, and a scientific advisory committee to gain their input and perspectives to ensure goals are inclusive and reflective of a diversity of perspectives. Structured decision-making is particularly useful when navigating complex, values-driven decisions because it invokes transparency and structure.

4.2 Identifying Restoration Goals

The following section captures some values that practitioners and managers may consider in identifying project-specific goals and statewide motivators for restoration. The goal categories described in this section are summarized in Table 2.

Table 2. Example goal categories that may motivate and guide restoration goals and actions, along with questions to help guide goal development.

Goal Category	Question(s) to inform goals
Ecological	**Ecosystem health and function:** What ecosystem functions are enhanced by this restoration? How are functions linked to condition and health? **Biodiversity:** How does this site improve native habitat quality and the associated biodiversity? **Climate and coastal resilience:** How does the project bolster coastal resiliency and adaptive capacity to climate change?

Goal Category	Question(s) to inform goals
Financial	**Economic benefits:** What are the additional benefits to the economy (e.g., jobs, tourism)? How will the enhanced ecosystem functions reduce the financial burden of associated risks to communities?
Social	**Equity:** How does the project advance equity and environmental justice? Are the derived benefits from the restoration equitably distributed? What types of knowledge and perspectives are incorporated into planning and decision-making? **Tribal collaboration:** How have Native American tribes been involved in scoping the restoration project? How can the project support tribal stewardship and/or co-management? **Access, recreation, and culture:** Does the project improve coastal access and recreational and cultural opportunities for communities? Does the project restore people's connection to nature? **Community:** Is the community generally supportive of taking proposed restoration action? Does the project support community resilience to climate change? **Education:** How can the restoration provide educational benefits either during or after it occurs?

4.2.1 ECOLOGICAL GOALS

Ecosystem Function

Ecological functions encompass the totality of the biophysical processes that mobilize, transform, and redistribute energy and matter within and among ecosystems. These functions are crucial for maintaining a healthy, thriving ocean and include provision of nursery habitats, nutrient cycling, water filtration, shoreline stabilization, and numerous other vital processes. When setting goals, practitioners may identify which functions are most degraded or at risk of being lost when deciding what to address. Practitioners should create a guiding image of a dynamic, healthy, and self-sustaining ecosystem that serves as a target to motivate the restoration effort and adaptive management strategies [36]. Under climate change, it is often appropriate to gauge restoration success in comparison to reference sites that contextualize what is achievable for a given system under current conditions [37]. The Sonoma-Mendocino Bull Kelp Recovery Plan, for example, relies heavily on Marine Protected Areas as reference sites for nearby restoration activities to provide insights into the environmental factors influencing kelp recovery [38].

While restoration determines success in comparison to historical baselines, climate change calls practitioners to consider shifting their approach to include not only what was historically possible, but also what will be both realistic and necessary in the future. This shift may focus on ecosystem function and resilience rather than historically representative assemblages [5]. Using a climate informed approach identifies future system functions that may be ecologically meaningful and achievable, even if those functions differ from historical or current baselines [5]. The RAD framework provides guidance for determining whether goals that attempt to resist, adapt, or direct change are most appropriate.

Conservation of Refugia

Refugia are areas of buffered environmental conditions or slower environmental change that enable the persistence of populations and communities under climate change [39]. In conservation science, many have suggested prioritizing protection of refugia as locations that are more likely to persist under future climate conditions [40]. In the event that short-lived stressors degrade a system, refugia in which ecosystem functions have been restored may be better suited to survive, and therefore can help facilitate recovery of that system even outside the restored area following the end of degrading events. A goal of perpetuating climate refugia can be particularly relevant when future climate impacts are anticipated to be high enough to undermine system persistence in many locations [41].

Ecological Rarity

Ecological and cultural rarity can be a decisive factor when selecting or prioritizing restoration sites in coastal California, where certain locations possess values that far exceed their spatial footprint. Sites that sustain uncommon species assemblages, rare geomorphic features, or singular oceanographic conditions (e.g. the biogeographic boundary at Point Conception) may exert disproportionate influence on regional biodiversity and ecosystem functioning. Likewise, places that hold deep cultural, spiritual, or historical importance for Indigenous nations and local communities may warrant elevated consideration. For example, the hill of Sat'wiwa in Ventura County, central to sunrise ceremony for the Chumash people, embodies a lineage of cultural identity, stewardship, and enduring place-based relationships that cannot be replicated elsewhere. Prioritizing restoration at such ecologically or culturally rare sites acknowledges that their loss would entail not only the disappearance of unique ecological functions but also the erosion of irreplaceable cultural heritage. Consequently, these locations may merit restoration investment even when adjacent sites may appear more tractable, because their singular significance confers benefits—biophysical, social, and cultural— that resonate far beyond their immediate boundaries.

4.2.2 SOCIAL GOALS

Site-specific project success relies upon on-the-ground practitioners who manage restoration work and support from the community that experiences the benefits produced through restoration practice and success. Therefore, local involvement in planning can promote connection to and support for restoration projects [42]. Project goals should incorporate the values, priorities, and lived experiences of tribes and other coastal communities. Community involvement can shape project design through integration of local

and traditional knowledge of the site to enhance project outcomes [43] while building community capacity and local knowledge through participation in the process.

Equity and Access

Practitioners may choose to set equity goals that seek to address past and present environmental injustices. In California, frontline communities, particularly low-income populations and communities of color, are often disproportionately affected by climate-related impacts [44]. These communities have faced and continue to face barriers to participation in decision-making processes, which have contributed to inequities in how and where resources are allocated. Equity-focused restoration goals may aim to ensure that restoration initiatives address past, current, and emerging environmental harms by ensuring that the ecological, economic, and social benefits produced through restoration are distributed more equitably [45]. This involves being responsive to the needs, priorities, and inputs of local and connected communities.

Practitioners may also choose to set restoration goals that enhance equitable access to restored ecosystems. Access to nature is critical to human health and well-being [46,47]

Restoration in Action: Restoring Malibu Creek to Benefit Biodiversity and Human Communities

The Malibu Creek Ecosystem Restoration Project (MCERP) is a State-supported initiative that will remove Rindge Dam from Malibu Creek. Rindge Dam was built in the 1920s on the ancestral lands of the Chumash and Tongva people to generate private water supply to the Rindge Ranch. The dam is no longer operational, and has been trapping sediment and altering natural hydrology since its construction, effectively severing upstream passage for fish and wildlife. Restoration of Malibu Creek by the California Department of Parks and Recreation (State Parks) will include removal of the dam, removing and/or remediating eight smaller upstream fish passage barriers, and removing 780,000 cubic yards of sediment behind the dam. These restoration actions will open 15 miles of stream habitat that have been inaccessible for migrating fish and aquatic species for nearly 100 years. Throughout project scoping, State Parks engaged with community members to understand the cultural value that a restored Malibu Creek could bring. This project represents a small step to restore cultural lifeways for tribal nations, and offers expanded recreational benefits through the restored watershed [52].

but access remains inequitably distributed across California due to systemic injustices [48]. Restoration of degraded habitats has the potential to improve equitable access, particularly for marginalized communities that have been separated from the coast due to discriminatory practices such as redlining [49]. Restoration can also improve recreational opportunities for local communities (e.g., helping to ensure that water is safe for swimming and seafood is safe to eat) [50]. Inclusion of tribes and local communities in restoration and monitoring work can provide valuable training and workforce development opportunities [51].

Tribally-Led Restoration

In California, a history of state-sanctioned genocide and the forceful separation of tribes from their ancestral lands and stewardship practices has harmed both people and nature. Despite the systematic exclusion of tribes from their roles and responsibilities as stewards, tribes have persisted and continue to practice their traditional lifeways– including traditional stewardship practices such as cultural burning – to support both ecosystem health and community well-being. This includes the restoration of degraded ecosystems in traditional tribal territories.

Restoration can advance self-determination by centering tribal leadership and governance and addressing historic and ongoing barriers to land access and stewardship [53]. This includes tribes acquiring land or management authority within their traditional territories, such as the Blue Lake Rancheria which was recently awarded $11.4 million to buy and restore lowlying lands for wetland restoration [54]. It also includes state-funded and tribally-led restoration projects, such as the Tolowa Dee-ni' Nation's Ghvtlh-k'vsh shu'-srnelh-'i project to train tribal natural resources staff in kelp monitoring skills and to host Indigenous youth kelp restoration workshops [55].

Restoration can also strengthen place-based identities, revitalize cultural practices, and support transmission of Indigenous and local ecological knowledge [56]. This includes restoring culturally-significant species, access to traditional harvesting areas, and the conditions necessary for cultural ceremonies and stewardship practices such as fire, shellfish tending, or wetland management [57]. Such goals link ecological renewal with the continuity of cultural lifeways and can enhance intergenerational learning and governance capacity. The State and external partners should work to support tribally-led restoration wherever possible. Where tribally-led work is not possible, for example due to limited tribal capacity, restoration practitioners should ensure that tribes are included as meaningful partners in restoration work.

Ecosystem Services

As previously described, ecosystem functions are the cumulative processes and flows of energy and matter that support an ecosystem. Ecosystem functions often translate into 'ecosystem services', or the benefits that are conferred to human communities [58]. Ecosystem services can be broadly categorized into four groups; provisioning services (food, freshwater, soil, wood, fiber, pharmaceutical compounds, genetic resources, etc.), regulation services (climate regulation, erosion control, flood regulation, air/water purification, pollination, etc.), cultural services (spiritual, recreation, ecotourism, aesthetic, inspirational, educational, cultural heritage, etc.), and supporting services (soil formation, nutrient cycling, primary production, habitat formation, detritus decomposition, etc.) [58,59]. Due to this direct relationship to the communities connected and impacted by habitats and their health, practitioners often center benefits to people in project goals [60]. Goals focused on restoring ecosystem services recognize the role that functioning ecosystems play in supporting healthy coastal communities and economic prosperity. They provide direct links between ecological recovery and human well-being. To understand what ecosystem services are important to human communities, this report recommends taking a structured decision-making approach to goal-setting as described in Section 4.1.

Community Health and Well-Being

Beyond physical access, restoration can directly support psychosocial and physiological health outcomes. Exposure to biodiverse, aesthetically intact environments is associated with improved cognitive function, lower stress biomarkers, and reduced incidence of chronic disease [61,62]. Restoration may also enhance food security (e.g., safe harvestable resources), provide heat mitigation benefits in coastal urban areas, and reduce exposure to pollutants. Explicitly framing health as a restoration goal broadens the rationale for public investment and fosters cross-sector partnerships [63].

Social Cohesion and Participatory Governance

Restoration efforts often create new opportunities for collaboration, conflict resolution, and shared decision-making across stakeholders. Building social capital including trust, reciprocity, and network connectivity enhances the restoration and a community's adaptive capacity to future disturbances [64]. Participatory governance goals may seek to institutionalize inclusive processes, increase transparency, and cultivate stewardship groups that persist well beyond project completion.

4.2.3 FINANCIAL GOALS

Economic benefits

Economic considerations are integral to restoration planning because restored ecosystem services generate direct and indirect economic value [51]. Restoration can increase fishery output (e.g., kelp restoration can increase harvestable red urchin biomass, which yields an expected increase in fishing revenue in the red urchin fishery) and have spillover economic benefits to local coastal economies [65]. Restoration investments also support a local restoration economy including jobs in planning, permitting, construction, implementation, and monitoring [66]. Financial considerations provide policymakers and coastal users with a tangible understanding of how time and resources spent on restoration can materially improve human lives. By explicitly integrating economic analyses into restoration planning, decision makers can better understand how, when, and where restoration projects should be prioritized so that they offer the greatest return across ecological, social, and financial dimensions.

Restoration in Action: Elkhorn Slough Eelgrass Restoration

In Elkhorn Slough, an estuary located within the Monterey Bay, eelgrass extent plummeted from ~26 hectares in the 1930s to its lowest extent of 3 hectares in 1980 due to hydrological alterations, impaired water quality, and trophic downgrading. Coincident with the recolonization of sea otters into the system, eelgrass began to recover from 1980-2010. From 2010-2015, eelgrass area plateaued ~15 hectares short of its historical extent. As described in the Restoration in Action box in Section 3.5 above, in 2015 and 2016, two small-scale experimental restoration projects were conducted to hasten the recovery toward 1930 levels. Given the profound hydrological alterations to the system that began in the 1930s, the goal was to restore eelgrass extent, not distribution, as eelgrass today was likely to occur in different areas. Suitable habitat for the restoration was based on existing natural eelgrass distribution within the estuary (- 2 to 0 m MLLW) in 2014, a desired minimal distance from natural meadows (e.g., >25 m), and adequate water clarity [31].

Harvested eelgrass was transplanted using the garden staple method, a method proven successful in high-flow environments [67]. In addition to facilitating further recovery of historical eelgrass extent, a second desired outcome was to track whether restored eelgrass was functionally equivalent to adjacent natural meadows within 3-yrs post-transplanting. To track progress towards success, a suite of structural (restored plot area, shoot density, canopy height, above- and below-ground biomass, internodal distances, blade width) and functional metrics (dissolved oxygen, temperature, pH, fish and invertebrate species density and abundance, community composition, TOM) were assessed. By 2018, the total area restored expanded from 29 to 2,513 m² (an increase of ~8,500%), the biological community quickly resembled that of the natural meadows, and certain biogeochemical functions (e.g., modulation of water quality) were comparable between restored and natural meadows, while others (e.g., carbon storage) were slow to reach the natural meadow target [31]. More recently, restored eelgrass plots expanded and coalesced, forming extensive meadows utilized by large rafts of sea otters in areas where eelgrass had not previously existed, increasing not only eelgrass extent in the system, but its known historical distribution.

4.3 Assessing Site Suitability

4.3.1 IDENTIFYING WHERE A SYSTEM MAY BE VIABLE

The first step in achieving restoration goals is to select a site with the highest probability of meeting project objectives. Determining an appropriate restoration site is often more important to the success of a restoration project than how the restoration is undertaken [68,69]. Therefore, the first consideration for determining where restoration is appropriate within a region is understanding where an ecosystem can persist and function. To do so, decision-makers should create spatially-explicit suitability maps. Suitability maps that are informed by traditional ecological knowledge, long-term monitoring, reference sites, and modeling can help managers weigh and identify the predicated viability of potential restoration sites [70]. Ecosystem monitoring data, discussed further in Section 6, is therefore critical for understanding a site's functional capacity, long-term spatiotemporal dynamics, and responses to stressors over time.

One consideration for determining which sites may be suitable for restoration is the historical and current extent of the focal system [71]. Historical records, including traditional knowledge (where tribes deem it appropriate to share such knowledge), enable practitioners to understand where ecosystems and species were able to persist without pressure from current stressors [72]. A system's current extent allows researchers to understand what sites support ecosystems under existing exposure to stressors. These sites may be undistributed systems or already recovered restoration sites that may act as a reference site for practitioners [73]. Reference sites can provide managers with standards for present and anticipated responses to environmental conditions, templates for designing the restoration, and a framework to understand the recovery of functions over time following the restoration [74].

In the absence of historical extent data or when anticipating a change in suitable habitat under climate change, decision makers can use topographic, geomorphological, hydrological, oceanographic, and species distribution modeling [70,75–78]. These models aim to characterize the physical, biological, and chemical conditions that shape where a system is most likely to survive. Modeling can be done by combining several factors, including known system locations and environmental conditions associated with both the presence and absence of the system, to determine which site hosts the most favorable conditions [79]. Climate change is projected to change the conditions of our

coasts and oceans, so incorporating climate change projections into modeling allows practitioners to evaluate not only where the best areas for restoration are currently, but also which areas may be suitable for restoration moving forward [75]. Modeling in conjunction with long-term monitoring data lays the groundwork for identifying where projects are most likely to succeed. For some restoration projects, particularly those involving reintroduction of foundation species, the use of more dynamic tools that mechanistically forecast population dynamics under future climate scenarios can project persistence as well as presence [80].

Restoration projects don't occur in a silo; they're components of larger, more complex systems. Restoration actions unfold within the broader social-ecological systems in which they are embedded. A single project interacts with upstream and downstream processes, cross-boundary material and energy flows, and governance structures that influence outcomes well beyond the project footprint. Connectivity and network effects therefore encompass far more than the movement or occupancy of particular focal organisms: they include hydrologic linkages, sediment transport pathways, biogeo-chemical exchanges, cultural and economic relationships, and management networks that shape cumulative system behavior and ultimately restoration success [81]. When restorations are planned with this systems-level context in mind, they can reinforce functional linkages, bolster resilience across interconnected habitats, and enhance the capacity of coupled human-natural systems to absorb disturbance and adapt to climatic shifts [82]. Exploring a potential site's suitability as one node in a larger network can help to encourage design choices that complement adjacent landscapes and seascapes, amplify regional benefits, and leverage existing system dynamics rather than relying solely on site-specific interventions.

4.3.2 ADDRESSING STRESSORS

Once habitat suitability for a region has been established, potential projects can eval-uate sites based on the local (e.g. point source pollution, sedimentation, etc.) and regional (e.g. marine heat waves, sea level rise, etc) stressors that may impact a project's long-term success [83]. Project teams will want to determine whether the stressor(s) that degraded the system have been adequately addressed or if they can be managed as part of a restoration project. If mitigation of local stressors is not a part of the resto-ration activities (e.g., if sedimentation is the primary cause of decline, but restoration occurs without any change to sediment deposition), the act of habitat restoration alone will not address the root causes of degradation and will likely limit a project's poten-

tial to achieve its desired outcomes [84]. Therefore, sites with greater opportunities for stress amelioration could be higher priority [85]. However, local management cannot dampen global stressors such as climate change, such that if global climate change is the root cause of degradation (e.g., marine heat waves in kelp forests), then this might shift project goals and approaches towards bolstering the capacity for the system, or target functions, to persist under climate change as described in Section 5.3.

4.3.3 CONSIDERING HABITAT CONVERSION

When stressors can't be mitigated at a specific location, one value judgment that may come up, particularly under a changing climate that shifts ecosystem suitability, is habitat conversion. In some cases, such as off-site and out-of-kind mitigation, one habitat type may be transformed into another (e.g., converting sandy bottom into subtidal rocky bottom where one did not previously exist). The decision of whether the habitat lost is worth the potential for a restored system can be less straightforward. Factors that can help inform value judgments on whether or not to convert a habitat include system productivity, regional rarity, and local interests. The RAD framework discussed in Section 2.2 provides a helpful blueprint for considering habitat conversion. Clearly communicating and weighing the tradeoffs between restoration and no-action alternatives during structured decision-making processes as described in Section 4.1 can help yield community-aligned and science-informed decisions.

Connecting Restoration Gains to Ecological Loss

Most mitigation is "in-kind" mitigation, meaning that lost resources are replaced with similar resources. An example of this is a kelp forest being restored as mitigation for impacts to a kelp forest. However, some mitigation projects are "out-of-kind" mitigation, meaning that the replacement resources are different from the lost resources, such as coastal wetlands being restored as mitigation for the impacts of once-through cooling systems on fish larva (e.g., the San Onofre Nuclear Generating Station Mitigation Program). In-kind mitigation is preferred over out-of-kind mitigation, but there are situations where in-kind mitigation is not possible or feasible. Determining the appropriate type and amount of out-of-kind mitigation is difficult because of the dissimilarity of the lost and created resources. While

in-kind mitigation might determine the amount of mitigation that is required for full compensation based on acreage or a habitat-specific functional assessment, this approach is not appropriate for out-of-kind mitigation. Instead, some sort of common currency could be applied to the lost and gained resources to attain full compensation. Current research underway in California aims to develop a framework for making these challenging out-of-kind and off-site mitigation decisions, which can be further explored at https://coastal-mitigation.org/.

4.4 Further Considerations for Selecting Restoration Sites

Potential restoration sites are first narrowed down by their ability to advance project goals (as described in Sections 4.1 and 4.2), their ecological suitability identified by historical occurrence or anticipated habitat suitability (as described in Section 4.3), and their potential for natural recovery (as described in Section 2) [70]. Beyond this, site-specific selection from within viable restoration areas can take into consideration additional factors to help prioritize restoration sites.

4.4.1 RISK APPETITE

Project teams may want to consider the irreducible risk of a project, or the susceptibility of systems to the effects of climate change and the disturbance regimes they face, when comparing potential restoration sites [82,86]. Highly sensitive systems (i.e., systems that have low tolerance to stress) may be a riskier investment because they may be more susceptible to collapse as climate change intensifies. This is especially true for areas subject to frequent and/or severe disturbance, where even the least sensitive systems will struggle to persist. However, under low disturbance regimes, less sensitive systems may be able to recover without intervention, so practitioners and decision-makers may consider prioritizing riskier projects [86]. There may also be strategic value in prioritizing riskier systems that hold high ecological or cultural significance. The acceptable amount of risk will depend on community values and interests, emphasizing the need for structured decision-making processes described earlier in this section. Risk tolerance and the need to explore innovative approaches to restoration are discussed in further detail in Section 5.3.

Risk considerations may also play into site selection when practitioners anticipate trialing innovative restoration techniques in the restoration. A practitioner piloting a restoration technique like assisted gene flow to introduce more stress tolerant individuals may decide that it would be less risky to do so in an isolated site without other habitat nearby where associated risks (e.g., disrupted fitness from outbreeding depression or domestication selection as described in Section 5.3) could transfer. Then, if such an approach moves beyond the pilot stage to the implementation stage with risk mitigation practices in place, placement in a more connected site could enable the spread of climate tolerant traits [87]. Alternatively, a practitioner whose restoration intervention is stressor management may choose to restore next to an occupied habitat which can act as a source population for species to minimize the need for additional assisted recovery [88,89].

4.4.2 COST EFFECTIVENESS

The cost of restoration projects can be highly variable, so policymakers and practitioners may consider the estimated cost per acre of restoration that a proposed site would require, as compared to the cost of no action, recognizing that costs can vary substantially with project scale, particularly between pilot projects and large-scale implementation [68]. Every dollar spent on one project represents an opportunity loss elsewhere, emphasizing the need for strategic prioritization of resources. Considering the restoration scale a site would require to manage stressors, restore functioning, and bring back equivalent habitat acres is important for maximizing limited resources. However, this cost should be contextualized to the site. Restoration in a more degraded or physically demanding/logistically challenging area may have higher associated costs but could still deliver outsized ecological, social, or resilience returns. Balancing short-term goals with long-term benefits is valuable to the sustainability of achieving California's statewide targets.

4.5 Designing Objectives and Metrics to Track Progress Towards Success

To effectively evaluate restoration interventions, the broad goals defined in Section 4.2 must be translated into specific, measurable, and time-bound objectives prior to project deployment. Objectives outline the intended outcomes and define the approach for accomplishing a project's goals [90]. To bridge goals, objectives, and the evaluation of success, metrics are developed that can assess the performance of a restoration relative to expectations [91]. Metrics must be quantifiable and appropriately reflective of the goal to which they track [36]. In mitigation contexts, metrics may be prescribed by a permit. For voluntary restoration, metrics can be more flexible to reflect desired outcomes. Regardless of the context, selecting metrics that accurately track progress toward meeting objectives is critical to guiding restoration practices.

Metrics describe what a successful project looks like. While definitions of success may vary among different participants and may require an agreement on what a successful restoration entails beforehand [92], success for most restoration projects is based on whether or not the restoration site behaves like a reference site and achieves the identified project goals. Reference sites should support systems that are comparable to the restoration in relation to ecosystem assemblage, structure, and exposure to regional

stressors. Metrics tracked at both the restoration site and reference site can then be compared to indicate whether a restoration is progressing toward project objectives. Setting expectations for metric progress based on a reference site can set a realistic expectation for how systems similar to the restoration site fare under regional stressors and broader climate change impacts.

California's Marine Protected Area Network could serve as important reference sites for restoration activities and would support understanding the effects of human activities on the structure and function of ecological communities [93–96]. Their associated baseline monitoring (2007-2018) and long-term monitoring data provide a robust data set that can track conditions and trends of marine populations, habitats, and ecosystems in order to understand how they change over time, which could be useful to inform the design and evaluation of restoration projects. The Decadal Management Review (Recommendation 18) highlighted the need to develop a framework to evaluate and approve appropriate restoration and mitigation actions in Marine Protected Areas and Marine Management Areas [97].

Effective metrics must also align with expectations at the different stages of a project: before restoration (i.e., the system's baseline), during the project, and after interventions have been deployed [98]. Ideally, the metrics chosen will be able to indicate whether a project is progressing as expected according to the estimated recovery trajectory, and ultimately, whether the goal has been achieved. Specifically, sequential, multi-stage monitoring metrics enable evaluation of whether progress is matching expectations at each phase of a project [36]. For example, having near-term metrics (e.g., reduced number of grazers; community involvement in restoration intervention), intermediate-term metrics (e.g., kelp self-recruitment; increased local access), and longer-term metrics of success (e.g., recovery of kelp-associated species or ecosystem function; Improved local connection and stewardship of the site) allow for accurate progress tracking.

Effective metrics will have the capacity to support adaptive management. Adaptive management is the iterative process of implementing decisions, monitoring outcomes relative to expectations, and adapting future actions based on lessons learned from monitoring [99,100]. As discussed in Section 6.2, the ability to adaptively manage a project is crucial for improved restoration practices through time. As such, metrics should be designed with flexibility to accommodate changes as new information is collected or new opportunities become available (e.g., additional funding, new permitting

pathways or policies). In some cases, this change may need to happen quickly. Anticipating this possibility early in the planning process allows the practitioner to be more responsive during the restoration than they could otherwise be.

For voluntary restoration where one of the goals is studying the impact of the project and/or effectiveness of interventions, practitioners may choose additional metrics to evaluate whether the intervention itself affected the restored site. This may include before-and-after site conditions, detached from a reference site, that allow practitioners to understand the impact the restoration had on various aspects of ecosystem function and value of the site to human communities.

5. Restoration Techniques

5.1 Selecting Restoration Interventions

As project goals are being defined and a site is being chosen, the next planning consideration involves selecting the most appropriate intervention method. Method selection will depend on the degree of intervention needed to enable natural recovery on management-relevant time scales. Well-designed projects located at an optimal site allow some ecosystems to recover gradually with management, where each incremental increase in effort and resources contributes to an incremental increase in system health and associated ecosystem functions. In contrast, other systems may respond non-linearly to restoration, requiring a certain threshold of effort before meaningful benefits are realized [8]. In a subset of these nonlinear cases, some systems might exhibit multiple stable states under the same environmental conditions, such that the threshold for ecosystem recovery differs from the threshold for the original decline [8]. Deciding the degree of restoration intervention (i.e. the restoration method(s) to use and how far to go with each of them) is therefore a function of the required input to

achieve the desired output. In some cases, managing stressors then allowing the system to recover naturally will be sufficient [101]. For other systems that have alternative stable states, deploying assisted recovery methods such as reintroduction of foundational species may be required after stressors are managed [102] .

As with project goals (Sections 4.1 and 4.2), the choice of restoration method(s) also depends on ecological, financial, logistical, permitting and social considerations. This is especially true for projects directing change under the RAD framework where the stakes of the intervention method may be seen as higher than resisting or accepting change [9]. Identifying potential unintended consequences to the extent possible can help human communities consider which restoration interventions are most aligned with their values [103]. This exemplifies the need for structured decision-making in selection of restoration interventions, as described with regard to restoration project goal-setting in Section 4.1 [104].

When there is ambiguity about which restoration methods will be most effective or feasible (socially, ecologically, etc.) for a given restoration project, practitioners may decide to conduct a shorter-term pilot study that tests the efficacy of multiple restoration methods, or engage in active adaptive management from the outset of the project [9]. Adaptive management is described in further detail in Section 6.2 of this document in the discussion of monitoring, but active adaptive management is raised here as a part of method selection because it can entail a choice of trialing multiple interventions. Specifically, active adaptive management applies the principles of multifactorial experimental design to restoration, allowing trial of multiple methods at once to determine which is best suited to project goals, site, and resources. This is in contrast to passive adaptive management where practitioners can sequentially trial restoration methods, then revisit approaches after comparing outcomes to expectations [105].

5.2 Summary of Restoration Techniques

This section and the accompanying appendix provide a starting point for those interested in understanding system status, stressors, and restoration techniques for seven coastal and marine habitats in California: tidal wetlands, oyster beds, sandy beaches and dunes, rocky intertidal, seagrasses, kelp forests, and mid-depth subtidal rocky bottom. The seven systems presented in this document were selected for inclusion because they are already focal systems for restoration, are broadly recognized as having high cultural
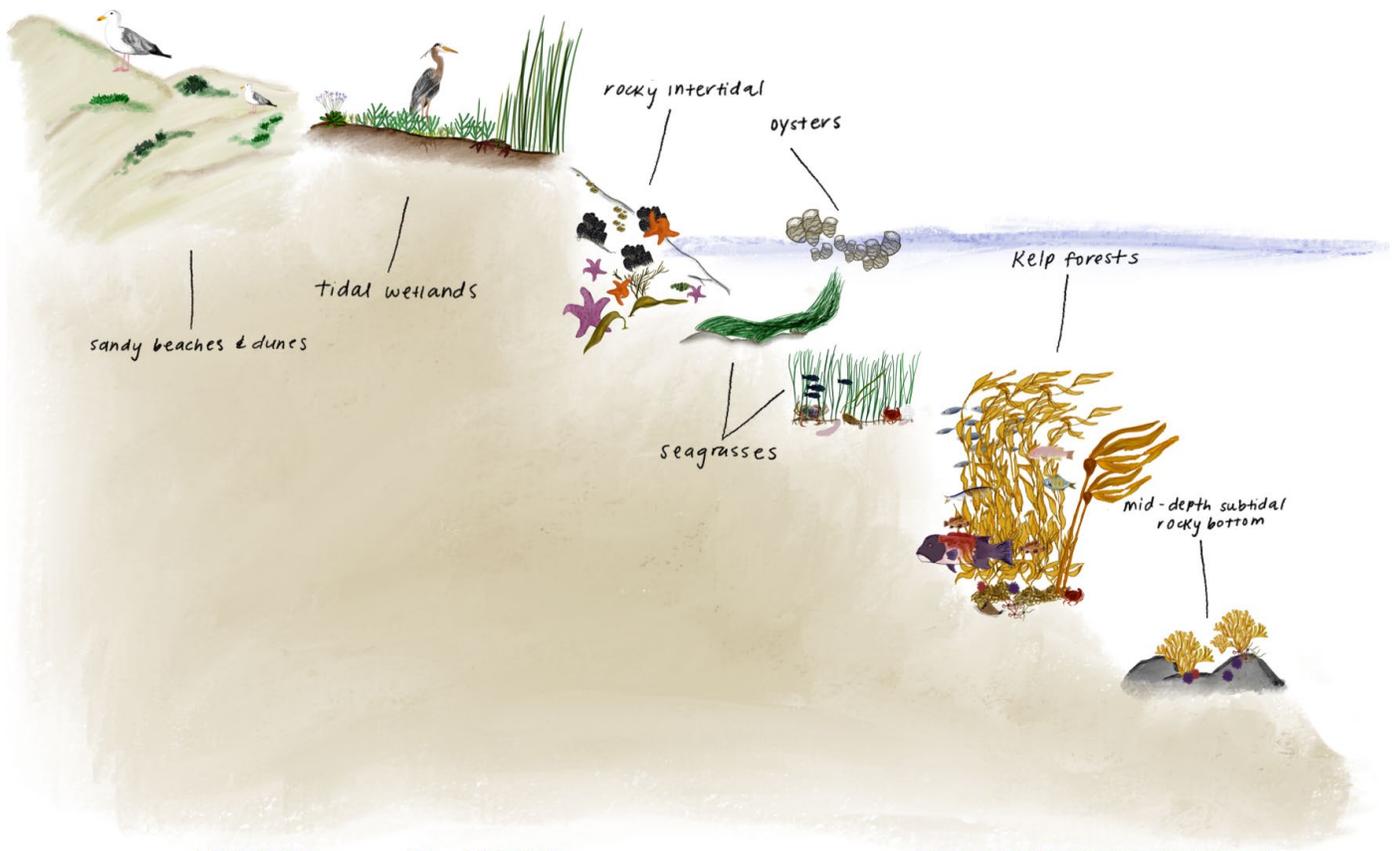
Figure 3. The seven coastal and marine habitats presented in Table 3 and the Appendix. Illustration by Dr. Kathryn Beheshti.

or ecosystem value, have experienced notable loss in recent decades, and/or are candidates for restoration intervention. Several of the systems discussed have substantial bodies of work conveying lessons learned from decades of restoration practice, while other systems are comparatively less studied, both in terms of ecosystem function and restoration practice. Maximizing the ecosystem services that are provided by healthy, functioning coastal ecosystems requires investments across a diversity of habitat types. Restoration investments in a thoroughly studied system support projects with a high likelihood of success, while restoration investments in less studied, but equally valuable, ecosystems can enable learning to improve practices, especially when implemented with an adaptive management approach that recognizes uncertainty and plans for learning as described in Section 6.2. Balancing confidence in outcomes and minimizing reducible risk while supporting projects which fill knowledge gaps in restoration practices will help the State continue to build its restoration capacity. To support further exploration of available resources to guide and inform restoration of these systems, a non-exhaustive list of system-specific publications is provided at the bottom of each subsection.

This report divides restoration interventions into two categories in this appendix: (1) stressor management, or methods to remove or mitigate abiotic and biotic stressors such as pollution and invasive species, and (2) assisted recovery, or methods to reintroduce or promote recovery of key species or processes or physical manipulation of the subject site. Identifying and mitigating site-specific stressors that cause degradation and limit or slow natural recovery can either enable natural recovery or improve the success of assisted recovery.

Table 3. Overview of habitat types and associated potential assisted recovery interventions. Source material is referenced for each assisted recovery intervention in the Appendix.

System	Potential Assisted Recovery Interventions
Tidal Wetlands	**Planting native wetland species** can help to stabilize sediment, improve sediment quality, and support ecosystem services. **Tidal channel creation or enhancement** moves water, sediment, and nutrients throughout the system. **Sediment augmentation** raises salt marsh plain elevation to increase ecological function.
Oyster Beds	**Rebuilding reef substrate** allows for larval settlement and growth. **Seeding** involves rearing oysters in hatcheries, seeding shells or cobbles with juveniles, and placing them at a restoration site. **Translocation** of adult oysters from one area to another can restore oyster beds.
Sandy Beaches and Dunes	**Dune revegetation** of native plants supports dune height and total sand accretion. **Installing sand fences** can help accrete sediment by stabilizing sand to promote dune formation. **Engineered structures**, such as groins, are generally discouraged but have potential environmental benefits for intensively used beaches.

System	Potential Assisted Recovery Interventions
Rocky Intertidal	**Outplanting, transplanting, and seeding of focal species**, such as rockweed, surfgrass, abalone, and mussels helps to provide physical habitat, ecological diversity, and ecosystem function. **Artificial tidepools and reefs** allow for habitat to migrate from rising seas.
Seagrasses	**Bare-root transplants** plant seagrass directly into a substrate. **Sediment-intact transplants** transfers shoots with the surrounding sediment to the restoration site. **Seed-based methods** are well suited for large-scale restoration but are limited in success by seed predation and germination rates.
Kelp Forests	**Seeding and outplanting** may reestablish kelp across large spatial scales. **Transplanting of adult kelp,** while limited in scalability, may help to create suitable habitat and spore sources. **Grazer mitigation** to reduce kelp herbivory and facilitate its recovery through recovery of urchin predators (e.g. sunflower star) or human mediated methods (e.g. urchin harvest). **Artificial reef installation** facilitates kelp settlement and growth.
Mid-depth Subtidal Rocky Bottom	**Artificial reef installation** replicates habitat complexity and promotes recruitment to the area.

5.3 Emerging Restoration Techniques Under a Rapidly Changing Climate

As the impacts of global climate change accelerate, many environmental stressors have the potential to extend beyond the control of local management, making conventional restoration methodologies and techniques potentially inadequate to restore ecosystems. In response, researchers and practitioners are exploring a range of innovative techniques to increase system resistance and resilience to climate change. Because these techniques are relatively new, some come with high uncertainty regarding effectiveness and potential unintended consequences on natural populations and ecosystems. The development of these techniques collectively represent a shift towards a more proactive approach to restoration that anticipates how climate change may necessitate larger-scale restoration and more climate-resilient systems. Broadly, these approaches fall under three categories: 1) protecting natural adaptive processes, 2) decelerating environmental stressors, and 3) enhancing the capacity of systems to adapt to change [15,106].

Protecting natural adaptive processes constitutes the least risky and most familiar category of emerging techniques. These strategies are often extensions of existing intervention methods that are expanded and contextualized under the framing of a changing climate. Strategies in this category may include efforts such as restoring connectivity of habitats along environmental gradients to enable range shifts towards higher latitudes in response to rising temperatures, or removing barriers to migration inland in response to sea level rise for intertidal systems. Protection of natural adaptive processes may also include the restoration of locations or processes that serve as climate refugia to enable natural buffering of populations and communities against climate impacts [39,41]. Strategies under this approach also include engineering advancement such as creating scalable restoration technologies that match the spatial and temporal reach of climate-driven impacts. For cases where in-situ protection isn't currently feasible, or to anticipate future restoration needs, tools for biobanking, such as cryopreservation, which allows for the long-term storage of species and genetic variability for future restoration use, may be considered.

A second subset of interventions to address changing conditions focuses on the deceleration of environmental stressors. While stressor management is already a component of restoration, future efforts may require greater intensity, broader scale, or more

technologically advanced methods to respond to projected climate futures. Substantially reducing stressors can allow for in-situ survival, acclimatization, and adaptation to occur. Deceleration of stressors can take many forms, from more traditional and well-established interventions such as water quality improvements, to larger-scale or untested interventions such as nutritional supplementation, new engineered structures for artificial habitat modification, or marine cloud seeding [107].

Beyond protecting naturally occurring processes, a third subset of interventions that practitioners may consider is how to selectively accelerate climate resistance and resilience within an ecosystem. This can be done in a number of ways. Practitioners might accelerate the capacity for populations to genetically adapt to change by introducing species genotypes expected to be more resistant to climate-driven impacts [108]. This can occur through approaches such as assisted gene flow (the movement of stress-tolerant traits within a species' range, such as from populations locally adapted to high-stress locations), assisted evolution (artificial selection for stress-tolerant traits in conservation aquaculture), assisted hybridization (hybridizing two closely-related species

or subspecies to enhance their adaptive capacity), or genetic engineering [15]. Targeting genetic diversity as a source of adaptive capacity can also constitute assisted gene flow if some of that diversity is nonlocal [109]. Resistance and resilience can also be bolstered through stress hardening, the physiological enhancement of stress tolerance by pre-exposure to said stress [110], and through microbiome manipulation to enhance tolerance to stress [111]. This subset of interventions also includes assisted migration, or the moving of species beyond their historic ranges to promote range shifts in response to climate change [112]. While many marine organisms with planktonic dispersal may not experience barriers to dispersal and therefore may not rely on assisted migration for range shifts, restoration that considers community composition more relevant to future than past climate conditions is essentially engaging in assisted migration. For example, frameworks and comprehensive considerations of these types of interventions in coral reef systems, see publications describing efforts in Australia [113] and the U.S. [87,114].

Collectively, these examples of emerging techniques represent an acknowledgment of a changing climate and the limitations that practitioners currently have to address that change. Placing these techniques in the context of the RAD framework described in Section 2.2, techniques to accelerate climate response exemplify "directing" response to climate change to a potentially new genetic, physiological, microbial, or community composition that might be better able to persist under future climate change, while techniques that protect natural adaptive processes exemplify "resisting" change by bolstering the system's ability to maintain its current state or return to a historically representative state or set of processes. In many cases, these techniques are novel, untested, and potentially risky, such that they raise questions about their potential efficacy, their risk assessment, the risk mitigation methods available, the risk appetite of communities where restoration is taking place (see Section 4.3.1), and the regulatory barriers for implementation [114]. Furthermore, the novel and untested nature of many of these techniques, including the knowledge necessary to know if they can exceed natural response capacity, means that they can risk investment in approaches that fail to achieve restoration goals. Many of these do not yet have the data available for implementation; for example, techniques to accelerate genetic adaptation rely on identification of genotypes associated with stress tolerance and an understanding of their trade-offs. Investment in research and development of these techniques might be more appropriate than inclusion in restoration projects at this time. However, they are included here with the recognition that knowledge can change quickly with research breakthroughs, and risk appetite can change rapidly with extreme events and associated system shifts.

Several tools can address the risk considerations and potential regulatory barriers to these techniques to enable a proactive, forward-looking approach. To account for the riskiness of these interventions, projects can set up structures that deliberately identify potential risks and unknowns. This includes having an independent scientific team review the risk assessment process for novel interventions [115] and inclusive social engagement in all stages of intervention deliberation [104]. More generally, an array of risk assessment tools enables evaluation of the risks of these interventions as compared to no action, which also carries its own risks [33]. In addition, identification of risks alongside engagement with community members to understand risk appetite enables monitoring for exceedance of risk tolerance levels to determine if and when a novel technique might need to be halted as described in Section 6.2 below. To address regulatory barriers, a number of approaches can balance the consideration of novel, riskier techniques with the need for robust regulatory frameworks that protect against potential ramifications, including a) partnership with practitioners to experiment with new techniques in designated testing areas (e.g., more isolated locations where risks are less likely to spread; "regulatory sandboxes"), b) scaling regulatory requirements according to the risk of a technique ("risk-weighted regulation"), and c) providing flexibility to iteratively revise rules after implementation ("discretionary review") [116].

6. Monitoring and Evaluating Restoration Projects

Monitoring is critical across all phases of restoration, from pre- through post-intervention, to assess restoration efficacy, enable learning for improved management through time, and to understand whether project or permit goals have been satisfied. Monitoring provides necessary data for evaluating outcomes, reducing risk, and guiding decisions in the face of uncertainty. The frequency, intensity, and type of metrics measured should tie directly to project goals and adapt as projects progress [117].

6.1 Pre-Restoration Monitoring to Establish System Dynamics

Pre-restoration monitoring serves two interrelated roles: 1) assessing ecosystem status and trends by distinguishing whether an ecosystem's current state reflects a naturally variable pattern of change or

is indicative of a directional shift in structure and function, and 2) setting a baseline to tie restoration metrics to site-specific, measurable reference values, allowing practitioners to evaluate the system's current state and strategically deploy a series of restoration interventions at spatially- and temporally-appropriate scales to maximize restoration investments [118]. Together, these functions ensure that restoration actions are accurately informed and contextualized to a site's condition.

Developing a comprehensive understanding of the site's conditions prior to intervention includes analyzing historical habitat extent, current level of degradation, stressors and exposure, and environmental conditions. Long-term monitoring data of sites and habitats along a gradient of conditions (i.e., sentinel site network) allows practitioners to contextualize a potential site's conditions with long-term trends in ecosystem health [73]. Pre-restoration monitoring also serves to establish the baseline value of ecological metrics that will be compared against reference site metrics [36]. Assessing metrics prior to intervention, both at a reference site and at the project site, is essential to understanding whether interventions are contributing to progress as intended.

The appropriate duration and frequency of pre-restoration monitoring should be determined based on the expected variability of the system, sensitivity of the project goals, permit requirements, chosen metrics for success, and possible trajectories of recovery [119]. Highly variable systems may require longer monitoring periods or more frequent sampling events to capture representative periods of a system's dynamics. Project goals whose chosen metric reflects a relatively sensitive or minor change in conditions may also require longer or more intensive monitoring to discern restoration impacts post-intervention. Similarly, project metrics that represent large-scale change or that apply to ecosystems with slow rates of change may require longer monitoring times to capture success. Therefore, the system, goals, and metrics will inform how long and methodologically how a project should be monitored to determine the success of the restoration intervention and to proactively address any relapse in positive restoration outcomes.

6.2 Monitoring During Restoration Implementation

During restoration, monitoring allows practitioners to understand if the project is progressing as intended. Monitoring during active project work is essential for enabling adaptive management because it can indicate whether changes in restoration methodology or additional interventions are needed to achieve project goals. Adaptive management is a structured, iterative approach that accounts for uncertainty and

plans for learning to improve practices through time [99,100]. This approach relies on monitoring, not only to measure restoration effects, but to determine whether those impacts align with expectations and desired outcomes. When discrepancies arise between observed conditions and expected outcomes, identifying reasons for these discrepancies leads to learning, which then enables corrective action. Adaptive management is distinct from learning through trial-and-error because it calls for targeted monitoring compared to anticipated outcomes to enable practitioners to refine interventions based on near real-time feedback [120,121]. Identifying triggers for adaptive management ahead of a project can enable an efficient response to unintended restoration consequences. Adaptive management allows for changes to be incorporated and extra resources to be dedicated before the intervention process is complete and it's more difficult, costly, or time-intensive to make those changes.

Project assessment and adaptive management can be informed by sequential, multi-stage monitoring of metrics that evolve in tandem with the project and its ecosystem. Pre-monitoring and monitoring early in the intervention phase are typically broader and more frequent to capture rapid change, while uncertainty and vulnerability of the newly restructured site is the highest. Short-term indicators, such as the survival rate of re-established species, offer near-term feedback. As a system stabilizes and goals are met, monitoring frequency and intensity can taper and narrow in focus. Monitoring can shift to medium-term metrics, such as reproductive rates of reintroduced species, and long-term metrics, such as population growth and recovery of ecosystem-level processes, to evaluate if project-specific goals are being achieved. Alongside the outcomes themselves for foundation species and associated ecosystems, monitoring potential drivers of outcomes, such as sediment and nutrient levels or invasive species, enables investigation into why an outcome may have occurred [122].

Throughout a restoration project, monitoring must be sensitive to risk. Restoration activities could inadvertently cause unintended off-site habitat degradation or disruption to non-target species. A robust restoration monitoring plan includes mechanisms for detecting negative side effects and responding to them to prevent unintended harm. This may be particularly true for the emerging techniques described in Section 5.3, which carry risks associated with their novelty and degree of intervention. If impacts exceed acceptable thresholds, monitoring during this period allows practitioners to modify or halt restoration activities to prevent further harm.

6.3 Post-Restoration Monitoring to Assess Project Success

Post-restoration monitoring can indicate whether a project was successful. A project's definition of success may differ depending on whether the restoration was conducted for regulatory (mitigation) or voluntary purposes. Mitigation monitoring is driven by the need to ensure that projects satisfy permit requirements. Since permit monitoring often ends within a 2-to-5-year timeframe, success metrics are typically more rigid. For voluntary restoration, success metrics are less rigid and focus on long-term management and therefore may be able to incorporate adaptive management beyond the restoration project's original timeline.

Project goals, ecosystem dynamics, and available resources shape the overall length and intensity of monitoring. While success from a regulatory standpoint may be achieved within 5 years of intervention, full ecological recovery may take decades to achieve. Funding constraints often limit long-term engagement with a restoration site, but projects should plan to monitor for as long as intervention may be needed to ensure success, mitigate risks, and maximize learning. Beyond this, localized organizations, programs, and communities may be suited for perpetual stewardship of place past the timeline of the restoration project.

The sampling effort of long-term monitoring programs may reduce over time so long as the monitoring is still fulfilling minimum data needs. To reduce sampling effort, practitioners need to define clear goals, select and test representative sites, and check that a simplified approach can still detect changes in metrics effectively enough to evaluate success [117]. For project success, monitoring should continue while the information collected may still lead to a change or improvement in management of the site and system [123]. Once data collection goes beyond the period where it can be incorporated into site or system management, information gain must be weighed relative to the cost of collecting that information. Beyond the goals of an individual project, long-term monitoring or the incorporation of restoration sites into a sentinel network may provide valuable data for restoration projects state-wide.

Mitigation in Action: SONGS Wheeler North Reef

As part of the San Onofre Nuclear Generating Station (SONGS) Mitigation Program, Southern California Edison and its partners were required to construct an artificial reef as in-kind mitigation to compensate for impacts to the kelp forest immediately offshore of the power plant and near the power plant's effluent diffuser pipes. The permit required that the artificial reef function similarly to natural reefs and support 28 tons of reef fish and a minimum of 150 acres of medium-to-high density adult giant kelp annually. The artificial reef, known as Wheeler North Reef, was constructed in multiple phases: Phase 1 (1999), a small-scale (25 acre) experimental reef that tested different reef designs, Phase 2 (2008), a mitigation reef (150 acre) designed to fulfill permit requirements, and Phase 3 (2019-2020), a remediation reef (198 acre) to increase the likelihood that Wheeler North Reef meet the fish standing stock and kelp acreage requirements.

Annual mitigation monitoring of Wheeler North Reef and two nearby reference reefs began in 2009 to assess whether the artificial reef was performing similarly to reference reefs and meeting specific design targets.

Wheeler North Reef's performance is evaluated based on metrics related to reef substrate, giant kelp, fish, and its associated benthic community of algae and invertebrates. Together, these performance standards indicate whether the artificial reef is meeting its intended goal of replacing the kelp forest resources damaged or lost by SONGS operations. Performance standards are measured both in absolute (evaluated only at Wheeler North Reef) and relative (in comparison to two nearby natural reefs) contexts to determine whether the reef has met its mitigation requirements.

Since expanding the reef's footprint, monitoring results indicate that Wheeler North Reef is demonstrating considerable promise in meeting many of its objectives. Wheeler North Reef is performing similarly to natural reference reefs across project metrics including reef fish standing stock, and as of 2024 has earned 6 years of the required 32 years of mitigation credit. In accordance with the permit (CDP 6-81-330A), annual monitoring efforts were reduced in 2024 [124]. Wheeler North Reef demonstrates both the challenges and opportunities associated with using artificial reefs

to restore ecological loss. Accurately calculating the full extent of ecological losses across the entire structure and functioning of an ecosystem is still an emerging science that continues to advance since the original estimates were created for Wheeler North Reef, including considering cumulative losses and accounting for losses to ecosystem services.

6.4 Making Monitoring Data Publicly Accessible and Usable

The field of restoration faces two persistent data challenges: a) monitoring data is not often publicly accessible, and b) when data is public, it is often not available in a usable state. Making monitoring data both publicly-accessible and functionally-usable are essential for informing regulators, managers, funders, and the public about the impacts of restoration projects. Applying open science principles, which state that data, analyses, software, and methodologies that are used to generate results are preserved and shared, helps to ensure that restoration projects are transparent and reproducible. Accessible monitoring data across projects and habitat types also allows the State to aggregate and track progress towards targets, and helps practitioners and scientists identify patterns of success and failure in restoration strategies.

A central challenge for practitioners is the lack of accessible, standardized, and well-documented monitoring data for restoration projects. This issue stems from a number of factors. Currently, there is no interagency regulatory requirement within project funding or permitting mechanisms to collect and submit monitoring data to a specified clearinghouse. This is further complicated by the lack of a centralized State repository to store and manage monitoring data even if reporting requirements were to be created. Although some open access repositories exist, practitioners often lack incentives to share data and metadata. Practitioners often don't receive institutional support to do so, lack recognition for data sharing, fear that their work could be plagiarized by others, and/or have concern that their data will be mischaracterized/misused [125]. Addressing these barriers requires coordinated public-private action to standardize data and metadata collection, establish data-sharing protocols, and create data sites that are publishable and citable to instill academic value [125].

One solution is to create (or modernize and institutionalize an existing) centralized, state-wide database for restoration monitoring data, which holds promise for fulfilling two core functions. First, a statewide database would standardize data and metadata intake [126]. A centralized database could collect consistent, structured data inputs and formats that are immediately usable and comparable across projects. Second, a centralized database could serve as a comprehensive data repository that allows access to both structured, standardized data, and broader, less formatted datasets to allow for deeper exploration and analysis of projects. Developing a database of this kind would require creation of a model for managing data, data structures, metadata, metadata structures, and semantic descriptions of each part of the database [127]. Project Tracker, part of EcoAtlas, which was funded by US EPA and the California State Water Resources Control Board, provides a potential model that could be expanded to create a comprehensive project tracking tool. The Estuary Marine Protected Area Monitoring Program website (https://empa.sccwrp.org) also provides a model for a data repository that could be leveraged to create a restoration-focused repository.

A centralized database should be developed and governed by FAIR and CARE data principles. FAIR principles mean that the data is findable, accessible, interoperable, and reusable to maximize the transparency and usefulness in future work [126]. CARE principles require that (1) the inclusion or use of Indigenous data must be for the collective benefit of Indigenous Peoples, (2) Indigenous Peoples' have authority to control and govern Indigenous data, (3) those working with Indigenous data have a responsibility to share how those data are used to support Indigenous People's self determination and benefit, and (4) Indigenous People's rights and wellbeing are the primary concern at all stages in data practices [128]. A database should also be designed to maximize compatibility and integration of features with existing state databases and other regional or national restoration and mitigation databases where possible to enhance data analysis and knowledge sharing.

To maximize the database's utility, practitioners should follow established best practices [129]. Projects should begin with data management plans to establish expectations for data collection, documentation, and preservation. Data management plants should include clear data sharing and attribution policies that apply once a project is complete. Throughout the project, all data, including the context, structure, collection methods, processing methods, software and workflows, should be fully documented for reproducibility and transparency. Publishing data and products in citable, open-access repositories will help to strengthen the long-term usability of restoration monitoring data.

State funders should recognize the importance of, and provide resources to allow for, the submission of project data and synthesis of results through reports and/or publications. To ensure that future restoration efforts are as effective as possible, the systematic collection and availability of monitoring data must be a core component of all restoration and mitigation projects. If a centralized database were to be established, then state-funded projects should be required to submit their monitoring data so long as it follows State and Federal law and respects tribal data sovereignty. A requirement to upload data could also be applied to projects that are privately funded by NGOs, industry, or others, as a requirement of restoration projects' permitting processes.

Establishing an open access, centralized data clearinghouse and promoting its use by practitioners can increase the efficacy of restoration. As California realizes the effects of climate stressors, having reliable and accessible monitoring data from previous projects across the State will be key to understanding ecosystem responses and improving project outcomes. As new techniques emerge, old paradigms are challenged and our understanding of ecological systems under climate stress evolve. Large-scale longitudinal meta-analyses will be vital in ensuring that the State can effectively restore its ecosystems. Having a centralized database would allow for an increase in efficiency and a decrease in costs to scale restoration efforts [130].

7. Conclusion

This document was written to meet the urgency of this moment. Climate change is accelerating the pace and scale of ecosystem loss, requiring the use of more targeted research, open data, and adaptive frameworks that can evolve alongside our developing understanding of climate conditions. Capturing the full breadth and depth of restoration practice, research, and theory in one document is not feasible. Instead, this document offers a broadly-applicable set of considerations for accelerating coastal and ocean restoration in California. This document is intended to support State-level decision-making on restoration targets and investment priorities, present a shared understanding of restoration practices that can build climate resilience, support restoration practitioners with project planning, and encourage a coordinated, statewide strategy for coastal and ocean restoration.

Restoration, both mitigation and voluntary, is increasingly implemented as a strategy to address ecological degradation. Coalescing scientific considerations for restoration planning

supports continued evolution of best practices for successful restoration, informed by how a changing climate may reshape the future of the California coast. For long-term viability of restored systems, restoration must integrate future climate considerations throughout all phases of the planning process. As climate change and our understanding of its impacts evolve, so should the assumptions, considerations, and expectations for restoration. This evolution creates a new paradigm for restoration informed by forward-looking, adaptive, and climate-resilient practices that can better support the future persistence of restored systems. Supporting restoration into the future calls on practitioners and the State to consider what resources should be made available to accomplish restoration priorities, and how climate change will increase uncertainty in restoration outcomes. This makes decisions surrounding where restoration should occur, how restoration should be done, and even what the definition of restoration should include all the more important.

Restoration is not a substitute for conservation (protection, management, and sustainable use) of California's natural resources and cultural heritage. Protecting existing ecosystems is the most effective approach for maintaining ecological function and resilience for future generations, balancing human needs with ecological well-being. However, when conservation is not enough, or is not possible, restoration becomes the next-best option. Traditionally, restoration has included stressor removal and recovery of lost habitat structure where it once existed. Under climate change, the definition of restoration may be better represented by the process of facilitating the holistic recovery of a system and its associated functions and services, even in locations where that system did not previously exist.

The Resist-Accept-Direct ("RAD") framework allows practitioners to evaluate their restoration approach under the realities of climate change. Specifically, the RAD framework supports decisions on whether to resist, accept, or direct ecosystem change to a new state that may be more resilient or self-sustaining under climate change. Deciding whether to resist, accept, or direct is a function of the input and values of the scientific and local community that the system serves. Decision-making for restoration should incorporate multiple knowledge streams, including scientific research, practitioner expertise, and traditional and local knowledge. A structured decision making framework can help practitioners and communities in making decisions that balance needs and priorities while improving the chances of achieving desired outcomes and enabling adaptive management over time.

Restoration project planning begins with identifying a portfolio of possible sites, informed by site suitability analysis that considers historical and projected extent, ability to address stressors, and modeling of current and future site conditions. It is advisable for practitioners to consult with relevant state agencies early in the planning process as goals are being scoped and project sites are considered. As candidate sites are evaluated, project goals are defined that specify what outcomes restoration is intended to achieve, which helps to further narrow down site selection. Because functional ecosystems provide considerable services, project goals may be ecological, social, economic, or more likely a combination of the three. As a result, restoration can embed equity and community benefits into statewide targets, site selection, project prioritization, and selection of restoration methodology.

Restoration interventions may involve simply removing stressors and allowing natural recovery, addressing stressors and pairing the intervention with an assisted recovery technique to accelerate natural processes, and/or experimenting with multiple approaches when the most effective method is uncertain. Climate change will require developing and employing innovative restoration and management techniques. This includes protecting natural adaptive processes, decelerating environmental stressors, and enhancing the capacity of systems to adapt to change. The choice will depend on the risk of these approaches compared to no action and the risk appetite of the affected community. A number of risk-assessment, risk-mitigation, and regulatory tools can enable balancing potential benefits of novel, climate-forward restoration techniques with the possible risk of unintended consequences.

Translating project goals into actionable objectives and trackable metrics allows for progress evaluation and is a necessary prerequisite to adaptive management. Long-term monitoring should be a core component of every restoration and mitigation project, including implementing a sentinel site network to identify appropriate references to understand what is achievable under current conditions and contextualize restoration success. Monitoring paired with adaptive management during and after intervention is critical to ensuring that restoration progress is aligning with expectations and, if not, addressing those issues before a project becomes unsuccessful. For the State's collective understanding of restoration to improve, the creation of a centralized location for project monitoring data to be uploaded to in a standardized and quality assured format is needed. Restoration project teams must then contribute their data to this database.

Statewide restoration targets (e.g. 30 x 30 area and biodiversity based targets) provide the foundation and strategic vision for restoration in California. Appropriately-calibrated statewide targets can align efforts, direct funding, enable consistency and collaboration, incentivize progress, and maximize limited resources. For statewide restoration targets to be effective, they must be ambitious, informed by available habitat to restore, and supported with consistent and sufficient funding. Incorporating lessons learned from past and ongoing restoration projects should inform State restoration targets, which relies on consistent monitoring and reporting. This is necessary for successful long-term restoration to occur at scale and beyond small-scale or pilot levels.

Future restoration success will rely on continued scientific advancement. This includes improving our understanding of future climate impacts, expanding regional monitoring of ecosystems and stressors, and continuing to develop and pilot emerging, climate-ready intervention methods. Looking forward, this document represents an opportunity to meaningfully improve restoration outcomes across California by explicitly incorporating climate change impacts into restoration planning. In doing so, this guidance can help ensure that restoration investments are more effective, resilient, and equitable by strengthening ecosystems and human communities into a changing future.

REFERENCES

1. Martin DM. Ecological restoration should be redefined for the twenty-first century. *Restor Ecol.* 2017;25(5):668-673. doi:10.1111/rec.12554

2. Gann GD, McDonald T, Walder B, et al. International principles and standards for the practice of ecological restoration. Second edition. *Restor Ecol.* 2019;27(S1):S1-S46. doi:10.1111/rec.13035

3. Palmer MA, Ruhl J. Aligning restoration science and the law to sustain ecological infrastructure for the future. *Front Ecol Environ.* 2015;13(9):512-519. doi:10.1890/150053

4. Dobson AP, Bradshaw AD, Baker AJM. Hopes for the Future: Restoration Ecology and Conservation Biology. *Science.* 1997;277(5325):515-522. doi:10.1126/science.277.5325.515

5. Harris JA, Hobbs RJ, Higgs E, Aronson J. Ecological Restoration and Global Climate Change. *Restor Ecol.* 2006;14(2):170-176. doi:10.1111/j.1526-100X.2006.00136.x

6. Hobbs RJ, Higgs E, Harris JA. Novel ecosystems: implications for conservation and restoration. *Trends Ecol Evol.* 2009;24(11):599-605. doi:10.1016/j.tree.2009.05.012

7. Suding KN, Gross KL, Houseman GR. Alternative states and positive feedbacks in restoration ecology. *Trends Ecol Evol.* 2004;19(1):46-53. doi:10.1016/j.tree.2003.10.005

8. Suding KN, Hobbs RJ. Threshold models in restoration and conservation: a developing framework. *Trends Ecol Evol.* 2009;24(5):271-279. doi:10.1016/j.tree.2008.11.012

9. Lynch AJ, Thompson LM, Beever EA, et al. Managing for RADical ecosystem change: applying the Resist-Accept-Direct (RAD) framework. *Front Ecol Environ.* 2021;19(8):461-469. doi:10.1002/fee.2377

10. Schuurman G, Cat HH, Cole D, et al. *Resist-Accept-Direct (RAD)—a Framework for the 21st-Century Natural Resource Manager.* National Park Service; 2020. doi:10.36967/nrr-2283597

11. Chapin FS, Carpenter SR, Kofinas GP, et al. Ecosystem stewardship: sustainability strategies for a rapidly changing planet. *Trends Ecol Evol.* 2010;25(4):241-249. doi:10.1016/j.tree.2009.10.008

12. Levin SA, Lubchenco J. Resilience, Robustness, and Marine Ecosystem-based Management. *BioScience.* 2008;58(1):27-32. doi:10.1641/B580107

13. Stein BA, Staudt A, Cross MS, et al. Preparing for and managing change: climate adaptation for biodiversity and ecosystems. *Front Ecol Environ.* 2013;11(9):502-510. doi:10.1890/120277

14. Thompson LM, Lynch AJ, Beever EA, et al. Responding to Ecosystem Transformation: Resist, Accept, or Direct? Published online 2020. Accessed January 6, 2026. https://dx.doi.org/10.1002/fsh.10506

15. Prober SM, Doerr VAJ, Broadhurst LM, Williams KJ, Dickson F. Shifting the conservation paradigm: a synthesis of options for renovating nature under climate change. *Ecol Monogr.* 2019;89(1):e01333. doi:10.1002/ecm.1333

16. National Parks Service. Resist-Accept-Direct Framework - Climate Change (U.S. National Park Service). Resist-Accept-Direct Framework. 2025. Accessed November 7, 2025. https://www.nps.gov/subjects/climatechange/resistacceptdirect.htm

17. Rogers-Bennett L, Yang G, Mann JD. Using the Resist-Accept-Direct management framework to respond to climate-driven transformations in marine ecosystems. *Fish Manag Ecol.* 2022;29(4):409-422. doi:10.1111/fme.12539

18. Gieger O, Landfield K, Nash A. Resist-Accept-Direct Framework Can Help As Conditions Change | U.S. Fish & Wildlife Service. U.S. Fish and Wildlife Service. June 9, 2022. Accessed January 13, 2026. https://www.fws.gov/story/2022-05/resist-accept-direct-framework-can-help-conditions-change

19. Glacier National Park Directs Change (U.S. National Park Service). National Parks. Accessed January 13, 2026. https://www.nps.gov/articles/000/glac-rad.htm

20. Baker AC, Baums IB, Davies SW, et al. Proactive assisted gene flow for Caribbean corals in an era of rapid coral reef decline. *Science.* 2025;389(6758):344-347. doi:10.1126/science.adx5842

21. Young TP. Restoration ecology and conservation biology. *Biol Conserv.* 2000;92(1):73-83. doi:10.1016/S0006-3207(99)00057-9

22. Robison J. State Coastal Commission Approves Diablo Canyon Certification. PGE. 2025. Accessed January 22, 2026. https://www.pge.com/en/newsroom/currents/future-of-energy/state-coastal-commission-approves-diablo-canyon-certification0.html

23. California Ocean Protection Council. Strategic Plan 2026-2030 Safeguarding Our Coast and Ocean for All Californians. Published online 2025. https://opc.ca.gov/wp-content/uploads/2025/11/2026-2030-OPC-Strategic-Plan-508.pdf

24. California State Coastal Conservancy. *Strategic Plan 2023-2027*. California State Coastal Conservancy; 2023. Accessed July 23, 2025. https://scc.ca.gov/files/2023/05/SCC-Strategic-Plan-2023.pdf

25. Mirzabaev A, Wuepper D. Economics of Ecosystem Restoration. *Annu Rev Resour Econ.* 2023;15(Volume 15, 2023):329-350. doi:10.1146/annurev-resource-101422-085414

26. Conathan M, Buchanan J, Polefka S. The Economic Case for Restoring Coastal Ecosystems. *Cent Am Prog.* Published online 2014.

27. California Natural Resources Agency. *California's Nature-Based Solutions Climate Targets.* 2024. https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Expanding-Nature-Based-Solutions/Californias-NBS-Climate-Targets-2024.pdf

28. Egan D, Howell EA. *The Historical Ecology Handbook: A Restorationist's Guide to Reference Ecosystems.* Island Press; 2001.

29. Greenler SM, Lake FK, Tripp W, et al. Blending Indigenous and western science: Quantifying cultural burning impacts in Karuk Aboriginal Territory. *Ecol Appl.* 2024;34(4):e2973. doi:10.1002/eap.2973

30. Pausch R, Alexander T, Howard E, Garske-Garcia L. On-site and in-kind: Compensatory mitigation of California Coastal Zone habitat impacts between 2010 and 2018. *J Environ Manage.* 2024;366:121674. doi:10.1016/j.jenvman.2024.121674

31. Beheshti KM, Williams SL, Boyer KE, et al. Rapid enhancement of multiple ecosystem services following the restoration of a coastal foundation species. *Ecol Appl.* 2022;32(1):e02466. doi:10.1002/eap.2466

32. Díaz S, Pascual U, Stenseke M, et al. Assessing nature's contributions to people. *Science*. 2018;359(6373):270-272. doi:10.1126/science.aap8826

33. Conroy M, Peterson J. *Decision Making in Natural Resource Management: A Structured, Adaptive Approach: A Structured, Adaptive Approach.* John Wiley & Sons, Ltd; 2013. doi:10.1002/9781118506196.ch2

34. Gregory R, Failing L, Harstone M, Long G, McDaniels T, Ohlson D. Structured Decision Making: A Practical Guide to Environmental Management Choices. 2012. Accessed July 23, 2025. https://onlinelibrary.wiley.com/doi/book/10.1002/9781444398557

35. Neckles HA, Lyons JE, Guntenspergen GR, Shriver WG, Adamowicz SC. Use of Structured Decision Making to Identify Monitoring Variables and Management Priorities for Salt Marsh Ecosystems. *Estuaries Coasts*. 2015;38(4):1215-1232. doi:10.1007/s12237-014-9822-5

36. Palmer M a., Bernhardt E s., Allan JD, et al. Standards for ecologically successful river restoration.
J Appl Ecol. 2005;42(2):208-217. doi:10.1111/j.1365-2664.2005.01004.x

37. Society for Ecological Restoration International, Science & Policy Working Group. *The SER International Primer on Ecological Restoration.* 2004. Accessed January 14, 2026. https://www.ctahr.hawaii.edu/littonc/PDFs/682_SERPrimer.pdf

38. Hohman R, Hutto S, Catton C, Koe F. *Sonoma-Mendocino Bull Kelp Recovery Plan For Greater Farallones National Marine Sanctuary and California Department of Fish & Wildlife.* 2019:166. https://farallones.org/wp-content/uploads/2019/06/Bull-Kelp-Recovery-Plan-2019.pdf

39. Morelli TL, Daly C, Dobrowski SZ, et al. Managing Climate Change Refugia for Climate Adaptation. *PLOS ONE*. 2016;11(8):e0159909. doi:10.1371/journal.pone.0159909

40. Keppel G, Van Niel KP, Wardell-Johnson GW, et al. Refugia: identifying and understanding safe havens for biodiversity under climate change. *Glob Ecol Biogeogr*. 2012;21(4):393-404. doi:10.1111/j.1466-8238.2011.00686.x

41. Backus GA, Clements CF, Baskett ML. Restoring spatiotemporal variability to enhance the capacity for dispersal-limited species to track climate change. *Ecology*. 2024;105(4):e4257. doi:10.1002/ecy.4257

42. Fox H, Cundill G. Towards Increased Community-Engaged Ecological Restoration: A Review of Current Practice and Future Directions. *Ecol Restor.* 2018;36(3):208-218. doi:10.3368/er.36.3.208

43. Ogar E, Pecl G, Mustonen T. Science Must Embrace Traditional and Indigenous Knowledge to Solve Our Biodiversity Crisis. *One Earth.* 2020;3(2):162-165. doi:10.1016/j.oneear.2020.07.006

44. Bedsworth L, Cayan D, Franco G, Fisher L, Ziaja S. *Statewide Summary Report. California's Fourth Climate Change Assessment.* California Governor's Ofce of Planning and Research, Scripps Institution of Oceanography, California Energy Commission, California Public Utilities Commission; 2018. Accessed January 8, 2026. https://www.energy.ca.gov/sites/default/files/2019-11/Statewide_Reports-SUM-CCCA4-2018-013_Statewide_Summary_Report_ADA.pdf

45. Löfqvist S, Kleinschroth F, Bey A, et al. How Social Considerations Improve the Equity and Effectiveness of Ecosystem Restoration. *Bioscience.* 2022;73(2):134-148. doi:10.1093/biosci/biac099

46. Houlden V, Weich S, Albuquerque JP de, Jarvis S, Rees K. The relationship between greenspace and the mental wellbeing of adults: A systematic review. *PLOS ONE.* 2018;13(9):e0203000. doi:10.1371/journal.pone.0203000

47. Maller C, Townsend M, Pryor A, Brown P, St Leger L. Healthy nature healthy people: 'contact with nature' as an upstream health promotion intervention for populations. *Health Promot Int.* 2006;21(1):45-54. doi:10.1093/heapro/dai032

48. Rowland-Shea J, Doshi S, Edberg S. *The Nature Gap: Confronting Racial and Economic Disparities in the Destruction and Protection of Nature in America.* 2020. Accessed January 14, 2026. https://www.americanprogress.org/article/the-nature-gap/

49. California Natural Resources Agency. *Outdoors for All Providing Equitable Access to Parks and Nature.* 2023. Accessed January 14, 2026. https://resources.ca.gov/-/media/CNRA-Website/Files/Initiatives/Access-for-all/Outdoors-for-All-Draft-Strategy-51823-English.pdf

50. Polizzi C, Simonetto M, Barausse A, et al. Is ecosystem restoration worth the effort? The rehabilitation of a Finnish river affects recreational ecosystem services. *Ecosyst Serv.* 2015;14:158-169. doi:10.1016/j.ecoser.2015.01.001

51. BenDor TK, Lester TW, Livengood A, Davis A, Yonavjak L. Exploring and Understanding the Restoration Economy. Published online 2014.

52. Malibu Creek Ecosystem Restoration Project. Malibu Creek Ecosystem Restoration Project Public Engagement Factsheet. Accessed January 22, 2026. https://static1. squarespace.com/static/637ea3c6e6e91161130d6ee8/t/6734f21b1135bb6a065 27d72/1731523110626/2024-MCERP_Public_Engagement_FactSheet_HORZ.pdf

53. Robinson JM, Gellie N, MacCarthy D, Mills JG, O'Donnell K, Redvers N. Traditional ecological knowledge in restoration ecology: a call to listen deeply, to engage with, and respect Indigenous voices. *Restor Ecol.* 2021;29(4):e13381. doi:10.1111/rec.13381

54. US EPA O. Biden-Harris Administration Announces Over $11 Million to Blue Lake Rancheria to Cut Climate Pollution. September 5, 2024. Accessed January 13, 2026. https://www.epa.gov/newsreleases/biden-harris-administration-announces-over-11-million-blue-lake-rancheria-cut-climate

55. Ghvtlh-k'vsh shu'-srnelh-'i (Kelp Guardians) | Cal Poly Humboldt. Accessed January 13, 2026. https://www.humboldt.edu/food-sovereignty/kelp-guardians

56. Barra MP, Jessee N. Restoration as Transformative Reparative Practice. Published online September 1, 2024. doi:10.3167/ares.2024.150111

57. Wehi PM, Lord JM. Importance of including cultural practices in ecological restoration. *Conserv Biol.* 2017;31(5):1109-1118. doi:10.1111/cobi.12915

58. Truchy A, Angeler DG, Sponseller RA, Johnson RK, McKie BG. Linking Biodiversity, Ecosystem Functioning and Services, and Ecological Resilience: Towards an Integrative Framework for Improved Management. In: *Advances in Ecological Research*. Vol 53. Academic Press; 2015:55-96. doi:10.1016/bs.aecr.2015.09.004

59. Millennium Ecosystem Assessment. *Ecosystems and Human Well-Being: Biodiversity Synthesis.* World Resources Institute; 2005. Accessed January 23, 2026. https://www.millenniumassessment.org/documents/document.354.aspx.pdf

60. Alexander S, Aronson J, Whaley O, Lamb D. The relationship between ecological restoration and the ecosystem services concept. *Ecol Soc.* 2016;21(1). Accessed January 14, 2026. https://www.jstor.org/stable/26270353

61. Jimenez MP, DeVille NV, Elliott EG, et al. Associations between Nature Exposure and Health: A Review of the Evidence. *Int J Environ Res Public Health.* 2021;18(9). doi:10.3390/ijerph18094790

62. Mitchell R, Popham F. Effect of exposure to natural environment on health inequalities: an observational population study. *The Lancet.* 2008;372(9650):1655-1660. doi:10.1016/S0140-6736(08)61689-X

63. Aronson J, Goodwin N, Orlando L, Eisenberg C, Cross AT. A world of possibilities: six restoration strategies to support the United Nation's Decade on Ecosystem Restoration. *Restor Ecol.* 2020;28(4):730-736. doi:10.1111/rec.13170

64. Dai H, Zhu Z, Trachung B, et al. Communities in ecosystem restoration: The role of inclusive values and local elites' narrative innovations. *People Nat.* 2024;6(4):1655-1667. doi:10.1002/pan3.10675

65. Balancing multiple interventions for dynamically e cient kelp forest restoration under marine heatwave uncertainty. *Univ Calif Davis.* Published online 2025. https://arefiles.ucdavis.edu/uploads/pub/2025/10/29/kimkyuminjob_market_papers_raw_Yd2clMR.pdf

66. Baker JM. Socio-economic Characteristics and Contributions of the Natural Resources Restoration System in Humboldt County, California. *Ecol Restor.* 2005;23(1):5-14. doi:10.3368/er.23.1.5

67. Ward M, Beheshti K. Lessons learned from over thirty years of eelgrass restoration on the US West Coast. *Ecosphere.* 2023;14(8):e4642. doi:10.1002/ecs2.4642

68. Bayraktarov E, Saunders MI, Abdullah S, et al. The cost and feasibility of marine coastal restoration. *Ecol Appl.* 2016;26(4):1055-1074. doi:10.1890/15-1077

69. Fraschetti S, McOwen C, Papa L, et al. Where Is More Important Than How in Coastal and Marine Ecosystems Restoration. *Front Mar Sci.* 2021;8. doi:10.3389/fmars.2021.626843

70. Giraldo-Ospina A, Bell T, Carr MH, Caselle JE. A site selection decision framework for effective kelp restoration. *Biol Conserv.* 2025;302:110980. doi:10.1016/j.biocon.2025.110980

71. Barak RS, Hipp AL, Cavender-Bares J, et al. Taking the Long View: Integrating Recorded, Archeological, Paleoecological, and Evolutionary Data into Ecological Restoration. *Int J Plant Sci.* 2016;177(1):90-102. doi:10.1086/683394

72. Uprety Y, Asselin H, Bergeron Y, Doyon F, Boucher JF. Contribution of traditional knowledge to ecological restoration: Practices and applications. *Écoscience*. 2012;19(3):225-237. doi:10.2980/19-3-3530

73. Walker JB, O'Connor K, Wasson K, et al. Sentinel site networks as a mechanism to evaluate progress toward meeting restoration goals in altered and unaltered landscapes. *Restor Ecol*. 2025;33(5):e70062. doi:10.1111/rec.70062

74. Brinson MM, Rheinhardt R. The Role of Reference Wetlands in Functional Assessment and Mitigation. *Ecol Appl*. 1996;6(1):69-76. doi:10.2307/2269553

75. Fejtek SM, Gold M, MacDonald GM, Jacobs DK, Ambrose RF. Best Practices for Southern California Coastal Wetland Restoration and Management in the Face of Climate Change. Published online October 1, 2014. Accessed May 9, 2025. https://escholarship.org/uc/item/3zx2j5br

76. Gourgue O, van Belzen J, Schwarz C, et al. Biogeomorphic modeling to assess the resilience of tidal-marsh restoration to sea level rise and sediment supply. *Earth Surf Dyn*. 2022;10(3):531-553. doi:10.5194/esurf-10-531-2022

77. Martin J, Richardson MS, Passeri DL, et al. Decision science as a framework for combining geomorphological and ecological modeling for the management of coastal systems. *Ecol Soc*. 2023;28(1). doi:10.5751/ES-13696-280150

78. Zellmer AJ, Claisse JT, Williams CM, Schwab S, Pondella DJ. Predicting Optimal Sites for Ecosystem Restoration Using Stacked-Species Distribution Modeling. *Front Mar Sci*. 2019;6. doi:10.3389/fmars.2019.00003

79. Bertelli CM, Stokes HJ, Bull JC, Unsworth RKF. The use of habitat suitability modelling for seagrass: A review. *Front Mar Sci*. 2022;9. doi:10.3389/fmars.2022.997831

80. Drake JM. Population Viability Analysis. In: Jørgensen SE, Fath BD, eds. *Encyclopedia of Ecology*. Academic Press; 2008:2901-2907. doi:10.1016/B978-008045405-4.00654-6

81. Preston J, Debney A, Gamble C, et al. Seascape connectivity: evidence, knowledge gaps and implications for temperate coastal ecosystem restoration practice and policy. *Npj Ocean Sustain*. 2025;4(1):33. doi:10.1038/s44183-025-00128-3

82. Simonson WD, Miller E, Jones A, García-Rangel S, Thornton H, McOwen C. Enhancing climate change resilience of ecological restoration — A framework for action. *Perspect Ecol Conserv.* 2021;19(3):300-310. doi:10.1016/j.pecon.2021.05.002

83. Allan JD, McIntyre PB, Smith SDP, et al. Joint analysis of stressors and ecosystem services to enhance restoration effectiveness. *Proc Natl Acad Sci U S A.* 2013;110(1):372-377. doi:10.1073/pnas.1213841110

84. Beechie TJ, Sear DA, Olden JD, et al. Process-based Principles for Restoring River Ecosystems. *BioScience.* 2010;60(3):209-222. doi:10.1525/bio.2010.60.3.7

85. Neeson TM, Smith SDP, Allan JD, McIntyre PB. Prioritizing ecological restoration among sites in multi-stressor landscapes. *Ecol Appl.* 2016;26(6):1785-1796. doi:10.1890/15-0948.1

86. Game ET, Watts ME, Wooldridge S, Possingham HP. Planning for Persistence in Marine Reserves: A Question of Catastrophic Importance. *Ecol Appl.* 2008;18(3):670-680. doi:10.1890/07-1027.1

87. National Academies of Sciences, Engineering, and Medicine. *A Decision Framework for Interventions to Increase the Persistence and Resilience of Coral Reefs.* National Academies Press; 2019. doi:10.17226/25424

88. Holl KD, Aide TM. When and where to actively restore ecosystems? *For Ecol Manag.* 2011;261(10):1558-1563. doi:10.1016/j.foreco.2010.07.004

89. Huxel GR, Hastings A. Habitat Loss, Fragmentation, and Restoration. *Restor Ecol.* 1999;7(3):309-315. doi:10.1046/j.1526-100X.1999.72024.x

90. Gregory RS, Keeney RL. Making Smarter Environmental Management Decisions. *JAWRA J Am Water Resour Assoc.* 2002;38(6):1601-1612. doi:10.1111/j.1752-1688.2002.tb04367.x

91. McKay SK, Linkov I, Fischenich JC, Miller SJ, Valverde LJ. Ecosystem Restoration Objectives and Metrics. Published online 2012.

92. Haeffner M, Finley S, de Rivera C, et al. Social and ecological connectivity: A Q-methodology investigation of coastal estuary perceptions in Oregon. *Biol Conserv.* 2025;309:111277. doi:10.1016/j.biocon.2025.111277

93. Carr MH, Woodson CB, Cheriton OM, Malone D, McManus MA, Raimondi PT. Knowledge through partnerships: integrating marine protected area monitoring and ocean observing systems. *Front Ecol Environ*. 2011;9(6):342-350. doi:10.1890/090096

94. Dayton P, Sala E, Tegner M, Thrush S. Marine reserves: Parks, baselines, and fishery enhancement. *Bull Mar Sci*. 2000;66:617-634.

95. Sainsbury K, Sumaila UR. Incorporating ecosystem objectives into management of sustainable marine fisheries, including "best practice" reference points and use of marine protected areas. In: *Responsible Fisheries in the Marine Ecosystem*. CABI Books. 2003:343-361. doi:10.1079/9780851996332.0343

96. Sala E, Ballesteros E, Dendrinos P, et al. The Structure of Mediterranean Rocky Reef Ecosystems across Environmental and Human Gradients, and Conservation Implications. *PLOS ONE*. 2012;7(2):e32742. doi:10.1371/journal.pone.0032742

97. California Department of Fish and Wildlife, California Ocean Protection Council. *California's Marine Protected Area Network Decadal Management Review*. 2022.

98. Eger AM, Earp HS, Friedman K, et al. The need, opportunities, and challenges for creating a standardized framework for marine restoration monitoring and reporting. *Biol Conserv*. 2022;266:109429. doi:10.1016/j.biocon.2021.109429

99. Holling CS. *Adaptive Environmental Assessment and Management*. John Wiley & Sons; 1978. Accessed July 8, 2025. https://pure.iiasa.ac.at/id/eprint/823/, https://iiasa.dev.local/

100. Runge MC. An Introduction to Adaptive Management for Threatened and Endangered Species. *J Fish Wildl Manag*. 2011;2(2):220-233. doi:10.3996/082011-JFWM-045

101. Danovaro R, Aronson J, Bianchelli S, et al. Assessing the success of marine ecosystem restoration using meta-analysis. *Nat Commun*. 2025;16(1):3062. doi:10.1038/s41467-025-57254-2

102. Chazdon RL, Falk DA, Banin LF, et al. The intervention continuum in restoration ecology: rethinking the active–passive dichotomy. *Restor Ecol*. 2024;32(8):e13535. doi:10.1111/rec.13535

103. Hobbs RJ, Hallett LM, Ehrlich PR, Mooney HA. Intervention Ecology: Applying Ecological Science in the Twenty-first Century. *BioScience*. 2011;61(6):442-450. doi:10.1525/bio.2011.61.6.6

104. Lawless S, Ogier EM, Streit R, et al. Promoting socially responsible governance of new marine climate intervention. *Cell Rep Sustain*. 2025;2(6). doi:10.1016/j.crsus.2025.100366

105. Williams BK. Passive and active adaptive management: Approaches and an example. *J Environ Manage*. 2011;92(5):1371-1378. doi:10.1016/j.jenvman.2010.10.039

106. McLaughlin BC, Skikne SA, Beller E, et al. Conservation strategies for the climate crisis: An update on three decades of biodiversity management recommendations from science. *Biol Conserv*. 2022;268:109497. doi:10.1016/j.biocon.2022.109497

107. Ricart AM, Ward M, Hill TM, et al. Coast-wide evidence of low pH amelioration by seagrass ecosystems. *Glob Change Biol*. 2021;27(11):2580-2591. doi:10.1111/gcb.15594

108. Hord AM, Fischer DG, Schweitzer JA, LeRoy CJ, Whitham TG, Bailey JK. Hybrid introgression as a mechanism of rapid evolution and resilience to climate change in a riparian tree species. *Commun Biol*. 2025;8(1):1173. doi:10.1038/s42003-025-08410-3

109. Rice KJ, Emery NC. Managing microevolution: restoration in the face of global change. *Front Ecol Environ*. 2003;1(9):469-478. doi:10.1890/1540-9295(2003)001%5B0469:MMRITF%5D2.0.CO;2

110. van Oppen MJH, Oliver JK, Putnam HM, Gates RD. Building coral reef resilience through assisted evolution. *Proc Natl Acad Sci*. 2015;112(8):2307-2313. doi:10.1073/pnas.1422301112

111. Santoro EP, Borges RM, Espinoza JL, et al. Coral microbiome manipulation elicits metabolic and genetic restructuring to mitigate heat stress and evade mortality. *Sci Adv*. 2021;7(33):eabg3088. doi:10.1126/sciadv.abg3088

112. McLachlan JS, Hellmann JJ, Schwartz MW. A Framework for Debate of Assisted Migration in an Era of Climate Change. *Conserv Biol*. 2007;21(2):297-302. doi:10.1111/j.1523-1739.2007.00676.x

113. McLeod IM, Hein MY, Babcock R, et al. Coral restoration and adaptation in Australia: The first five years. *PLOS ONE*. 2022;17(11):e0273325. doi:10.1371/journal.pone.0273325

114. National Academies of Sciences, Engineering, and Medicine. *A Research Review of Interventions to Increase the Persistence and Resilience of Coral Reefs*. 2019. doi:10.17226/25279

115. Intervention Risk Review Group. Reef Restoration and Adaptation Program. Accessed July 23, 2025. https://gbrrestoration.org/our-team/advisory-and-working-groups/intervention-risk-review-group/

116. Fisher MC, Baskett ML, Baker AC, Kidd A, Springborn MR, Scott TA. Preparing Regulation for Climate-Resilient Restoration: Learning From Emerging Technologies. *Conserv Lett*. 2025;18(4):e13128. doi:10.1111/conl.13128

117. Beheshti KM, Smith RS, Raimondi P, Reed D. Sensitivity analysis to reduce sampling effort of a long-term monitoring program. *Ecol Indic*. 2024;158:111585. doi:10.1016/j.ecolind.2024.111585

118. Reed D, Schroeter S, Page M. *Proceedings from the Second Annual Public Workshop for the SONGS Mitigation Project, February 27, 2002*. 2002. https://www.coastal.ca.gov/energy/songs-workshop-mm2.pdf#page=11

119. National Academies of Sciences, Engineering, and Medicine. *Clean Coastal Waters: Understanding and Reducing the Effects of Nutrient Pollution: Chapter: 7 The Role of Monitoring and Modeling*. National Academies Press; 2000:9812. doi:10.17226/9812

120. Walters CJ, Holling CS. Large-Scale Management Experiments and Learning by Doing. *Ecology*. 1990;71(6):2060-2068. doi:10.2307/1938620

121. Zedler JB. What's New in Adaptive Management and Restoration of Coasts and Estuaries? *Estuaries Coasts*. 2017;40(1):1-21. doi:10.1007/s12237-016-0162-5

122. Campbell SP, Clark JA, Crampton LH, et al. An Assessment of Monitoring Efforts in Endangered Species Recovery Plans. *Ecol Appl*. 2002;12(3):674-681. doi:10.1890/1051-0761(2002)012%5B0674:AAOMEI%5D2.0.CO;2

123. McDonald-Madden E, Baxter PWJ, Fuller RA, et al. Monitoring does not always count. *Trends Ecol Evol*. 2010;25(10):547-550. doi:10.1016/j.tree.2010.07.002

124. Reed D, Beheshti K, Smith R, Page M. *Annual Report of the Status of Condition C: Kelp Reef Mitigation. San Onofre Nuclear Generating Station (SONGS) Mitigation Program.* Marine Science Institute UCSB; 2024. https://marinemitigation.msi.ucsb.edu/sites/default/files/documents/artificial_reef/2024_annual_report-SONGS_kelp_reef_mitigation.pdf

125. Reichman OJ, Jones MB, Schildhauer MP. Challenges and Opportunities of Open Data in Ecology. *Science.* 2011;331(6018):703-705. doi:10.1126/science.1197962

126. Wilkinson MD, Dumontier M, Aalbersberg IjJ, et al. The FAIR Guiding Principles for scientific data management and stewardship. *Sci Data.* 2016;3(1):160018. doi:10.1038/sdata.2016.18

127. Chamanara J, König-Ries B. A conceptual model for data management in the field of ecology. *Ecol Inform.* 2014;24:261-272. doi:10.1016/j.ecoinf.2013.12.003

128. Carroll SR, Garba I, Figueroa-Rodríguez OL, et al. The CARE Principles for Indigenous Data Governance. *Data Sci J.* 2020;19(1). doi:10.5334/dsj-2020-043

129. Michener WK. Ecological data sharing. *Ecol Inform.* 2015;29:33-44. doi:10.1016/j.ecoinf.2015.06.010

130. Ladouceur E, Shackelford N. The power of data synthesis to shape the future of the restoration community and capacity. *Restor Ecol.* 2021;29(1):e13251. doi:10.1111/rec.13251

131. Frankham R. Genetic adaptation to captivity in species conservation programs. *Mol Ecol.* 2008;17(1):325-333. doi:10.1111/j.1365-294X.2007.03399.x

132. Middelburg JJ, Levin LA. Coastal hypoxia and sediment biogeochemistry. *Biogeosciences.* 2009;6(7):1273-1293. doi:10.5194/bg-6-1273-2009

133. California Natural Resources Agency. *State of the State's Wetlands: 10 Years of Challenges and Progress.* 2010. Accessed July 23, 2025. https://resources.ca.gov/CNRALegacyFiles/docs/SOSW_report_with_cover_memo_10182010.pdf

134. Thorne KM, Buffington KJ, Osland MJ, et al. Nature-based solutions could offset coastal squeeze of tidal wetlands from sea-level rise on the U.S. Pacific coast. *Sci Rep.* 2025;15(1):11443. doi:10.1038/s41598-025-93437-z

135. Blair EM, Allen BJ, Whitcraft CR. Evaluating Monoculture Versus Polyculture Planting Regimes in a Newly-Restored Southern California Salt Marsh. *Bull South Calif Acad Sci.* 2013;112(3):161-175. doi:10.3160/0038-3872-112.3.161

136. Finstad K, Parry C, Schwartz E. *Digging In: A Guide to Community-Based Habitat Restoration.* California Coastal Commission; 2008. https://www.coastal.ca.gov/publiced/unbweb/diggingin.pdf

137. Hood WG. Applying tidal landform scaling to habitat restoration planning, design, and monitoring. *Estuar Coast Shelf Sci.* 2020;244:106060. doi:10.1016/j.ecss.2018.12.017

138. Fard E, Brown LN, Ambrose RF, et al. Increasing Salt Marsh Elevation Using Sediment Augmentation: Critical Insights from Surface Sediments and Sediment Cores. *Environ Manage.* 2024;73(3):614-633. doi:10.1007/s00267-023-01897-8

139. Polson MP, Zacherl DC. Geographic Distribution and Intertidal Population Status for the Olympia Oyster, Ostrea lurida Carpenter 1864, from Alaska to Baja. *J Shellfish Res.* 2009;28(1):69-77. doi:10.2983/035.028.0113

140. zu Ermgassen PSE, Spalding MD, Grizzle RE, Brumbaugh RD. Quantifying the Loss of a Marine Ecosystem Service: Filtration by the Eastern Oyster in US Estuaries. *Estuaries Coasts.* 2013;36(1):36-43. doi:10.1007/s12237-012-9559-y

141. Boyer K, Zabin C, Cruz SDL, et al. San Francisco Bay Living Shorelines: Restoring Eelgrass and Olympia Oysters for Habitat and Shore Protection. In: *Living Shorelines.* CRC Press; 2017.

142. Lee L. The West Coast's Native Oyster. Alta Online. January 4, 2022. Accessed July 23, 2025. https://www.altaonline.com/dispatches/a38325907/west-coast-native-oyster-lydia-lee/

143. California Department of Fish and Wildlife. Native Oyster Restoration. Accessed July 23, 2025. https://wildlife.ca.gov/Conservation/Laboratories/Shellfish-Health/Restoration

144. Wasson K, Zabin C, Bible J, et al. A Guide To Olympia Oyster Restoration And Conservation: Environmental Conditions And Sites That Support Sustainable Populations In Central California. Published online 2014. Accessed July 23, 2025. https://repository.library.noaa.gov/view/noaa/44193

145. Lawlor JA, Arellano SM. Temperature and salinity, not acidification, predict near-future larval growth and larval habitat suitability of Olympia oysters in the Salish Sea. *Sci Rep.* 2020;10(1):13787. doi:10.1038/s41598-020-69568-w

146. Sanford E, Gaylord B, Hettinger A, Lenz EA, Meyer K, Hill TM. Ocean acidification increases the vulnerability of native oysters to predation by invasive snails. *Proc R Soc B Biol Sci.* 2014;281(1778):20132681. doi:10.1098/rspb.2013.2681

147. Ridlon AD, Marks A, Zabin CJ, et al. Conservation of Marine Foundation Species: Learning from Native Oyster Restoration from California to British Columbia. *Estuaries Coasts.* 2021;44(7):1723-1743. doi:10.1007/s12237-021-00920-7

148. Bromley C, McGonigle C, Ashton EC, Roberts D. Bad moves: Pros and cons of moving oysters – A case study of global translocations of *Ostrea edulis* Linnaeus, 1758 (Mollusca: Bivalvia). *Ocean Coast Manag.* 2016;122:103-115. doi:10.1016/j.ocecoaman.2015.12.012

149. Dahl E. Some Aspects of the Ecology and Zonation of the Fauna on Sandy Beaches. *Oikos.* 1952;4(1):1-27. doi:10.2307/3565072

150. Sigren J, Figlus J, Armitage A. Coastal sand dunes and dune vegetation: Restoration, erosion, and storm protection. *Shore Beach.* 2014;82(4):5-12.

151. Rodríguez-Revelo N, Espejel I, García CA, Ojeda-Revah L, Vázquez MAS. Environmental Services of Beaches and Coastal Sand Dunes as a Tool for Their Conservation. In: Botero CM, Cervantes O, Finkl CW, eds. *Beach Management Tools - Concepts, Methodologies and Case Studies.* Springer International Publishing; 2018:75-100. doi:10.1007/978-3-319-58304-4_5

152. Patsch K, Griggs G. Littoral Cells, Sand Budgets, and Beaches: Understanding California's Shoreline. Published online 2006. https://www.coastal.ca.gov/coastalvoices/resources/2006-LittoralCells.pdf

153. Griggs G, Patsch K, Lester C. Groins, sand retention, and the future of Southern California's Beaches. *Shore Beach.* 2020;88:1-23. doi:10.34237/1008822

154. Defeo O, McLachlan A, Schoeman DS, et al. Threats to sandy beach ecosystems: A review. *Estuar Coast Shelf Sci.* 2009;81(1):1-12. doi:10.1016/j.ecss.2008.09.022

155. Houston JR. The economic value of America's beaches — a 2018 update. Published online 2018. Accessed May 9, 2025. https://asbpa.org/wp-content/uploads/2018/05/Houston_Spring-2018_86_2_color.pdf

156. Busiek J. Why California's beaches are shrinking, and what we can do to save them - UC Research and Innovation. June 28, 2024. Accessed July 23, 2025. https://uckeepresearching.org/why-californias-beaches-are-shrinking-and-what-we-can-do-to-save-them/

157. Slagel MJ, Griggs GB. Cumulative Losses of Sand to the California Coast by Dam Impoundment. *J Coast Res.* 2008;24(3):571-584.

158. McGraw S, Nelson JL, Shen Y, Villegas A. Coastal dune invasion and restoration at Point Reyes: the ecology of European sea rocket, Cakile maritime. *CEC Res Vol 1.* Published online 2017:Issue 1. doi:10.21973/N3694S

159. Pejchar L, Warner K. A River Might Run Through It Again: Criteria for Consideration of Dam Removal and Interim Lessons from California. *Environ Manage.* 2001;28(5):561-575. doi:10.1007/s002670010244

160. Johnston KK, Dugan JE, Hubbard DM, Emery KA, Grubbs MW. Using dune restoration on an urban beach as a coastal resilience approach. *Front Mar Sci.* 2023;10. doi:10.3389/fmars.2023.1187488

161. Leitzell K. MPA update: Observing the space between land and sea. California Sea Grant. July 9, 2020. Accessed July 23, 2025. https://caseagrant.ucsd.edu/news/mpa-update-observing-space-between-land-and-sea

162. Whitaker SG, Ambrose RF, Anderson LM, et al. Ecological restoration using intertidal foundation species: Considerations and potential for rockweed restoration. *Ecosphere.* 2023;14(3):e4411. doi:10.1002/ecs2.4411

163. Lucas BJ, Smith JR. Alterations in human visitation patterns and behaviors in southern California rocky intertidal ecosystems over two-decades following increased management efforts. *Ocean Coast Manag.* 2016;121:128-140. doi:10.1016/j.ocecoaman.2015.12.014

164. Worden S. California's Ocean Habitats: The Rocky Intertidal Zone. 2021. Accessed July 23, 2025. https://cdfwmarine.wordpress.com/2021/08/04/californias-ocean-habitats-the-rocky-intertidal-zone/

165. Raimondi P, Smith J. *Assessment of Rocky Intertidal Habitats for the California Marine Protected Area Monitoring Program: Decadal Report.* 2022. Accessed May 9, 2025. https://caseagrant.ucsd.edu/sites/default/files/MPA_Rocky_Intertidal_decadal_report_FINAL_1_12_2022.pdf

166. Kaplanis NJ, Edwards CB, Eynaud Y, Smith JE. Future sea-level rise drives rocky intertidal habitat loss and benthic community change. *PeerJ*. 2020;8:e9186. doi:10.7717/peerj.9186

167. Thompson RC, Crowe TP, Hawkins SJ. Rocky intertidal communities: past environmental changes, present status and predictions for the next 25 years. *Environ Conserv*. 2002;29(2):168-191. doi:10.1017/S0376892902000115

168. Ambrose R, Smith J. *Restoring Rocky Intertidal Habitats in Santa Monica Bay*. Santa Monica Bay Restoration Commission; 2004. https://www.cakex.org/sites/default/files/documents/10.1.1.495.3891.pdf

169. Bull JS, Reed DC, Holbrook SJ. An Experimental Evaluation of Different Methods of Restoring Phyllospadix torreyi (Surfgrass). *Restor Ecol*. 2004;12(1):70-79. doi:10.1111/j.1061-2971.2004.00258.x

170. California Sea Grant, UC Davis Bodega Marine. Captive Breeding Program: Tracking the success of the White Abalone Captive Breeding Program. 2022. Accessed July 23, 2025. https://storymaps.arcgis.com/collections/f2fe722568fd4d25b90086b6f2a9e0e2

171. Paxton AB, Runde BJ, Smith CS, et al. Leveraging built marine structures to benefit and minimize impacts on natural habitats. *BioScience*. 2025;75(2):172-183. doi:10.1093/biosci/biae135

172. Sherman K, DeBruyckere LA. *Eelgrass Habitats On The U.S. West Coast: State Of The Knowledge Of Eelgrass Ecosystem Services and Eelgrass Extent*. 2018. https://www.pacificfishhabitat.org/wp-content/uploads/2017/09/EelGrass_Report_Final_ForPrint_web.pdf

173. Waters T, Gold Z, Obaza A, Ambrose RF, Eagle RA. Environmental DNA metabarcoding reveals distinct fish assemblages supported by seagrass (Zostera marina and Zostera pacifica) beds in different geographic settings in Southern California. *PLOS ONE*. 2023;18(10):e0286228. doi:10.1371/journal.pone.0286228

174. Lee G, Suonan Z, Kim SH, Hwang DW, Lee KS. Heavy metal accumulation and phytoremediation potential by transplants of the seagrass Zostera marina in the polluted bay systems. *Mar Pollut Bull*. 2019;149:110509. doi:10.1016/j.marpolbul.2019.110509

175. Fourqurean JW, Duarte CM, Kennedy H, et al. Seagrass ecosystems as a globally significant carbon stock. *Nat Geosci.* 2012;5(7):505-509. doi:10.1038/ngeo1477

176. Duarte CM, Losada IJ, Hendriks IE, Mazarrasa I, Marbà N. The role of coastal plant communities for climate change mitigation and adaptation. *Nat Clim Change.* 2013;3(11):961-968. doi:10.1038/nclimate1970

177. Bernstein B, Merkel K, Chesney B, Sutula M. *Recommendations For A Southern California Regional Eelgrass Monitoring Program.* National Marine Fisheries Service; 2011. https://ftp.sccwrp.org/pub/download/DOCUMENTS/TechnicalReports/632_EelgrassRMP.pdf

178. Da Silva NJ. *Impact of Submerged Aquatic Vegetation (Zostera Marina and Ruppia Maritima) on Habitat Parameters and Macroinvertebrate Community Composition within an Urbanized Coastal Lagoon.* California State University, Long Beach; 2020. Accessed January 19, 2026. https://www.proquest.com/openview/8a6b04df80ec af9f68e9dceb593e2ee7/1?pq-origsite=gscholar&cbl=51922&diss=y

179. U.S. Fish and Wildlife Service. *Recovery Plan for Tidal Marsh Ecosystems of Northern and Central California.* 2013. Accessed January 19, 2026. https://ecos. fws.gov/docs/recovery_plan/TMRP/20130923_TMRP_Books_Signed_FINAL.pdf

180. Reed DC, Holbrook SJ. *An Experimental Evaluation of Methods of Surfgrass (Phyllospadix Torreyi) Restoration Using Early Life History Stages.* Coastal Research Center, Marine Science Institute, University of California, Santa Barbara, California; 2003. Accessed January 19, 2026. https://www.coastalresearchcenter.ucsb.edu/ cmi/files/2003-034.pdf

181. Ward. Assessing existing data, models, and opportunities for California's blue carbon ecosystems in the context of California Air Resources Board's 2027 Climate Change Scoping Plan. Published online 2024.

182. National Marine Fisheries Service. *California Eelgrass Mitigation Policy and Implementing Guidelines.* 2014. https://media.fisheries.noaa.gov/dam-migration/ cemp_oct_2014_final.pdf

183. Beheshti KM, Ward M. Eelgrass Restoration on the U.S. West Coast: A Comprehensive Assessment of Restoration Techniques and Their Outcomes. Published online 2021.

184. Tan YM, Dalby O, Kendrick GA, et al. Seagrass Restoration Is Possible: Insights and Lessons From Australia and New Zealand. *Front Mar Sci*. 2020;7. doi:10.3389/fmars.2020.00617

185. Long HA, Grosholz ED. Overgrowth of eelgrass by the invasive colonial tunicate Didemnum vexillum: Consequences for tunicate and eelgrass growth and epifauna abundance. *J Exp Mar Biol Ecol*. 2015;473:188-194. doi:10.1016/j.jembe.2015.08.014

186. Wernberg T, Krumhansl K, Filbee-Dexter K, Pedersen MF. Chapter 3 - Status and Trends for the World's Kelp Forests. In: Sheppard C, ed. *World Seas: An Environmental Evaluation (Second Edition)*. Academic Press; 2019:57-78. doi:10.1016/B978-0-12-805052-1.00003-6

187. California Department of Fish and Wildlife, California Ocean Protection Council. *Marine Protected Area Monitoring Action Plan*. 2018.

188. Eger AM, Marzinelli EM, Beas-Luna R, et al. The value of ecosystem services in global marine kelp forests. *Nat Commun*. 2023;14(1):1894. doi:10.1038/s41467-023-37385-0

189. Nielsen KJ, Stachowicz JJ, Carter H, et al. Emerging Understanding Of Seagrass And Kelp As An Ocean Acidification Management Tool In California. Published online 2018. Accessed May 9, 2025. https://repository.library.noaa.gov/view/noaa/40895

190. Esgro M, Ray J. *Interm Action Plan for Protecting and Restoring California's Kelp Forests*. California Ocean Protection Council; 2021.

191. Gravem S, Heady W, Saccomanno VR, et al. Pycnopodia helianthoides. IUCN Red List of Threatened Species 2021. Published online 2021.

192. Michaud KM, Reed DC, Miller RJ. The Blob marine heatwave transforms California kelp forest ecosystems. *Commun Biol*. 2022;5(1):1-8. doi:10.1038/s42003-022-04107-z

193. Parnell PE, Miller EF, Cody CEL, Dayton PK, Carter ML, Stebbinsd TD. The response of giant kelp (Macrocystis pyrifera) in southern California to low-frequency climate forcing. *Limnol Oceanogr*. 2010;55(6):2686-2702. doi:10.4319/lo.2010.55.6.2686

194. Harrold C, Reed DC. Food Availability, Sea Urchin Grazing, and Kelp Forest Community Structure. *Ecology*. 1985;66(4):1160-1169. doi:10.2307/1939168

195. Grime BC, Sanders R, Ford T, Burdick H, Claisse JT. Urchin Gonad Response to Kelp Forest Restoration on the Palos Verdes Peninsula, California. *Bull South Calif Acad Sci*. 2023;122(1):1-18. doi:10.3160/0038-3872-122.1.1

196. McHugh T, Abbott D, Friewald J. Phase shift from kelp forest to urchin barren along California's North Coast. Sonoma-Mendocino Bull Kelp Recovery Plan. 2018.

197. McPherson ML, Finger DJI, Houskeeper HF, et al. Large-scale shift in the structure of a kelp forest ecosystem co-occurs with an epizootic and marine heatwave. *Commun Biol*. 2021;4(1):1-9. doi:10.1038/s42003-021-01827-6

198. Rogers-Bennett L, Catton CA. Marine heat wave and multiple stressors tip bull kelp forest to sea urchin barrens. *Sci Rep*. 2019;9(1):15050. doi:10.1038/s41598-019-51114-y

199. Cieri K, Spector P. *Update on Implementation of OPC's Kelp Action Plan*. California Ocean Protection Council; 2023.

200. Saccomanno VR, Bell T, Pawlak C, et al. Using unoccupied aerial vehicles to map and monitor changes in emergent kelp canopy after an ecological regime shift. *Remote Sens Ecol Conserv*. 2023;9(1):62-75. doi:10.1002/rse2.295

201. Smith JG, Malone D, Carr MH. Consequences of kelp forest ecosystem shifts and predictors of persistence through multiple stressors. *Proc R Soc B Biol Sci*. 2024;291(2016):20232749. doi:10.1098/rspb.2023.2749

202. Bell JJ, Micaroni V, Harris B, Strano F, Broadribb M, Rogers A. Global status, impacts, and management of rocky temperate mesophotic ecosystems. *Conserv Biol*. 2024;38(1):e13945. doi:10.1111/cobi.13945

203. Foster MS, Schiel DR. Loss of predators and the collapse of southern California kelp forests (?): Alternatives, explanations and generalizations. *J Exp Mar Biol Ecol*. 2010;393(1):59-70. doi:10.1016/j.jembe.2010.07.002

204. Eger AM, Marzinelli EM, Christie H, et al. Global kelp forest restoration: past lessons, present status, and future directions. *Biol Rev Camb Philos Soc*. 2022;97(4):1449-1475. doi:10.1111/brv.12850

205. Ward M, McHugh TA, Elsmore K, et al. *Restoration of Northern California Bull Kelp Forests - A Partnership-Based Approach*. Reef Check Foundation; 2022. Accessed July 23, 2025. https://www.reefcheck.org/wp-content/uploads/2022/06/Restoration-of-Northern-Califorina-bull-kelp-RCF-final-report-to-OPC.pdf

206. McHugh TA, Grime B, Hamilton S, et al. Accelerating North Coast Kelp Recovery. The Nature Conservancy. February 2025. Accessed January 6, 2026. https://bullkelp.info/sites/default/files/2025-03/ANCKR_Interim_Report_2025_TNC_03122025.pdf

207. Marks L, Reed D, Obaza A. Assessment of control methods for the invasive seaweed Sargassum horneri in California, USA. *Manag Biol Invasions*. 2017;8(2):205-213. doi:10.3391/mbi.2017.8.2.08

208. Reed DC, Schroeter SC, Huang D, Weisman D, Beheshti KM, Smith RS. The ecology of giant kelp colonization and its implications for kelp forest restoration. *J Phycol*. 2024;60(5):1121-1138. doi:10.1111/jpy.13487

209. Alsuwaiyan NA, Filbee-Dexter K, Vranken S, et al. Green gravel as a vector of dispersal for kelp restoration. *Front Mar Sci*. 2022;9. doi:10.3389/fmars.2022.910417

210. Heady WN, Beas-Luna R, Dawson MN, et al. Roadmap to recovery for the sunflower sea star (Pycnopodia helianthoides) along the west coast of North America. The Nature Conservancy. 2022. Accessed January 6, 2026. https://www.nature.org/content/dam/tnc/nature/en/documents/tnc_Roadmap_to_Recovery_for_the_Sunflower_Sea_Star_Nov2022.pdf

211. Galloway AWE, Gravem SA, Kobelt JN, et al. Sunflower sea star predation on urchins can facilitate kelp forest recovery. *Proc R Soc B Biol Sci*. 2023;290(1993):20221897. doi:10.1098/rspb.2022.1897

212. Arroyo-Esquivel J, Baskett ML, McPherson M, Hastings A. How far to build it before they come? Analyzing the use of the Field of Dreams hypothesis in bull kelp restoration. *Ecol Appl*. 2023;33(4):e2850. doi:10.1002/eap.2850

213. Lanari M, Horta PA, da Silva Copertino M. Functional redundancy and stability in a subtidal macroalgal community in the Southwestern Atlantic coast. *Mar Environ Res*. 2022;173:105519. doi:10.1016/j.marenvres.2021.105519

214. Reed DC, Schroeter SC, Huang D, Anderson TW, Ambrose RF. Quantitative assessment of different artificial reef designs in mitigating losses to kelp forest fishes. *Bull Mar Sci.* 2006;78(1):133-150.

215. Pondella DJ, Williams J, Claisse J, Schaffner B, Ritter K, Schiff K. The Physical Characteristics of Nearshore Rocky Reefs in The Southern California Bight. *Bull South Calif Acad Sci.* 2015;114(3):105-122. doi:10.3160/soca-114-03-105-122.1

216. Starr R, Caselle J, Kahn A, et al. *Monitoring and Evaluation of Mid-Depth Rock Ecosystems in the California MLPA Marine Protected Area Network.* Ocean Protection Council; 2022. Accessed July 23, 2025. https://www.opc.ca.gov/webmaster/_media_library/2022/05/MIDDEP3.pdf

217. NOAA Fisheries. Rocky Reef on the West Coast. NOAA. September 14, 2022. Accessed July 23, 2025. https://www.fisheries.noaa.gov/west-coast/habitat-conservation/rocky-reef-west-coast

218. Williams JP, Williams CM, Pondella DJ, Scholz ZM. Rebirth of a reef: As-built description and rapid returns from the Palos Verdes Reef Restoration Project. *Front Mar Sci.* 2022;9. doi:10.3389/fmars.2022.1010303

219. Reed DC, Schroeter SC, Huang D. An Experimental Investigation Of The Use Of Artificial Reefs To Mitigate The Loss Of Giant Kelp Forest Habitat. Published online 2006. Accessed July 23, 2025. https://repository.library.noaa.gov/view/noaa/42125

APPENDIX: RESTORATION TECHNIQUES

Rather than act as a State endorsement of restoration techniques, this section briefly summarizes the available knowledge of restoration interventions that range in efficacy, development, deployment, maturity, and consensus. This section is intended to act as a broad orientation of systems, their stressors, and known intervention methods for those who may be unfamiliar with restoration in action but it is not a comprehensive or methodological description of restoration actions. It would likely be useful to have State prioritized interventions and a decision framework for choosing interventions for each system based on site-specific conditions, but that is beyond the scope of this document.

This report divides restoration interventions into two categories: (1) stressor management, or interventions to remove or mitigate abiotic and biotic stressors, and (2) assisted recovery, or interventions to reintroduce or promote recovery of key species or processes. While restoration methods are presented within these two categories, interventions often fall on a continuum of actions from 'natural recovery' (previously known as 'passive restoration') to assisted restoration (previously known as 'active restoration') [102]. Stressor management, or identifying and mitigating site-specific stressors that cause degradation, can enable natural recovery through native recruitment or can be paired with assisted recovery interventions.

Some of the assisted recovery methods described below involve in-lab cultivation practices. Captive breeding is essential for many reintroduction efforts such as seagrass restoration and kelp outplanting, but captive breeding has the potential to result in genetic adaptation to captivity. Captive environments differ from natural environments, which can yield genetic variants that are advantageous in cultivation settings but unfavorable for natural environments. This can limit population success when cultivated populations are reintroduced to the wild [131]. To mitigate the potential for adaptation to captive conditions, practitioners can a) minimize generations in captivity, b) minimize

genetic selection by making the captive environment similar to the natural environment, c) pool or exchange between individual captive populations fragmented to reduce risk, or d) continually introduce wild-origin individuals in captive breeding populations [131].

A.1 Tidal Wetlands

BACKGROUND

Tidal wetlands provide resting, feeding, and nesting habitat for thousands of migratory shorebirds, colonial seabirds, and wintering waterfowl, including state- and federally-listed threatened and endangered species (e.g., Light-footed Ridgway's Rail, California Least Tern, Western Snowy Plover, Belding's Savannah Sparrow). Tidal wetlands are also home to many ecologically- and economically-important fish and invertebrate species. Tidal wetlands are often considered nature-based solutions as they protect coastal communities against flooding, dissipate wave energy, sequester carbon, and improve water quality via nutrient filtration [75].

Tidal wetlands include a diversity of habitat types, including subtidal habitat, mudflats, salt marsh, tidal channels and creeks, and salt pannes. Subtidal zones support two habitat types: soft-sediment bottom and submerged aquatic vegetation (e.g., *Zostera marina*). Mudflats are typically exposed during low tides and occur at tidal elevations too low to support vascular plants and too high to support submerged aquatic vegetation. Historically, some mudflats once supported large and robust native Olympia oyster populations, which are now mostly extirpated. Mudflats form along the margins of large creeks and rivers, estuaries and lagoons, and tidal channels. The diverse assemblage of infaunal species that inhabit mudflats provide food chain support for larger macroinvertebrates, fishes, birds, and marine mammals. As elevation increases, tidal inundation frequency decreases. In salt marshes, the interaction between tidal elevation and inundation drives plant and animal community composition. Salt marshes are composed of deep mud and peat, which is made from decomposing plant matter. As a result of regular tidal inundation and fine-grain sediment, salt marshes foster a hypoxic sediment environment with relatively slower decomposition [132]. Salt pannes are located within the high salt marsh zone. These shallow depressions or pools of hypersaline standing, or poorly drained water, often dry out during extended periods of exposure and high temperatures, forming cracked salt crusts inhospitable to plant life.

STRESSORS

Primary threats to tidal wetlands include climate change, urban development, hydrological alterations, nutrient pollution, and invasive species. Sea level rise is a significant climate-related threat to tidal wetlands since as sea levels rise, the migration potential of wetland ecosystems are limited by human development and infrastructure. As with "coastal squeeze" in the rocky intertidal, there is finite, limited space to accommodate landward migration of wetland habitats, which unmitigated will lead to complete loss of valuable wetland habitats [75]. Dredging and diking for urban and commercial development also pose a significant threat to tidal wetland ecosystems [133]. There are numerous invasive species that compete with native species in tidal wetlands and shallow subtidal habitats. Of particular concern is the cordgrass hybrid *Spartina* and the seaweed *Caulerpa prolifera*.

RESTORATION TECHNIQUES

Stressors Management

Removing water control features to restore freshwater and tidal flows where necessary to coastal wetlands can facilitate the natural functioning and resilience of such wetland systems. Managing sediment sources and restoring the tidal regime can offset the impacts of sea level rise [134]. Managing coastal development to accommodate landward migration of wetlands can mitigate the effects of sea level rise on wetland extent statewide. Physical removal or herbicide treatment can be effective methods for reducing the invasion of non-native species in wetlands.

Assisted Recovery

Assisted recovery methods for wetlands include:

- **Planting native wetland species:** Planting polycultures of native salt marsh plants, including *Spartina foliosa*, *Salicornia pacifica*, *Jaumea carnosa*, and *Distichlis spicata*, can help stabilize sediment, improve sediment quality, and improve ecosystem services and functions [135,136]. Species choice will depend on tidal wetland elevation and associated salinity and inundation tolerance.

- **Tidal channel creation:** Construction of tidal channels conveys water and sediment to mid and high marsh zones, provides conduits for fish to access marsh plains, moves sediment and nutrients throughout the system, and increases habitat heterogeneity, which can support higher levels of biodiversity [137].

- **Sediment augmentation:** Land subsidence, groundwater overdraft, freshwater diversion, and coastal erosion can contribute to wetland loss. In these instances, using sediment augmentation (e.g., thin layer sediment addition) to raise the elevation of the salt marsh plain can be an effective approach to increasing ecological function (e.g., productivity, sediment trapping). Sediment composition and applied thickness will vary based on site-specific needs [138].

ADDITIONAL RESOURCES

1. Fejtek, S., Gold, M., MacDonald, G., Jacobs, D., Ambrose, R. 2014. Best Management Practices for Southern California Coastal Wetland Restoration and Management in the Face of Climate Change. University of California Los Angeles, Institute of the Environment and Sustainability.

2. Philip Williams & Associates, Ltd., and P. M. Faber. 2004. Design Guidelines for Tidal Wetland Restoration in San Francisco Bay. The Bay Institute and California State Coastal Conservancy, Oakland, CA.

3. Zedler, J.B. 2001. Handbook for Restoring Tidal Wetlands. CRC Press.

4. Zedler, J.B. 1996. Tidal Wetland Restoration: A Scientific Perspective And Southern California Focus. California Sea Grant College System & Pacific Estuarine Research Laboratory.

A.2 Oyster Beds

BACKGROUND

Olympia oysters (*Ostrea lurida*) are the only oyster species native to the Pacific northwest coast of North America. Olympia oysters range from Sitka, Alaska to Baja California, Mexico [139] and reside in estuarine habitats, serving as an important foundation species. They provide habitat for other marine species [139], improve water quality through increased filtration [140], reduce wave action and shoreline erosion [141], and are culturally important to California tribes [142].

STRESSORS

Olympia oysters have been subjected to multiple interacting stressors. Overharvesting in the 19th and 20th centuries removed natural oyster beds from California [143]. Coastal development, sedimentation, and shoreline hardening have created a loss of suitable substrate for larval recruitment and oyster growth [144]. Excessive sedimentation can smother oyster beds and reduce the availability of hard substrates for larval settlement [144]. Water conditions such as low salinity events [145], low dissolved oxygen [144], low air temperatures [144], and ocean acidification [146] pose a threat to oyster health [144]. Once larvae are able to grow, invasive snails, particularly the Atlantic and Japanese oyster drill, decimate oyster populations through intense predation pressures. Olympia oysters are also threatened by the invasion of the competitively dominant oyster, *Magallana gigas*, and through predation from invasive predatory snails known as oyster drills [144].

RESTORATION TECHNIQUES

Stressors Management

Strategies to reduce sediment and nutrient input into bays and estuaries depends on the source of runoff but can include changing agricultural practices, rerouting urban runoff, improving wastewater treatment, and restoring upslope vegetation in living shoreline designs that can act as a first line of defense between oyster beds and agricultural or urban areas. Reducing nutrient loads can also have the benefit of preventing hypoxia events that are harmful for oysters [144]. Effective management of non-native oysters and oyster predators involves physically removing invasive species from the site. Minimizing direct human impact can be achieved through implementation of oyster protections via no-take areas, educational signage, reducing boat wake, and other deterrents that help oyster beds self-sustain.

Assisted Recovery

Approaches to assisted recovery of habitat type and species reintroduction to reestablish Olympia oyster populations include:

- **Rebuilding reef substrate:** Restoration of lost oyster habitat involves rebuilding reef substrate to allow for larval settlement and growth in areas where sufficient natural recruitment exists. Rebuilding reef substrate is often done using clean oyster shells (either loose or in bags) and can also include crushed rock or baycrete to create hard surfaces. Strategic placement of substrates can help reduce

interactions with common stressors. In some cases, outplanting individual live Olympia oysters will constitute hard substrate for future oyster settlement, so outplanting raised oysters contributes to an increase in available hard substrate [147].

- **Seeding:** Restoration of the species, particularly in areas where broodstock is insufficient to provide reliable recruitment, involves rearing oysters in hatcheries and setting juvenile oysters onto various materials (often using shell, rock, or other hard substrates). Materials embedded with set oysters are then placed on strings and/or small cobbles at a restoration site [144].

- **Translocation:** Relocating adult oysters to other areas to act as broodstock is possible. However, this is often only used when natural recruitment or seeding isn't possible as it can harm the donor site and introduce disease or invasion to the restoration site [148].

ADDITIONAL RESOURCES

1. Schubel, J.R., Center, S., Lenihan, H. 2017. From British Columbia to Baja, California Restoring The Olympia Oyster (Ostrea lurida). Aquarium of the Pacific & UC Santa Barbara Bren School.

2. Wasson, K., Zabin, C., Bible, J., Ceballos, E., Chang, A., Cheng, B., Deck, A., Grosholz, T., Latta, M., Ferner, M. 2014. A Guide to Olympia Oyster Restoration and Conservation. San Francisco Bay National Estuarine Research Reserve.

3. Baggett, L.P., S.P. Powers, R. Brumbaugh, L.D. Coen, B. DeAngelis, J. Greene, B. Hancock, and S. Morlock. 2014. Oyster Habitat Restoration Monitoring and Assessment Handbook. The Nature Conservancy.

A.3 Sandy Beaches and Dunes

BACKGROUND

California's coastline includes more than 420 public beaches. Sandy beaches are some of the most-frequented coastal habitats by humans, attracting a flourishing tourist economy in California. Not only do sandy beaches provide economic benefits in the form of recreation and tourism, but they also provide critical habitat for many species, ranging from meiofaunal (e.g., amphipods) to macrofaunal species (e.g., shorebirds) [149].

Sandy beach habitats are typically unvegetated and consist primarily of sand and wrack (drift marine and anthropogenic debris). Coastal dunes are also an important part of the land-sea transition. Dunes help to stabilize sediment for sand accretion, dissipate wave energy, and buffer against storm surges and coastal flooding [150]. Dunes also provide habitat for beach-dwelling organisms as well as nesting sites for birds [151].

Sandy beaches and coastal dune systems form a dynamic transition area between the land and ocean. Sandy beaches and dunes are formed from sediment deposition from coastal bluffs and rivers [152]. This ecotype is dynamic, as sandy beaches and dunes are subject to high variability in response to storms and tides. A number of California's beaches exist at a wider extent than they would naturally as the result of nearly a century of beach nourishment projects along the coast [152]. Beach nourishment may be considered restoration in specific cases in which replenishment efforts are centered around ecological goals and considerations. For the most part, however, beach nourishment in California serves the primary purpose of creating recreational areas for people. If beach replenishment activities continue, approval should be based on ecological best practices, including use of appropriate grain size and placement methods that minimize harmful impacts to habitat and species. This method is most effective when paired with other restoration efforts to prevent future loss of sand.

Behind the beach, dune systems develop with establishment of coastal plants whose roots stabilize sediment, eventually forming mounds of sand. These ecosystems are highly variable and sensitive to human activities such as coastal development and watershed management that diverts freshwater and critical sediment from reaching coastal waters. Some efforts across California have sought to deposit dredged sediment from shipping channels, bays, and harbors for beach and dune replenishment [153].

STRESSORS

Globally, nearly every sandy beach ecosystem is threatened by anthropogenic impacts [154]. In the U.S., there are about 20,000 miles of eroding shoreline, 2,700 miles of which are considered "critically eroding" [155]. Sea level rise, reduction in sediment inputs, hardening of the coastline via shoreline armoring, and proliferation of human development such as dams, have generally combined to reduce both the spatial extent and fundamental dynamism critical to the ecological functioning of sandy beaches [156,157]. The effects of 'coastal squeeze,' or the reduction in available space for coastal habitats caught between rising seas and hard infrastructure, will become more

evident on sandy beaches into the future. Beach assemblages are further stressed by intense, localized disturbances, including mechanical grooming and pollutant exposure, with these stressors concentrated along the most urbanized segments of coastline [154]. Given how highly trafficked sandy beaches are, and their close proximity to infrastructure and human communities, the effectiveness of restoration interventions will be limited by continued human activity and presence.

Coastal dunes are subject to many of the same stressors as sandy beaches, but dunes are also susceptible to the effects of invasive species. Invasive dune species can alter physical processes and outcompete native dune species. Common invasive species in California coastal dunes include *Carpobrotus edulis*, known as iceplant, and *Cakile maritima*, or European sea rocket [158]. Iceplant was initially introduced in California to promote soil stabilization, but has since dominated many coastal dune landscapes statewide.

RESTORATION TECHNIQUES

Stressors Management

Beach restoration often emphasizes restoration of sand delivery, including watershed management to remove dams or implement sand bypasses. Dam removal, particularly for dams no longer providing hydropower or irrigation benefits, offers substantial potential for restoring sand delivery [159]. At a local scale, removal of abandoned artificial surfaces and materials that are occupying and displacing beach and dune habitat, such as oil and transportation infrastructure, can restore sediment movement and reduce barriers to landward migration. Reducing physical disturbances by limiting grooming and protecting key habitat areas through fencing and signage can also support the natural dynamism of these habitats [160]. Removal of invasive species, particularly iceplant, helps to restore the natural dynamism of coastal dune systems. However, iceplant acts as a stabilizer for dunes by providing structural integrity, so the assisted recovery methods below include strategies for stabilizing sand and promoting dune formation coupled with iceplant removal.

Assisted Recovery

For sandy beaches and dunes, assisted recovery can help to more rapidly stabilize sand, establish geomorphic structure, and restore ecological function. These techniques often center around retaining and rebuilding sand within the ecosystem and include:

- **Dune revegetation:** Vegetation recovery of native plants through seeding and outplanting has proven to support increases in dune height and total sand

accretion. Revegetation can support transition away from iceplant as a dune stabilizer, while also providing habitat for dune invertebrates and shorebirds [160].

- **Installing sand fences:** Installing sand fences can help accrete sediment by stabilizing loose sand and promoting dune formation. This restoration approach is a relatively inexpensive and sustainable approach to shoreline protection to erosion and sea level rise.

- **Engineered structures:** Most restoration for sandy beach loss is motivated by the installation of engineered structures (e.g., harbor breakwaters, seawalls), which change local sand deposition patterns. These efforts primarily focus on compensating for the loss of non-ecological beach services to protect onshore infrastructure (often houses or roadways) or recreation (maximizing "towel area"), typically via either permanent structures (e.g., groins) designed to accrete sand during longshore drift or ephemeral, pulsed sediment pumping/deposition from harbors or other nearby reservoirs. However, the use of nature-based solutions should be considered prior to permanent, hard structures as these structures can have adverse downdrift effects, such as erosion.

ADDITIONAL RESOURCES

1. King, P.G., McGregor, A.R. 2013. Managing Sandy Beach Ecosystems. BEACON.

A.4 Rocky Intertidal

BACKGROUND

Rocky intertidal ecosystems exist as a narrow ribbon along the California coast comprising between five-to-fifteen square miles across the entire State [161]. Despite its relatively limited spatial extent, rocky intertidal habitats provide a variety of ecological functions for California by supporting high species diversity and providing shelter and nursery grounds for fish and invertebrates [162]. The rocky intertidal also provides significant recreational, cultural, and economic value to the people of California, particularly for many tribes. Rocky intertidal habitats are highly accessible in comparison to other marine environments and are thus popular destinations for class field trips and recreational tidepooling [163].

California's rocky intertidal ecosystems can be divided into three vertical zones defined by exposure to tidal fluctuations. The high zone is closest to land and is the first to be exposed as the tide falls. Organisms that live in the high zone experience the greatest variation in temperature, salinity, and potential for desiccation, followed by the middle and low zones, respectively [164]. Rocky intertidal zones are composed of various features such as rock crevices, tidepools, and rocky beaches. This habitat type is exceptionally diverse, hosting a variety of ecologically and economically important plants and animals [165].

STRESSORS

Rocky intertidal habitats face a range of anthropogenic threats including pollution (mainly from terrestrial sources), human disturbance from trampling, invasive species, sedimentation, and overexploitation through unsustainable collecting [165–167]. Intertidal habitats are vulnerable to climate-related stressors, particularly sea level rise and increased ocean and air temperatures. As sea levels rise, intertidal habitats lacking space for landward migration will lose the tidal influence that defines their ecosystem. Steep cliffs and hard infrastructure prevent landward migration of rocky intertidal ecosystems, a phenomenon known as coastal squeeze.

RESTORATION TECHNIQUES

Stressors Management

Reducing direct human disturbances of rocky intertidal ecosystems is a key step in allowing for the persistence and recovery of these habitats. Recovery strategies in response to direct human disturbance fall into two categories: 1) creation or expansion of education programs to encourage responsible tide pool use, and 2) creation or expansion of enforcement activities. Expanding public education efforts include installing signage, using docent programs, working with educational institutions to improve awareness, and changing trampling and handling behavior of those visiting [168]. Public education paired with increased enforcement of harvesting restrictions and enhanced protected area designations may further deter high-impact human behavior [168]. For rocky intertidal habitats facing threats from pollution or sedimentation, recovery will depend on addressing land-based sources of both stressors. Addressing coastal squeeze can include removing physical barriers to landward migration.

Assisted Recovery

In rocky intertidal systems, active restoration methods often rely on restoring target species. Foundation species such as canopy-forming kelp, surfgrass, or ecologically-important invertebrates help structure physical habitat while stabilizing ecological diversity and composition. Focal species will depend on project-specific outcomes, site conditions, and the intertidal zone targeted for restoration, but are likely to include:

- **Rockweed,** a group of brown seaweeds that are often the dominant macroalgae within the mid- to upper-intertidal zone. The most common genera of rockweed include *Silvetia* and *Fucus*. Restoration of rockweed species involves transplanting adults to the restoration site and using transplanted organisms to seed surrounding areas for continued recruitment and restoration [162].

- **Surfgrass,** an abundant and ecologically important nearshore seagrass species. Much like eelgrass, restoration for surfgrass includes using both seeding methodologies and rhizome transplants secured to rocks [169].

- **Abalone,** mollusks that are both ecologically valuable within the low intertidal zone and culturally important to California's history. There are seven species of abalone native to California, all of which have been nearly wiped out in a subset of sites across the state that historically supported high densities. Restoration for abalone includes captive breeding and outplanting of juvenile species into rocky habitat [170] as well as translocating individuals from donor sites to sites where abalone have been lost (e.g., black abalone).

- **Mussels,** habitat-forming foundational species found within the mid-intertidal zone, provide structural complexity to intertidal habitats. Restoration techniques include transplanting mussels or using mesh and plates to allow mussel spat to recruit to the area.

Additional methodologies could include creating living sea walls, which include grey and green elements, composed of artificial tidepools and reefs [171], to increase habitat heterogeneity landward so that intertidal species have habitat to recruit or migrate to with refugia from rising seas. However, hybrid habitats like living sea walls generally have not been found to support the full range of structure and function of naturally-occurring habitat of living shorelines.

ADDITIONAL RESOURCES

1. Gaines, S., Denny, M.W. 2007. Encyclopedia of Tidepools and Rocky Shores. University of California Press.

2. Ambrose, R.F., and Smith, J. 2004. Restoring Rocky Intertidal Habitats in Santa Monica Bay. University of California, Los Angeles.

A.5 Seagrasses

For federal guidance on eelgrass conservation measures and monitoring methods, please reference the National Marine Fisheries Services' California Eelgrass Mitigation Policy (CEMP).

BACKGROUND

Seagrasses are marine flowering plants that grow along California's coast in sheltered bays and estuaries, as well as the open coast [172]. Healthy seagrasses are able to support diverse assemblages of fish [173], enhance water quality [174], sequester carbon dioxide [175], and attenuate wave energy, thereby protecting shorelines from coastal erosion [176]. In California, there exists both soft-bottomed seagrass (*Zostera sp.* and *Ruppia maritima*) and rock-associated seagrass species (*Phyllospadix sp.*). The most spatially-extensive seagrass is common eelgrass (*Zostera marina*), found in bays and estuaries [177]. In the semi-protected coastal waters of Central and Southern California, Pacific eelgrass (*Zostera pacifica*) occurs in subtidal areas of sand and gravel substrate typically in the lee of prominent headlands and capes; however, Pacific eelgrass is relatively rare with limited statewide extent. *Ruppia maritima* (Widgeon grass) is an important component of coastal wetlands with documented tolerances for warmer, less saline, and more eutrophic waters [178]. While this might make it an important species for consideration under climate change, much of the work focused on *Ruppia* has been conducted through coastal wetland restoration. Previous examples include restoration projects that created shallow lagoons which supported recovery of *Ruppia maritima* [179]. Similarly, there has been relatively little restoration of *Phyllospadix torreyi* within California. While restoration is feasible, it is more technically challenging than *Zostera* restoration. As a rock-associated species, *Phyllospadix sp.* requires laboratory-grown seedlings attached to mesh or sprigs harvested from a donor bed that are epoxied to a hard substrate at the restoration site [169,180]. As sea level rise continues to threaten

Phyllospadix sp. habitat, conservation of suitable habitat will be critical since restoration techniques for the species are still in early stages.

Current inventories from aerial coverage estimate that there are over 60km² of eelgrass habitat, but that value is highly uncertain [181]. Collectively, just five estuarine systems support more than 80 percent of known eelgrass extent in the state, including Humboldt Bay, San Francisco Bay, San Diego Bay, Mission Bay, and Tomales Bay [182].

STRESSORS

Seagrasses face a range of natural and anthropogenic stressors that have contributed to their declines in extent and resilience. These stressors include light limitation, disease outbreak, algal blooms from eutrophication, sedimentation, dredging, invasive epifauna (often the tunicate *Didemnum vexillum* in California), and increased frequency and intensity of coastal storms [67]. These stressors reduce light availability needed for growth and cause physical disturbances to seagrasses. Additional stressors on seagrasses include increased water temperature and coastal development. When closed, estuaries can form sizable submerged aquatic beds of *Ruppia maritima* (widgeongrass) and other brackish water SAV species, in addition to floating mats of macroalgae or phytoplankton blooms. Abrupt opening of a tidal inlet due to storm events or management actions can completely change tidal elevations and salinity regimes, effectively replacing or restructuring over a period of days the dominant species.

RESTORATION TECHNIQUES

Stressors Management

When environmental conditions are suitable, seagrasses can recolonize areas naturally without assisted recovery. To do so, restoration must, in part, address the stressors that caused seagrass to be lost in the first place. This is achieved primarily by improving water quality to enhance light availability and limiting mechanical disturbances to beds. Successful approaches for improving water quality include establishing total maximum daily loads for pollution, maintaining tidal flushing, reducing land-based nutrient application, stabilizing sediment to improve water clarity, and minimizing overwater structures [183]. For physical and biological disturbances, minimizing dredging and anchor damage, removing debris, and managing invasive species can create conditions necessary for seagrass to naturally recolonize [183].

Assisted Recovery

Once stressors have been addressed, assisted recovery can complement and accelerate the restoration process. Seagrass restoration methodology typically falls into two categories: i) outplanting of adult seagrasses, or ii) distribution and/or planting of seagrass seeds [184]. Scientists have documented high variability in shoot densities and bottom cover across sites, seasons, and even within individual beds over time throughout California's seagrass ecosystems. Therefore, seagrass restoration designs should mimic the natural seagrass density for the site at the time of project implementation to ensure assessment of success approximates reference conditions. The selection of appropriate techniques depends on site-specific conditions, donor material, and restoration objectives. Methods for seagrass reintroduction include

- **Bare-root transplants:** Manual planting of individual shoots or shoot bundles into a substrate either alone or staked using material such as popsicle sticks, garden staples, bamboo, or rebar [67]. This methodology helps to stabilize plants during establishment and is preferred in high-energy environments. Best practice for bare-root transplants includes freshwater rinses prior to outplanting to help remove invasive epifauna that grow directly on shoots and rhizomes [31,185].

- **Sediment-intact transplants:** This method transfers shoots with the surrounding sediment, known as plugs, to the restoration site [67]. This method helps to preserve root structure and associated microbial and infaunal communities for higher restoration success, but is more technically challenging to execute at scale.

- **Seed-based methods:** The two most common seed-based methods include broadcast dispersal or targeted burial of seagrass seeds in restoration plots. This technique, when executed with the appropriate mariculture infrastructure, is well suited for large-scale restoration projects but can be limited by seed predation and seed germination success [67].

ADDITIONAL RESOURCES

1. Hughes, B.B., Beheshti, K.M., Boyer, K.E., Williams, W. 2024. Seagrass restoration handbook: the how, when, and where of restoring seagrass habitat through transplantation. The Anthropocene Institute.

2. Beheshti, K.M., Ward, M. 2021. Eelgrass Restoration on the U.S. West Coast: A Comprehensive Assessment of Restoration Techniques and Their Outcomes. Prepared for the Pacific Marine and Estuarine Fish Habitat Partnership.

3. NOAA Fisheries. 2014. California Eelgrass Mitigation Policy and Implementing Guidelines.

4. McCune, K., Gillett, D.J., Stein, E.D. 2020. Methods and Guidance on Assessing the Ecological Functioning of Submerged Aquatic Vegetation in Southern California Estuaries and Embayments. Southern California Coastal Water Research Project.

5. Thom, R., Gaeckle, J., Borde, A., Anderson, M., Durrance, C., Kyte, M., Schlenger, P., Stutes, J., Weitkamp, D., Wyllie-Echeverria, S., Rumrill, S., Boyle, M. 2008. Eelgrass (Zostera marina L.) Restoration in the Pacific Northwest: Recommendations to Improve Project Success. U.S. Department of Energy.

6. Fonseca, M.S., Judson, K.W., Gordon, W.T. 1998. Guidelines for the conservation and restoration of seagrasses in the United States and adjacent waters. NOAA Coastal Ocean Program decision analysis series no.12.

A.6 Kelp Forests

For a cohesive kelp management strategy, please look towards the forthcoming Kelp Restoration and Management Plan (KRMP) from the California Department of Fish and Wildlife and the California Ocean Protection Council (tentative release 2027). For artificial reefs, please look towards the forthcoming California Artificial Reef Program Plan (CARP) from the California Department of Fish and Wildlife. The following section serves as a broad orientation to kelp forest restoration and does not supersede either of the aforementioned State plans.

BACKGROUND

Kelp forests are spatially and temporally dynamic environments and are among the most biodiverse and productive ecosystems on the planet [186]. Kelp forests in California grow along the entirety of the coastline in shallow rocky subtidal areas at depths of ~3-25 m. This depth range encompasses what the State defines as shallow rocky bottom habitat which is found from 0-30 m [187]. Hundreds of canopy-forming, stipitate (seaweeds that have a stalk or stipe), and understory seaweeds (some of which are kelp) provide food, habitat, and shelter to thousands of organisms, thus constituting a kelp forest.

There are two predominant types of canopy-forming kelp in California: giant kelp (*Macrocystis pyrifera*), a perennial species that dominates the coast south of San Francisco, and bull kelp (*Nereocystis luetkeana*), an annual species that dominates the coast north of Santa Cruz. Recent inventories estimate 72 km² of canopy-forming kelp across the state [181]. *Macrocystis* and *Nereocystis* are foundation species that provide a variety of functions and ecosystem services [186]. Kelp forms a complex three-dimensional habitat, serves as a food source for herbivores and detritivores, supports coastal nutrient cycling, and may help to mitigate ocean acidification at very local scales [188,189]. Kelp forests also support a variety of commercial, recreational, and tribal fisheries and provide recreational opportunities such as diving, kayaking, and wildlife viewing. Through these ecological, economic, recreational, and cultural services, kelp forests contribute to the state's $44 billion marine economy [190].

STRESSORS

Kelp forests are under a combination of anthropogenic stressors, including the direct and indirect effects of global climate change. Kelp forests are often affected by multiple, compounding stressors, which can cause a decline in kelp health and prevent natural recovery from discrete events. Broad drivers of loss along the California coast include marine heatwaves and associated nutrient deficiencies, disease outbreaks in sea re predators, and more frequent and intense coastal storms [191–193]. More localized stressors include burial and reduced light availability from sedimentation, invasive algal competition, pollution, and sea urchin overgrazing. In California, sea urchins are a native and natural component of kelp forest systems. When kelp densities and urchin predator densities are sufficiently high, satiation on drift kelp and fear of predators promotes passive kelp consumption by urchins, where they hide in crevices and primarily consume drift kelp (kelp fronds that break off and float the sea floor). However, low kelp and predator densities, which often coincide with persistent warming, starvation, and a lack of fear/predation, lead to active urchin grazing on kelp that causes kelp mortality. In extreme cases, kelp forest systems can shift to an alternate state devoid of kelp and with high densities of urchin known as urchin barrens. In urchin barrens, urchins can persist for extended periods in a dormant state and can impede kelp recovery. Natural recovery from urchin barrens can occur, such as following natural disease urchin outbreaks or highly favorable conditions for kelp growth [194], but restoration interventions can be relevant in cases of persistent and extensive urchin barrens [195].

Off the coast of Sonoma and Mendocino Counties, scientists have observed a greater than 95% decrease in *Nereocystis* canopy since 2014 due to a combination of inter-related stressors, including sea star wasting disease, the 2014-2016 marine heat wave events, and an ensuing population explosion of purple sea urchin [196–198]. As of 2023, total kelp canopy coverage in these counties remains at less than 10% of its historical average [199]. These same events also led to a patchy mosaic of *Macrocystis* loss in select regions of central California, resulting in a 70% reduction of giant kelp along the Monterey-Carmel Peninsula area [200,201]. This was followed by a subsequent recovery of 96.8% in Central California and 68.9% across Southern California as of 2021 [202].

RESTORATION TECHNIQUES

Stressors Management

To address local stressors, practitioners can improve water quality by addressing sedimentation, pollution, and heat [203], reduce localized urchin populations through culling urchins or harvesting by hand or vacuum [204,205], outplant kelp to boost spore source supply [206], and reduce competition from invasive species like *Sargassum horneri* [207] or *Undaria pinnatifida*.

ASSISTED RECOVERY

The potential for natural recovery at a given site might be limited by dispersal potential, recruitment success, and subsequent establishment. Understanding factors that affect dispersal dynamics, particularly distance from the nearest source population, as well as the potential for regeneration from a germ bank, can help inform whether assisted recovery may be necessary, or if kelp may be able to reestablish itself once local stressors have been addressed on an acceptable timeline [208].

The suitability of the following assisted recovery techniques is dependent on causes of loss or degradation, size of the restoration project, and specific project objectives, and are often used in conjunction with one another depending on specific site management needs:

- **Seeding and outplanting:** Seeded lines or spore bags are used to disperse kelp across large spatial scales. This method can result in high mortality of kelp propagules [204,208] but selecting for multiple life stages and the most appropriate method for specific contexts can increase the likelihood of success [206]. For example, *Macrocystis* can be outplanted using green gravel in which small gravel

is seeded with kelp propagules [209] and *Nereocystis* can be outplanted at juvenile stages on Arrays to Recover Kelp Ecosystem Vegetation (ARKEVs) [206].

- **Transplanting:** Transplanting kelp is the movement of entire kelp individuals from donor beds to restoration sites. Kelp holdfasts are affixed to reef surfaces using glue, rope, and mesh mats. This methodology allows kelp to create suitable habitat conditions and act as a spore source for the restored area [204,208]. However, scalability of this method is limited by how resource intensive it is.

- **Recovery of urchin predators:** Supporting recovery of dominant urchin predators, particularly the sunflower sea star (*Pycnopodia helianthoides*), is the focus of ongoing research and may be a method to help facilitate natural recovery [210]. Experiments and models predict that recovery of *Pycnopodia* could increase urchin predation, help kelp forest recovery [211], and aid in ecosystem resilience under future marine heat waves [212]. Building functional redundancy, or increasing the number of taxonomically distinct but functionally similar species such as urchin predators, has the potential to reduce the negative effects of stressors and can increase a kelp ecosystem's functional resilience [213].

- **Artificial reef installation:** This method involves the placement of artificial reefs, or hard substrate, to facilitate kelp settlement and growth. This is sometimes referred to as kelp afforestation, which requires converting existing soft sediment to hard substrate appropriate for kelp attachment [214]. Although this method involves habitat conversion from subtidal soft bottom ecosystems, and therefore may not be considered restoration as traditionally defined, this document discusses the importance of a more climate change inclusive definition of restoration that includes directing habitats for their persistence, and therefore artificial reefs would fall under this updated definition of a restoration action.

ADDITIONAL RESOURCES

1. Giraldo-Ospina, A., Bell, T., Carr, M.H., Malone, D., Caselle, J.E. 2023. Where, when and how? A guide to kelp restoration in California using spatio-temporal models of kelp dynamics. A report to California SeaGrant and California Ocean Protection Council.

2. Eger, A.M., Layton, C., McHugh, T.A., Gleason, M., Eddy, N. 2022. Kelp Restoration Guidebook: Lessons Learned from Kelp Restoration Projects Around the World. The Nature Conservancy.

3.   Gleason, M.G., Caselle, J.E., Heady, W.N., Saccomanno, V.R., Zimmerman, J., McHugh, T.A., Eddy, N. 2021. A Structured Approach for Kelp Restoration and Management Decisions In California. The Nature Conservancy.

A.7 Mid-Depth Subtidal Rocky Bottom

BACKGROUND

Shallow rocky subtidal areas are defined as depths from approximately 0-30 meters [215] and mid-depth subtidal rocky bottom ecosystems to be between 30 and 100 meters of depth [216]. Shallow reefs are often dominated by canopy-forming algae, such as giant kelp, and as such are addressed in the section above (Section A.6). In this section, subtidal rocky bottom refers to the mid-depth range of rocky reefs. Subtidal rocky bottom habitats are areas of hard substrate that are often referred to as rocky reefs. Some rocky bottom areas are extensions of shoreline rocky features such as headlands, cliffs, or rocky intertidal habitat, while others exist as isolated regions of rock surrounded by soft bottom substrate. Rocky reefs have varied topography and rugosity; ranging from rocky reefs that are 0-1 meters above the seafloor to high relief reefs that can extend above the surface to form islands.

Subtidal hard bottom areas are known for their abundant and diverse biological communities including macroalgae, sponges, corals, invertebrates, and fish. Variable topography, substrate characteristics, and depths within and among rocky reefs produces a plethora of microhabitats. Mid-depth rocky reef habitats beyond the depth range of canopy-forming kelp (> 25 meters depth) include banks and outcroppings, underwater pinnacles, and submarine canyons [164]. However, in comparison to shallower, near-shore coastal habitats, the ecology and vulnerability to climate change of this habitat type are less understood, which inhibits robust and effective management of deep rocky reef habitat.

Subtidal rocky bottom restoration offers numerous ecological and socioeconomic benefits including increased habitat for fish and invertebrates, enhancement of coastal productivity, coastal protection from wave energy, and increased recreational value for diving and tourism [217].

STRESSORS

Subtidal rocky bottom stressors may differ depending on depth. Mid-depth subtidal rocky bottom is most threatened by changes in ocean conditions (temperature, acidification and hypoxia), sedimentation, nutrient availability, disruptive fishing practices, and underwater infrastructure like subsurface cables [202].

RESTORATION TECHNIQUES

Stressors Management

For mitigating stressors in mid-depth rocky reefs, controlling coastal erosion and reducing land-based sediment input can be helpful in preventing the burial of rocky reefs. Protecting subtidal habitats from physical damage by boats, bottom trawling, and underwater infrastructure can further reduce habitat degradation and fragmentation.

Assisted Recovery

Assisted recovery for subtidal rocky habitats can prioritize replication of habitat complexity and promote recruitment in the area [218], which may include artificial reef construction to restore reef rugosity. Artificial reefs include manmade or natural material intended to replicate the physical habitat structure that has been damaged or lost. Artificial reef substrate is typically quarry rock but can also include concrete, reef balls, and other hard structures [214]. Reef size, use of natural or artificial materials, footprint, and other design considerations can have an effect on the outcome of the restoration effort [219]. The California Artificial Reef Program Plan currently under development and expected in early 2027 provides guidance on materials, design and siting considerations.

ADDITIONAL RESOURCES

1. AMEC Environment & Infrastructure, Inc. 2014. Review of Subtidal and Intertidal Habitat Compensatory Mitigation Approaches. California State Lands Commission.