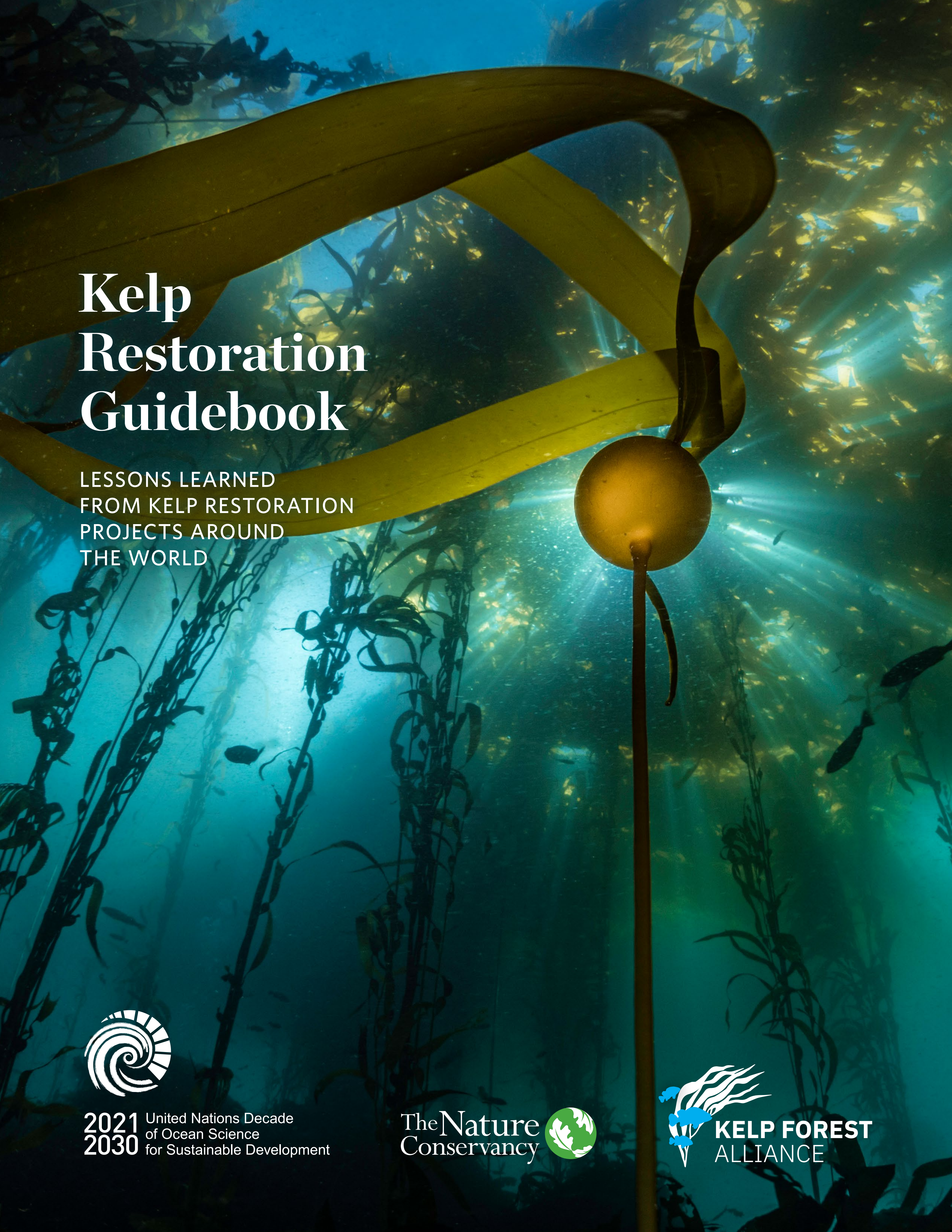

Kelp Restoration Guidebook

LESSONS LEARNED
FROM KELP RESTORATION
PROJECTS AROUND
THE WORLD

2021 2030 United Nations Decade of Ocean Science for Sustainable Development

The Nature Conservancy

KELP FOREST ALLIANCE

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SUMMARY

The field of marine habitat restoration has developed rapidly over recent years and will likely accelerate with both the UN Decade of Restoration and UN Decade of Ocean Science for Sustainable Development (2021–2030). These programs will support efforts to collectively manage and reverse declines in ocean health and generate increased investment in the conservation of marine ecosystems and the communities they support.

Despite a relatively long history in places like Japan, Korea, and California, the science and practice of kelp forest restoration is still in its infancy, and there remains a wealth of knowledge to be learned and shared from our collective failures and successes. To date, many projects have remained disconnected and had limited opportunities to share their experiences and learnings. The practice of kelp forest restoration will be greatly enhanced with collaborative, science-based efforts, where all stakeholders and custodians are engaged in decision-making and even short-term failures can yield insights that contribute to longer-term success.

The development of the Kelp Restoration Guidebook was informed by a series of global workshops, and an expert panel of authors and editors, with the aim to share and distil lessons learned from kelp restoration efforts globally. The intent is for this guidebook to serve as a starting point for practitioners, researchers, managers, and custodians to learn about the steps of restoration and access an active community of practice—all to improve the likelihood of success for future restoration projects. The broad lessons contained herein can then be extended and refined to suit local kelp species and circumstances. Ultimately, by cultivating an alliance of kelp forest restoration practitioners around the world, we can work together to ensure that kelp forests flourish in our planet's changing seas.

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Suggested citation for document: Eger, A. M., Layton, C., McHugh, T. A, Gleason, M., and Eddy, N. (2022). *Kelp Restoration Guidebook: Lessons Learned from Kelp Projects Around the World.* The Nature Conservancy, Arlington, VA, USA.

CHAPTER AUTHORS:
Suggested citation for chapters (example)—Eger, A. M. and Wernberg, T. (2022). Introduction. In *Kelp Restoration Guidebook: Lessons Learned from Kelp Projects Around the World*, (Eger, A. M., Layton, C., McHugh, T. A., Gleason, M., and Eddy, N.), pp 5-9. The Nature Conservancy, Sacramento, CA, USA.

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ISBN: 978-0-578-38123-7

CONTENTS

CHAPTER

1.0 INTRODUCTION

Authors: Aaron M. Eger and Thomas Wernberg

Synopsis: This chapter introduces kelp forests, their ecology, and the core themes of kelp forest restoration knowledge and practice. It also provides an overview of how this guidebook is laid out, how it may be used, and introduces the Kelp Forest Alliance, which is an online platform and network for researchers and practitioners to collaborate and share their kelp restoration knowledge.

1.1 STATE OF KELP RESTORATION AND GUIDEBOOK MOTIVATION

Kelp forest restoration or enhancement has occurred in some form since at least the 1700s in Japan, and more regularly since the 1950s elsewhere in the world. The field is now truly global, with projects in at least 16 countries and multiple languages as of 2021 (Eger et al., 2021b). Across these projects, the approaches to restoring kelp forests are truly varied, with many different methods tried and tested. Restoring kelp forests and the services they provide to coastal communities is a societal challenge, and a diversity of groups from universities, governments, local communities, non-governmental organizations (NGOs), and businesses have led projects.

Motivations for restoration differ among projects, but the desire to reinstate healthy productive kelp forests remains a common unifier across time and localities. Despite such a rich and potentially informative history, projects have often remained disconnected, and there has been little communication between practitioners from different regions. Many of the previous lessons learned about restoring kelp forests have gone unnoticed or remained unconsolidated in reports on the causes of decline and assessments of individual projects.

More recently, heightened awareness and concerns about the growing threats and observed declines in kelp forests have motivated several papers in the scientific literature on recommendations for kelp forest restoration (Layton et al., 2020b; Morris et al., 2020; Eger et al., 2021b). The primary audience of these papers has been the scientific community, and valuable information about how to conduct restoration has not been easily accessible to multiple sectors of society. Further, the field of kelp restoration has lagged that of other marine ecosystems, with fewer projects and smaller attempts at restoration (Saunders et al., 2020; Eger et al., 2021b; Feehan et al., 2021). As such, there is a compelling need to consolidate knowledge and establish guidelines for best practices for kelp forest restoration.

This guidebook, an initiative by The Nature Conservancy and the Kelp Forest Alliance (KFA) (kelpforestalliance.com), aims to distil lessons from past kelp restoration experiences around the world and to provide suggestions for how to manage and restore kelp forests. The work is informed by the authors and editors as well as by a global four-part series of workshops hosted in 2020. Because the field is rapidly evolving, the guidebook does not purport to contain all the answers but instead presents the best available information in an easily accessible format in hopes of advancing the field. We encourage users to be active participants of the KFA and to share their experiences and lessons learned at the KFA website.

In addition to the steps outlined in the following pages, we also provide a series of examples of **restoration in practice** that detail success stories, the challenges faced, and lessons learned in restoration.

1.1.1 Using the guidebook and target audience

This guidebook was developed for restoration project leaders and practitioners. The purpose of this guidebook is to assist users interested in restoring kelp forests by helping introduce and inform them of the various considerations, steps, and decisions required throughout the restoration process. Further, we provide detailed examples of **restoration in practice** (Fig. 1.1) to facilitate learning from previous restoration efforts. Users may consider each chapter individually depending on their needs or follow guidance from start to finish. Individual projects will always need to consider the local circumstances and ultimately ensure that the recommendations provided are appropriate for any specific project.

Further, a project database detailing ~200 recorded restoration projects is available at kelpforestalliance.com (Eger et al., 2021b). Users may find this helpful to see what successful projects look like and find commonalities with their own projects. We also encourage users to upload their own projects and so contribute to advancing kelp forest restoration efforts.

1 NORTHERN CALIFORNIA
Bull kelp

2 SYDNEY
Operation Crayweed

3 HAIDA GWAII
Gwaii Haanas

4 TASMANIA
Urchin control

5 KOREA
Seaforestation project

6 JAPAN
Hainan transplants

7 SOUTHERN CALIFORNIA
Palos Verdes

8 NORWAY
Quicklime

9 ITALY
Cystoseira

10 NORWAY
Green gravel

11 CHILE
Chimera trials

Figure 1.1 Map of kelp restoration projects from around the world

1.2 DIVERSITY AND DISTRIBUTION OF KELPS

Kelp forests in the orders Laminariales and Fucales are marine ecosystems characterized by the presence of large brown seaweeds that form habitat over the seafloor (Wernberg and Filbee-Dexter, 2019). They can grow very fast and rapidly produce a vast amount of biomass (Mann, 1973; Krumhansl and Scheibling, 2012) and create a three-dimensional structure that alters their surrounding physical environment (Reed and Foster, 1984; Eckman et al., 1989; Wernberg et al., 2005). Therefore, kelp forests provide habitat, shelter, and food to many species (Teagle et al., 2017; Miller et al., 2018). Kelp forests dominate along approximately one-third of the world's coastlines in polar/subpolar and temperate latitudes in both hemispheres (Krumhansl et al., 2016; Wernberg and Filbee-Dexter, 2019). Their diverse variety of habitat types delivers a broad range of valuable ecosystem services (Bennett et al., 2016; Blamey and Bolton, 2018; Eger et al., 2021a).

The orders Laminariales and Fucales encompass different species and functional groups across the globe (Fraser, 2012; Wernberg and Filbee-Dexter, 2019). Major genera within these groups include *Macrocystis* (North America, South America, Southern Australasia), *Nereocystis* (North America), *Laminaria* and *Saccharina* (Europe, Asia, and part of North America), *Ecklonia* (Asia, Southern Australasia, Southern Africa), *Lessonia* (South America, Southern Australasia), *Sargassum* (Pacific and Atlantic Ocean), *Cystoseira* (Mediterranean, Indian, and Pacific oceans), *Fucus* (Europe, Greenland, North America), and *Phyllospora* (Australia). Species in these orders comprise the three major functional groups: 1) Floating surface canopy forming species such as *Macrocystis, Nereocystis,* some *Sargassum* 2) Intertidal or subsurface stipitate kelps such as *Ecklonia, Laminaria,* and *Saccharina,* and 3) Low lying prostrate forms that occur in the subtidal (*Phyllospora,* some *Sargassum*) or intertidal (*Fucus, Cystoseira*). Species are either annual (e.g., *Nereocystis*) or perennial (e.g., *Macrocystis*) and can live up to 10 years or more (Fig. 1.2).

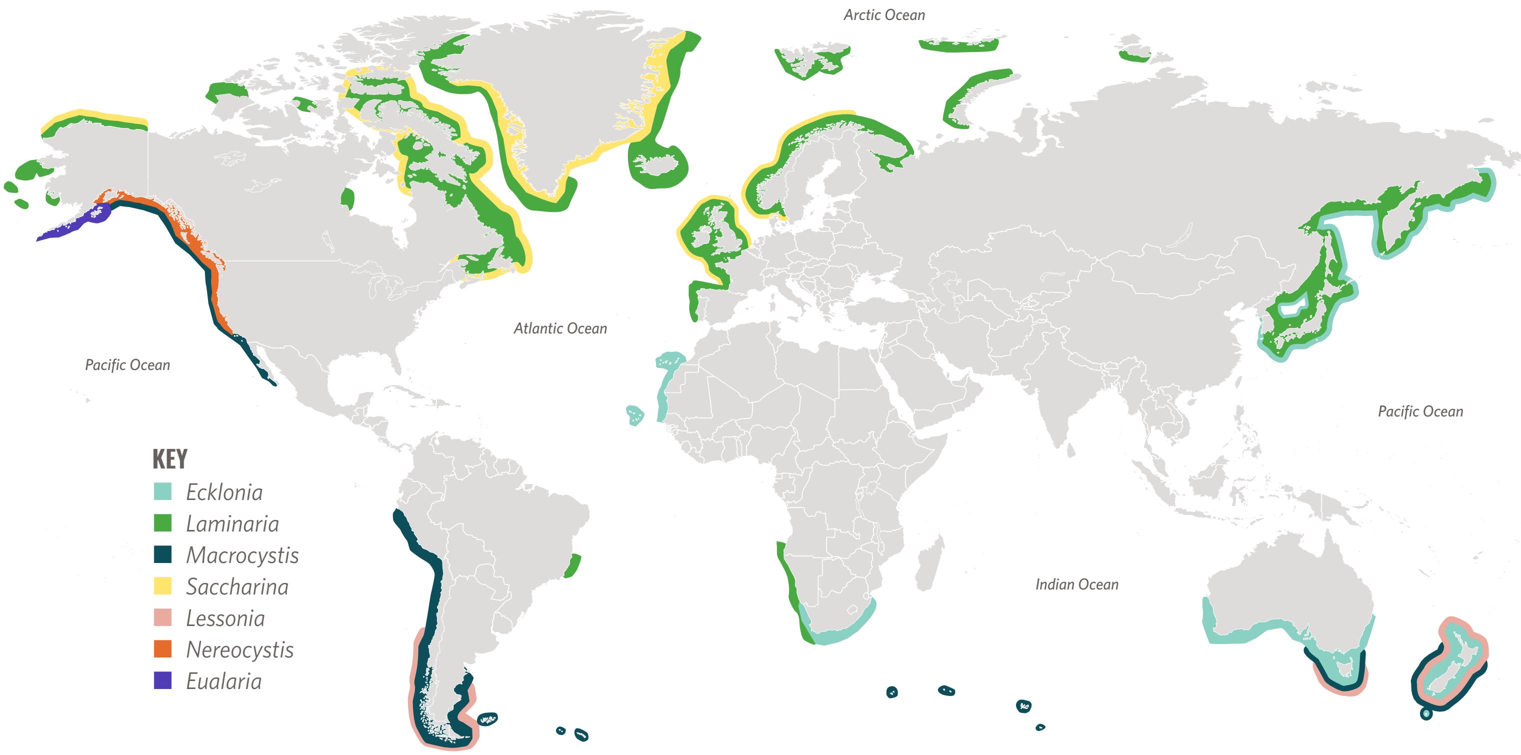

Figure 1.2 Global distribution of kelp forests by genera

1.3 DECLINE OF KELP FORESTS

Kelp forests have declined around the world and in some cases have nearly disappeared entirely from a region (Thibaut et al., 2005; Fujita, 2011; Johnson et al., 2011; Vasquez et al., 2014; Blamey and Bolton, 2018; Rogers-Bennett and Catton, 2019; Filbee-Dexter et al., 2020). The cause of these declines range from local stressors, such as pollution, to global impacts, particularly climate change (Wernberg et al., 2019). Early declines of kelp forests in the 1800s have been linked to population expansion of sea urchins, most often facilitated by the removal of urchin predators from the ecosystem (Roberts, 2007). Subsequent kelp population declines in the 20th century were driven by threats such as direct harvest of kelp or high levels of water pollution from urban areas (Wilson and North, 1983; Vogt and Schramm, 1991; Coleman et al., 2008; Connell et al., 2008).

These stressors are still relevant to contemporary kelp ecosystem management but are now also combined with climate change, a phenomenon that has multiple consequences for kelp forests (Smale, 2020). Increasing water temperatures and marine heatwaves have resulted in large contractions of kelp populations as they are pushed past their physiological limit (Arafeh-Dalmau et al., 2019; Kang, 2010; Tegner and Dayton, 1991; Wernberg et al., 2016). Warmer sea water temperatures have also facilitated the range expansion of herbivorous sea urchins, which can overgraze entire forests and create urchin barrens, a phenomenon identified in most countries that contain kelp across the world (Fujita, 2010; Filbee-Dexter and Scheibling, 2014; Ling et al., 2014). More recently, temperature-driven shifts in the ranges of herbivorous fishes are also causing similar declines in kelp forests near the warm edge of their distribution (Vergés et al., 2014; Vergés et al., 2016). Such extensive losses have dramatic ecological and economic impacts. For instance, kelp losses have caused the closure of lobster, abalone, sea urchin, and kelp fisheries in several regions around the globe (Steneck et al., 2013; Bajjouk et al., 2015; Rogers-Bennett and Catton, 2019).

1.4 THE VALUE OF KELP AND CASE FOR RESTORATION

Kelp forests are integral to temperate and arctic seascapes and are linked to people and sustainable use of the ocean (Fig. 1.3). A global analysis of *Laminaria, Ecklonia, Nereocystis, and Macrocystis* species found that they generate > 100 thousand USD per hectare per year and billions of dollars annually (Eger et al., 2021a). Because people can interact with kelp forests in so many ways, there are several reasons and motivations for wanting to restore and maintain healthy kelp forests. It is therefore important that the human element, outlined in **chapter 3**, is incorporated into any kelp forest restoration project plan. This incorporation can include working with communities to conduct restoration, ensuring that restoration meets the needs of the community, and integrating different knowledge sources into making decisions about kelp restoration.

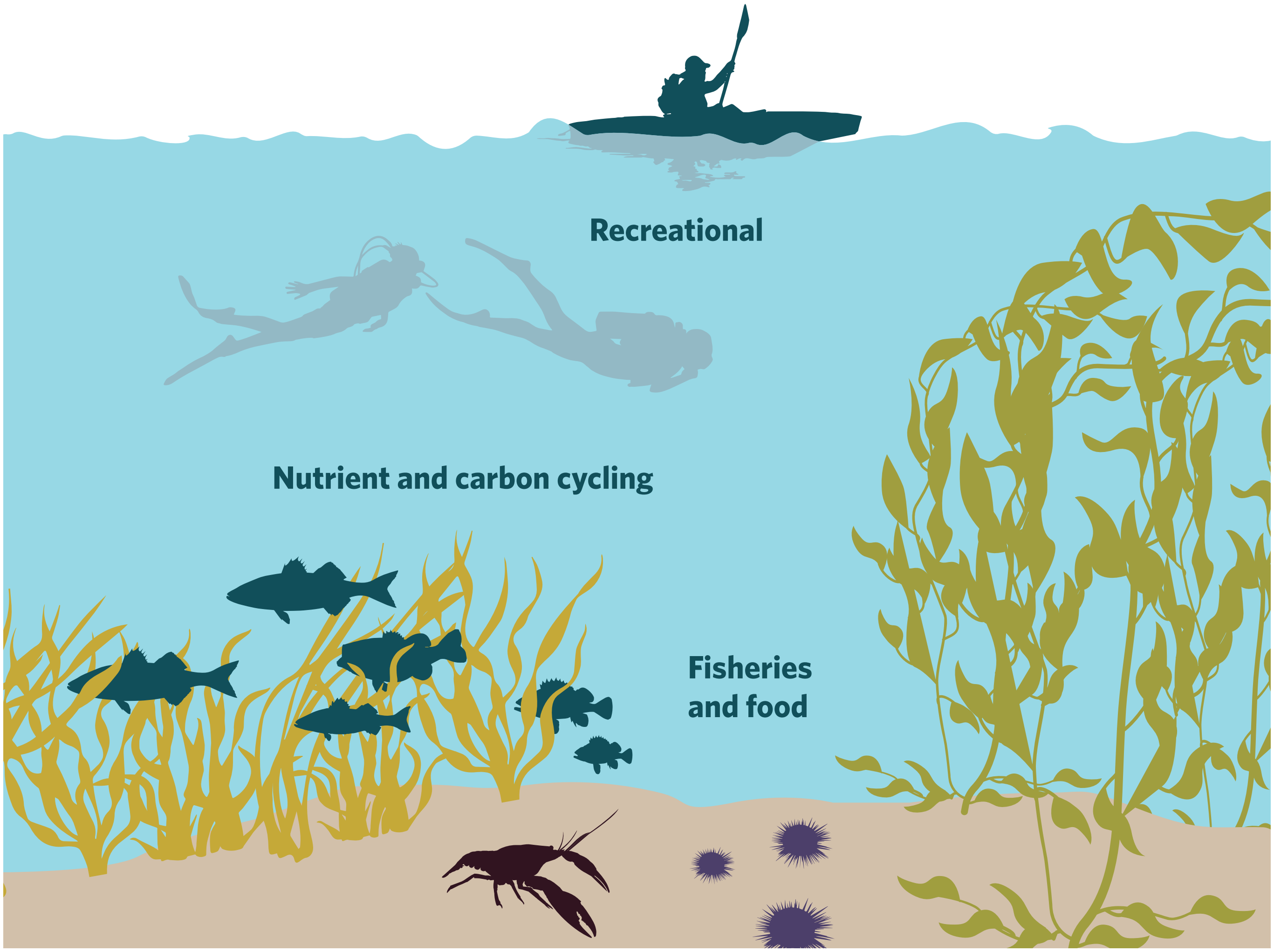

Figure 1.3 Ecosystem diagram of kelp forests, including services; illustration by Jon Ferland

Human motivations for kelp forest restoration ultimately shape the goals for restoration and may be driven by market or non-market forces. Market driven motivations include the extraction and use of kelp itself (Buschmann et al., 2014) or the organisms supported by kelp forests such as fish and invertebrate fisheries (Mayfield et al., 2012), biopharmaceutical products (Bokov et al., 2020), and the emerging markets for nutrient and carbon credits (Vanderklift et al., 2018). Nonmarket motivations are human cultural, recreational, and educational experiences within a kelp forest. The specific motivations for a restoration project will shape the metrics used to measure its success (**chapters 4 and 6**).

1.5 IDENTIFYING PATTERNS AND CAUSES OF KELP DECLINE

As predominantly temperate and polar/subpolar species, kelps grow best in cooler waters, and indeed temperature is often the best predictor of kelp distribution at large scales (Wilson et al., 2015; Assis et al., 2018; Martínez et al., 2018). Local factors that influence distribution include available nutrients and light for growth and photosynthesis, rocky substrate for attachment, wave exposure (high to low depending on the species), and the presence of grazers such as sea urchins or herbivorous fishes (Steneck et al., 2002; Schiel and Foster, 2015; Wernberg et al., 2019).

Persistent stressors pose perhaps the greatest challenges for kelp forest restoration. Stressors such as warm water events, sedimentation, and nutrient pollution must be mitigated before successful restoration can occur. Stressors like sedimentation and nutrient pollution are best managed from the source, and strict controls on water pollution are essential for kelp forest restoration (**chapter 2**, Sydney: Operation Crayweed). A combination of each or all these stressors can cause tipping points wherein kelp forests transform into urchin or turf barrens. Returning these barrens to kelp forests is difficult, as there is often a hysteresis effect wherein it is easier to shift to the barren state than to restore it back to the kelp state (i.e., lower levels of a stressor are required to recover than to tip the system; **Box 2.3**). As such, it is advised that, if possible, managers should look to prevent these shifts from occurring as opposed to reacting after the shift.

Because kelp forests can exhibit naturally high population fluctuations, it is important to determine whether an observed population decline is within the normal range of variation or indicative of an unusual event that requires intervention (Reed et al., 2015). Making this distinction is not an easy process and relies on detailed records of past kelp distribution and abundance. Such historical data also serves as a critical reference for establishing meaningful restoration targets and for determining whether restoration projects are successful in meeting their intended goals. The longer the time series of the historical data, the easier it is to determine if kelp restoration is needed (**chapter 2**).

Even in cases where restoration is desirable, it is still important to consider if it is wise. The local environmental conditions will inform whether restoration is feasible and therefore worthwhile to attempt. Feasibility often hinges on the initial cause of decline. Success is more likely to be achieved in situations where the cause can be mitigated (e.g., water pollution sedimentation) compared to those that have permanently shifted (e.g., above the species' temperature tolerance) (**chapters 2 and 7**).

1.6 USING THIS GUIDEBOOK AND CONDUCTING RESTORATION

Once you decide to get started with restoration, there are several considerations before you begin the restoration process (**chapter 2**). It is important to set clear goals and objectives that are informed by your motivations and objectives prior to starting any restoration project. Restoration is a social endeavour, and you must also consider how the social (**chapter 3**) *and* ecological elements of your ecosystem influence your project. These objectives will help inform your approach to restoration and ultimately inform whether you were successful in your attempt (**chapter 4**). Concurrently, you should establish where you would like to conduct restoration. Site selection can also be informed by both ecological and social circumstances (**chapter 3 and 4**). Sites may have special significance to the community and take precedence as a desired place to restore, or sites closer to existing kelp forests can provide a natural population source and enhance your restoration efforts (**chapter 4.4**).

Low-cost pilot projects can help you trial differing methods, test your assumptions, and evaluate sites for restoration before committing to large scale efforts (**chapter 4.5**). All projects must obtain the appropriate permits and consider the associated biosecurity risks (**chapter 4.2**). These steps are often lengthy and should be started early.

Naturally, you will need to consider how you are going to restore kelp to your area. It may be possible to restore kelp populations by simply removing the stressor (e.g., **chapter 5.2** herbivores) or adding habitat (**chapter 5.6**) with no further intervention. If not, you will need a source population of kelp to restore to the environment (seeds or adults, **chapter 5.3, appendix 1**). Once you have your kelp stock, you will then decide if you are going to work to transplant kelps (**chapter 5.5**), seed (**chapter 5.4**), and if you will combine these efforts with grazer management (**chapter 5.2**) or added habitat (**chapter 5.6**). The cause of decline, availability of parent populations (natural or sourced—**appendix 1**), the technical ability of the restorationists, and the financial budget of the project will determine the appropriate methodology for your project. We explore these requirements and considerations in further detail in **chapter 5**.

You will need to monitor your site prior, during, and after restoration activity. This process will determine if restoration is needed, the impacts of your actions, and if you achieved your project goals. While often overlooked, this is a necessary step in any restoration project, and you should plan for it before work begins. We cover different approaches to monitoring and evaluations in **chapter 6**.

Global oceans are rapidly changing, and it may no longer be possible or advisable to restore the same species or population to an area where it once was. If you expect long-term changes, such as increased water temperatures in your restoration site, it is worth considering how you might restore today while planning for the future. We discuss available and emerging approaches to genetic selection, stress tolerant kelp, and "future proofing" in **chapter 7**.

1.7 FURTHER READING

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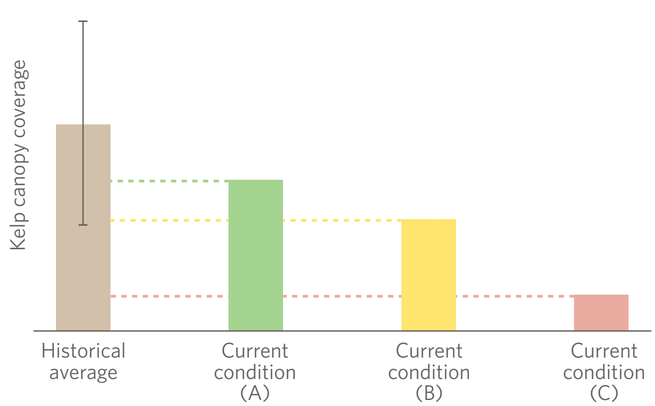
CHAPTER 2.0 EVALUATING THE NEED FOR KELP FOREST RESTORATION

Authors: Cayne Layton and Mary Gleason

Synopsis: This chapter concentrates on understanding whether restoration is needed and appropriate. It presents a set of core questions to help address this decision-making process, including: Have kelp forests declined in your area, and if so, why? Is restoration achievable, given the cause of kelp decline and the resources available? And what are the opportunities, risks, and challenges of restoration?

Whether to intervene is one of the first and most fundamental decisions when considering how to manage kelp forest loss and restoration. This decision-making process can be refined down to a relative comparison of the risks of action versus inaction. To that end, this process is best informed by several core questions, including the degree of concern about current and predicted kelp losses, the cause(s) of decline, and the resources and restoration approaches that may be available. Altogether, this knowledge provides the foundation of the early planning phases and helps focus resources on defining the problem at hand and the aims of the intervention (**chapter 4**). Since there is currently limited understanding of potential adverse consequences that may arise from kelp forest restoration actions, a precautionary approach to restoration should be adopted, especially where there may be risks to existing kelp forests or the services they provide (e.g., fisheries).

The knowledge and data necessary to inform restoration and answer the questions described below can sometimes be relatively sophisticated, hard-to-find, or even unknown. Ecological experiments and small-scale trials can help test assumptions and solidify any knowledge-gaps (Sydney: Operation Crayweed). It is also advisable that restorationists plan collaboratively with a variety of stakeholder partners, some of whom may be able assist with collecting, accessing, and interpreting technical data. Such organizations might include local environmental managers and regulators or universities and other research organizations. The success of restoration programs typically requires multi-disciplinary cross-sectoral involvement regardless (**chapter 3**), so forming collaborative partnerships at these early stages can be an excellent start to a project.



2.1 FIVE KEY QUESTIONS WHEN CONSIDERING RESTORATION

2.1.1 What are the status and trends of kelp abundance over time?

Kelp forests are famously dynamic ecosystems, with natural variations in kelp abundance differing across scales from tens of metres to kilometres, and combined with pronounced fluctuations within and across seasons, years, and longer-term cycles such as El Niño/La Niña (Steneck and Johnson, 2014; Krumhansl et al., 2016; Wernberg et al., 2019). For example, giant kelp (*Macrocystis pyrifera*) forests are often characterised by boom-and-bust cycles, such that some seemingly severe local losses may simply be natural and unexceptional variations (Schiel and Foster, 2015), while other losses can be indicators of a fundamental and alarming change in kelp forest health and abundance (Johnson et al., 2011). Understanding these fluctuations is therefore fundamental to understanding whether observed kelp losses are within or beyond the range of historical natural variability (Fig. 2.1) and thus whether a management intervention such as restoration is necessary (Johnson et al., 2016).

Figure 2.1 Evaluating kelp declines against natural population cycles. Hypothetical graphical depiction of current kelp canopy coverage (in three different scenarios A, B and C) compared to a historical average kelp coverage to guide potential response actions. In this example, standard deviation of historical average is used to reflect the natural range of variability in historical kelp coverage to assess level of concern about current condition; Scenario A is within natural range of variability, Scenario B is just falling below, and Scenario C is well below historical average.

One contemporary consideration is that historical trends of kelp forest abundance and variability may not be an accurate predictor of future kelp forest health, due to our rapidly changing climate and oceans. In these instances, a precautionary approach to kelp management may be advisable, with any interventions weighed against the predicted future conditions and the risks of inaction and kelp forest loss.

2.1.2 What is the spatial and temporal scale of the problem (i.e., what area of kelp has been lost and over what amount of time)?

While this question is interrelated to the status and trends of a kelp forest over time, explicitly framing the problem in terms of scale can help clarify some of the more immediate and on-the-ground considerations for restoration actions. These might include identifying potential sites and methods that are most appropriate, the likelihood of success, and the urgency of any interventions. As such, this question can be useful when developing a plan for intervention and addressing the often-challenging aim of scaling restoration impact to the scale of kelp loss. Understanding the challenges and opportunities of scale can also help when addressing resource considerations, such as costs, permitting, and necessary levels of logistic support.

Scale is also important when considering the ecology of the system, including spatial and temporal variation of environmental drivers (i.e., nutrients, temperature, local oceanography), stressors (see **chapter 2.1.3**), and connectivity. Connectivity at various scales within your system can have both positive (e.g., nearby sources of kelp propagules) and negative (e.g., nearby sources of urchin recruitment) effects on restoration (Layton et al., 2020a; Vanderklift et al., 2020). Assessing these aspects of scale can help develop a clear problem statement and identify the right aims and objectives for the intervention.

2.1.3 What is the primary cause(s) of kelp loss in your region? Which are manageable, and which are not?

For any restoration intervention to be effective at scale, the primary cause of kelp decline must first be understood and overcome. Drivers of kelp forest loss (Fig. 2.2) are diverse and encompass a variety of physical and biological factors, such as overgrazing and overharvesting, pollution, coastal development, and ocean warming and other climate-related stressors, Fig 2.3, (Steneck and Johnson, 2014; Krumhansl et al., 2016; Wernberg et al., 2019). Moreover, these factors can act in isolation or synergistically to drive kelp decline (Rogers-Bennett and Catton, 2019) and can themselves vary at different spatial and temporal scales.

Some stressors, such as overgrazing/overharvesting, water pollution, or sedimentation, may be manageable at local and/or regional scales (Sydney: Operation Crayweed). Where applicable, ameliorating such stressors should

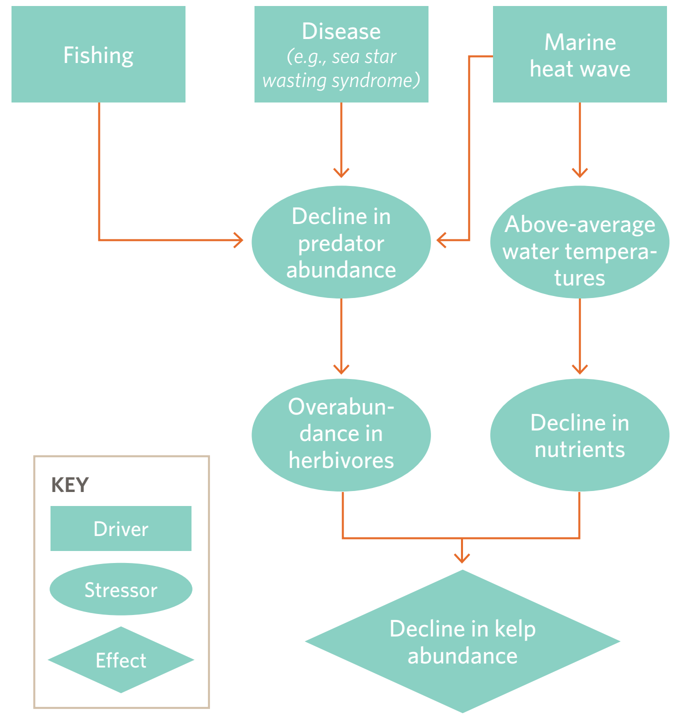


Figure 2.2 Multiple drivers and stressors of kelp forest loss

always be a critical early focus of any restoration initiative. Overcoming these stressors may also require regulatory/policy intervention and multi-jurisdictional support, and management actions should therefore be considered in collaboration with responsible local agencies.

On the other hand, it may not be possible to overcome or remove large-scale drivers of kelp loss (e.g., climate-change), at least at local scales or over short to medium timeframes. Nonetheless, these still need to be considered during the decision-making processes. Such circumstances may also motivate some form of 'future-proof' restoration intervention (see **chapter 7**). Moreover, some factors might only be manageable at specific spatial and temporal scales, and that too can influence decision-making (e.g., seasonality of restoration) and overall chances of restoration success.

Ultimately, while some drivers of kelp loss can be alleviated or overcome, others cannot, and there will be instances where kelp restoration at the scale necessary to achieve the project goals is not advisable or possible. In these cases, tactical or small-scale restoration interventions may still be feasible but likely ongoing and costly. These circumstances may also provide impetus and support for resources instead to be allocated to protecting and/or improving the resilience of existing kelp populations (**see Box 2.1**). Nonetheless, there may be instances in which small-scale restoration is desirable and is the goal, for example to protect local habitat for a threatened species or particularly valuable fisheries stock.

Box 2.1 Preventative or pro-active restoration

Restoration is not just a tool to rehabilitate completely degraded locations where kelp forests have been entirely lost. Indeed, kelp forest restoration may be easiest and most successful at sites that have experienced only minor kelp losses, and where it can take advantage of positive feedbacks within the kelp forest ecosystem (Layton et al., 2019; Eger et al., 2020a). As such, restoration-type activities (e.g., urchin removal, kelp seeding or planting) might also be considered as a tool to boost and maintain the health and resilience of existing kelp forests that have only experienced minor disruption. In these cases, restoration can be considered as a proactive tool to manage kelp forests and prevent widespread losses. However, it is imperative that any such restoration efforts employ a precautionary approach and ensure that interventions pose no risk to the existing kelp forest and its inhabitants.

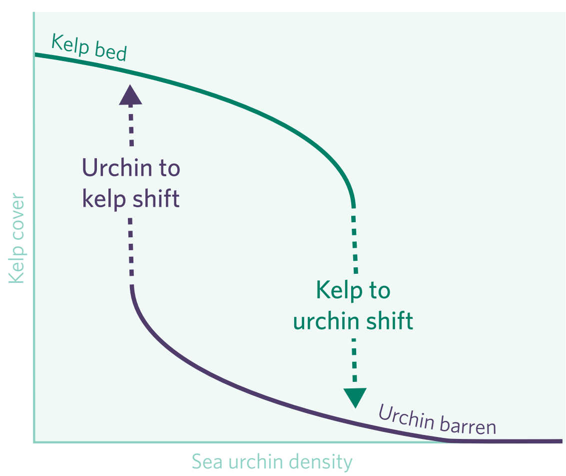


Figure 2.3 Hysteresis and phase shift. The process of hysteresis as it relates to kelp ecosystems (after Filbee-Dexter et al. 2014). Note that the sea urchin density at which a system shifts from kelp to barrens is greater than the density required to create the opposite shift.

2.1.4 Is there hysteresis in the system? Is the system at risk of 'tipping' into an alternative and less desirable state (or has it already tipped)?

Even once the causes(s) of kelp forest loss have abated or been removed, there may be circumstances where kelp establishment and recovery are impeded due to **hysteresis** in the system (Fig. 2.3). Hysteresis is when both environmental factors and the 'history' of the system determine its current state, and it is often described as a shift from one ecosystem state (e.g., a kelp forest) to another state (e.g., an urchin barren) (Steneck and Johnson, 2014; Filbee-Dexter and Wernberg, 2018). Fundamentally, this means that once a kelp forest system has 'tipped' into a degraded state (e.g., turf algae or an urchin barren), it can be far more difficult to reverse than it was to tip it in the first place. Hysteresis can be hard to detect, but it is important to consider, especially where urchins or turf algae are pervasive problems and barriers to kelp restoration.

As an example, the transition from kelp forest to urchin barrens in many systems (e.g., Australia, Canada, New Zealand, Norway, USA) has been shown to involve hysteresis (Ling et al., 2015), such that the number of urchins on a barren that is needed for natural kelp recovery to occur is often an order of magnitude lower than what was needed for the barren to be created in the first place (Tasmania: Urchin control). So, if it takes urchins numbers to build up to 10 urchins/m^2 to tip a healthy kelp forest into an urchin barren, it could typically require achieving an urchin density as low as 1 urchin/m^2 to reverse the effect and achieve kelp recovery. This obviously has very serious applications in terms of urchin harvesting and culling and replanting efforts. Similar responses have also been observed in terms of turf algae cover and kelp recovery (Filbee-Dexter and Wernberg, 2018).

These situations arise due to ecosystem feedbacks that act to reinforce one state over the other, and so where kelp has been lost and hysteresis is present, there is a very low likelihood of natural kelp recovery. In these cases, while external interventions such as restoration can help to move the system back towards the desirable state, they often require significant resources and sustained effort (e.g., continued large-scale urchin removals) to tip the system back to a kelp forested state.

Box 2.3 Positive feedbacks

While ecosystem feedbacks can reinforce and maintain degraded ecosystem states such as urchin barrens, they can also be harnessed to optimise kelp restoration efforts and maintain resilience of kelp forests to prevent such shifts in the first place (see, Halpern et al., 2007; Layton et al., 2019; Eger et al., 2020a).

Another benefit of understanding hysteresis and tipping points is that they can help illustrate the risk or vulnerability of a system tipping from one state to the other. This can then inform management decisions based on risks versus consequences of action/inaction. For example, if a kelp forest is close to the tipping point of shifting to an urchin barren, there is a greater sense of urgency for a management intervention relative to a system that has already shifted and is a stable urchin barren. Understanding habitat

Box 2.5 Structured decision making

Structured decision making provides a framework to combine and assess what information may trigger a decision to restore kelp forests, including key stakeholders, participants, and the specific problem that needs to be addressed (such as the status of kelp and the nature of the stressors). From there, objectives can be identified, as well as the types of approaches and alternatives that are available to meet the objectives. These alternatives may sit along a spectrum of response strategies, the choice of which might depend on the status of kelp (relative to historic variability), the manage-ability of the stressors, and the resources available (for further reading see Gleason et al. 2021).

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

vulnerability also demonstrates the potential for **proactive restoration (Box 2.1)**, with the aim to boost ecosystem resilience and lessen the chances of shifting from the kelp forest state to another less desirable state.

2.1.5 What is possible with the available resources and what are the potential resource constraints?

Restoration in marine environments is typically resource intensive, and the subtidal and/or exposed nature of most kelp forests can make their restoration even more difficult and expensive than that of other marine habitats (e.g., mangroves or saltmarshes) (Eger et al., 2020b; Stewart-Sinclair et al., 2021). Resources are not only needed to initiate (**chapter 4**), implement (**chapter 5**), and monitor (**chapter 6**) restoration interventions, but they may also be required over the longer term to manage persistent stress-ors (e.g., grazer abundance) and thus ensure restoration success. Fundamentally, a clear understanding of financial constraints and opportunities will help guide decisions on the scale, impact, and methods for interventions.

The assessment of available and potential resources can also aid long-term project development (Korea: Seaforestation project), especially when considering project support beyond the initial phases/funding. Are ongoing resources needed for maintenance, and if so, how will that be secured? Is the funding base diversified among participants and stakeholders? Is funding for monitoring available, and if so, for how long? Depending on the nature of the intervention and jurisdiction, permitting may be time (and resource) intensive, while regulatory frameworks may mandate stakeholder engagement or periods of public comment and consultation. Indeed, 'cultural capital' and community support are equally important resources to consider during these early planning stages (**chapter 3**).

Though kelp forest (and marine restoration in general) can be costly upfront, it is important to also consider the benefits and return-on-investment of restoration actions. In some cases, despite the high costs of restoration, the environmental and economic benefits can be equally (or even more) significant (Stewart-Sinclair et al., 2021). Describing intervention costs in terms of 'investment' and the benefits in terms of 'returns' can help clarify the value-proposition of restoration and encourage further investment and support for a 'restoration economy' (BenDor et al., 2015).

Overall, while this question is relatively straightforward, it can help ensure that resources are appropriately utilised at the scale they are intended and where they can have the most impact, and that any potential barriers and impediments are explicitly considered. Fundamentally, it is important to know what needs to be achieved at each stage (e.g., data gathering, permitting, implementation), and what level of resourcing is required and available for each necessary component.

2.2 STRUCTURED DECISION-MAKING AND DEFINING PROBLEMS AND GOALS

The best-available knowledge from the above questions can then be used to define the specific problem at hand and inform a final and structured decision-making process (e.g., see Box 3.5; (Gleason et al., 2021). The answers to the above questions can also help during the early-project stage to prioritise resources and identify the best management responses given the local factors and desired outcomes. Altogether, this information can be used as the foundation to decide whether to implement restoration. Indeed, there will be circumstances where restoration is not possible or advisable, or at best is limited to the local scale.

Structured decision making can also promote transparency and shared understanding among participant groups of the problem being addressed and the intervention's objectives (**chapter 3**). A clearly defined problem statement is an invaluable early step in this decision-making process.

Generally, the problem needs to be stated in a form that is broad enough to address assumptions while clarifying the core issue and any perceived constraints, identifying potential unintended consequences, and generating solutions. Often, you can then express the statement as a decision to select a course of action that addresses a specific requirement or problem. The problem statement should therefore propose an *action* (**chapter 5**), which is predicted to lead to *outcomes* (**chapter 6**) that fulfil the desired *objectives* (**chapter 4**).

2.3 FURTHER READING

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CHAPTER

3.0 THE HUMAN ELEMENTS: COMMUNITIES AND PARTNERS IN KELP RESTORATION

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Synopsis: This chapter serves as a guide to integrating social, cultural, and economic aspects into what are often ecologically focused restoration initiatives. The core themes discussed include: (1) the importance of engaging with communities and partners to collaborate, co-develop initiatives, and make decisions; (2) ways to identify the communities and partners needed in restoration initiatives; (3) specific avenues for engaging and communicating with diverse communities and interests.

Socially responsible restoration initiatives must consider the role of ocean users and local communities in deciding if, when, where, and how to conduct kelp forest restoration (Elias et al., 2021). Coastal communities are deeply dependent on the health of coastal marine environments for ecosystem services such as food security, economic benefits, cultural practices and more. Ocean users within these communities are often the first to detect changes and declines in the health of an ecosystem. Further, they are the most affected by changes in the local marine environment and can be critical to the successful restoration of degraded ecosystems and the maintenance of healthy ones.

Co-developing projects and exchanging knowledge about ecosystem conditions and changes over time with the community can help determine if, and where, you need to conduct restoration, what your short- and long-term methods and targets for restoration are, and if you effectively succeed in restoration. While working with communities and making these considerations is conceptually straightforward, it requires considerable time and resources. You must therefore make this investment right from the outset to maximize meaningful engagement and collaboration throughout the initiative.

3.1 WHY: THE IMPORTANCE OF ENGAGING WITH COMMUNITIES AND PARTNERS

Every community is unique, dynamic, and diverse in customs, practices, and values. Developing an understanding of the affected communities, their motivations, and context for decision-making is therefore a critical early step for you to take. Indigenous rights holders, coastal residents, ocean users, and other interest groups are some key examples of the communities of people and partners potentially involved in the process to conduct restoration.

Community members often possess diverse place- and expertise-based traditional, local, and scientific knowledge about the socio-ecological context of local kelp forests that external experts may be unfamiliar with. At the same time, external experts can bring knowledge and capacity from broader experiences that can augment community-based knowledge. Collaboration between communities and other partners interested in restoration presents opportunities to respectfully weave together multiple ways of knowing while broadening perspectives to build a more holistic understanding of the restoration context (Northern California: Bull kelp & Haida Gwaii: Gwaii Haanas).

Engagement and participation approaches that create space for active listening and meaningful dialogue can provide reciprocal benefits for communities and restoration initiatives. For example, by actively engaging with community members, you may be able to identify community capacity that can be factored into implementation plans, including the use of existing capacity and the building of future capacity as part of an initiative. Learning, sharing, and actively working on restoration can also enhance the sense of community surrounding coastal stewardship, which can in turn improve overall community well-being and contribute to better restoration outcomes from an ecological standpoint (DeAngelis et al., 2020).

Academic, government, and/or non-government organizations, working internally or externally with communities and partners, can provide a wide range of scientific, regulatory, logistical, and management expertise to restoration initiatives, along with additional funding. These skill sets, insights, and funding can help shape and provide resources to meet the needs of the community. In some cases, however, it may be more appropriate for the community to guide the decision-making process and/or lead implementation of restoration work. The collaboration between communities and specific experts can facilitate important capacity-building and knowledge-sharing with benefits that ripple through other initiatives and places to inform and improve future restoration efforts.

Building a collective understanding of the local socio-ecological context can help you articulate the rationale and motivation for each initiative and guide co-development of goals and objectives (**Chapter 4.1**) as well as future communications, outreach, and education efforts. Foundational questions such as the following can help ensure that community values and perspectives are reflected in the co-development process:

- Why are kelp forests important to you?
- What kelp forest changes have you noticed here over the years and decades?
- What do you think is causing these changes?
- How have these changes affected you?
- Do you think kelp restoration is needed? Why or why not?
- What would you want to see from restoration initiatives?
- What questions would you want answered?
- What issues would you want addressed?
- How do you see yourself and others in your community engaged in restoration initiatives?
- What benefits, opportunities, and challenges do you think restoration initiatives will bring to you and others in your community?

As communities become involved in the conversations and actions around restoration, they can develop new and closer relationships with the places where they live. Restoration initiatives present novel opportunities to collaboratively address broad- and fine-scale social-ecological issues specific to each place and can advance the resolution and impact of restoration work regionally and globally. Further, collaboration among a broad range of rights and interest holders can address implementing the UN Declaration on the Rights of Indigenous Peoples (UNDRIP), heighten transparency and accountability, incorporate diverse perspectives, and formally recognize the many voices that contribute to any initiative (Wong et al., 2020; Lee et al., 2021).

Regardless of who is leading or co-leading the initiative, taking the time and energy to understand the many perspectives involved allows you to consider, discuss, and assess multiple, diverse restoration approaches that can address interconnected ecological and social-cultural objectives. Restoration that explicitly recognizes the importance of multiple pathways to knowing and doing makes space for ongoing learning and capacity-building among coastal communities and partners (Fig. 3.1). Diverse collaborations can therefore lead to synergistic effects that contribute to success and longer-term resilience of restoration initiatives through local stewardship that benefits people and place beyond the life of any individual initiative (Vergés et al., 2020; Lee et al., 2021).

Figure 3.1 Different ways of knowing and different ways of knowledge-sharing

3.2 WHO: IDENTIFYING KEY COMMUNITIES, DECISION-MAKERS, AND PARTNERS

Based on the unique context of each restoration initiative, a broader or narrower range of communities and interest groups will need to be engaged in co-development and decision making. In decision-making contexts, collaborative work must be particularly cognizant of fundamental differences between rightsholders such as Indigenous Peoples, interest holders such as conservation groups, and stakeholders such as industry associations. In some cases, co-management arrangements with, and/or approvals by, Indigenous rights and title holders will be necessary to recognize their governance authorities over stewardship of traditional territories (Haida Gwaii: Gwaii Haanas). These arrangements can help ensure respectful inclusion in decision-making and facilitate appropriate ownership and access to information related to the initiative.

Decision-making processes will therefore need to be adaptable to the specific context of each place. For example, using a semi-formal or formal structured decision-making approach can improve transparency and ensure that decisions and actions are more likely to meet specified restoration objectives (Gleason et al., 2021). Although no single approach will be applicable across all initiatives, the foundations must build on any existing rights and titleholder laws, customs, and practices. All partners in the restoration initiative must have a genuine desire to work together and agree at the outset on a process for how decision-making will take place.

It is important for you to understand both the decision-making context and the various interests in relation to local kelp condition and trends, what/who is prompting action, and what/who is impacted. This understanding will help identify the range of values and concerns, and therefore the objectives, that stake holders may have in restoration. Some exploratory questions to help identify communities and partners in co-developing restoration initiatives are (Gleason et al., 2021):

- What is/are the issues, and how do different communities and interests see the issue(s)?
- Who and what are the rights, interests, and stakeholders related to the issue(s)?
- What are the concerns and values that need to be considered?
- Who defines the issues and values, and is there adequate representation by those who will influence and be impacted?
- Who has the authority to make what decisions, and how are additional interests incorporated into the decision-making process?
- How can an interdisciplinary approach (governance, ecology, culture, society, traditional knowledge, local knowledge, scientific knowledge, etc.) enrich the initiative from individual or collective perspectives?
- What data, information, and knowledge systems are available to scope the issue, and who has access to this information?
- What approvals and/or permits are required for planning and implementation, and from which communities and organizations?

Taking the time to understand who is concerned with kelp forest loss, who is being impacted, and who can influence the outcome will help determine who needs to be involved. Further discussions can then assist in collectively defining what capacity and/or role different parts of the communities and partners will play in restoration, and how they will be engaged. Involvement could be as project leads, co-leads, experts, active participants, funders, background supporters, and more.

Awareness and consent from all participants in their level of collaboration and how their information will be used (e.g., publications, policy/regulatory change, outreach), will be key to building strong relationships and trust. Importantly, developing a human connection by taking the time to get to know one another and genuinely understand each other's perspectives is a critical and worthwhile element that will foster unique and long-lasting relationships.

3.3 HOW: METHODS FOR ENGAGING WITH DIVERSE COMMUNITIES AND PARTNERS

Providing opportunities for learning and sharing knowledge and perspectives about restoration in the coastal communities where restoration takes place is a highly effective method to engage with diverse communities and partners. In the initial stages, different avenues and platforms for engagement can help reach a broad range of people and interests. Public forums, small group 'coffee table' meetings, and one-on-one conversations are all potential ways to initiate open-ended dialogue around foundational questions such as those in **chapter 3.1**. Each community engagement approach will have various pros and cons. For example, well-advertised public forums allow open dialogue across diverse perspectives that can establish collective reasons to address kelp restoration and provide transparency. However, the 'loudest voices' can sometimes overwhelm public forums; therefore, one-on-one conversations or small group meetings provide alternative venues for all voices to be heard. Everyday conversations where knowledge is informally shared can be some of the most rewarding avenues to lay groundwork for restoration by drawing from personal experiences and interests.

As you document knowledge and data from different ocean user and interest groups in informal, semi-structured, or structured ways, it is important to always follow appropriate research protocols (e.g., community-based research permits, human research ethics permits, university mandated paperwork). Regardless of the means of collecting data, it is important to acknowledge and respect your knowledge sources when disseminating, sharing, interpreting, or publishing the information in order to ensure respectful communications and honour the value of the information shared. In many instances, it will be essential to provide partners with opportunities to review communications materials and activities, including publications, before you distribute or implement them.

Using multiple avenues of communication in outreach and education will encourage more equitable engagement and participation. (Table 3.1) While scientific publications add to global restoration literature, a greater diversity of communications approaches is necessary to incorporate other ways of understanding the world, as well as to reach different target audiences. Avenues include websites, speaker series, videos, short films, newspaper articles, social media, media campaigns, and interactive cultural and scientific activities (e.g., art meets science, interpretative field outings, workshops, school programs). For community-based restoration projects in particular, including local experts and leaders can be especially important (Sydney: Operation Crayweed), and some of the many ways that partners and community members can actively contribute to restoration initiatives are:

Table 3.1 Avenue of Outreach and Education

	Use Case
Websites	Provide a centralized location to collate information (e.g., partners, goals, objectives, funders, milestones, publications, reports), advertise upcoming events (e.g., speakers series, community events), and invite feedback (e.g., contacts, post discussion forums).
Videos and short films	Attract a broad suite of users as they are available on demand
News and social media	Can relay real-time or near real-time information and maintain regular engagement
Hands-on activities	Can serve to strengthen community support and foster longer-term stewardship (e.g., citizen/community science and volunteer opportunities to participate in active restoration through seeding, diving, etc.; crowdfunding to achieve fundraising goals; etc.)
Cultural activities	Are linked to specific sites and can encompass a broader set of values

Engagement and communication strategies and campaigns are ideally developed and implemented in collaboration with all project partners throughout the restoration initiative. Updates on progress, outcomes, and findings can help maintain community interest and foster existing and new collaborations. In turn, these collaborations can extend the often short timelines of individual initiatives into longer-term, community-based stewardship. Importantly, progress updates also provide opportunities for insights to inform adaptive and iterative restoration in a way that is responsive to dynamic social and ecological conditions.

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CHAPTER

4.0 GETTING STARTED WITH RESTORATION

Authors: Tristin Anoush McHugh, James Ray, Mary Gleason, Aaron M. Eger, Norah Eddy

Synopsis: This chapter details the first actionable steps to restore kelp forest habitat. It starts by focusing on planning and assessing feasibility for restoration, including identifying objectives and appropriate methods, permitting and biosecurity, and site selection; it then outlines project monitoring and evaluating measures of success, along with a strategy (or strategies) for scaling-up restoration pilot projects.

There are multiple ways of beginning a kelp forest restoration project. Each project will vary depending on the individuals involved, their values, the resources available, the biological composition of the ecosystem, and the desired project outcomes. However, there is a general theme that previous, successful restoration projects have followed, and we designed this chapter, "Getting Started," to assist in identifying key considerations in the initial stages of the restoration process.

4.1 OBJECTIVES

Setting clear objectives for the restoration intervention is a critical early step in planning and deciding upon restoration (this is also critical for project monitoring and evaluation, **chapter 6**). Identifying why you desire kelp forest restoration is essential for setting project objectives. As described in **chapter 3,** "The Human Element," there can be a diversity of values and rationales for restoration among different members of a community. Fundamentally, you can distil your project objectives down to the questions, "What do all participant groups value about kelp forests, and/or what do they want to protect/restore and why?"

The answers to these questions are, by nature, multi-faceted and may encompass values related to environmental services (e.g., biodiversity, carbon/nutrient cycling), economics (e.g., fisheries and harvesting), social/health (e.g., recreational spaces, or mental and cultural wellbeing), or regulatory obligations (e.g., offsetting).

4.1.1 Fundamental and Means Objectives

Clearly defining the objectives of a restoration project will help determine the methodologies used and the ultimate lifespan of the project. You should ensure that you design the planned interventions to meet the desired objectives before starting a new project. These objectives are distinguished in two forms: fundamental and means (Conroy and Peterson, 2013; Gleason et al., 2021).

Fundamental objectives are the important and crucial reasons that we care about a decision. These are often the desirable outcome (e.g., biodiversity enhancement, socioeconomic revival, area restored, legal framework) of a project and the reason we initially care about restoration. For example, a fundamental objective could be total area of kelp canopy restored. Decisionmakers (I.e., project managers and/or resource managers) typically set fundamental objectives and aim to set realistic parameters and carefully craft achievable outcomes that are manageable.

Means objectives are not necessarily the desired outcome in themselves, but instead, they are the matters and conditions we care about because they help achieve the fundamental objectives. They are the "how" (manner, methods, logistics) for achieving fundamental objectives. For example, if the fundamental objective is to recover 10 hectares of kelp in a location, the means objective might be to reduce grazing pressure of urchins to less than two urchins per square meter. Means objectives help build the hypotheses by addressing the "how," specifically underpinning and conceptualizing the mechanisms to which a successful restoration project can ensue.

Both the fundamental and means objectives should include a unit of measure (e.g., area of kelp to restore/protected, number of indicator species present and at particular densities, reduction of herbivore pressure to threshold density), direction for units (e.g., increase/decrease minimize/maximize), or a benchmark goal (e.g., hectares of kelp restored, abalone fishery reopened).

Distinctively, fundamental objectives for kelp restoration typically focus on three main facets: 1) maintaining remnant kelp, subsequent associated species, and biological/genetic diversity, 2) restoring kelp and/or species to an established benchmark, 3) rebuilding kelp forest services such as fishery species for harvest, carbon sequestration, or wave attenuation.

Means objectives then prioritize the logistical considerations necessary to reach the fundamental objectives such as identifying appropriate tools to protect and enhance remnant kelp beds via grazer reduction, regulating harvest, mapping, and monitoring and/or adding kelp to the ecosystem (**chapter 5**).

With a clear definition of the fundamental and means objectives, the next step is to understand the potential interventions available to achieve objectives (**chapter 5**). Further, developing a conceptual model and a hypothesis that link the problem statement (**chapter 2.2**) with the objectives is essential and will help identify the alternative interventions necessary to accomplish fundamental and means objectives. While working through this process, there may be objectives of competing interest, or ones that may not be attainable for any number of logistical, ecological, legal, or financial reasons. Charting a course of action with consideration to sensible and appropriate solutions is crucial to ensuring the achievement and ultimately the success of the project. For more on using fundamental and means objectives in kelp restoration planning, "A Structured Approach for Kelp Restoration and Management Decisions in California" (Gleason et al., 2021), is a helpful document.

Defining the problem and restoration objectives is often an iterative process, and as you collect new information, you may refine and evolve the problem statement. The remainder of this chapter highlights several specific topic areas that you should consider during the planning process prior to conducting restoration.

It is increasingly accepted that a reference ecosystem may instead be a 'composite vision' synthesised from several locations, values, objectives, and historical and predictive records (McDonald et al., 2016). Regardless of whether you use an existing ecosystem or a 'composite vision' as a reference, the goals you set for restoration should reflect the values and objectives established at the outset of the project as well as those of the local community. This composite vision will be linked to the fundamental question of what users want out of a system in the future. Goal setting can be one of the most challenging parts of beginning a restoration process.

Box 4.1 Reference Ecosystems

Historically, reference ecosystems represent the unperturbed, natural, or historical baseline of the ecosystem. Ecosystem function, and the biomass and biodiversity within these ecosystems, often inform the desired goals for restoration. However, in many instances the human perception of the reference ecosystem may be skewed to a recent point in time, to which the individual has personally interacted with the environment and, therefore, that state is deemed to be the baseline (a concept known as 'shifting baselines'). In other circumstances, identifying reference ecosystems may no longer be possible, for example, where ecosystem loss has occurred prior to collection of adequate data (e.g., many shellfish reefs) (McAfee et al., 2020). As a result, these historical baselines may no longer be sensible targets for restoration when current or predicted environmental conditions (e.g., water temperature) are incompatible with known historical conditions or kelp forest community (Perring et al., 2015; Wood et al., 2019), also see **chapter 7.**

4.2 BIOSECURITY AND PERMITTING

To make any modifications to the marine environment, appropriate permits and permissions are required. Permitting is a mechanism for the relevant ocean managers to evaluate the potential impacts of a restoration project on natural, cultural, and economic resources. It also ensures compatibility with other resource use designations and regulations (e.g., marine protected areas, designated commercial fishing zones, culturally significant areas). These approvals can range from government permits to manipulate the environment to community approval to work in a particular area.

In most instances, restoration permitting and approval is a lengthy process ranging from weeks to months to years, and you should start as early as possible prior to project initiation. You can usually find information on necessary approvals by contacting your local environmental management office as well as bodies responsible for governing the marine environment (municipal, traditional landowner, state, federal). In many cases, the groups involved in issuing these permissions will have a vested interested in the project's success, and you can incorporate their input early with proper consultation. Once you establish a working relationship, additional permissions may be granted at a faster rate.

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4.2.1 Starting the permitting process

The permitting process begins by starting a dialogue with the appropriate groups and/or agencies, such as municipal, traditional owners, state, and federal agencies (**chapter 3**). These jurisdictions are not exclusive, and it is important to consult with all applicable levels of government and obtain the necessary permissions. The previously described project objectives may assist in determining the appropriate regulatory pathway to get the project underway. Because early consultation starts a dialogue between the project manager and the relevant authorities, there may be opportunities to foster new approaches to kelp forest restoration, especially in rapidly changing social and environmental contexts. Further, working directly with agency decision-makers or other relevant permitting authorities will identify likely project bottlenecks and allow you to incorporate them into project timelines. Investing effort into navigating the regulatory landscape is therefore essential to successful restoration and should begin early in the planning process.

Permitting is often a complicated task with multiple considerations. Acquiring permits may require detailed, time-intensive project plans for approval, and they may also have an application fee, both elements that should be taken into consideration in the planning process. In many cases, the loss of kelp in a region is novel and associated with anomalous ecological and oceanographic conditions (e.g., invasive sea urchins, warm water temperatures). Similarly, kelp restoration is a nascent and evolving practice. As such, high degrees of uncertainty around potential risks of interventions can often constrain access to permits. This process can be particularly difficult when you are seeking to apply novel solutions to addressing the complex and dynamic ecological challenges associated with kelp restoration.

This uncertainty emphasizes the importance of building strong working relationships with regulators as early in the process as possible while having a thorough understanding of the project's purpose and methods. Groups interested in advancing restoration may be able to advance restoration-enabling policy and regulatory changes by working constructively with local managers and communicating the need for new or altered policies related to kelp forest management.

4.2.2 Biosecurity

Kelp restoration projects seeking to introduce biological materials into the environment must address biosecurity concerns related to pathogens and genetic integrity (Campbell et al., 2020; zu Ermgassen et al., 2020). We describe some of these concerns here.

4.2.2.1 Pathogens

The accidental introduction of pathogens and parasites has caused significant ecological and economic damage worldwide (Torchin et al., 2002). As such, transplanting organisms or biological material from areas that may have different pathogen assemblages is concerning to regulators. It is important to not only understand the distribution of pathogens specific to the target restoration species but also other pathogens that may be present in the water column or could reasonably adhere to target samples (e.g., shellfish viruses). In general, you can address these concerns by ensuring good hygiene when handling biological material (**chapter 5.3** and **Appendix 1**) and selecting source material from areas close to the intended transplant site(s), as they are likely to have the same pathogen and environmental profiles and may decrease the risk of introducing or enabling a pathogen. In situations where there is no source material close to the restoration area (i.e., there are no local kelp populations), kelp restoration practitioners should work with regulators to identify appropriate source locations and potential mitigation measures to reduce pathogen risk. If applicable, it may be useful to consult with local seaweed aquaculturists for this step.

4.2.2.2 Genetic considerations

Natural resource managers typically seek to maintain or restore the historic properties of populations. This goal includes preserving the underlying genetic diversity and structure, as these characteristics ensure populations are most optimally adapted to current environmental conditions and provide sufficient diversity for future adaptation.

Ensuring that source materials for restoration transplants are locally adapted and unlikely to erode local population genetic composition/structure through the introduction of novel genotypes is an important consideration for permitting. Ideally, kelp restoration practitioners should assess the population genetic structure and diversity in their region to help inform the selection of appropriate source materials. In the absence of this information, selecting source material within close proximity to the restoration site is a best practice. In any instance, restoration practitioners should work with regulators and other experts to identify the most appropriate source material for transplant efforts. In systems with large scale loss, propagules may not be available

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from a nearby site. This absence does not have to prohibit restoration, but rather may serve as a point for discussion with managers and permitting authorities regarding risk tolerance in achieving restoration objectives. It may be that in cases of catastrophic loss, decision-makers are willing to accept a higher degree of risk related to pathogens and/or genetic diversity and structure in order to restore the ecosystem (**chapter 2.1.6)**.

With rapid climate change and the inability of some species to adapt, there is growing interest in exploring 'future proofing' of restoration efforts (See **chapter 7**). From a permitting and policy perspective, modifying the genetic composition of real-world populations as a marine resource management tool is currently not accepted in most jurisdictions. Practitioners interested in future-proofing kelp restoration projects should discuss with regulators before getting too far into their planning process.

4.3 EVALUATION OF SUCCESS AND MONITORING

Monitoring is necessary to determine if goals and objectives are being met and can facilitate adaptive mid-course modifications to the project. Monitoring can take a few different forms (**chapter 6.2.1**.) to address a broad suite of objectives and should be incorporated into planning and budgeting accordingly.

Ideally, you should first conduct monitoring to establish a pre-restoration baseline of the area to be restored and reference ecosystems, and then survey repeatedly during and following restoration to understand if you met your fundamental objectives (e.g., X area of kelp biomass present, increase in kelp or fish recruitment, target fishery species restored). Should this be infeasible due to capacity constraints, you can direct limited resources to monitoring the restoration site only. But it may be more difficult to attribute change to your restoration action. It is important to determine the monitoring process and ensure adequate resources are available for this step prior to conducting restoration in order to objectively evaluate these targets and the success of the project. We give further detail on designing monitoring and evaluation programs in **chapter 6**.

4.4 SITE SELECTION

Logistical and environmental factors will influence the likeliness of a successful restoration project and are an important consideration in site selection and determining project objectives (Lester et al., 2020). It is therefore important to monitor and assess potential sites for attributes that will increase the chances of success (Table 4.1). Ultimately, the specific location for a restoration site should be one that has the best possible chance of success while maintaining focus on the objectives set for the project (see Table 4.1: key elements for site selection).

Table 4.1 Key elements for site selection and rationale

Potential site selection criteria to consider	Rationale	Category
Distance to existing or remnant kelp forests	Leverage existing beds for genetic resilience and spore distribution	Biotic
Heat stress	Heat stress (typically found in the warmest season) can push kelp past physiological limits, reduce their fitness, or cause mortality. Can impact both where and when to restore	Abiotic
Sedimentation	Sedimentation can prevent the settlement and development of new kelp	Abiotic
Nutrient pollution	High nutrient pollution can cause algae blooms, which limit photosynthesis and create conditions that allow competitors (e.g., turf algae) to out compete kelp	Abiotic
Negative anthropogenic activity	Areas with low human use (e.g., harvesting) may have fewer disturbances and thus better chances for success as well as fewer chances of conflict between user groups	Human
Stewardship	Areas with high levels of stewardship may benefit from enhanced monitoring of restoration, higher enforcement of protections, and potential volunteers to aid in the restoration process	Human
Grazer presence and density	High populations of grazers (e.g., sea urchins) can reduce kelp biomass and prevent new populations from developing	Biotic
Reef topography	Topography may determine the feasibility of different restoration techniques (e.g., urchin culling, transplanting)	Abiotic
Wave exposure	High wave exposure can inhibit in-water restoration activity, but many kelp favor high wave exposed environments. Some gazers (e.g., urchins) are deterred from similar environments	Abiotic
Ease of access for restoration	Ability for practitioners to frequently visit the restoration site while considering site ownership/management, costs, safety, and environmental conditions (this is related to wave exposure, e.g., sheltered cove vs. exposed area)	Human
Predator presence or density	Large predator populations can exert pressure on grazers and enable kelp growth	Biotic
Historic presence of kelp	Historical presence of beds (as identified through long-term aerial imagery data sets, traditional knowledge, or remotely sensed data if available) may be indicative of resistance or resilience	Biotic
Depth and substrate of reef	Maximum suitable habitat for restoration activities within species growing range	Abiotic
Freshwater input	Can be detrimental to kelp health, can limit grazer encroachment	Abiotic
Shelter from large waves and swell	Sites that offer protection from swell and high wave energy are easier to conduct restoration and monitoring	Abiotic

Once you select a general area to restore, determining the boundaries and outlining a discreet 'area of restoration' is important, as you will use these boundaries to evaluate the outcomes of the process (e.g., X area restored). Explicitly mapping the reef or target area assists with understanding how much restoration may need to happen at a given location. For example, if you select a cove as a restoration site and establish a boundary (i.e., by drawing a polygon) within the cove (X hectares), you can quantify how much area is suitable habitat for restoration (e.g., rocky reef) and how much restoration area is desired (Y hectares). Understanding the size and shape (the 'polygon') of the targeted restoration area is a way to estimate costs and logistics as well as set realistic expectations for how much you can restore. In addition, permitting and resource agencies will require you to have a clear understanding of your designated restoration area before permits will be issued.

4.5 DESIGNING RESTORATION PROJECT

The first step in a project is to identify the actions that will address the stated problem and objectives as well as fill any knowledge gaps. People around the world have used a variety of methods and approaches for marine restoration to date, and these attempts have yielded valuable and insightful findings. Given the novelty of kelp restoration and the rapidly emerging field, there is still a high level of uncertainty in most aspects of kelp restoration. Therefore pilot projects, with lower financial risk and uncertainty, are an ideal platform to catalyse the transition from idea to action and may facilitate strategic upscaling of the restoration activity.

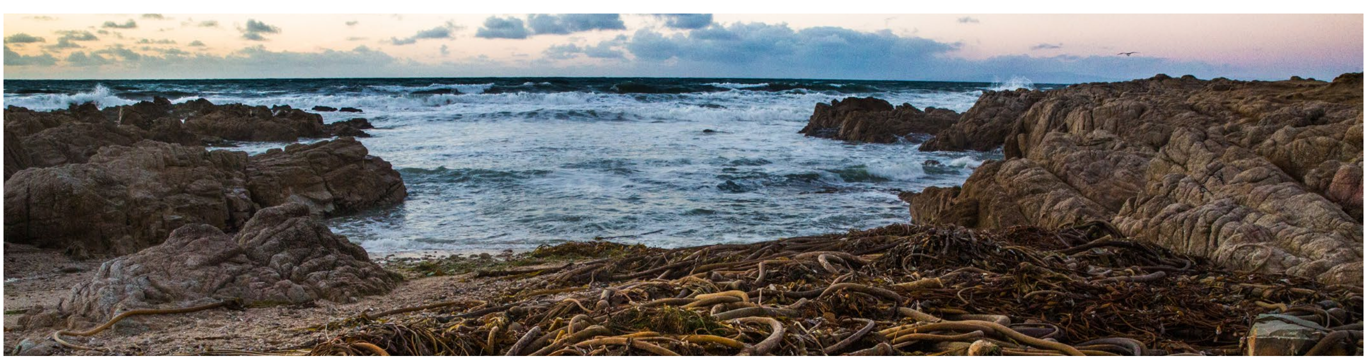
Whatever the circumstances for a particular place and community, the process of launching a restoration project should begin by setting clear objectives, understanding regulatory pathways (biosecurity and permitting), and developing manageable expectations through conceptual models and pilot projects.

Pilot projects should remain grounded in the established project values, and you can design them to meet any number of learning objectives, from testing assumptions and demonstrating interventions (South California: Palos Verdes & Japan: Hainan transplants) in a local context, to informing and strengthening community involvement (Haida Gwaii: Gwaii Haanas & Sydney: Operation Crayweed), to demonstrating approaches to inform management and/or support proposals for larger financial or institutional investments. As projects progress, what started as several pilot projects may eventually contribute to a larger restoration action or take the form of a single large project.

The idea behind these projects is that they serve as a 'proof of concept' and can catalyse future interest, investment, and subsequent action. These smaller-scale, localized projects will help you better approximate the financial and logistical investments associated with a given approach in a specific place. Pilot projects can also be the most challenging aspect of the restoration process, because they are the moment when an idea or desire to conduct restoration becomes a reality and are often the first step to remedying the habitat loss. While it may be enticing to immediately get started with a pilot project, it is still important to run through logistics and formulate the idea into a conceptual model and hypothesis.

4.6 PILOT PROJECTS TO SCALE

After a successful pilot project, you will need to consider how to scale up the size of the restored area from the pilot project scale (often 10s to 100s of m^2) to the scale of kelp loss (often km^2). All the principles outlined above and below are still relevant to large-scale projects while the main constraint will typically become project resourcing and funding (**chapter 2.1.5**). As you have demonstrated your proof of concept, you will need to focus on replicating that success over a much larger area. Typically, this transition utilizes the same methods but with more materials (e.g., transplants, seed vectors, reefs) and person hours (e.g., installation, urchin management, monitoring) and these costs may not scale in a linear way. Large-scale projects from Japan and Korea (Eger et al., 2020b) demonstrate that large- scale projects can restore areas at marginally lower costs than small-scale projects (low 10s of thousands vs. hundreds of thousands of dollars). Nevertheless, these costs are still significant, and an adequate resourcing and project management plan is needed to go from small-scale to large-scale restoration.



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CHAPTER

5.0 KELP FOREST RESTORATION IN ACTION (METHODS)

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Synopsis: In this chapter we describe the approaches available for kelp restoration and emphasize that you will need to consider the best suited approach(es) for your particular project (Fig. 5.1). The selected methodology will depend on the expertise of your group, project budget, the stressors present, environmental conditions, and whether kelp can return naturally or needs re-introduction.

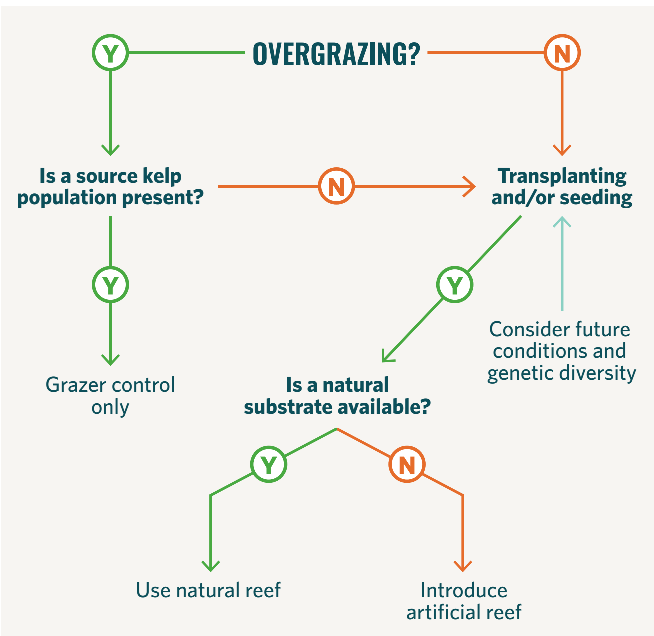

Figure 5.1 Flow chart of restoration methods

5.1 RESTORATION METHODOLOGIES AVAILABLE

Project methodologies are not mutually exclusive, and projects may desire or need to combine approaches simultaneously or sequentially. Examples and considerations are given for the four main approaches to kelp forest restoration (**grazer management 5.2, seeding 5.4, transplanting 5.5, and artificial reefs 5.6**). All projects need to consider if the environment will allow for the growth of introduced kelp materials; these conditions may have shifted from previous baselines, and you will need to consider which kelp species you are working to restore (**chapter 7**). A common threat to kelp forest projects is overgrazing by herbivores such as sea urchins and herbivorous fish. Any project with overabundant herbivores will need to consider grazer management as an essential element of their project (**chapter 5.2**). If there are parent populations of kelp nearby, grazer management may be enough to restore a kelp population. Otherwise, projects will need to introduce reproductive kelp material into the ocean; you can achieve this either via seeding (**chapter 5.4**) or transplanting (**chapter 5.5**). Projects that are looking to enhance kelp forests as opposed to restoring them on natural reef may consider using artificial reefs, which provide new habitat for nearby kelp or act as installation sites for transplant and seeding efforts (**chapter 5.6**). We detail the advantages and disadvantages of these methods along with their key considerations in this chapter.

5.2 HERBIVORE MANAGEMENT

Herbivores, i.e., grazers, often have strong interactions in shaping kelp forest ecosystems. Species such as sea urchins, herbivorous fish, and gastropods (marine snails) have historically been integral parts of kelp ecosystems and have consumed or removed kelp material at rates enabling it to regrow. Herbivores only become problematic to a kelp forest when their populations, and thus their grazing rate, outpaces the recovery of the local kelps. Herbivore population explosions on temperate reefs can occur because of multiple factors such as the loss of the herbivore's predators, or strong recruitment events and/ or the expansion of the herbivore into a new habitat (Filbee-Dexter and Scheibling, 2014, Ling et al. 2015). Additionally, behavioral shifts from 'normal' grazing to 'destructive' grazing can occur due to reductions in local drift-kelp supply (Kriegisch et al., 2019). As herbivores are often natural components of the ecosystem, a value decision is made when choosing to control them or not. Whether this decision is justified will ultimately depend on their impact on kelp forests, the local community, and governance of the desired ecosystem state (**chapter 3**).

Herbivores can be managed by increasing mortality rates via culling, harvesting, rebuilding natural predators, or restricting them from a kelp forest. Here, we outline how to measure the state of grazing in your ecosystem and the options available to manage grazer populations. Due to the prevalence of urchins as the primary destructive grazer of kelp, the focus of this section will be on sea urchins, but we will also consider how you can extend these techniques to herbivorous fishes, an increasingly common problem. Gastropods are not covered as there are few examples of them preventing kelp restoration, although they do influence natural kelp recruitment (Vasquez and Buschmann, 1997; Krumhansl and Scheibling, 2011).

For successful kelp restoration, grazing pressure needs to be reduced so that kelp growth and recruitment can exceed losses of kelp biomass. Kelp biomass production can be increased by either removing the grazer from the system or limiting its access to the kelp forest. Because herbivores, notably urchins, form alternate stable states in kelp forests (i.e., an urchin barren versus a kelp forest, **chapter 2.1.4, box 2.3**), the target density required to restore a kelp forest must be explicitly considered. This density depends on the local conditions, but large reviews have found that < 70 grams of urchin/m^2 or < 2 urchins/m^2 are general targets and can facilitate the return of a kelp forest (Ling et al., 2015). While having zero urchins is an unrealistic and often undesirable goal, initially reducing and maintaining urchin density as low as possible will provide the best chance for converting urchin barrens to kelp forests. A study in Western Australia found that a system transformed back into a kelp forest when herbivorous fish biomass was <700 grams/m^2 (Bell, unpublished), although this value needs verification in other locations.

Herbivore densities required for restoration are likely dependent on the 'health' of the local kelp forest, and positive factors such as high abundances of natural predators, low sedimentation loads, low nutrient pollution, nearby kelp adults, and low harvest rates can all help to create more resilient kelp beds, which may tolerate higher numbers of herbivores (Ling et al., 2009; Kriegisch et al., 2016). If grazing is a consistent problem, it may be best paired with transplanting as opposed to seeding, because adults can withstand greater grazing pressures than juveniles.

5.2.1 Herbivore harvest, culling, or translocation

Herbivores can be removed from an ecosystem by harvesting, culling, or translocating them. The logistics of harvesting and culling are often the same (e.g., hand removal), but culling processes do not have an end use (e.g., food or fertilizer). *In situ* culling involves crushing or puncturing the test (i.e., shell of the sea urchin) and leaving it in the water. If the urchins are being used as a food resource, they are first removed from the water, then processed on the boat or on land. If you are transporting the urchins, the animals are transported unharmed and released into an alternate location. You can conduct fish culling via nets—usually seine nets—or possibly by hooks or spearfishing.

5.2.1.1 Mechanical culling of urchins

There are several different tools for removing sea urchins *in situ*, including hammers, rollers, crow bars, hooks, tridents, or poles. You can use these tools while SCUBA diving, freediving, or in some rare cases from the surface. You kill urchins when you break their test (i.e., shell), alternatively, a hole, > 2cm x 2cm effectively incapacitates them. Selecting which combination of in-water access and tool for culling is mostly dependent on the skillset of the people doing the culling. The tool of choice will depend on diver preference, but we suggest rollers and rakes in flat areas and crowbars and hooked poles to reach into crevices.

Anyone who can safely work underwater can conduct urchin culling. This range of people includes professional divers (commercial fishing fleet), scientists, and qualified volunteers (Northern California: Bull kelp). Indeed, many projects have successfully recruited volunteers to cull urchins. As the user's skill level increases, so does their culling rate, and it may therefore be most beneficial to focus on training the same people and having them work consistently as opposed to recruiting new people (i.e., volunteers) each time. However, recruiting and managing volunteers is also a laborious process that requires a dedicated coordinator. So, while the culling labor may be "free," you still require other inputs. As working underwater is an inherently dangerous process, it is imperative that all people involved are properly trained and, if appropriate, that the project has insurance for people to work underwater. Industry divers (e.g., commercial abalone divers) are often motivated to remove sea urchins, as their fisheries benefit from kelp recovery (Haida Gwaii: Gwaii Haanas & Tasmania: Urchin control).

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Culling urchins in combination with dive harvesting of other species, e.g., abalone, is also practiced but typically only effective at small "incipient barrens" scales as you spread your focus across two tasks. Researchers in Japan and Norway are currently trialling a new approach using a vacuum pump. This approach allows a diver to stay underwater for longer, as they do not have to manually transport their catch to the surface. Divers may dive on SCUBA, hookah, or freediving, as diver experience permits. All removal strategies should be consistent in the locations targeted, with efforts focused on select locations over time, as opposed to efforts spread too thin (Southern California: Palos Verdes).

5.2.1.2 Chemical control

You can use a compound called quicklime (Calcium Carbonate, CaO) to cull sea urchins and other echinoderms (Norway: Quicklime). Quicklime is typically a by-product of lime production and is inexpensive to acquire (< 10$/ kg). When quick lime is put in contact with water, it creates a strong base that causes lesions in the tests of sea urchins ($CaO + H_2O \rightarrow Ca(OH)_2$. Quicklime is lethal to echinoderms and can affect abalone (Keane, 2021) but has limited effects on other organisms, especially mobile ones such as fish (Bernstein and Welsford, 1982; Strand et al., 2020; Keane, 2021). You apply quicklime from the surface or underwater while diving, and the particles (0–2 mm in size) distribute into the water column. These pieces then float to the benthos and dissolve the urchin test upon contact. Not all particles reach the seafloor, but all particles eventually dissolve, and the base is diluted in the seawater in less than an hour.

Using quicklime is attractive and low cost, can be applied without divers, and can cover a large spatial area. However, it is controversial, as it involves some level of collateral damage. Collateral damage can be minimized by targeting areas that are mostly populated by urchins or by using divers to deploy quicklime closer to the seafloor. There have been some reports that quickliming is less effective in colder waters, but new research shows that liming is not significantly impacted by temperature at a low range (2° vs 10°C, Strand et al., 2020) but may be less effective at higher temperatures. Strong consideration must be given to determine if quickliming is justified and socially permissible in each situation.

5.2.1.3 Urchin trapping and baiting

Urchin trapping or baiting increases the densities of catches of targeted urchin species and allows for more efficient urchin removal. In Norway, trapping was found to be an economically viable alternative to harvesting urchins in comparison to diving (James et al., 2017). This Norwegian study evaluated bait composed of fish and algae and found that fish bait attracted more diversity and by-catch compared to algae. The most successful trap was a round collapsible trap, and they suggested that traps sit in the water for three to eight days. You can also use traps and bait to aggregate urchins in one location and facilitate quicker culling efforts.

5.2.1.4 Removal of fishes

While there has been little focus on managing herbivorous fish populations, the topic is expected to become more relevant as expansion of herbivorous tropical fish into temperate waters is facilitated by warmer waters (Vergés et al., 2019). In shallow waters (< 5 meters) in Japan (Japanese Fisheries Agency, 2021), herbivorous fish removal has been accomplished using seine nets. However, this technique does not discriminate by species and requires a high level of skill to conduct. While you can return bycatch species to the ocean, stress and mortalities are inevitable. These factors can be mitigated by proper animal care procedures but cannot be eliminated entirely. As a result, a great deal of care and justification should be required before attempting to seine net an area for culling purposes. Spearfishing is a low by-catch alternative for removing herbivorous fish but requires more skill and removes fish at a much slower rate than seining.

Box 5.1 Harvesting herbivores for food

As both sea urchins and fishes are consumed as human food, there is the potential to remove these species from target sites and sell them to cover project costs, or even to turn a profit. The market is most developed for sea urchin roe, or "uni," which is a common food item in Japan, the Mediterranean, and increasingly worldwide. There is no known international market for the common herbivorous fishes, but some are consumed locally, and perhaps new marketing campaigns could encourage their consumption. Additionally, urchin barrens may not contain sufficient food sources to sustain healthy urchins, and the quality of urchin roe suffers and is not worth selling. An innovative market driven solution created to address this problem is "urchin ranching," where people collect the poor-quality urchins of a particular size class from the ocean, culture, enhance, and then sell them. This process adds additional costs but can create higher value and market price for "uni" and may prove to be an economically viable venture. If such operations prove unprofitable, they could be run as philanthropic projects, or government subsidies can help fund project costs (Tasmania: Urchin control).

5.2.2 Localized urchin exclusion

While less commonly used, in some cases it may be necessary to exclude urchins from kelp habitats. It is possible to create herbivore exclusion structures using f loating nets, rigid fences, bubble cages, or with other habitat formers such as octocorals (Ling et al., 2020; Sharma et al., 2021). One project also succeeded by planting artificial kelp alongside live transplants. The artificial kelp creates a whiplash effect in the current and can deter urchin grazing (Vasquez and McPeak, 1998). This technique might be most useful for targeted small areas in order to protect outplants or allow for new recruits to grow.

5.2.3 Positive species interactions

Projects will never achieve lasting results without an effective and long-term solution to overgrazing. The methods described above can require regular intervention and are thus logistically challenging as well as costly. Ideally, an ecosystem would be able to sustain itself without regular human intervention. The best way to achieve this goal is by ensuring that the (non-human) predators of herbivores (e.g., fishes, lobsters, sea stars, otters) are present in sufficient numbers. Because most predators have declined due to human harvest, marine protected areas (MPA) or reserves that limit or eliminate harvest pressures can help achieve this goal and ensure healthy predator populations. Synthesized evidence suggests that MPAs can indeed restore or maintain kelp forests, but there remain instances where increases in predators' numbers do not result in increases in kelp populations. Therefore, MPAs cannot be considered a universal fix for kelp restoration but can certainly play an important role in maintaining, if not restoring, healthy kelp forests (Eger et al., 2020a). Once predators are re-established, limited take and sustainable fisheries policy can help ensure their populations do not fall again.

5.2.5 Key considerations for herbivore control

Urchin types: Not all urchins are equal in creating barrens; some species are more prone to creating barrens than others. It is not advisable to indiscriminately remove sea urchins but rather to consider the dynamics in your system and choose your management strategy accordingly.

For example, scraper species (e.g., *Centrostephanus rodgersii*) are more likely than opportunistic grazers (e.g., *Heliocidaris erythrogramma*) to create urchin barrens, as long as there is a sufficient supply of drift algae. Alternatively, more mobile species such as *Strongylocentrotus droebachiensis* may be likelier to cause barrens. In addition, some species are important to fisheries and subject to management regulations (e.g., *Mesocentrotus franciscanus*).

Consistent intervention: Herbivores can grow at fast rates, disperse as larvae over hundreds of kilometres and over tens of metres as adults, and only require relatively low densities to maintain a barren (as low as ~70 grams of urchin biomass m^{-2}). As a result, it is essential that work to remove/manage herbivores is consistent over space and time. If you distribute management efforts across too many locations or only once, it is often not possible to reduce the herbivores to the critical threshold required to restore a kelp forest.

We recommend that projects work in concentrated locations and plan (including budget) to maintain a site for multiple years before commencing.

Table 5.1 Pros and cons of herbivore control solutions

	Pros	Cons
Herbivore culling—mechanical	• Targeted removal	• Requires divers • More time intensive • Cannot harvest species • Public perception can be negative
Herbivore culling—chemical	• Doesn't require divers • Scalable over large areas • Low cost	• Collateral damage • Cannot harvest species • Public perception can be negative
Herbivore exclusion	• No killing of animals is involved • Better public perception	• Time and resource intensive to set up • Can only be applied over a small area • Often requires introduction of foreign materials into the ocean
Positive species interactions (i.e., trophic cascades enhanced through MPAs)	• Long term permanent solution if successful • Most "natural" solution • Large scale solution	• Can take years to realize effects • Predators are not guaranteed to return to MPAs • Potential conflict with other ocean users

Proximity to existing kelp sources: Because kelp species are typically short dispersers, we recommend that projects select culling sites that are close to existing kelp forests. This proximity will help facilitate natural repopulation of the kelp forest.

Removal strategies: You should first target herbivore removal efforts at the edges of the barren and then work towards the centre as urchin numbers are reduced: i.e., propagate kelp recovery from adjacent beds to maximise local sources of kelp propagules to recolonise barrens once urchin densities have been sufficiently reduced.

Prevention and pre-collapse: Because it is easier to prevent an urchin barren from forming than reversing an existing barren, it is more cost efficient to be proactive and to manage herbivores in a degrading but not collapsed kelp forest (**chapter 2.1.6**).

Site topography and habitat: Sites with natural barriers such as sand stretches and rock formations can help prevent urchins from encroaching on a site. Therefore, selecting these sites to cull urchins may increase the chances of success.

Ease of culling: It will be easier to cull urchins from sites that are flat, where you can sweep the urchins off the rock or ensure they are impacted by quicklime. Otherwise, it is difficult to locate and remove all urchins from sites that contain hiding places for urchins such as boulders or other crevices, in which case multiple culling efforts are often required to remove individuals missed on the first pass. Baiting urchins may draw them out into the open and congregate them to facilitate easier culling.

5.2.6 Further reading

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Keane, J., 2021. Resetting urchin barrens: liming as a rapid widespread urchin removal tool.

5.3 SOURCING KELP MATERIAL FOR SEEDING AND TRANSPLANTATION

Sourcing kelp material is a key step in seeding (**chapter 5.4**) or transplanting (**chapter 5.5**) kelp for restoration. You can source kelp material for kelp restoration projects in two ways: 1) direct use of wild materials (e.g., transplants, spore solution, and spore bags; see Sydney: Operation Crayweed) and 2) lab culturing (Korea: Seaforestation project, **Appendix 1**). Here, we classify culture methodologies as those that increase the amount of reproductive material (i.e., more individuals regardless of life stage). Unless you use a commercial seed stock, all these processes start from a wild population. Each of these methods has several pros and cons (Table 5.2) that we describe in more detail later in the chapter.

5.3.1 Genetic diversity in restoration

It is important to consider the genetic diversity of the kelp material used in all stages of the restoration process. Higher genetic diversity in a population can increase the likelihood of surviving a stress event (Wernberg et al., 2018) and allows populations to adapt to changing environmental conditions. Incorporating genetic diversity into restoration will also preserve different phenotypes (Camus et al., 2018) and unique evolutionary lineages (Robinson et al., 2013) and can also influence associated biodiversity and biomass, as well as ecosystem functions (Wood et al., 2019). While not all projects may have access to sequencing infrastructure, genetic diversity can be considered in the process of selecting the parental kelp.

When collecting seed material from donor populations, one can ensure that a sufficiently large number of different individuals are sampled to obtain a more genetically diverse seed stock (a general rule is 20–50 individuals). Collecting from different spatial areas of the population can also help ensure higher genetic diversity as individuals in close proximity (< 10 km) are more likely to be genetically similar (Alberto et al., 2010). It is also important to consider biosecurity (**chapter 4.2.2**) and the match between the environmental conditions of the donor and outplanting sites when selecting kelp for restoration.

In most cases, restoration aims to re-establish populations that are most similar to those lost in the past. However, more forward-looking restoration strategies to increase resilience to climate change are increasingly explored in **chapter 7** (Coleman et al., 2020).

Table 5.2 Pros and cons of wild versus cultured materials

	Pros	Cons
Wild materials	• More affordable if commercial culture and/or facilities are not available • Quicker immediate timeline if facilities are not available • Less equipment required • Lower chance of biosecurity issues	• Higher pressure on wild population • Collections must occur close to time of restoration • Less opportunity for genetic selection
Cultured materials	• Less pressure on wild populations • Can store cultured material for later (create a seed bank) • Easier to work with genetic selection (**chapter 7**) • Can produce large batches • Can restore anytime not only when wild populations are reproductive	• Requires more equipment, resources, and technical knowledge • Higher potential biosecurity issues

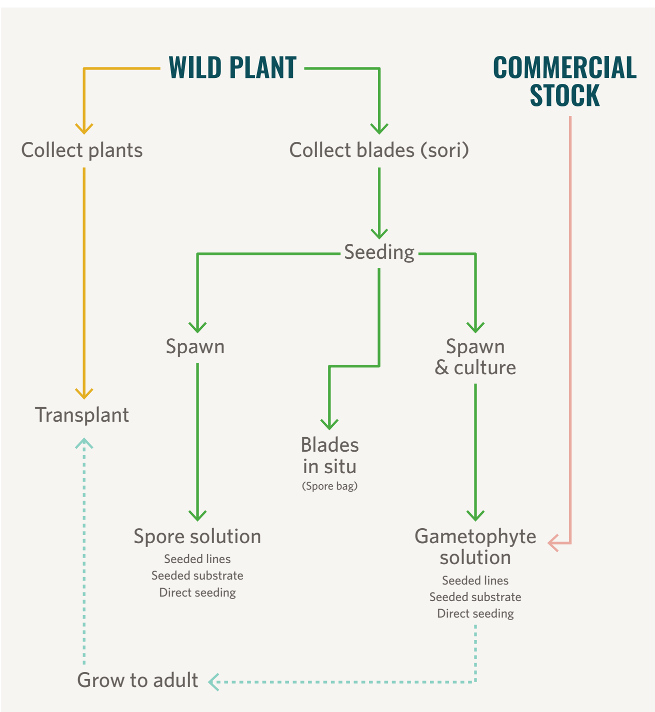

Figure 5.2 Flow chart for sourcing kelp material for restoration

5.3.2 Kelp collection

If you are not using a commercial stock, you must collect the kelp material to use for seeding or transplanting. Transplanting involves collecting the entire kelp, including the holdfast, while in seeding you only need to collect the reproductive tissue located on the blades (the sorus, Fig. 5.2), which does not kill the individual.

5.3.2.1 Collecting kelp for transplantation

The kelp thallus (i.e., the entire individual) is primarily composed of three sections: the holdfast, the stipe, and the blades. Some species also possess a single or even multiple floats that allow the plant to stay upright in the water column. Sourcing material for transplantation involves the collection of the entire thallus. Holdfasts provide the only attachment point, and thus a critical aspect of the collection procedure is the detachment of the holdfast from the rocky substratum. Notably, kelp cannot be grown from cutting or fragments taken from other individuals.

Depending on the species and how strongly attached the holdfast is to the reef, holdfast detachment can be done via snorkel or SCUBA diving. The diver needs to introduce a knife or flat blade (abalone knives are ideal but large dive knives also work) between the bottom of the holdfast and the rock and detach the entire holdfast. It is important that you insert the knife along most of the diameter of the holdfast and reduce damage by ensuring most/all of the holdfast is detached in one piece.

You can bag detached kelp in the field using mesh-bags for ease of transportation. For most, if not all, species it is important that transplantation to the recipient site occurs within a few hours or at least the same day of collection. It is also important that you keep kelp shaded, cool, and moist during transportation to the recipient site. Keeping them in the mesh-bags used for collection and covering them with towels/tarpaulins works very well. If short transport time is not possible, kelps can be kept in mesh bags in the ocean overnight (e.g., tied off a dock) or stored in a large aquarium with aeration and water flow.

5.3.2.2 Collecting kelp material for seeding and culturing

We do not provide detailed instructions for culturing each type of kelp. Instead, we provide a set of general recommendations that work well for Laminarian species (also see gametophyte review by Veenhof et al., 2021). Any specific details below may not work for all species and are only described as starting points if species-specific information is not available. You may find a list of persons conducting kelp restoration of your target genera at kelpforestalliance.com.

Fundamentally, the culturing process typically requires releasing spores from reproductive tissue collected from the field, with spore release usually being triggered by 'stressing' the collected tissue through a process of exposure to low and then high light and/or mild drying before rehydrating. The released spores are then maintained under stable light and temperature conditions, and over the following days/weeks they are allowed to mature to subsequent life stages.

One critical and consistent aspect of kelp culturing is the importance of cleanliness and avoiding contamination. Common and problematic contaminants of kelp cultures include diatoms, flagellates, some molds and other fungi, algae, and bacterial growth. Reproduction in most kelps typically peaks during certain times of the year. You will need to research the appropriate time to collect kelp material depending on your target genus and region.

During collection, you are targeting the sorus tissue (sori for plural). Depending on the species, the sori are located on the blade or stipe, but we suggest targeting the blade tissue that is least destructive to the kelp (Fig 5.3). Within the sorus tissue is the sporangia, which contains the spores used for kelp reproduction. This tissue is typically held in the middle of the blade and is slightly raised and often dissimilarly coloured to the surrounding tissue (Fig. 5.4). While you can identify sorus tissue in the field, it is easiest to collect the entire blade and transport it back to the lab. When collecting blade tissue, you will want to look for healthy kelps.

Collecting blades

- Ensure you are collecting during the reproductive season
- Check local water conditions (e.g., tides, current, swell)
- Collection materials
- Choose your collection site
- Target healthy kelps
- Try to minimize damage to the kelp
- Take only what you need, do not over harvest
  - » 20–50 plants are suggested for creating a gametophyte solution
- Transport your collected material back to the lab
  - » Keep at water temperature from which the individual was collected

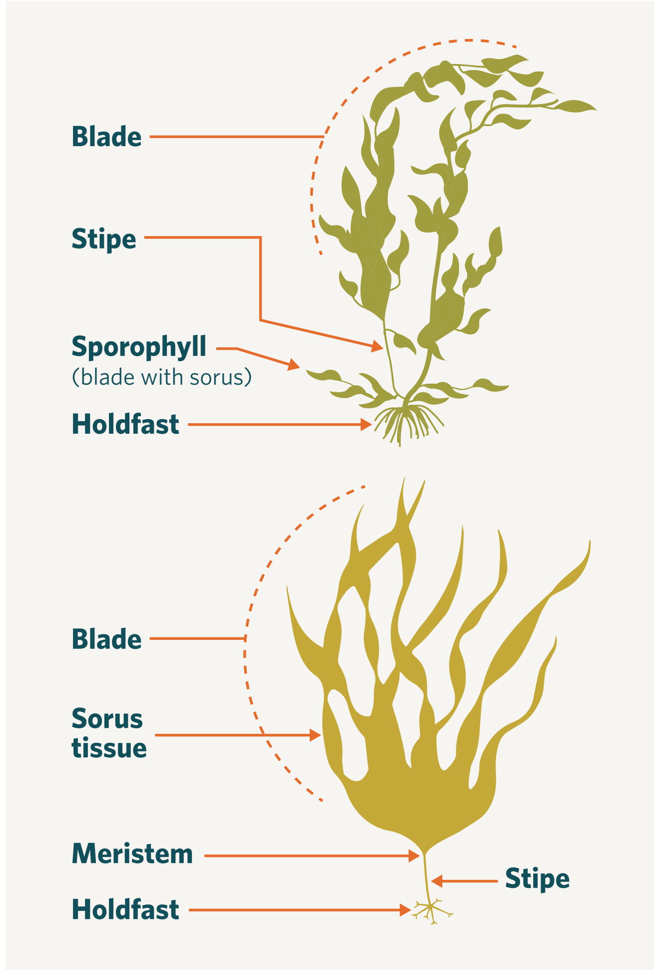

Figure 5.3 Anatomy of kelp; illustration by Jon Ferland

Figure 5.4 The sorus. This tissue is typically held in the middle of the blade and is slightly raised and often coloured a shade darker than surrounding tissue; © Ralph Pace

5.3.3 Spawning the sori and creating a gametophyte solution

We discuss the specific instructions to create a spore or gametophyte solution for a model species (*Laminaria digitiata*) in **Appendix 1**. The exact details of these steps (e.g., temperatures, nutrient concentrations) differ among species and regions; therefore we recommend consulting local experts (e.g., universities, culture facilities) when in doubt.

5.3.4 Applying spore/gametophyte solution to substrate or the environment

Once you have created your spore, gametophyte, or sporophyte solution, you will next want to apply it to your substrate of choice (rope, hard materials, directly into the ocean, see **chapter 5.4 and 5.5**). For rapid deployment, you will want to wait a minimum of 24 to 48 hours to ensure the spores or gametophytes have settled before introducing this material into the ocean (see **considerations 5.3.6**). During this time, it is important to maintain the environmental conditions (temperature, light, nutrients, salinity) suitable for growth.

Culturing to sporophytes (juveniles/adults)

You may choose to culture your stock further and grow it to a juvenile or adult sporophyte stage. Taking this step can be advantageous, as optimal environmental conditions and a lack of grazing generally increase survivorship. Survival is also greater for more mature kelps than for younger individuals. While advantageous, it also requires more time in culture and thus more resources. We do not cover the steps required to grow your gametophytes into adults as that is beyond the scope of this guide (i.e., aquaculture), but see Flavin et al. 2013 for a comprehensive description on culturing (including steps covered here).

5.3.5 Spore bags

If you are using spore bags, you may skip many of the steps outlined here. When using spore bags, take the section that contains the sori (blades or holdfast), dry them for ~12 hours in a shaded, cool, well-ventilated area, and then add them to the bag material directly. While transporting, minimize heat stress by using damp cloth and shading from the sun. Do not immerse in water as this will trigger spawning. Once you deposit the bags in the ocean, the ocean water should initiate the previously described spawning process. Be careful getting the blades wet beforehand, as you may prematurely induce spawning.

5.3.6 Key considerations for sourcing kelp material

Seasonal timing: It is best to mimic the natural reproductive cycle of kelps.

Processing: It is best to extract the reproductive material as early as possible after collection and from the cleanest part of the blade.

Culture time: If outplanting sporophytes, cultivate for enough time to allow developing sporophytes to grow past more vulnerable life stages (1-2 months, few cm length); NB: Kelps grown to sporophytes and left too long in the lab may become too adapted to optimal lab conditions and perform poorly after deployment.

Water flow: The cultivation setup should try to mimic water flow from the collections sites so that sporophytes develop sufficiently strong holdfasts.

Outplanting timing: You should outplant into the field during periods with high nutrient availability (winter/spring), adequate water temperature, and during times of low grazer abundance or algal competitors.

Target plants: Try to collect younger kelp, as they may be most fit for reproduction and there is evidence that collecting larger, older kelp can be more harmful to the natural population.

5.3.7 Further reading

Flavin, K., Flavin, N., Flahive, B., 2013. Kelp Farming Manual: A Guide to the Processes, Techniques, and Equipment for Farming Kelp in New England Waters.

Rolin, C., Inkster, R., Laing, J., Hedges, J., & McEvoy, L. (2016). Seaweed Cultivation Manual. Shetland Seaweed Growers Project 2014, 16.

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Merrill, J.E., Gillingham, D.M., 1991. Bull kelp cultivation handbook. [National Coastal Resources Research and Development Institute], [Portland, Or.].

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5.4 SEEDING

Seeding is a common approach for ecosystem restoration in terrestrial systems but is currently less commonly applied in the marine environment. Broadly defined, seeding involves dispersing and/or growing the juvenile life stage (i.e., seeds, gametophytes, propagules, zoospores) of the kelp into the ocean. Seeding is advantageous because it is less resource intensive than transplanting, seeds can be grown in large quantities, selective breeding can choose desirable traits, and it has lower impacts on wild populations of kelps. Conversely, the microscopic life stage of kelp is more sensitive to disturbances like pollution, grazing, and waves than the macroscopic and adult life stages. When seeding, you must consider your seed source (**chapter 5.3)** as well as how and where you distribute them.

You can introduce the seed material into the environment in two main ways: direct release of propagules or *ex situ* seeding on substrata and outplanting. Propagules that are directly released into the environment are expected to settle on available natural rocky substrata and mature. You will disperse seed material that you have produced *ex situ* in the environment together with its vector substrata (i.e., rocks, ropes) and may produce new zoospores once reaching reproductive maturity.

If the substrate is covered by other organisms that would prevent kelp growth (e.g., coralline algae, turf), projects can work to clear the substrate prior to seeding. Clearing of the substrate can be effectively achieved by using a high-pressure air gun, scraper, or grinder. While air guns and grinders are more effective methods over large areas, they are also very costly and intensive.

5.4.1 Spore bags

Spore bags (i.e., seed bombs) introduce reproductive material (kelp material with sori) into the environment to allow for the natural release of zoospores that can settle onto available rocky substrate. Spore bags consist of mesh bags filled with mature blades and are either placed on the substrate or suspended in the water column (Fig. 5.5). The parent material can either consist of wild collected, unprocessed kelp blades or of processed blades that you have prepared to induce spawning (**chapter 5.3.5**). Once you fill the bag, you attach it to a rope with one end anchored on the sea floor and the other on a float. The spores are then distributed across the benthos as the blades spawn. Following the spawning event, you should remove the bag, rope, anchor, and float from the ocean.

5.4.2 Seed lines

Seed lines are most used in aquaculture, but you can also apply them in a restoration context. Lines are typically made of nylon, but interest is growing in using biodegradable materials as well (e.g., cotton, though it is important to consider that some natural fibres require pre-treatment such was autoclaving or soaking in seawater). First, you inoculate seed lines with spores in a culture facility and then grow them out in the lab or in the field. Inoculation can involve spraying a spore solution on coils of lines that are out of seawater or adding the spore solution to seawater containing submersed lines. Grow out involves holding lines in tanks with clean filtered seawater. Once the lines are ready for installation, you will suspend them in the water column using a series of buoys and anchors. Small seed lines can be wrapped around larger ropes. A benefit of floating lines is that the kelps are free from urchin grazing and may have higher survival rates. These adults are then the propagule source for the future generation and can seed the benthos beneath the seed lines. Lines are typically removed after one spawning event as the line material degrades due to wear and tear.

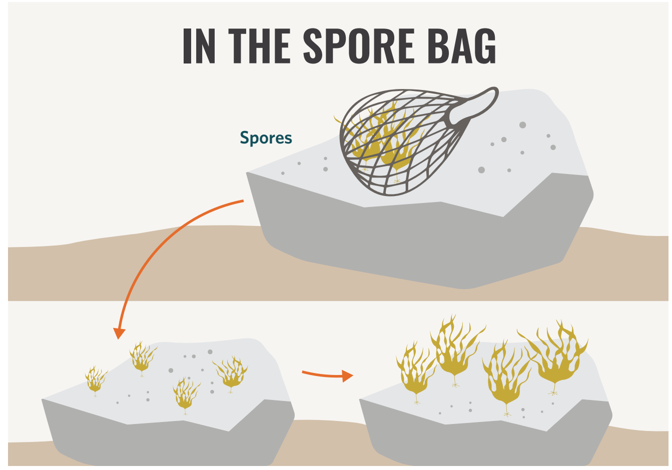

Figure 5.5 Spore bags; illustration by Jon Ferland

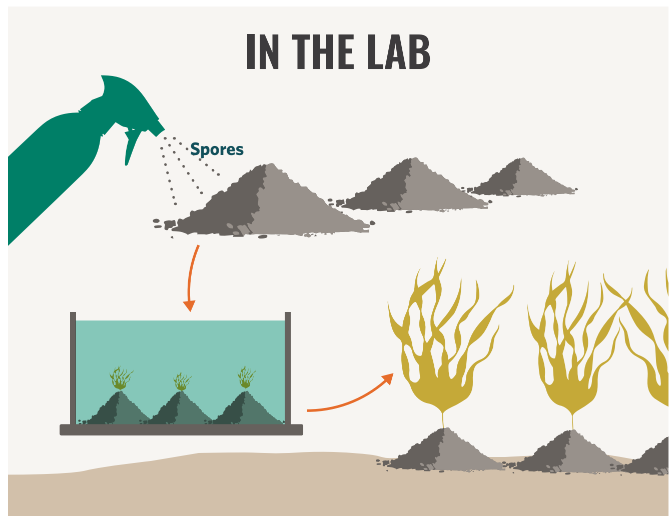

Figure 5.6 Inoculating hard substrate; illustration by Jon Ferland

5.4.3 Attached to a hard substrate

You can apply the principles described above for inoculating hard substrates with kelp spores as a seeding vector. Rocks and stones are the most common substrates used for this purpose. A newly developed approach, termed "green gravel" (Norway: Green Gravel, greengravel.org) works by inoculating small stones (i.e., gravel or pebbles) with a spore culture, growing them to a young life stage in the lab and then dispersing them into the environment (Fig.5.6). You can disperse the stones by dropping them off the side of the boat, eliminating the need for scuba divers, while increasing scalability and reducing associated costs. You can apply a similar approach *in situ* by placing the settlement substrate underneath the canopy of reproductive kelp plants during the spawning period. The released spores naturally settle on the available substrate, and you can then collect and transport them to the restoration site.

The new kelp recruits will grow throughout the growing season and ultimately spawn within the new habitat. Depending on the size of the stone used, the kelp holdfast may also overgrow the vector material and attach directly to the sea floor.

5.4.4 Direct dispersal

The direct seeding approach is the most different from the others and the one least tested. Direct seeding simply involves distributing a kelp culture directly into the water column or on the benthos in intertidal habitats. Subtidally, this work can either be done from the surface or underwater using a hose or other apparatus to "spray" the seafloor (Fig. 5.7). When working intertidally, the gametophytes/sporophytes are expected to attach to the rock before being washed away by the incoming tide.

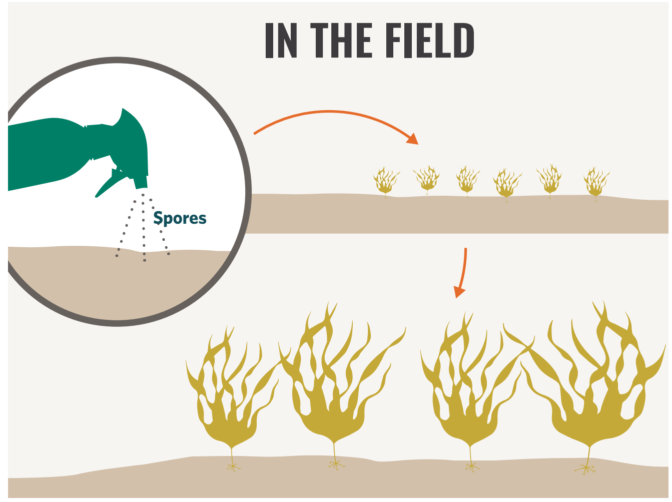

Figure 5.7 Direct dispersal; illustration by Jon Ferland

Table 5.3 Pros and cons of seeding methods

	Pros	Cons	Reference
Spore bags/ Seed bombs	• Limits grazing of source tissue • Relatively cheap at small scale • Invisible from surface	• Generally requires wild harvest • Requires removal of higher amounts of material • Suited for low current areas • Difficult to assess if propagules have settled	(FIRA, 2020)
Seed lines—floating	• Established protocols from aquaculture • Covers large area • Kelps are protected from urchin grazing (but not fish) • Applicable over large scales	• Costly deployment • Requires removal of material • Suited for low current areas • Needs to be deployed for longer time periods than aquaculture lines to reach reproductive stage	(Shaw et al., 2018)
Seeded substrate—cultured (e.g., green gravel)	• No divers required • No clean up required • Lower cost	• Suited for low wave/current areas • May be some introduction of foreign material	(Fredriksen et al., 2020)
Seeded substrate—wild spawn	• No culture required • Using larger substrate pieces (e.g., rocks, boulders) can make it more suitable for high wave areas	• Requires divers • Stones/substrate may be expensive and hard to source in some areas	Japan: Hainan transplants
Direct dispersal	• Low equipment required • Very little material removal required	• Need a culture • Smaller area covered if performed by diver • Special equipment required	(FIRA, 2020)

5.4.5 Key considerations for seeding

Grazers: Sea urchins are problematic for many seeding methods; in such instances, projects may need to 1) manage the grazer population (**chapter 5.2**) or 2) select areas or seasons with low grazing pressure. Elevated reefs or areas isolated from urchin habitat by sand patches may provide areas with lower urchin grazing pressure.

Available surface/site selection: Propagules will need suitable surface to settle, adhere, and grow on. You can choose areas so that they have: 1) low sedimentation rates, 2) low cover of competing species (e.g., turf, bryozoans), 3) suitable rocky reef, 4) optimal wave exposure. In some cases, the addition of substrates can overcome this limitation.

Turf algal and sub-tropical macroalgal reefs often fluctuate seasonally in cover, so targeting seeding for periods when cover is low may help address the challenge of competition for settlement surface. Suspending culture lines of seaweeds in the water column can also shade out some of these competing algal species, or if you attach the lines on the seafloor, the larger kelps could scour off the turf.

Selecting substrates with a high surface rugosity can also help improve the strength of attachment and decrease the likelihood of detachment.

Seasonality: Most kelp species have optimal periods of reproductivity during the year. Therefore, you need to time seeding with this period or maintain efforts for multiple years to cover multiple reproductive seasons.

Wave exposure/currents: High wave exposure and/or currents will increase the difficulty of successfully seeding an area. You should try to ensure that work conducted in these environments releases the propagules close to the substrate. While difficult, working in these areas may indeed be beneficial as high wave action can deter sea urchins, and kelps grow faster in these areas. Storms may also be seasonal, and you should plan seeding attempts for calm weather seasons.

5.5 TRANSPLANTING

Transplantation (i.e., transplanting) of kelps has been the most common active method used in past kelp restoration efforts. We define transplanting as the introduction of the adult life stage of kelp into the marine environment, specifically on the benthos. The ultimate goal of transplanting is to provide a canopy that may facilitate kelp recruitment from nearby populations and/or allow propagules to settle and grow into adults. As such, the long-term focus is the survival of the second generation, not the initial transplants.

Transplanting is advantageous because it uses older life stages that are typically more resistant to stressors such as grazing, pollution, and waves, and thus it has higher survival rates than seeding, creates a canopy that facilitates recruitment and growth of juveniles, and is very targeted in its placement. Conversely, transplanting is resource intensive, may not be viable at large scales, and often requires kelps sourced from local populations. When choosing the best transplanting method, it is important to consider the local conditions and trial approaches before scaling up.

You may attach kelps to the rock in many ways, but all approaches work to secure the holdfast to the seafloor and, depending on the species and method, the kelps may overgrow the substrate and attach to the seafloor. See **chapter 5.6** for details on using artificial reefs together with transplants.

5.5.1 Mesh mats

Researchers have used this method for transplanting *Lessonia nigrescens, Ecklonia radiata, and Phyllospora comosa* (Correa et al., 2006; Marzinelli et al., 2009, Sydney: Operation Crayweed), but it may be less successful for species that require firm attachment. You first attach plastic mesh mats to the seafloor and then use them as an anchoring point for transplants. Garden mesh (trellis pattern) is easy to source and relatively inexpensive, and the mesh size can range from 25 to 50 mm. You secure the mesh to the seafloor using pre-installed anchors points (Fig. 5.8). You secure these anchor points by drilling holes into the rock, installing screws and wall plugs or anchor bolts, and screwing/bolting into the plug/anchor.

Once you have created the attachment points in the rock, you should clear the rock of fouling materials, lay the mesh overtop the rock, and fasten the anchors/bolts overtop with a washer to secure the mesh to the rock (Fig. 5.8). There should be a minimum of three attachment points in

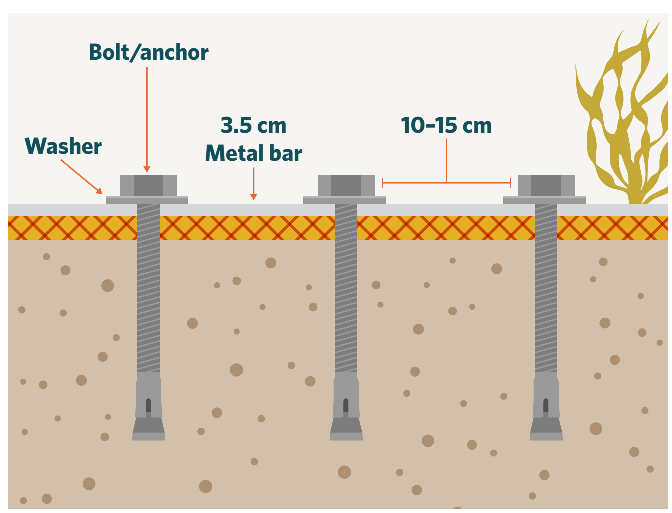

Figure 5.8 Mesh mats; illustration by Jon Ferland

a triangular formation, but we recommend four or more attachment points (in a square or diamond). You can also use metal bars (three to five cm thick), which effectively act as washers running along the mats to achieve better attachment on the rock. You place these bars between the mesh and the bolt head and should bolt them into the rock every 10 to 20 cm.

After you install the mesh, you secure the transplants using four cable ties per individual. The first cable tie is lightly fastened around the stipe, just above the holdfast. It is important to reduce friction damage to the holdfast by covering this cable tie in rubber tubing. You should loop the three remaining ties through the first and then secure it to the mesh. Work to create a triangular attachment pattern around the holdfast of the kelp.

We recommend plastic or metal due to their longevity as current biodegradable options decompose too quickly. In both instances, there needs to be a plan for removal post restoration.

5.5.2 Green gravel

Also covered in the seeding section, an approach termed "green gravel" (greengravel.org) works by inoculating small stones (i.e., gravel or pebbles) with a spore culture, growing them to juveniles or adults in the lab and then dispersing them into the environment. You can spread green gravel by dropping them off the side of the boat, eliminating the need for scuba divers while increasing scalability and reducing associated costs. If the vector (i.e., gravel) is small enough and there is low wave action, the kelps may overgrow the material and work as a transplantation method, as previously described.

5.5.3 Tiles

Tiles made of clay or other materials can be a convenient method to attach transplants on the seafloor (Italy: *Cystoseira*). First, you must attach kelps to the tiles, either with rubber bands, adhesives, or naturally cultured on the tile. Tiles can then be secured in the marine environment. You can screw or bolt these tiles into the rock in a similar manner to the mesh mat method described above.

5.5.4 Glues, rubber bands, and holdfasts

Past projects have successfully used the below methods, but they are unlikely to be viable for large-scale restoration projects.

Glue: A small amount of glue, epoxy, or putty may be used to adhere the holdfast to the rock, although it is important to ensure that it can cure underwater (cyanoacrylate, i.e., superglue and marine epoxy work well for this). Ensure that both the holdfast and the rock are clean and dry before using the adhesive. Place firm pressure on the holdfast so that it sets to the rock substrate. If working intertidally, maximize the amount of time the adhesive must set before the tide comes in. This method has achieved some success, but positive results have not been widespread and may carry a high risk of failure.

Rubber bands: Holdfasts can be secured onto existing reef structure using industrial rubber bands (Layton et al., 2021). Look for rock outcrops that are easy to stretch the band across; conversely this method isn't feasible if the reef is flat and has no attachment points, or in exposed locations. While low cost, these bands have lasted over two years in sheltered sites but may be less efficacious in wave-exposed sites. This longevity can be beneficial for the longevity of the holdfast, but it is an important point regarding their removal from the ocean following restoration.

Holdfasts: You may use the existing holdfast of another kelp as the attachment points for new transplants. Look to find holdfasts that are still firmly attached to the rock and are near the area you want to restore (i.e., patch edge). You can then tie the transplant onto the existing holdfast, attaching it using industrial rubber bands, cable ties, or thick line.

5.5.5 Line attached to bottom

Seeded lines are often used in aquaculture, but you can also use them in a restoration context. Lines are typically made of nylon, but interest is growing in biodegradable materials as well. Seed lines are either inoculated directly with kelp spores in a culture facility (i.e., direct seeding) or twine/string is first inoculated with spores until reaching a certain size and then wrapped around the larger culture/grow line. You can culture the lines in the lab or in the field. Once the seeded lines are ready for installation, you can anchor them on the sea floor using a similar approach described in the mesh mat section. It is important to use enough attachment points such that the line does not move significantly with the waves. Excessive movement of the lines (side-to-side or up and down) can prevent the holdfast from attaching to the rock.

An alternative approach is to secure wood strips to the seafloor using bolts and nail/staple/screw the line into the wood. This approach results in less movement of the line but requires more time and materials. Select a wood that is rot-resistant and will not decompose quickly in the marine environment (e.g., hardwood).

Table 5.4 Transplantation pros and cons

	Pros	Cons	Reference
Mesh mats and cable ties	• Durable (years) • Attach multiple kelps per mat • Good for wave exposed areas • Applicable for many types of substrates	• Potential for plastic pollution • Limited to small scales • Challenging to install	(Campbell et al., 2014)
Gravel	• Scalable • Lower cost • Can seed and culture kelp in lab • Diving not required	• Kelps may not move from gravel to substrate • Vulnerable to wave exposure	(Fredriksen et al., 2020)
Glue	• Quick • Low cost • Easy to apply	• Sensitive to wave exposure and disturbance	(Westermeier et al., 2014)
Tiles	• Can grow kelps on the tiles • No plastic	• Fewer kelps per attachment point in the rock • Expensive • Time intensive	(De La Fuente et al., 2019)
Existing holdfasts	• Low cost • Few introduced materials	• Relies on existing kelp • Not scalable • May have competition if attached to a different species	(Hernandez-Carmona et al., 2000)
Line attached to bottom	• Durable • Covers large area • Line can be seeded and cultured in a lab and/or in marine environment	• Kelps may not move from the line to the rock • Logistically challenging • Expensive • Labour intensive	(FIRA, 2020)
Rubber bands on reef	• Low cost • Quick	• Can be challenging to attach elastic to flat/natural reef substratum • Requires divers	(Vásquez and Tala, 1995)

5.5.6 Key considerations for transplanting

Transplant density: Ensure sufficient density to help promote recruitment, population growth, and avoid overgrazing. Optimal densities will vary by species and local environmental conditions; aim to mimic densities of naturally occurring populations in the area, although it is worth noting that initial transplanting densities may exceed these values to account for transplant mortality. Density is especially important for intertidal species that are exposed to sunlight and rely on canopy cover to avoid desiccation.

Patch size and shape: At the patch scale (1s-100s of meters), larger patches should help modify the environment to facilitate further growth. Patches with less edge-to-area ratios may also be less susceptible to grazing and disturbance.

Kelp life stage: It is best to collect young kelps (< 1 year) for transplantation as they can have higher growth rates and survivorship than mature plants, and there is evidence that removing large adults can damage wild populations, especially for perennial species.

Patch proximity: At the seascape level (100s-1000m's of meters), we encourage users to consider creating a network of patches within close proximity in order to better mimic a natural kelp forest. There is evidence that kelp begets kelp, but exact distances and alignments need further testing before we can make more specific recommendations.

Removal of non-degradable materials: Always make sure to remove any materials introduced into the marine environment after the life cycle has completed or the project has expired.

Substrate: Identify and select substrate that is free from competitors such as turf algae, crustose algae, or other marine life (e.g., tunicates, bryozoans, sponges).

Local provenance/origin: Individuals collected from a site may be best adapted at living in those environmental conditions. Aim to match the environmental conditions between donor and transplant sites.

Wave exposure: Selecting a site with reduced wave exposure or days when wave conditions are low can make transplanting when diving considerably easier. Transplants will also be more likely to remain attached at low wave exposure sites.

Timing of outplanting: The ideal time to outplant will be species- and location-specific, but it is preferable to outplant when factors such as water temperatures are low, grazing pressure is low, reproductive output is high, and/ or light intensity encourages growth.

Time out of water: It is important to minimize the time that kelps spend out of the water, while ensuring you keep them cool, wet, and out of direct sunlight (**chapter 5.3**).

Grazer presence: See **chapter 5.2.5**

5.6 ARTIFICIAL REEFS

The addition of artificial reef may be required due to lack of kelp habitat, if the habitat was destroyed, or because it is easier to transplant or seed on a reef than on natural substrate. People use artificial reefs to introduce new habitat structure for kelps, other seaweeds, benthic invertebrates, and fishes into the marine environment (Baine, 2001). Smaller reefs may also be used in experiments to test methods and ecological theory (Shelamoff et al., 2020). Structures are composed of any added hard material: typically concrete but other materials include stones and metals (Tickell et al., 2019).

Artificial reef installation has a long history outside of kelp forest restoration and afforestation. There are numerous legal, environmental, engineering, and logistical considerations required for installing reefs that are outside the scope of this guidebook. The fields of oyster reef restoration and reef fisheries enhancements have made significant progress in addressing these considerations and may be a good point of reference to learn more about the process (**chapter 5.6.4**). Here we briefly outline the basics of artificial reefs and how they may be used, but **further consultation is required** before creating a reef.

Reefs are a potentially useful method because they are deployable at an exact location, are raised off the seafloor, and protect kelps from urchin grazing and surface disturbances. They also can be designed to facilitate transplanting and seeding, and they do not require existing natural reef (FIRA, 2020). The downsides to using reefs are that they can be very expensive (Eger et al., 2021b), may only cover small areas, may be colonized by species other than kelp (Ohno et al., 1990), and you may face resistance because you are adding materials to the ocean and replacing other habitats (typically sandy bottom). Indeed, installing reefs in areas where kelp has never existed (e.g., sandy bottoms) is afforestation as opposed to restoration. Because reefs can grow new populations that seed nearby populations, we consider them here as a potential tool for restoration.

While there are examples of subtidal reefs being created with a variety of materials (including cars, trains, bombs, and ships in the past), we will only recommend the addition of inert materials designed for the purpose of building a reef (e.g., concrete, stones, and pure metals). We do not advise that you add any unwanted materials to the marine environment. As with any restoration activity, be sure to obtain the proper permits and permissions before commencing work.

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Figure 5.9 Concrete reefs; illustration by Jon Ferland

5.6.1 Concrete reefs

Concrete blocks of almost any shape and design may be used to build an artificial reef (Reed et al., 2006; FIRA, 2020). You should make sure to elevate the reef off the seafloor to protect kelps from urchin grazing and sedimentation (if needed). You should also select materials that are large enough to withstand wave action and not become dislodged, and be sure to place the reef in a location that minimizes habitat reduction and disruptions to other marine activities. You can add reef blocks to the ocean by using cranes to lower them in off barges, and by using GPS technology you can add them to the ocean with high accuracy (United States Army Corp of Engineers, 2019).

You may modify the structure of the reef such that it is easy to install transplants or seed the area. For instance, you can create slots for substrate containing kelp transplants to be added (Fig. 5.9). These slots or the transplants themselves may be attached on the surface, right before deployment. Attaching the materials above water considerably increases the efficiency of transplanting. For seeding, you can create reefs with attachment points for seed bags to be clipped or tied onto (FIRA, 2020). Reefs may also be combined with floating seeded line structures to help seed the surrounding area (Korea: Seaforestation project). Lastly, because increased rugosity helps kelp propagules attach, it can also be beneficial to use a textured surface on the reef structure.

Some projects have experimented with infusing concrete material with nutrients that accelerate kelp growth. Oyamada et al. (2008) added these nutrients (iron and nitrogen fertilizers) to the concrete during the manufacturing process, and the nutrients are slowly released as the block weathers underwater. This approach may be useful in areas where nutrients are limiting to growth.

Figure 5.10 Building an artificial reef. Photo supplied by the authors.

5.6.2 Natural substrate

You may also use natural rock material to provide substrate in the ocean. Different compositions such as granite, andesite, basalt, and sandstone—depending on what is natural, available, and cost efficient for the region—are suggested. These stones are added to ocean by pushing them off a barge, either with an excavator or small bulldozer (Fig. 5.10). These materials may be less expensive than using concrete, but they do not allow the specific modifications that concrete structures do. As a result, you should only use rock materials if the goal is to increase the amount of area available for kelp settlement, and you should not consider them an easier way to complete transplants compared to concrete reefs.

5.6.3 Key considerations for artificial reef deployment

Location: It is possible to build a reef with high location specific accuracy; therefore it is worthwhile considering the location of the reef. You may want to place the reef in an area with high kelp settlement, or when installing multiple reefs in an area, you may want to position them so that there is connectivity among the installed populations. For example, when considering kelp recruitment and increasing chances of successful settlement onto the artificial reef, you can use local current models to assess and determine how kelp propagules will travel and float in your restoration location.

Structure size and shape: The materials must be large enough so that they do not move with wave action or during storms. Projects may also construct the structure in order to minimize drag (e.g., with holes) or place it parallel to the prevailing current direction. These steps will stop the reef from eroding as quickly.

Permanency and removal: Because of their size and weight, it is usually cost prohibitive to remove artificial reefs from the ocean. Therefore, you should consider these installations permanent, as reefs will typically last for at least several decades.

Time of deployment and succession: Artificial reefs remain in the water for many years, but it is still worthwhile considering when you add the materials in the marine environment. The installation process requires calm waters for the barges, boats, and cranes to operate, so you should avoid stormy months.

Further, if the reefs are installed without any kelp material, it may be beneficial to install them during the reproduction period of your target species. Following this approach means that the target species are some of the first to settle and grow on the reef. If you miss the reproduction period, other species may colonize the reef first.

Adding kelp to the reef: Transplanting or seeding kelp on the reef at the time of installation may be the best way to ensure the desired kelp species are the first to colonize the available space.

5.6.4 Further reading

Baine, M. (2001). Artificial reefs: a review of their design, application, management, and performance. Ocean & Coastal Management, 44(3-4), 241-259.

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CHAPTER

6.0 MONITORING AND EVALUATION

Authors: Cayne Layton, Jodie Toft, Bryan DeAngelis

Synopsis: This chapter outlines the motivations and methods for monitoring and evaluating kelp restoration efforts, including what to consider before monitoring; important considerations when designing and implementing a monitoring program; and common methods for collecting kelp forest monitoring data.

Monitoring and evaluation are fundamental to informing whether habitat restoration is necessary (**chapter 2**), what type of intervention may be required (**chapters 4 and 5**), and what the objectives for restoration might be (**chapter 4**). They are also critical for assessing a project's effectiveness once it has begun. Together, this information allows for **adaptive management** and improvements at both the project level (e.g., refining the methods or design) and across multiple projects. The latter can be especially useful for improving general recommendations for kelp restoration practices, such as site selection, restoration methods, or appropriate goals and timelines. These 'programmatic' improvements are especially important for kelp forest restoration, given the relative infancy of the practice and the need to better understand and refine the efficacy, effort, and cost-effectiveness of the various restoration approaches (**chapter 5**).

6.1 WHY MONITOR?

The monitoring of restoration projects is generally conducted to achieve two separate but interconnected objectives. First, monitoring is needed to understand whether the initial restoration action was implemented as intended: so called **implementation monitoring**. The core purpose is to evaluate the immediate restoration method or action (**chapter 5**). Implementation monitoring may therefore focus on kelp-specific metrics (e.g., the number of kelp transplanted) but might also assess other organisms (e.g., the area harvested of urchins) and even technical/construction metrics (e.g., kilograms of seeded gravel deployed; number of artificial reefs installed). This type of monitoring may seem obvious; however, it can be valuable when working with commercial contractors (especially for larger-scale projects) or communicating early milestones and deliverables to funders and regulators. This type of monitoring is also critical in adaptively improving restoration techniques: for example, adjusting the volume/density of seeded gravel based on kelp growth and survival from previous efforts. Accordingly, the second monitoring type is **performance monitoring**, which is used to evaluate the trajectory of kelp forest recovery and whether the restoration activity is achieving its desired objective(s). Performance monitoring tends to focus on ecosystem and environmental conditions (e.g., fish assemblages; sedimentation/turbidity) in addition to the kelp themselves (e.g. recruitment of juvenile kelp).

6.2 KEY CONSIDERATIONS WHEN DESIGNING AND IMPLEMENTING A MONITORING PROGRAM

Performance monitoring needs to occur iteratively and over a longer period than implementation monitoring and ideally should begin *before* the restoration action (further details below). Monitoring should also occur long enough to encompass both short (<1 year) and medium term (>1–5 years) goals, especially since the recovery of kelp forests and their ecosystem services can take many years (Dayton et al., 1992; Babcock et al., 2010; Layton et al., 2020b). Implementation monitoring typically occurs over shorter timeframes but may be iterative and over extended periods when projects have multiple phases or staged restoration actions.

Regardless of the monitoring type, several key concepts are important for any habitat restoration monitoring program. These include planning, establishing clear objectives, and using systematic and standardised monitoring protocols before and after the restoration intervention (DeAngelis and Geselbracht, 2019; Gann et al., 2019).

6.2.1 The importance of objectives and of systematic monitoring

The primary motivation for restoration is to improve or enhance a degraded habitat towards some preferred state, as defined by a 'reference' ecosystem and the primary objective(s) (**chapter 4**). A critical, but often overlooked, first step of any restoration project is therefore to identify the objectives or reference conditions that determine restoration success. A reference ecosystem or site would ideally be a healthy, local, natural kelp forest that is representative

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of the restoration objectives, although a reference model may be developed in those instances when a physical site is not available (**chapter 4**).

Essentially, these objectives and reference conditions become targets for the restoration program and are critical in guiding what monitoring **criteria** or **metrics** will be measured (**Table 1**). Having clear objectives also ensures the most efficient use of monitoring resources, and can aid **adaptive management** or flexible decision-making, which allow for modifications and improvements to restoration programs already underway.

To fully assess whether a project is meeting its objectives, it is necessary to conduct systematic monitoring *before* and *after* the restoration action at the restoration or *impact* site itself, but also at a *control* site. For kelp restoration projects, the control site would likely be an unrestored area that represents the before or pre-restoration conditions (e.g., bare or degraded reef). This is a so called **Before-After-Control-Impact** (BACI) design (e.g. Northern California: Bull kelp & Haida Gwaii: Gwaii Haanas), and together with the *reference* site as a target, allows fair comparison between different sites and their conditions over time and accurate evaluation of restoration effectiveness (Baggett et al., 2014; Gann et al., 2019). Fundamentally, this approach allows the evaluation of any improvements at the restoration site relative to the control location(s), but also the trajectory of recovery and how the restored site is performing compared to the reference site or conditions. To enable fair comparisons, control and natural reference sites should have physical characteristics similar to the restoration site (e.g., flow, wave action, tidal range, salinity, water temperature, substrate type, water depth). Lastly, when pre-restoration monitoring is not possible, the comparisons between the restored and control site(s) become even more critical, as is the need to supplement any findings with comparisons to a reference kelp forest, where possible.

Implementing systematic, reproducible, pre- and post-restoration monitoring also allows for comparison of results across projects, since it eliminates the potential that observed changes are simply due to a difference in monitoring methods. Comparisons across projects can aid assessment of programmatic and/or landscape scale outcomes and help untangle the reasons behind success and failure across different locations. Well-planned monitoring programs also enable data collection to address research questions, which can apply across broader spatial scales and promote general improvements in kelp forest restoration methods and outcomes.

6.2.2 Seasonality and monitoring

An important, but sometimes overlooked, consideration for habitat monitoring programs is the seasonality and frequency of sampling. Seasonal changes can cause natural variations in environmental and biological metrics that might be misinterpreted as impacts from a restoration activity (e.g., animal presence/absence, changes in water quality). Seasonality also directly influences the kelp themselves, including their reproductive cycles, and patterns of growth and perennial/annual survival. As such, it is important that monitoring of specific metrics is relevant and aligned with seasonal patterns. Likewise, the frequency or regularity of monitoring must also be considered relative to the metric being assessed. For some metrics (e.g., adult canopy cover) lower-frequency sampling (e.g., monthly or seasonal) may be sufficient, whereas higher-frequency sampling (e.g., weekly) might be needed where responses may be more rapid or unknown (e.g., survival of outplanted juvenile kelp) (also see **chapter 5**).

6.2.3 Citizen science monitoring programs

Well-managed citizen science programs can help alleviate some of the financial and resource burdens of monitoring, while also facilitating valuable public engagement. When citizen scientists are trained and involved in monitoring, they can provide critical support for evaluating project performance and can serve as project ambassadors who help build community support and understanding of restoration projects. This can be especially useful for marine restoration projects, where limited accessibility and visibility can often cultivate an out-of-sight and out-of-mind mentality among the public. There are several citizen science projects linked with kelp forest restoration and monitoring programs, including urchin control for kelp restoration (e.g. Northern California: Bull kelp (Watanuki et al., 2010; House et al., 2018) and mapping of kelp forest loss and recovery (Kelp Tracker, 2019; (Rosenthal et al., 2018; NW Straits, 2021).

6.3 APPROACHES TO MONITORING

Several resources already describe a range of standardised monitoring methods for rocky reefs, kelp forests, and marine restoration projects (**Box 6.1**). Here we highlight some basic approaches to kelp forest monitoring that we consider most relevant for restoration practitioners. Nonetheless, no single monitoring approach or method is ideal for every application and circumstance, and so when developing a monitoring program, restoration projects should adopt several approaches that best suit their needs.

Box 6.1 Kelp forest and reef habitat monitoring resources

- Effective monitoring of restoration guidebook (NASEM, 2017)
- PISCO kelp forest sampling protocols (PISCO, 2016)
- Puget Sound kelp forest ecological surveys (PSRF, 2020)
- Reef Life Survey methods manual (RLS, 2021)

6.3.1 In-water

In-water surveys are perhaps the most widely used, detailed, and valuable of the monitoring approaches. These surveys can be conducted on the surface by snorkellers or SCUBA divers. Each method depends on a range of factors, including site access, water depth and clarity, and the biological/physical metrics being assessed (**Table 6.1**). In-water approaches do have limitations and restrictions, however, and can be difficult to scale to large areas due to their time- and resource-intensive nature. Divers may also require additional training and qualifications when using specialised breathing and technical equipment.

6.3.2 Remote sensing

Remote sensing uses technology to remotely monitor and survey habitats. Previously, this primarily relied on aerial imaging from aircraft and satellites (Butler et al., 2020; Hamilton et al., 2020; Moro-Sota et al., 2020). However, remote sensing and monitoring from drones is ever-increasing, as are remote approaches for in-water surveys such as Remotely Operated Vehicles (ROV) and Autonomous Underwater Vehicles (AUV) (Marzinelli et al., 2015; Schroeder et al., 2019; Cavanaugh et al., 2021). Due to the remote nature of these approaches, they can be very effective at monitoring and observing very large areas (e.g., hundreds of kilometres), although they can have drawbacks regarding the level of detail and inability to survey many subtidal environments. Remote sensing approaches also typically require access to specialised technical equipment, training, and analyses, although the accessibility and availability of this equipment is rapidly improving.

6.3.3 Coastal or on-water surveys

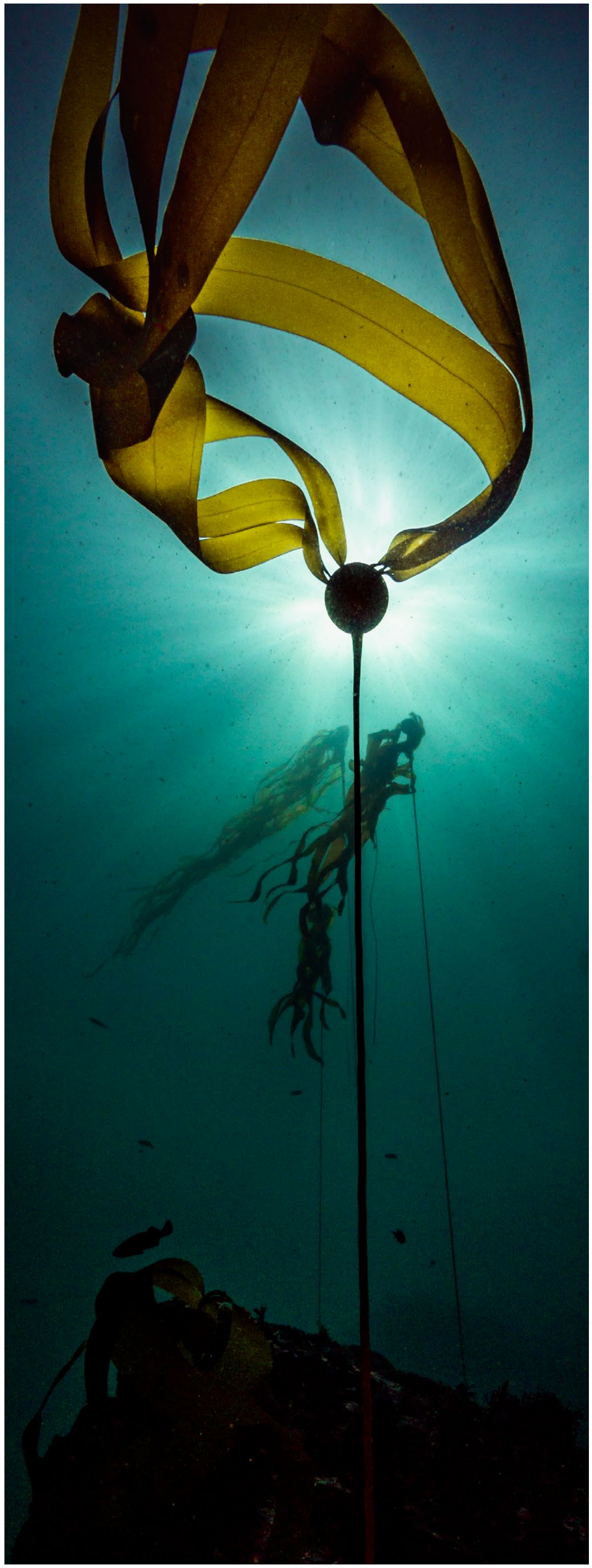
These cover a suite of on-the-water methods that do not involve in-water surveys. Often, these approaches use watercraft, such as kayaks or powered vessels, to survey kelp canopies or biological and physical metrics from the surface. Similar observations can also take place from land in areas where kelp forests (especially those with floating canopies) grow close to the coast. These might also incorporate beach surveys to assess drift seaweed or 'wrack.' These surveys can be low-cost and are not especially resource intensive, and they can also be conducted by relatively unskilled observers, which means they can be effective at covering wide spatial scales. However, these benefits can come at the expense of the level of detail, and there may be physical limitations in assessing some critical kelp forest parameters from the surface.

Box 6.2 Recording project data

Projects must ensure that they archive their project survey information in order to track their progress over time, learn from past mistakes, and share information. Selecting which variables to record and the appropriate formatting can be a difficult process, but consistent data archives can help advance the field of restoration and promote knowledge exchange between projects. We stress that all project outcomes should be recorded, since we can often learn just as much from our failures as we do from successes. Data storage and sharing also allows for formal analysis of project outcomes. As with some other aspects of kelp restoration, data analysis can require specialised or technical skills, but these can likely be facilitated and provided by local regulators and managers, environmental consultants, or universities. The Kelp Forest Alliance has a standardized data sheet, and we recommend that projects use it as a template and upload the results of their project on the kelp forest alliance website (kelpforestalliance.com).

Table 6.1 Examples of monitoring metrics for kelp forest restoration. These are broadly organised as either implementation or performance monitoring metrics, but this categorisation is not strict and can often become mixed. Moreover, some metrics (marked with *) can be considered **ecosystem services** (e.g., fisheries' benefits, carbon cycling), which themselves may also be objectives or even methods of restoration (e.g. improvements in water quality) (**chapter 4**).

Examples of common monitoring metrics
Implementation monitoring
• Area and/or amount of kelp transplanted • Area and/or amount of seeded material deployed • Area and/or amount of artificial substrate deployed • Area and/or number of urchins removed
Performance monitoring
Kelp-specific • Area or percent cover of kelp canopy • Height, density, biomass, or survivorship of individuals • Recruitment of juveniles • Presence/quantity of reproductive tissue (i.e., Sori/ sporophylls) • Indicators of health (e.g., fouling, pigmentation)
Associated community • Mobile organisms (e.g., fishes, large invertebrates) • Sessile and/or benthic organisms (e.g., other seaweeds, sessile invertebrates) • Epiphytes, micro-organisms • Particular species-of-interest » Positive (e.g., commercially valuable species)* » Negative (e.g., destructive grazers/herbivores) • Community production (i.e., nutrient and carbon cycling)*
Environmental/physical factors • Hydrodynamics (e.g., water flow, currents, wave action)* • Subcanopy light levels • Sedimentation* • Turbidity* • Water quality (especially nutrient levels)* • Water temperature



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CHAPTER

7.0 FUTURE-PROOFING KELP FOREST RESTORATION FOR CLIMATE CHANGE

Authors: Cayne Layton, Alejandro Pérez Matus, Alejandra V. González, Melinda Coleman

Synopsis: This chapter outlines the concept of 'future-proofing' in restoration, which encompasses a range of novel approaches in response to kelp loss due to ongoing climate change. These situations are complex because the driver of kelp forest decline cannot be directly ameliorated, and so innovative solutions are needed to boost resilience and optimise restoration success.

For restoration to be effective, the cause of habitat decline must be understood and ameliorated (**chapter 2**). But this is problematic when climate change drives habitat loss, since it cannot be directly overcome before restoration (chapter 1) and will be an ongoing and persistent threat to kelp forests. Given the scale and rate of ongoing climate-change worldwide, there is growing recognition of the need to plan adaptively and 'future-proof' restoration interventions by ensuring that kelp forests can cope with future, and not just current, environmental conditions (Wood et al., 2019; Coleman et al., 2020). Future-proofing can also help us buy time and manage kelp forests while governments pursue the urgent and crucial aim of reducing greenhouse gas emissions to curb ocean change. Nonetheless, even if emissions are rapidly reduced in the near future, there are still decades of warming and change locked in due to climate inertia and lags between today's emissions and tomorrow's climate (IPCC, 2021). It is therefore critical to ensure that restoration interventions are as dynamic as the environments in which they occur.

Kelp forests are in decline in many regions globally due to direct and indirect impacts from climate change (Johnson et al., 2011; Filbee-Dexter et al., 2016). Across these regions, climate change is outpacing the ability of kelps to adapt, while episodic events (e.g., marine heatwaves) and ongoing stressors (e.g., ocean warming) are eroding the adaptive capacity and genetic resilience of kelps (Coleman et al., 2020; Gurgel et al., 2020; Wood et al., 2021). Proactive and innovative future-proofing strategies are therefore required for kelp forest restoration, and not only in the medium- to long-term but even short-term in those regions where climate-driven impacts are already causing kelp loss.

7.1 FUTURE-PROOFING STRATEGIES

There are three general and intersecting strategies for future-proofing restoration interventions: genetic rescue, assisted gene flow, and genetic manipulation and assisted expansion (Van Oppen et al., 2017; Coleman et al., 2020; Wood et al., 2021). The optimal strategy will depend on the underlying vulnerability and adaptability of the kelp species under consideration. Moreover, these strategies are not mutually exclusive, and a combined or portfolio approach is often recommended. The fundamental goal of all strategies, however, is to facilitate and accelerate the rate of naturally occurring evolutionary processes in order to boost ecosystem resilience to future conditions and change. We describe these strategies here in approximate order of the severity of the intervention. While some approaches have been investigated at the research-scale for kelp forests, many are still hypothetical and under debate.

7.1.1 Genetic rescue

Diversity at the genetic level underpins any populations' ability to respond to change. Yet many natural populations are now genetically degraded due to habitat fragmentation and loss. The strategy of 'genetic rescue' focuses on enhancing the genetic diversity of such populations to boost their adaptive potential and resilience to future conditions. This might include planting and restoring individuals from genetically diverse populations (but the same species) to disconnected or depauperate populations (Wood et al., 2019, 2020). Such populations may have been connected historically but since become isolated and degraded due to human impacts (Coleman et al., 2020; Gurgel et al., 2020; Wood et al., 2020). This approach may be especially useful where there is no current direct climate-driven threat to a kelp forest and thus only limited climate-driven current selective pressure. Also see Sourcing and Provenance in **chapter 5.3.**

7.1.2 Assisted gene flow

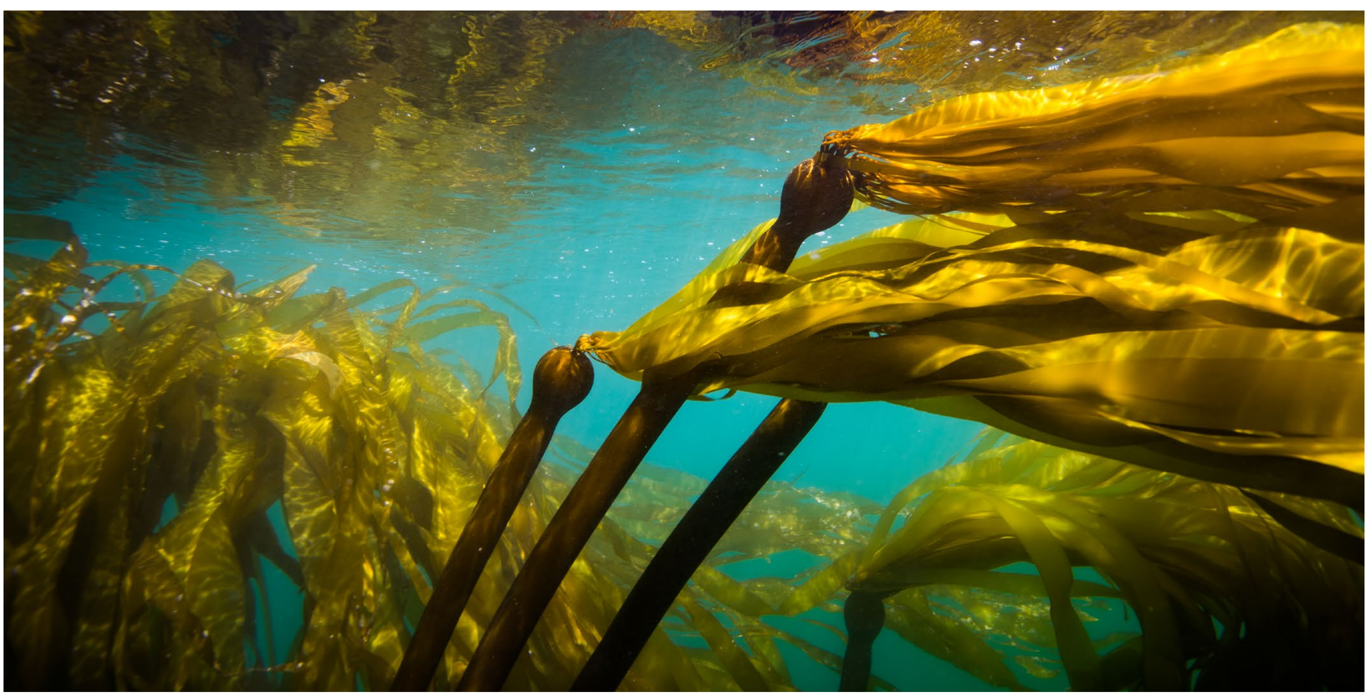
Taking this a step further, an 'assisted gene flow' strategy focuses on the movement and restoration of naturally adapted or tolerant individuals into threatened populations in order to increase resilience to an identified stressor (e.g., ocean warming). This approach may suit circumstances with current or anticipated near-future climate-drivers of kelp forest loss, and where increasing genetic diversity (via genetic rescue) may be counter-productive and inefficient since selective pressure may instead favour (or require) a better adapted genotype (Coleman et al., 2020; Miller et al., 2020; Vranken et al., 2021). Selective-breeding approaches can be used to identify and breed the adapted or tolerant individuals to be used for restoration trials. Such approaches are already being considered/trialled in locations where climate-driven kelp losses have been particularly severe (CASEAGRANT, 2021; Layton and Johnson, 2021). Similar breeding techniques and cultivar development are more common among kelp aquaculture operations (Goecke et al., 2020) and demonstrate the potential for knowledge-sharing and collaboration among the restoration and aquaculture sectors.

7.1.3 Genetic manipulation, assisted expansion, and novel communities

Other more extreme strategies to future-proof restoration efforts include sophisticated genetic techniques and those that assist a species' expansion outside their native range. These might include genetic engineering to enhance or introduce specific traits (Coleman and Goold, 2019; Jueterbock et al., 2021) or the use of naturally occurring (or artificially stimulated) co-species 'chimeras' that are better adapted to novel conditions (Chile: Chimera trials). Assisted expansion, on the other hand, may aim to shift an at-risk species to a new, more suitable 'refugia' environment to aid its long-term persistence if it cannot survive in its current range. Alternatively, new species of kelp (or other seaweeds) that are better suited to future conditions might be restored instead. The intent there would be to create novel ecological communities to maintain the function of the ecosystem as a whole, rather than to maintain the presence of a particular kelp species (Vergés et al., 2019).

7.2 DECISION-MAKING AND PLANNING FOR FUTURE-PROOFING

Evidence-informed dialogue and decision-making are critical to planning, developing, and achieving support for future-proofing solutions. The innovative nature of these approaches raises challenging scientific and ethical questions (Coleman and Goold, 2019; Filbee-Dexter and Smajdor, 2019), since the intention is not to restore a pre-existing or historical community but instead to modify it to be more adapted and resilient to modern environmental conditions. Accordingly, the potential risks of action (e.g. maladaptation, genetic pollution) must be assessed alongside the current and potential risks of inaction and ongoing kelp loss (Coleman and Wernberg, 2020). This balance of risks suggests future-proofing interventions may be more amenable where and when kelp forest losses have already



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been severe (or are predicted to be in the near-future) or may cause particularly damaging effects on ecological and human communities. This logic also highlights the potential of preventative and proactive future-proof restoration (i.e., taking action prior to severe losses) to boost resilience and ensure kelp forests do not experience such precipitous declines in the first place.

The decision-making and planning process for future-proof interventions must incorporate dialogue among researchers, practitioners, managers, policymakers, and the broader community (Coleman and Bragg, 2020; Gaitán-Espitia and Hobday, 2020; Gaitán—Espitia and Hobday, 2021). Critically, there must be community-wide input and consensus on how we want kelp forests to look and function in the future, and what services we want/need them to provide. Together, these considerations will dictate when and how to restore, whether future-proofed interventions are desired or required, and what type of intervention may be most suitable.

7.3 KNOWLEDGE GAPS, AND TOOLS TO SUPPORT FUTURE-PROOFING

The design of future-proofing interventions relies on understanding patterns of overall and adaptive genetic diversity and gene flow among populations and also predicting how these may change under future conditions (Vranken et al., 2021; Wood et al., 2021). Unfortunately, this knowledge is scant or absent for most kelp species, which impedes our understanding of a species' adaptability/vulnerability and the pathways for potential restoration. In those cases, modelling and simulations can be useful to predict patterns of natural dispersal from desirable to vulnerable populations (Quigley et al., 2019) or to evaluate environmental and biological factors and identify potentially resilient, vulnerable, or refugia populations of kelps (Martínez et al., 2018; Davis et al., 2021). However, even where resilient individuals/populations have been identified (Miller et al., 2020; Layton and Johnson, 2021), we currently have little understanding of the physiological mechanisms that underpin their improved performance and adaptation.

Considering ongoing kelp declines and the potential for genetic interventions to be combined with restoration efforts, there should be increased focus on the conservation of kelp genetic diversity via the use of seedbanks or genebanks (Barrento et al., 2016; Wade et al., 2020; Layton and Johnson, 2021). These can help preserve the genetic heritage and/or unique local-scale diversity, support future restoration and conservation efforts, and provide contingency in the case of severe environmental losses. As with selective breeding, these banking operations have significant crossover with kelp aquaculture operations and represent areas of high potential for collaboration and co-investment between kelp restoration and aquaculture sectors.

Ultimately, while careful planning and research are essential to the development and implementation of future-proofed kelp forest restoration, these actions must be considered alongside the risks of inaction. Even now, 'pristine' or undisturbed kelp forests may not exist, and there is increasing agreement that recreating past (or even present) communities can be challenging given the rate and scale of ongoing change in our oceans. It is therefore critical that we do not restore nostalgically but instead restore for the future and to ensure the long-term survival of the kelp forests we want and need.

7.4 Further reading

Coleman et al. 2020a, Restore or redefine: future trajectories for restoration.

Gaitán-Espitia & Hobday 2020, Climate change adaptation efforts for conserving species must not be antagonistic to natural evolutionary responses.

Goecke et al. 2020, Cultivar development of kelps for commercial cultivation—past lessons and future prospects.

CHAPTER

8.0 CONCLUSION

We anticipate a bright future for the field of kelp forest restoration, one that will grow rapidly in response to changes in kelp forest dynamics around the world. Many new projects are emerging, and there is a widespread interest in kelp forest ecosystems that did not exist a decade ago. This guidebook aims to synthesize knowledge from global experts from a diverse set of backgrounds and experiences in the field and provide recommendations and pathways that can be applied by local restorationists in order to achieve their unique objectives for kelp restoration. Kelp restoration is a long term, multifaced venture that influences many different ocean users. We therefore encourage readers and restorationists to consider *all* the elements of the restoration process that have been outlined here and work to make restoration a holistic process.

Following this guidebook does not guarantee project success but can help ensure that restorationists are well informed about the options available to them and how various approaches have been applied in projects to date. The fundamental elements of kelp restoration will not change, but the methodological approaches will almost certainly be further adapted and improved as the field continues to evolve. As such, more information will continue to become available, and users should stay informed as to the latest updates and lessons learned from restoration projects.

We encourage users of this guidebook to engage with the global kelp forest restoration community, document and share the outcomes of their project(s), and view newly available information about restoration at the Kelp Forest Alliance website (kelpforestalliance.com). As kelp forests continue to face threats and suffer declines from climate change and human impacts, the role of kelp restoration in securing a future for these important marine ecosystems will only grow. Further collaboration and knowledge exchange between restorationists can help ensure growth in the field and enhance kelp forest restoration around the world.

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ACKNOWLEDGEMENTS

We would like to thank the participants of four kelp restoration workshops, whose input helped to guide and inform the writing of this guidebook. We would also like to thank the people who engaged in discussions and conversations about their experiences with restoration, the lessons they learned, and the work that would be most useful to the kelp restoration community. In particular we would like to thank Tom Ford, Dan Reed, Rietta Hohman, John Minnehan, Alejandro Buschmann, Natalio Godoy, Julio Vasquez, Hartvig Christie, Camilla With Fagerli, Pippa Moore, Hannah Earp, and Ines Louro.

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RESTORATION IN PRACTICE: PROJECTS FROM AROUND THE WORLD

Summary

The following are examples of kelp restoration in practice from around the world. They span a range of environments, approaches, and target species. Together, they provide examples of coordinated restoration programs and explain why restoration was necessary and initiated, who was involved, the methods used and whether they were successful, the costs involved, and, importantly, the lessons learned. The case studies are not intended to provide step-by-step instructions for restoration; rather, these models can be referred to while reading the guidebook chapters, and they provide many on-the-ground examples of the topics and concepts discussed herein. Restoration practitioners may also be interested in reviewing the studies most similar to their circumstances and conditions, or they may benefit from exploring how kelp forest restoration is done in different regions and with different species.

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Bull Kelp Restoration in the Mendocino Region of Northern California

Authors: James Ray, Tristin Anoush McHugh, Michael W. Esgro, Kristen Elsmore, Jan Freiwald

KEY TAKEAWAYS

- Collaboration and communication among managers, fishers, researchers, and the community enabled adaptive management and modifications to ongoing urchin harvest activities in order to facilitate kelp recovery.
- Commercial urchin divers were used to reduce urchin densities to <2 /m^2, and initial evidence suggests signs of kelp recovery.

BACKGROUND

Bull kelp (*Nereocystis luetkeana*) is the foundation species of the nearshore kelp forest ecosystem along California's North Coast (Springer et al. 2010). Between 2013 and 2020, a combination of oceanographic and ecological stressors led to unprecedented declines of over 96% of bull kelp canopy and habitat across much of the 350 km region (McHugh et al. 2018; Rogers-Bennett and Catton 2019; McPherson et al. 2021). Stressors included elevated water temperatures, potentially increased recruitment of native purple sea urchins (*Strongylocentrotus purpuratus*), and the absence of urchin predators (Okamoto et al. 2020). The near extinction of sunflower sea stars (*Pycnopodia helianthoides*), beginning in 2013 due to sea star wasting syndrome, compounded the loss of sea otters (*Enhydra lutris)* extirpated around the mid-nineteenth century. This rapid and expansive decline of kelp severely disrupted ecosystem functions and services leading to the declaration of a federal fishery disaster for the region's valuable commercial red sea urchin (*Mesocentrotus franciscanus*) fishery in 2015-2016 and the closure of a $44 million USD recreational red abalone (*Haliotis rufescens*) fishery in 2018 (Rogers-Bennett and Okamoto 2020). Persistent high densities of purple sea urchins continue to suppress kelp recovery in the region, despite marine heatwave conditions subsiding (McPherson et al. 2021).

THE PROJECT

In order to create a network of bull kelp refugia to create habitat, preserve genetic diversity, and maintain spore sources to facilitate broader bull kelp recovery (Hohman et al. 2019), local communities and state agencies began exploring opportunities to address kelp forest loss in the region. In early 2020, the Mendocino Kelp Forest Restoration Project (KFRP), managed by the non-profit Reef Check Foundation and the California Department of Fish and Wildlife, was designed to evaluate the feasibility of such a management approach by reducing urchin grazing pressure, with key objectives being: 1) reducing urchin density at restoration sites to <two urchin/m^2 by working with commercial urchin divers to harvest urchins; and 2) accurately documenting cost/benefits of removals to assess potential scalability. This project is being leveraged by collaborators from other institutions to further enhance understanding of kelp restoration practices and ecosystem outcomes including evaluating kelp outplanting methods as an approach to restoration (Moss Landing Marine Lab); investigating the effects of kelp on modulating current and wave hydrodynamics (University of California Davis); and exploring the utility of high-resolution aerial drones for monitoring canopy cover recovery at restoration sites (The Nature Conservancy). Importantly, project partners from the community have generated education and outreach materials, including classroom materials, public exhibits, and presentations to disseminate information on kelp forest ecology, drivers of kelp decline, and ongoing restoration efforts. The California Ocean Protection Council provided $617,000 USD of funding over 1.5 years for the KFRP, with The Watermen's Alliance, a non-profit sport diver organization, contributing an additional $60,000 USD. Funding was allocated approximately evenly between urchin removal efforts and scientific monitoring and outreach.

The project targets two restoration sites in Mendocino County—Noyo Harbor and Albion Cove—each approximately four hectares in size and ranging from 2-15 m in depth. Restoration sites were selected (1) to be adjacent to remnant kelp patches in order to maximize protection of existing kelp and enhance potential natural recolonization of the restoration site; (2) to minimize urchin encroachment after removals; (3) to have historic persistence of kelp; and (4) to be accessible for divers. To understand ecological impacts of the restoration activities, the algal, invertebrate, and fish communities at the restoration sites, as well as unmanipulated control sites, are monitored using fixed transects and Reef Check California's monitoring protocol. A Before-After-Control-Impact study design is being used to evaluate the outcomes of the restoration efforts based on the monitoring data. To understand the effects of restoration activity on urchin biology at the sites and evaluate the effectiveness of removal techniques, gut content, reproductive potential (gonad weight), size-frequency, and bycatch of harvested urchins are also monitored.

To deploy divers efficiently, restoration sites were demarcated with a 150 m benthic cable using markers every 10 m that could be referenced when coordinating urchin and research divers. Commercial divers were then asked to run meter tapes from assigned markers perpendicular to the benthic cable (creating "swim lanes" or "cells") to systematically remove urchin from targeted areas and report distance of area cleared. Research divers then performed quality control surveys to capture urchin densities within "cells" to best guide removal efforts. Combining fishermen's observations with almost real time information on urchin distribution and density allowed project managers to systematically guide commercial dive efforts and improve diver accountability.

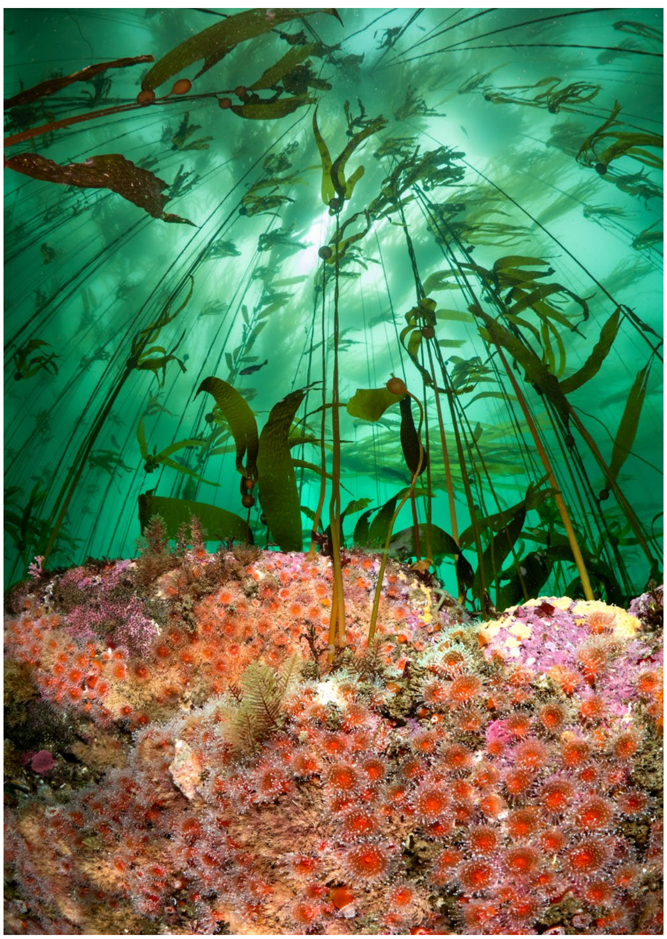
Efforts to remove purple urchin at Noyo Harbor began in August 2020, and the season concluded in November 2020. Within this time, purple urchin density was reduced to 40% of pre-restoration levels, representing over 11,800 kg in purple urchin wet weight. Across 49 individual diver days (two divers/vessel), the target threshold of two purple urchin/m^2 was achieved. However, when combined with red urchin, the total urchin density exceeded 2 urchin/m^2, potentially hindering kelp recovery. Divers were able to harvest approximately 453 kg of legal-sized red urchin from the site; however, urchin size-frequency surveys indicated most red urchin at the site were of sub-legal-size class and not commercially harvestable, necessitating an adaptive adjustment in our approach to further reduce all urchin densities.

This project is ongoing, and quantitative results on broader ecological responses of the grazer reduction efforts are currently being published. Anecdotally, young kelps began to appear at the site within weeks of beginning urchin removals. In some areas within the restoration site, kelp individuals reached the surface and were reproductive by May 2021. Kelp canopy has increased between survey dates, and quantitative results are pending.

Noyo Harbor, site of kelp restoration work in Mendocino County, California. Photo provided by the authors.

LESSONS LEARNED

Engaging with diverse management, scientific, and community partners early in the process resulted in a project that addresses necessary technical and regulatory considerations but also identifies important local perspectives on project goals and approaches and builds trust. For example, monitoring data indicated red urchin removal was necessary to reach the project goal of <2 urchins/m^2. Collaborative dialogue with commercial urchin divers affiliated with the project, who rely on red urchins for their livelihoods, resulted in adaptive solutions to red urchin removals that were in alignment with both project and partner goals. Solutions included adjusting the location of a proposed restoration site to avoid an area with known high red urchin density and translocating red urchins from restoration sites to appropriate locations via a scientific collection permit, rather than sacrificing them. In continuing this approach throughout project implementation, adaptive changes were made transparently, driven by project data where possible, and included consultations with all partners. Although this approach sometimes reduces the speed of decision making, it is important for maintaining positive collaborative relationships.



Bull kelp forest in northern California. © Patrick Webster

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PROJECT 2

Operation Crayweed

Restoring Sydney's Missing Underwater Forests and Engaging Local Communities

Authors: Adriana Vergés, Derrick Cruz, Madelaine Langley, Georgina Wood, Damon Bolton, Alexandra H. Campbell, Melinda A. Coleman, Peter D. Steinberg, Ezequiel M. Marzinelli

KEY TAKEAWAYS

- Community engagement, art-science collaborations, and science outreach all cultivated marine stewardship for local kelp forests and helped generate resources for their restoration.
- The installation of mesh mats on bare rock with adults tied to the mats can be an effective way to transplant adult kelp in relatively high wave environments.

BACKGROUND

Crayweed (*Phyllospora comosa*) is one of Australia's most ecologically important seaweeds, which forms extensive underwater forests along ~5,100 km of coastline in south-eastern Australia and around Tasmania. As a foundation species, crayweed supports a unique ecological community that includes two of Australia's most valuable fisheries: abalone and rock lobster (or crayfish, from which it gets its name). Crayweed completely disappeared from 70 km of Sydney's metropolitan coastline in the 1980s, although scientists only documented this in the mid 2000s. The disappearance was linked to major sewage pollution at the time. Although water quality improved dramatically along the city's shoreline following the installation of deep ocean outfalls in the 1990s, populations of crayweed did not re-establish in the region, resulting in a persistent fragmentation of this species' distribution.

THE PROJECT

A pilot restoration experiment involving scientists from multiple universities, the New South Wales government, and community volunteers, successfully re-established crayweed at two Sydney sites in 2011. Crayweed from existing populations, north or south of Sydney, were transplanted onto Sydney reefs by scuba divers using mats drilled into the seafloor, cable-ties, and silicon tubing. Survival and reproduction of crayweed, as well as associated biodiversity, were monitored and compared to crayweed forests outside of Sydney and to non-restored sites in Sydney. Transplanted crayweed showed comparable survival rates to natural populations and reproduced in their new habitats. Recruitment rates were higher than in natural populations at one experimental site, while herbivory emerged as an important factor limiting restoration success at the other site. Some components of biodiversity, such as epifauna, started to resemble those found in extant crayweed forests (monitoring continues to date).

A science communication and crowdfunding campaign was launched to raise funds to scale-up crayweed restoration efforts. A name (Operation Crayweed), logo, website (www.OperationCrayweed.com), short film and associated social media pages were created. The crowdfunding campaign was launched in November 2015 and asked the public to "give an underwater tree" for Christmas. The project was featured in multiple national TV news bulletins as well as in national and international print and online media, leading to the team doubling their initial funding target (AU$20,000). These efforts led to an Australian Research Council Linkage grant and significant philanthropic support.

Following this funding success, genetic studies were integrated into the scaling-up of crayweed restoration efforts at five new reefs across Sydney. Donor sites were selected following the genotyping of nearby extant populations in an effort to replicate regional population genetic diversity and structure. Although donor provenance influenced survival, with transplants from northern sites surviving for longer than southern transplants, genotyping of the next generation showed a mix of genes from both north and south populations. Genomics of populations along the entire latitudinal distribution of crayweed is currently being used to identify donor populations/genotypes that may be tolerant of warmer waters in order to future-proof restored sites.

One important aim of Operation Crayweed is to engage local coastal communities in order to raise awareness about the importance of kelp forests and to showcase how science can be effectively used to reverse environmental degradation. One event, Sculpture by the Sea, involved over 100 local school children and attracted over 450,000 visitors. This science, art, and education collaboration has continued throughout the lifespan of the project, leading to field excursions, laboratory lessons, and the creation of a short animated film. The Operation Crayweed team also led a month-long Seaweed Forests Festival in 2021. By combining art, food, and science, this festival engaged people to get them to emotionally invest in the extraordinarily important seaweed ecosystems that underpin the Sydney coastline, the broader importance of seaweed to Australia's marine ecosystems, and the potential of seaweed to address current world problems.

The strategy of Operation Crayweed to re-establish crayweed forests along the Sydney coastline of Australia employs/ed an "applied nucleation" approach, whereby crayweed is/was transplanted onto small (<25 m^2) plots in different reefs, acting as propagule sources for subsequent natural establishment. Crayweed restoration has been attempted in 16 Sydney reefs over a 10-year period (2011-2021), including sites where scientific experiments tested additional factors such as optimal size of transplant plots, the impact of herbivores, and the importance of genetics. Seven of these 16 sites are now self-sustaining, with crayweed recruiting onto the reefs with expanding distributions and without further interventions from the team (total area ~ 4,300 m^2). Biodiversity associated with some of these forests is starting to resemble that found in reference locations. Restoration at three of the other sites started very recently, so it is too early to assess results. In six of the remaining sites, restoration was either fully or partially unsuccessful (few individuals recruited), due mostly to high levels of herbivory and/or burial by sand.

Estimated revegetation costs are US$46,250/ hectare (2018 year of evaluation). This figure includes materials, transport, and personnel, but excludes project management, genomic assessments, and monitoring, as well as initial and ongoing scientific research done to develop and optimise the restoration methods. The figure also excludes outreach activities, such as collaborations with artists and other events.

LESSONS LEARNED

- It matters when, how, and where transplants are placed within a reef (the best results are obtained when plants are physically transplanted in relatively sheltered areas where donor plants are more likely to persist for longer, near other benthic macroalgae to enhance recruitment and there is higher survival/recruitment over colder seasons).
- Some sites may be more vulnerable to herbivores or storms than others and may need more frequent monitoring and multiple plantings before they are successful.
- Knowledge of genomics of donor populations allows the restoration of genetically diverse populations and can be used to inform future-proofing strategies.
- Associated biodiversity in restored sites may take time to resemble biodiversity in extant, reference forests.
- Storytelling/science communication increases engagement, public benefit, and funding for restoration.

Operation Crayweed crew member Damon Bolton attaches adult crayweed from a donor site onto plastic mesh plots, which are drilled onto rocky reefs and removed once self-sustaining populations become established. © John Turnbull

Community restoration planting in Freshwater (Sydney, Australia). By engaging local communities, the Operation Crayweed project aims to increase awareness about the importance of underwater forests. © Leah Wood

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PROJECT 3

Haida Gwaii, Canada

Chiix̱uu Tll iinasdll, Nurturing Seafood to Grow, and Kelp Forest Restoration in Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve, and Haida Heritage Site

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KEY TAKEAWAYS

- This project engaged rightsholders and stakeholders in the restoration process, which enabled inclusive representation and provided tangible benefits due to the diverse sources of knowledge and expertise.
- Monitoring at control sites helped determine whether population fluctuations at the restoration site were the result of environmental factors or the restoration actions.

BACKGROUND

Kelp forests along the coast of British Columbia (BC), Canada, have been diminished since the loss of a coastal keystone predator, ḵuu—sea otter (*Enhydra lutris*), due to the maritime fur trade. On X̱aayda Gwaay—Haida Gwaii, a remote archipelago in northern BC, ḵuu have been functionally extirpated since the early to mid-1800s. Absence of sea otter predation led to hyperabundance of their invertebrate prey, including sea urchins. In more recent years, dramatic declines of a formerly ubiquitous mesopredator, sunflower star (*Pycnopodia helianthoides*), from sea star wasting disease has also contributed to high urchin grazing rates. Losses of important predators of urchins and changing ocean conditions that are unfavorable for kelp have further diminished kelp forests here.

THE PROJECT

To improve kelp forest habitat for culturally and ecologically important kelp-dependent species like northern abalone, rockfishes, herring and salmon, Gwaii Haanas cooperative management partners—Council of the Haida Nation, Parks Canada, and Fisheries and Oceans Canada—worked collaboratively with urchin fishing industry partners to mimic sea otter predation by reducing urchin abundance by 75-95% at the restoration site through commercial fishing, traditional fishing, and cracking of urchins underwater. Importantly, this restoration work is guided by Haida ethics and values (Fig. 1): Yahguudang—Respect, 'Laa guu ga ḵanhllns—Responsibility, Gina 'waadluxan gud ad kwaagid—Interconnectedness, Giid tlljuus—Balance, Isda ad dii gii isda—Giving and Receiving, and Gina k'aadang.nga gii uu tll k'anguudang—Seeking Wise Counsel. Acknowledging the complex nature of ecosystem linkages and dynamic ocean conditions, we gave careful consideration to the restoration method, given that urchins are natural parts of kelp forest communities and that guuding.ngaay—red urchins (*Mesocentrotus franciscanus*) can live for over a century. In this case, we decided that targeted red urchin removals, along with removal of less abundant green and purple urchins, could help achieve culturally and ecologically meaningful restoration gains.

The Gwaii Haanas kelp forest restoration site lies within a strict protection zone and Abalone Stewardship Area that is normally closed to commercial urchin fishing, encompassing ~20 hectares of shallow subtidal rocky reef along 3 km of shoreline from 0-15 m depth. Although time-consuming and costly, urchin removal by scuba divers using hand tools ensured that non-target species and habitat were unharmed by restoration activities. Urchin removal and crushing occurred in two events: (1) fall 2018 with 49-person dive days, and (2) spring 2019 with 80-person dive days. These initial efforts removed ~90% of the urchins, reducing urchin densities from ~6.5 to ~0.6 urchins /m^2, and we are working with commercial harvesters to annually maintain similarly low urchin densities at the restoration site over the longer term. Gwaii Haanas Parks Canada and the Haida Nation also prioritized sharing guuding.ngaay—red urchin, styuu—green urchin (*Strongylocentrotus droebachiensis*) and daws styuu—purple urchin (*S. purpuratus*), which are traditional foods, with local communities as a cultural component of the urchin removals. School programs, outreach at community events, and public and scientific presentations to share knowledge about ecology and traditional Haida values associated with kelp forest ecosystems are also integral to the project.

By collaborating with multiple academic partners, we are leveraging restoration actions to advance knowledge about how kelp restoration alters ecosystem structure and function, including effects on key species. We established permanent monitoring transects to survey for annual changes in algal, invertebrate, and fish communities at the restoration site and a nearby control site. Pre-restoration monitoring occurred in summers 2017 and 2018, and post-restoration monitoring in summers 2019, 2020, and 2021. Research throughout the project includes investigating changes in the growth rates, respiration rates, and food sources for abalone and red urchin, and in red urchin gonad mass.

Some ecosystem responses were rapid. Compared to pre-restoration conditions, post-restoration 2019 surveys showed a 15-fold increase in kelp stipe density and four-fold increase in kelp canopy cover, increased kelp depth from 0.5 to 8 m depth, continued low urchin densities, increased quantity of roe in red urchins, and maintenance of northern abalone densities. Control site surveys provided baselines for natural processes. Ecosystem responses varied between the two post-restoration surveys with much stronger kelp responses in 2019 than in 2020, potentially attributed to differences in kelp recruitment. Post-restoration monitoring and research will continue to track kelp forest community structure and dynamics.

Parks Canada is primarily funding and supporting the five-year project from 2017-2022 for ~$2.9M Cdn. Restoration work is being implemented through in-kind management support from Fisheries and Oceans Canada, and contracted support from Haida Fisheries Program and Pacific Urchin Harvesters Association. Monitoring and research are funded and in-kind from Florida State University, University of Oregon, University of British Columbia, University of New Brunswick, Hakai Institute/Tula Foundation, and Haida Fisheries Program. In-kind longer-term restoration maintenance work is being discussed with the Pacific Urchin Harvesters Association, and additional research funding will be pursued to track longer-term changes.

LESSONS LEARNED

Respectfully engaging management partners, collaborators, community values and knowledge systems from the start fosters success. Actively building and maintaining relationships and trust among collaborators right from project inception has been critical to our project success. Broad engagement helps incorporate diverse perspectives and funding support throughout the project. Our guiding principles are based on Haida ethics and values that are supported through cooperative management between the Haida Nation and Canada via the Gwaii Haanas Archipelago Management Board. This co-governance model further prioritizes involvement and capacity building for Haida citizens in restoration and monitoring activities within Haida traditional territory. Together, Haida traditional and western scientific knowledge systems provide critical multi-faceted expertise that draws on strengths of both worldviews. A technical team (with representatives of all collaborators), a higher-level steering committee with representatives from governance bodies, and an external kelp restoration expert all provided guidance for project logistics, monitoring, implementation, and research. Incorporating communications and outreach plans, particularly for local communities and schools, help to establish and maintain community support and foster a broad base of long-lasting knowledge.

Creative partnerships can help achieve longer-term success towards shared conservation goals. By building partnerships with local communities, the commercial urchin fishing association, and fisheries management, we could harvest urchins that had grazed sufficient kelp to develop high quality roe for community food or markets as part of the urchin removals for restoration work. These partnerships may be able to help maintain low urchin densities at the restoration site by working with the commercial fishing association to continue fishing and urchin cracking as part of the red urchin commercial fishing season each year. By allowing a limited Haida-monitored fishery in the closed area, long-term restoration maintenance is possible and may also help reduce urchin densities in adjacent areas.

Staying adaptive and flexible promotes project resilience in light of rapidly changing ecosystem conditions. Differences in kelp recovery between summers 2019 and 2020 reinforced that restoration outcomes are subject to changing ocean conditions and consistent results between years should not necessarily be expected. Changing ocean conditions highlight the benefits of establishing a control site, longer-term site maintenance, monitoring for environmental change, and research to understand restoration-related ecosystem dynamics. For example, in spite of continued low urchin densities at the restoration site, kelp recovery in the second post-restoration year was greatly reduced compared to the first year, and higher seawater temperature may be negatively affecting kelp recruitment and growth; yet the recent natural return of sea otters to Haida Gwaii should maintain and enhance restoration gains when k̲uu move into the area. When and to what degree these and other changes will happen are unknowns that we will try to anticipate before adjusting plans as needed.

GUIDING PRINCIPLES

These guiding principles are based on ethics and values from Haida law. They were adapted to support planning on Haida Gwaii and have been modified for the Gwaii Haanas context. They align with principles of ecosystem-based management described in scientific, planning and management literature.

Yahguudang—Respect.
We respect each other and all living things. We take only what we need, we give thanks, and we acknowledge those who behave accordingly.

'Laa guu ga kanhllns—Responsibility.
We accept the responsibility to manage and care for the land and sea together. We work with others to ensure that the natural and cultural heritage of Gwaii Haanas is passed on to future generations.

Gina 'waadluxan gud ad kwaagid—Interconnectedness.
Everything depends on everything else. Healthy ecosystems sustain culture, communities and an abundant diversity of life, for generations to come.

Giid tlljuus—Balance.
The world is as sharp as the edge of a knife. Balance is needed in our interactions with the natural world. Care must be taken to avoid reaching a point of no return and to restore balance where it has been lost. All practices in Gwaii Haanas must be sustainable.

Gina k'aadang.nga gii uu tll k'anguudang—Seeking Wise Counsel.
Haida elders teach about traditional ways and how to work in harmony with the natural world. Like the forests, the roots of all people are intertwined. Together we consider new ideas, traditional knowledge and scientific information that allow us to respond to change in keeping with culture, values and laws.

Isda ad dii gii isda—Giving and Receiving.
Reciprocity is an essential practice for interactions with each other and the natural and spiritual worlds. We continually give thanks for the gifts that we receive.

GUIDING PRINCIPLES	ECOSYSTEM-BASED MANAGEMENT PRINCIPLES
Yahguudang—Respect	Precautionary approach
'Laa guu ga kanhllns—Responsibility	Inclusive and participatory
Gina 'waadluxan gud ad kwaagid—Interconnectedness	Integrated management
Giid tlljuus—Balance	Sustainable use
Gina k'aadang.nga gii uu tll k'anguudang—Seeking Wise Counsel	Adaptive management
Isda ad dii gii isda—Giving and Receiving	Equitable sharing

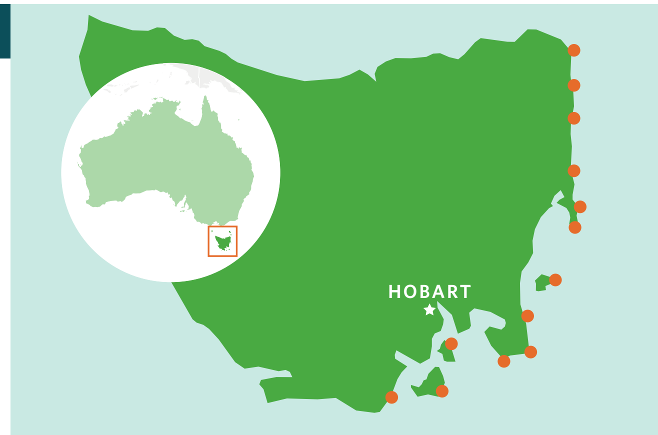
Figure 1 Haida ethics and values as guiding principles. Excerpt from Gwaii Haanas Gina 'Waadluxan KilGuhlGa Land-Sea-People Management Plan 2018, https://www.pc.gc.ca/en/pn-np/bc/gwaiihaanas/info/consultations/gestion-management-2018 with permission from the Gwaii Haanas Archipelago Management Board and Haida artist Iljuuwaas Tyson Brown.

Each row, left to right from top: (a) Chiix̱uu Tll iinasdll remote field crew including Haida Fisheries Program divers, academic researchers, contract scientific divers, camp cook, and Gwaii Haanas Parks Canada staff. (b) Hauling harvested guuding.ngaay red sea urchins onto a transport vessel to bring into town for community food and outreach as part of restoration work. (c) Haida staff at Gwaii Haanas delivering school program about kelp restoration and guuding.ngaay, a traditional food. Typical underwater site conditions at the Gwaii Haanas kelp restoration area (d) pre-restoration, (e) during restoration work, and (f) in the first summer post-restoration, where stipe density of annual kelps increased dramatically from 0.09 to 1.33 stipes per m^2. Restoration gains were less marked two summers following restoration work at 0.73 stipes per m^2. Urchin densities remained much lower than pre-restoration conditions, however, did increase slightly between the first and second post-restoration summers from 0.58 (± 0.15 SE) to 1.05 (± 0.17 SE) urchins per m^2, highlighting the need for continued restoration maintenance work. Photos supplied by a & e-f, Ryan Miller/millermarine.ca; b, Charlotte Houston/Parks Canada; and c, Gwaii Haanas/Parks Canada.

PROJECT 4

Diver Control of Long-spined Sea Urchin in Tasmania

Authors: John P. Keane, Scott D. Ling



KEY TAKEAWAYS

- An urchin fishery was established to provide financial incentives to control a range-extending and destructive urchin species.
- Spatially discrete subsidies and modified harvesting strategies were used to manage and optimise harvests efforts, with the long-term aims of facilitating industry stability and natural kelp recovery.

BACKGROUND

Due to chronic coastal warming, the long-spined sea urchin (*Centrostephanus rodgersii*) has extended its range south from New South Wales to eastern Tasmania where it is causing widespread overgrazing of productive kelp forests (Ling 2008, Ling et al. 2009, Ling et al. 2015); see Figure 1. Since first detection at St. Helens in 1978 (Fig. 1), the population of *Centrostephanus* in Tasmania reached ~20 million individuals by 2017 (Ling and Keane 2018). Importantly, when local urchin populations build to more than ~700 grams/m^2 (or ~2.2 urchins/ m^2), productive kelp forests are overgrazed and urchin barrens ensue; in contrast, only less than ~70 grams/m^2 (or ~0.3 urchins/m^2) is required to maintain barrens, with this hysteresis effect making recovery of kelp very difficult once barrens have formed (Ling et al. 2015). Prior to invasive urchin establishment, urchin barrens, as formed by the native urchin (*Heliocidaris erythrogramma*), were rare and highly localized (Ling et al. 2010). Driven by invasive urchin overgrazing, by 2001 urchin barrens constituted ~5% of eastern Tasmanian reefs (sites 1-9, Fig. 1) and had reached ~15% by 2016/17 (Ling & Keane 2018). That is, 95% of coastal reefs in eastern Tasmania were dominated by kelp forests in 2001/02, declining to 85% by 2016/17. Based on current trajectories of unmitigated population growth, *Centrostephanus* threatens to form barrens across ~50% of nearshore reefs in eastern Tasmania (sites 1-9) by ~2030 (Ling and Keane 2018). Collapse of kelp forests at this scale would further reduce productivity of lucrative Tasmanian abalone and lobster fisheries, plus continue wholesale collapse of biodiversity associated with kelp forests (Ling 2008). Here we summarise three diver-based methods of urchin control.

THE PROJECT

The commercial harvest of long-spined sea urchin began in Tasmania in 2009, with harvest progressing at low to moderate levels. Limiting the industry was the lack of urchin processing knowledge and export quality processing facilities, as well as concerns about the overall profitability. From 2016, the Tasmanian Abalone Council and the state government under the Abalone Industry Reinvestment Fund (AIRF) provided harvest subsidies at a value of $0.75/kg to accelerate the urchin harvest with the objective to protect and restore key kelp habitat for blacklip abalone (*Haliotis rubra*) and southern rock lobster (*Jasus edwardsii*). The subsidy gave confidence in the commercial processing industry to invest in sea urchin processing infrastructure, and, following private investment, catches rose from an average of 50 t/year to 180 t in 2018, followed by 560 t in 2019. The fishery now averages landings of over 460 t/year (2019 to 2021; Fig. 2). These harvest levels are approximately twice the rate of historical annual (unfished) biomass increase (Ling and Keane, 2018), and if sustained into the future are expected to place significant downward pressure on local urchin populations. Localised areas of kelp recovery at the heavily fished shallow (10-14 m depth) fringing kelp margins of extensive barren grounds are becoming apparent (Fig. 2a; pers. obs.).

To spatially direct the urchin fishing effort, variable subsidies were introduced mid-2019 and now range between $0 and $2.50/kg. The spatially structured subsidy has resulted in a shift in fishing effort and has enhanced urchin removal in regions deemed ecologically or commercially important. Average catch rates of the commercial harvest vary between 190 and 300 kg/hr (~475 – 750 individuals), depending on barren patch density (Creswell et al., 2019). The retainment of small urchins on reefs is a potential limitation of the harvest fishery as a kelp restorative measure, since long-spined sea urchins at a test diameter of <85 mm are considered uneconomical to process and are not removed by fishers. While kelp recovery in some areas has been observed, high abundances of small urchins appear to be maintaining barrens in others, particularly boulder reefs (pers. obs.).

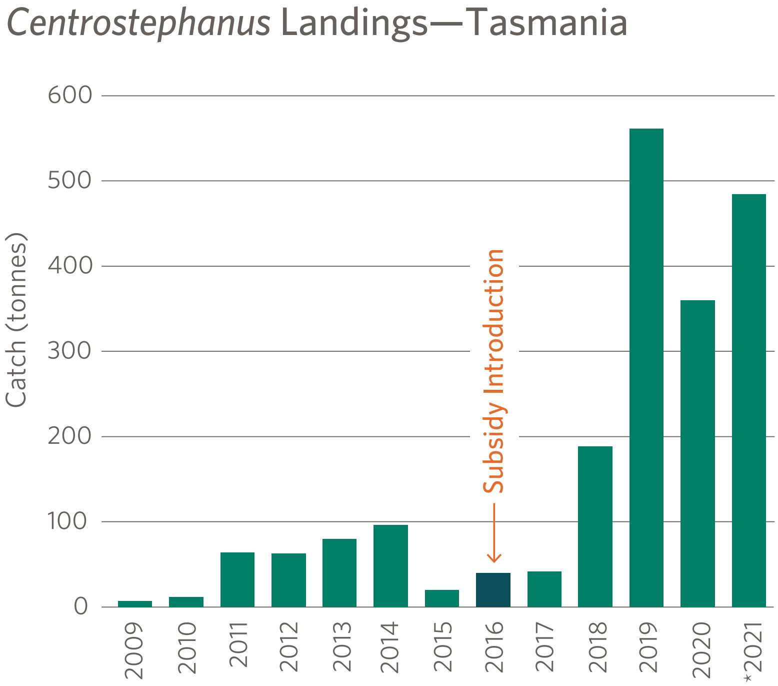


Figure 1 Commercial fishery landings of long-spined Ssa urchin in Tasmania since the commencement of the fishery in 2009. Photo provided by the author.
** Incomplete season data*

To overcome small urchins maintaining barrens, a 'take-all' harvest initiative supported by the AIRF has been trialled. A 'take-all' harvest is defined by divers taking all size-classes of urchins, not just those suitable for roe processing. Funded by the Tasmanian government, the first 'take-all' harvest removed 34.7 t of long-spined sea urchin at a cost of $101K ($2.90 /kg) from incipient barrens in southeast Tasmania in May 2020 (Larby, 2020). The trial involved 16 divers over 13 harvest days and covered 82 hectares of reef, removing urchins at a rate of 491/hr. The region was reported to have ~4% urchin barren, consisting of low-density incipient urchin barrens with relatively higher numbers of small urchins (Fig. 2b), in 2017 (Ling and Keane, 2018). The region was uneconomical to fish under normal operations but was assisted by the 'take-all' trial aimed at preventing further barren expansion in productive abalone ground. Of the 34.7 t harvested, 66% of the biomass (50% by number of urchins) was processed by industry and the roe sold to market.

Urchin culling (i.e., the killing of urchins underwater by divers) is a proven method to facilitate localized kelp regrowth within short time periods (~18 months) (Ling 2008; Tracey et al., 2015; Sanderson et al. 2015). Similar to 'take-all' harvesting, the method removes all size classes of urchins from the system. Commercial culling activities were conducted by commercial fishers in incipient barren areas adjacent to the abovementioned take-all harvest in 2019/2020 and funded by the state government. Cull rates and associated costs of cull activities were equivalent to that of catch rates from the take-all harvest (Larby, 2020). Diver culling rates increase as the barren type increases from incipient to extensive, and they have been reported as high as 2200 urchins/hr on extensive barren grounds (Creswell et al., 2019).

LESSONS LEARNED

The establishment of a large-scale sea urchin harvest industry requires the development of substantial knowledge and intellectual property pertaining to the processing of roe for high-end consumer markets, as well as significant financial investment in facilities to meet export standards. Acknowledging these two critical limitations from the onset of a fishery, and providing means to overcome them, will facilitate rapid fishery development, put downward pressure on intensive sea urchin grazing, and hopefully contribute to kelp recovery. In Tasmania, a harvest subsidy provided the processing sector with confidence to invest in infrastructure, as well as take early financial hits while acquiring knowledge, in order to develop a large-scale export industry. Such a subsidy from the onset of the fishery could have fast-tracked the industry by up to 10 years. A sustainable sea urchin fishery intertwined with targeted take-all culling activities appears to be the most feasible and cost-effective means to control sea urchins and facilitate kelp recovery, and they are the subject of ongoing research and management.

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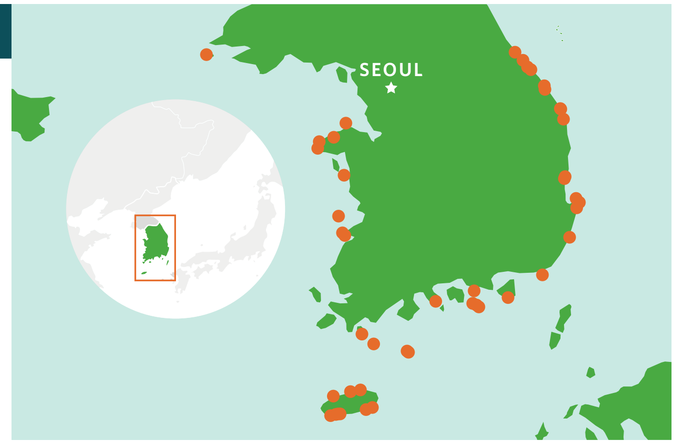
Figure 2 (a) Early signs of macroalgal regrowth on incipient barrens at 12 m depth at the heavily harvested site of Sloop Rock (St. Helens), March 2019. (b) Incipient barren in southeast Tasmania (Forestier Peninsula) where subsidised harvesting has been in effect (up to $2.50 /kg), and where ~35 tons of urchins were harvested in 2020 as part of a 'take-all' harvest strategy. Photos provided by the authors.

PROJECT 5



Kelp Restoration at the National Scale

The Seaforestation Project in Korea, 2009–2030

Author: Aaron M. Eger

KEY TAKEAWAYS

- This nationally coordinated large-scale kelp forest restoration program was possible due to adequate support and financing.
- This program provides standards for site selection, restoration methods, and project monitoring and evaluation.

BACKGROUND

The Korean peninsula is bounded by three seas and has a long history as a maritime nation that harvests fish, invertebrates, and seaweeds. Kelps (incl. *Ecklonia* spp., *Saccharina* spp., *Sargassum* spp., *Undaria* spp.) are directly consumed and support other valuable marine fisheries in Korea. Declines in kelp forests have been mostly caused by sea urchin overgrazing along the east coast, while declines on the south coast and the island of Jeju are mainly due to coastal development and habitat loss. The area of deforestation increased rapidly in the 1990s; it is estimated that Korea now loses ~1200 ha of kelp forests per year (Sondak and Chung, 2015). These losses are now monitored using aerial hyperspectral imaging and help provide a robust understanding of kelp populations in the country. Marine conservation efforts in Korea have historically been manipulative, and government-led efforts in the 1960s focused on marine ranching, installing structures in the ocean, and stocking them with commercially valuable fishes and invertebrates. Focus then shifted to restoration of kelp species and small-scale projects started in 2002. However, these projects failed to achieve their goals, and there was still public demand to address the loss of kelp forests across Korea.

THE PROJECT

These initial attempts at restoration, coupled with a demand for action, led to the creation of the Korean government's flagship marine afforestation program. The project, led by the Korean Fisheries Research Agency (FIRA), is the largest kelp forest restoration program in the world. Starting in 2009, the FIRA project runs until 2030 with a yearly budget of $29 million USD (FIRA, 2020) and aims to restore 50,000 hectares of kelp forest. As of 2019, the project has already installed over 20,000 hectares at 173 sites (Lee, 2019). Initially, FIRA relied on protocols developed for projects earlier in the decade and used transplants or seeds on artificial reefs, often borrowing approaches from the aquaculture industry (e.g., seeded lines and working with cultured outplants). Aquaculture techniques have helped the project obtain larger scales of restoration than would be achievable using wild harvested kelp stocks. However, there were some protests related to the widespread use of artificial reefs, and they are now working on the best ways to restore forests on rocky reefs that once held kelp forests (Yang et al., 2019). The projects in Korea have been largely led by the federal government, but there has been considerable input from local universities, which research different restoration techniques, provide historical baselines and targets, and advise ongoing management efforts. For the foreseeable future, it appears that most kelp restoration work in Korea will occur under the FIRA marine afforestation program with input from university researchers.

The FIRA project has developed a systematic approach to selecting, installing, and monitoring restoration sites. Potential project sites are first identified and proposed by municipal and state groups and are informed by guidelines provided by FIRA and the Ministry of Oceans and Fisheries (MOF). These guidelines include consultation and support from local marine users (e.g., fishers), budget restrictions, site access, desirable ecological features, and synergies with other marine management strategies. Each year, sites are selected by committee and funds are distributed to enact the projects. After a project has been completed, FIRA conducts water surveys twice a year to monitor the kelp population, environmental parameters, and urchin numbers. If a project does not meet its goals, adjustments are made to try and facilitate project success (e.g., urchin removal, water clean-up, supplemental transplants). This process of monitoring and maintenance is carried out for four years; after this point, ownership of the project is transferred from FIRA to the local government group for continued care.

LESSONS LEARNED

The Korean government investment in kelp restoration is unique and has led to a large scale, systematic approach to restoration. This approach has been underpinned by financial and logistical support over two decades and has shown impressive results. Indeed, the project has restored tens of thousands of hectares and impressively done so at a cost of ~$12,000 USD per hectare, substantially lower than other active kelp restoration projects (Eger et al., 2021). While the project has achieved results, it has relied on using artificial reefs and is now investigating alternative methods to restoration. Monitoring of kelp populations has also revealed that not all projects are successful, and a greater understanding of the mechanisms that lead to project failure is required to address those problems.

Detailed information about the project history, site selection process, restoration methods, and monitoring plan can be found in a FIRA technical document entitled, "The Process for the Marine Forest Project" (translated copy available at www.kelpforestalliance.com/kelp-resources).

The FIRA project demonstrates that with the right policy mechanisms, incentives, and funding streams, kelp forest restoration is achievable at large scales and relatively low costs. While the specifics will vary region to region, this project serves as a good model of a coordinated and long-term approach to kelp forest restoration.

1. Sufficient and consistent financing can enable sustained and large-scale kelp forest restoration.
2. Working with cultured stocks of kelp can help alleviate pressures on wild stocks and increase the amount of material to be restored.
3. A national framework for restoration can connect multiple projects across the country and ensure they are conducted and evaluated in a consistent manner.
4. Collaborations between government, resource users, and universities can create projects that meet multiple goals, are well funded, and have access to the latest research.

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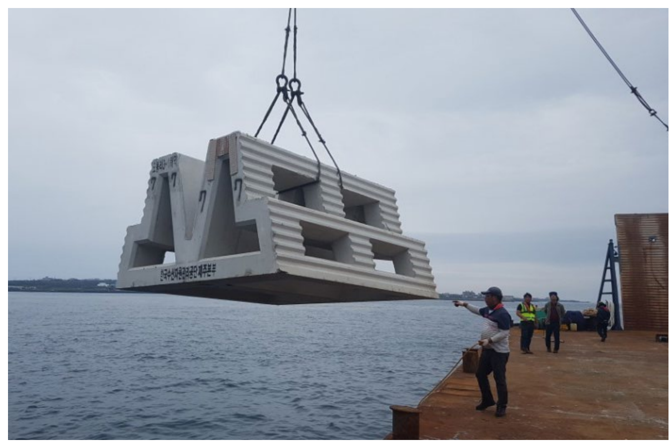


Installation and monitoring of artificial an reef. Photos provided by the authors.

PROJECT 6

Restoration of isoyake (Deforested) Area

Kelp Forest Restoration along the Hainan Coast of the Shizuoka Prefecture in Japan

Authors: Masatoshi Hasegawa, Daisuke Fujita

KEY TAKEAWAYS

- Pilot projects are useful approaches to establish proofs of concept and can be used to identify problems with the methodology and demonstrate feasibility before restoring at scale.
- Using cultured kelp outplants can help scale up the area that is restorable.

BACKGROUND

The Hainan Coast, in Shizuoka Prefecture, Japan, runs for ~50km around the Cape of Omaezaki with Suruga Bay in the east and Enshuu Nada in the west. Its shallow waters (0–20 m) are home to an 8,000-ha kelp forest, predominantly comprised of *Ecklonia cava* (hereafter *Ecklonia)* and *Eisenia nipponica* (hereafter *Eisenia),* which is the largest in Japan. Historically, the kelp forest was a highly productive abalone fishing location, yielding 10-20 ton of abalone/year since the helmet diving fishery of abalone began in the Meiji Era (1867-1911). In modern times, managers have worked to enhance abalone in the area by stocking 100,000-400,000 juvenile abalone every year since 1980s. The region also has had a long kelp (*Eisenia*) fishing industry since the year 700 CE, with harvest peaking at 20-40 tons per year in the 1980s.

THE PROJECT

The locals' relationship with the sea was first threatened when isoyake (deforestation) was observed by Izu Branch of Shizuoka Prefectural Fisheries Experiment Station (IB-SPFES). Based on their reports, losses of *Eisenia* started in 1985 and were followed by *Ecklonia* losses in 1990. By the year 2000, the entire kelp forest had almost disappeared. Such losses resulted in dramatic declines in both the kelp and abalone fisheries, previously strong contributors to the local economy. Given the threat to their livelihoods, the fishers of Hainan engaged Shizuoka Prefectural Government (SPG) to investigate the causes of isoyake and restore the kelp forests, a job that was ultimately tasked to IB-SPFES.

The researchers of IB-SPFES dove the area and identified several causes for kelp forest decline. First, increased turbidity caused lower light conditions, which reduced kelp productivity and created enabling conditions for isoyake. Kelp losses were then magnified by an increase in the population of warm water herbivorous rabbitfish (*Siganus*

A hexapod block used for early transplantation; an x-shaped block used for later transplantation. Photos provided by the authors.

fuscescens), which increased in 1984 and now remain as waters have gradually warmed.

To begin the remediation of habitat loss, a small-scale pilot project was initiated by IB-SPFES in 1997. IB-SPFES transplanted adults of *Ecklonia* sporophytes in deforested areas along the coast and confirmed that the plants could survive when planted on artificial structures. Further, this pilot project suggested that careful transplantation of *Ecklonia*sporophytes could lead to the recovery of the kelp forest off Sakai-Hirata (east of Omaezaki).

Larger scale restoration efforts, proposed by IB-SPFES and financed by the SPG, then started in 1999. First, concrete blocks (hexapod of 5 tons, 2.1 x 2.1 x 1.1 m) were placed in nearby healthy kelp forests and left from October 1999 to March 2000 to collect recruits of *E. cava*. The naturally seeded blocks were then transferred to deforested areas in Hainan to establish core kelp forests. This initial effort was successful, partly because the height of grown kelp was elevated by the concrete blocks and received more light and less sedimentation. However, success was short lived, and the transplants disappeared within three years after they were browsed by herbivorous fishes.

After securing further financial support from the national government, the SPG started a second attempt in 2005. Instead of seeding blocks in the field, juveniles of *Ecklonia* sporophytes were cultured on strings and tied with ropes to 2,162 x-shaped concrete blocks (weight: three tons, dimensions: 1.85 x 1.85 x0.63 m). Importantly, SPG, with local fishers, fishing cooperatives, and municipal government created a subsidy to pay fishers to remove herbivorous fishes from coastal areas using set nets and gill nets.

After sustained removal of herbivorous fish, the project was ultimately deemed successful. Monitoring started in 2007 and revealed 55 hectares of restored kelp forest, a number which has grown to 870 hectares in 2018, the date of the last survey. As the *Ecklonia* forests were restored, so were the abalone populations. The result has been so successful that the fishery cooperative is planning a trial re-opening of the abalone fishery in 2021. However, *Eisenia*forests have not returned yet, likely because this species is more susceptible to herbivorous fishes browsing, even in mixed stands with Ecklonia.The total budget for projects carried out between 2002 and 2010 was $ 5.21 million (USD, 2010).

LESSONS LEARNED

- Transplanting sporophytes on elevated substrata can help ameliorate the effects of low light and sedimentation, which might otherwise kill the plant.
- Pilot projects are useful approaches to establish proofs of concept and can be used to identify problems with the methodology and demonstrate feasibility before restoring at scale.
- If there is persistent overgrazing pressure, it is important to continually manage this stressor, otherwise fish might overgraze the restoration outplants.

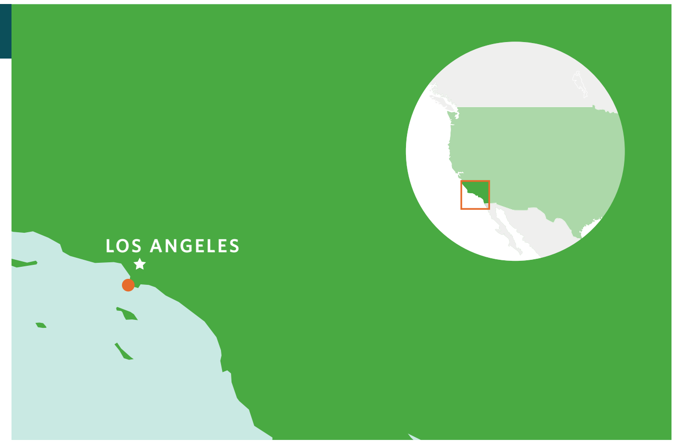
Ecklonia cava forest restored on bedrock. Photo provided by the authors.

Abalones appeared on the restored forest. Photo provided by the authors.

PROJECT 7

Palos Verdes Kelp Forest Restoration Project

Authors: Tom Ford, Heather Burdick, Ben Grime, Rilee Sanders



KEY TAKEAWAYS

- This project involved stakeholders from NGOs, the fishing sector, government, community groups, and academic institutes, which enabled a highly coordinated and systematic project to reduce purple sea urchin numbers.
- Urchin culling activities, in conjunction with a natural mass urchin mortality event, have led to kelp restoration on ~23 ha of urchin barrens over seven years.

BACKGROUND

The Palos Verdes Peninsula (PVP) is a large rocky headland separating the Santa Monica and San Pedro bays in southern California, USA. Pronounced declines in giant kelp (*Macrocystis pyrifera*) canopy have been identified along PVP since the late 1940s (Revelle and Wheelock 1954, Foster and Schiel 2010). In total, this region lost ~80% of its kelp canopy in the latter half of the 20th century (Ford and Meux 2010, MBC 2019). Surveys conducted in the late 1960s found a near total absence of adult giant kelp (Wilson et al. 1977, Foster and Schiel 2010). Subsequent surveys conducted from 2005 to 2010 described large expanses of rocky reef supporting purple sea urchin (*Strongylocentrotus purpuratus*) densities of ~25 /m^2. This number of urchins is an order of magnitude greater than the ~2 /m^2 density of purple sea urchins found in natural giant kelp forests in southern California (North pers. comms, Williams et al 2021). In addition to the establishment of the persistent urchin barrens, other stressors impeded kelp recovery, including storms and coastal development and related sedimentation, urban runoff, and pollution (Revelle and Wheelock 1954, Foster and Schiel 2010, Ford and Meux 2010).

THE PROJECT

The goal of the project was to restore giant kelp to its historical extent, as established in the Action Plan of the Comprehensive Conservation and Management Plan of the Santa Monica Bay National Estuary Program (SMBNEP Action Plan 2018). The core aim was therefore to address the expansive urchin barrens on PVP as an ecological restart for one of southern California's most valued and productive rocky reef systems.

A decade of pilot-scale testing informed the approaches to systematic purple sea urchin control employed by the Palos Verdes Kelp Restoration Project (Grime et al. 2020). Since 2013, a collaboration comprising The Bay Foundation, NOAA Restoration Center, Montrose Settlements Restoration Program Trustees, Vantuna Research Group, Commercial Sea Urchin Harvesters, and Los Angeles Waterkeeper comprehensively monitored and culled (via hammering) purple sea urchins from barrens. Restoration operations were directed by The Bay Foundation utilizing a system of GPS coordinates, subsurface markers, navigational aids, and numerical targets, to ensure system spatial coverage and tracking of restoration efforts.

To date, these efforts have reduced purple sea urchin densities down to the targeted ~2 /m^2 across ~23 hectares. From June 2013 to June 2020, this required culling of ~4.2 million urchins and >10,000 hours of diving by contracted commercial fishers (Grime et al 2020).

Monitoring occurred at restoration sites before and after culling activities. Data was collected along a 30 x 2m transect on both purple and red (*Mesocentrotus fransicanus*) sea urchin density, but also giant kelp density and depth, water temperature, substrate type and rugosity. Reductions in urchin densities at the restoration sites were assessed within two weeks of culling and used to confirm consistent reductions of purple sea urchins to 2 /m^2 at all restoration sites. The monitoring effort required 2,000 hours of diving effort from June 2013 to June 2020 (Grime et al. 2020).

Performance monitoring of kelp forest recovery and ecology was led by the Vantuna Research Group, who conducted annual assessments of the rocky reef communities within natural kelp forests, barren control sites, and barren restoration sites. Key monitoring metrics included changes in density, biomass, and percent cover of select macroalgae, benthic invertebrates, finfish, and exposed bare rock, and occurred from 2011-2020 (Williams et al 2021). These data were also used to assess habitat productivity and potential benefits for the red sea urchin fishery, as affected by this project (Claisse et al 2013).

Notably, the project's urchin culling efforts coincided with a mass mortality event of purple sea urchins (which may have also impacted other echinoderms) sometime around spring 2015-spring 2016. Regardless of whether purple urchin density was reduced by the disease or culling efforts, we observed a rapid return of kelp in areas that were previously barrens (Williams et al 2021). Approximately six months following the reductions in urchin density, the restored areas' kelp recovery was quite similar to the natural kelp reference sites, and these similarities continued to increase over the following five years (Williams et al. 2021).

LESSONS LEARNED

Permitting for this project, by California Department of Fish and Wildlife, was extensive and further refined methodologies and approaches to the restoration sites. Other significant changes to these methods came from the scientifically trained staff as well as the commercial sea urchin divers contracted to selectively remove the purple sea urchins over the course of the project. The teams were constantly assessing the approaches used to maximize the effectiveness of the diving effort required by this project. In that regard, adaptive management was a constant, if often subtle, aspect of the overarching effort. Central to the success of this project were frequent clear communications and trust among those involved in the execution and management of the subtidal restoration work.

This project could not have been achieved without the sustained support provided by the Montrose Settlements Restoration Program and the technical expertise and involvement of NOAA Restoration Center personnel. The cost of the PVKFRP was >US$3.5 million. Based on 10 years of pilot-scale testing, the scale and resources supporting the PVKFRP were strategically developed and informed from historical records, scientific studies, prior restoration efforts, and extensive mapping by scuba divers.

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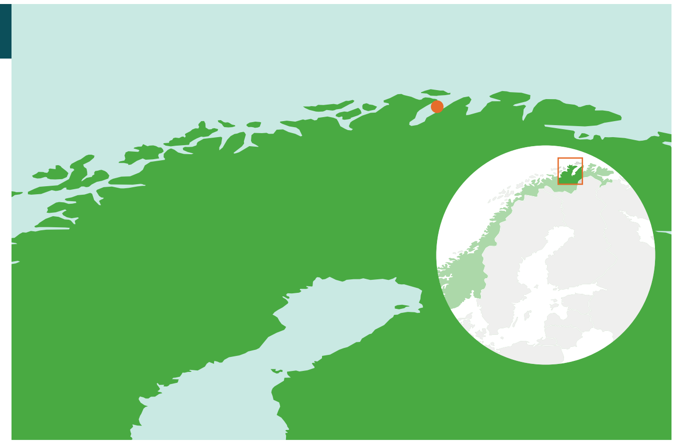
PROJECT 8



Quicklime and Restoration of Kelp Forest Lost to Sea Urchin Grazing in Norway

Author: Hans Kristian Strand

KEY TAKEAWAYS

- Application of quicklime is effective in reducing urchin densities in cool-temperate conditions (5-10 °C), but future studies are needed to better understand the causes of variable results and quantify non-target mortality.
- Quickliming is most effective when urchins are relatively large and hiding places are few. To effectively treat urchin barrens with the optimal quicklime particle sizes below depths of ~5 m, surface application is unlikely to be effective.

BACKGROUND

Norway has the largest continuous kelp forest in Europe, and one of the largest in the world (Pedersen *et al.*, 2012; Pessarrodona *et al.*, 2018). However, an explosive increase in *Strongylocentrotus droebachiensis* sea urchin populations in the 1970s resulted in the most severe grazing event observed in the Northeast Atlantic (Norderhaug og Christie, 2009). The large increase in sea urchin densities was probably caused by overfishing of urchin predators in the coastal zone in the 1950-60s (Norderhaug *et al.*, 2020). Approximately 2000 km^2 of 'cuvie' (*Laminaria hyperborea*) was lost during these grazing events (Sivertsen, 1997), and later estimates also suggest that sugar kelp (*Saccharina latissima*) and other marine vegetation were denuded over several times that area in the fjords and inner sheltered regions of the coast (Gundersen *et al.*, 2010).

THE PROJECT

Since sea urchin gonads are a highly valued seafood product, a harvest fishery would be the preferred option for sea urchin control. However, gonad content in urchins on barrens is typically too low to be commercially viable, and although 'fattening' protocols have been successful at lab scale (Siikavuopio *et al.*, 2006), they have not yet been successfully implemented at commercial scales. One alternative to a fishery and to aid kelp restoration is to cull the sea urchins using an environmentally friendly chemical such as quicklime.

Quicklime, or calcium oxide (CaO), is produced by heating ordinary lime (calcium carbonate, $CaCO_3$) to ~1000 °C. When the quicklime is mixed with water, it reacts back to lime. The reaction is exothermic and produces a short-lived but highly alkaline environment that is highly damaging to echinoderms (urchins, sea stars sea cucumbers etc.), but to which creatures protected by shells (e.g., snails, mussels, crabs, etc.) or slime (e.g., fish) are less susceptible. In 2008, the Norwegian Institute of Marine Research (IMR), in collaboration with the Norwegian Institute for Water Research (NIVA) and the private lime enterprise Franzefoss Minerals AS, started to test whether quicklime could reduce sea urchin stocks on barrens in the north of Norway. The initial inspiration to test this quickliming method came from Californian and Canadian studies (Bernstein og Welsford, 1982). However, those studies were somewhat discouraging because they hinted that lower water temperatures may have been responsible for the less successful applications of quicklime in colder Canadian waters relative to California. Since water temperatures in the north of Norway are regularly below 10 °C, and we commenced our first tests in late autumn when temperatures were below 5 °C, we started out very cautiously with the application of only a few tens of kilograms of quicklime, followed by larger tests of several hundred kilograms in the waters near the research station.

Despite the low temperatures, we observed high sea urchin mortality, and the following year we recorded abundant kelp recovery in the treated areas, while nearby untreated sites remained barren and dominated by sea urchins. The likely source of the new kelp recruits was nearby (i.e., 10-100 m) residual patches and individual kelp from exposed locations and crevices, which were protected from urchins. After several additional studies in the lab and field, we conducted a large-scale liming experiment where we applied 200 ton over ~0.6 km^2 of urchin barren. Similarly, these applications caused high sea urchin mortality and abundant kelp recovery (Fig. 1).

However, when we decided to apply the same protocol in another large-scale experiment in a different fjord system in 2017, the results were discouraging, with almost no kelp

Figure 1 Treatment of stable sea urchin barrens with quicklime in the Porsangerfjord resulted in kelp recovery within a year. Photos provided by the authors.

recovery in the year following treatment. Follow-up studies led us to conclude that although the treatment caused high urchin mortality, there were still substantial numbers of small unaffected urchin recruits hiding in the gravel, with the potential to emerge and feed on kelp sporelings as they settled throughout the winter (Strand *et al.*, 2020) (Fig. 2).

LESSONS LEARNED

These trials revealed that quicklime treatment can turn stable urchin barrens into dense kelp forests within a year, even in cold temperate waters (5-10 °C), although treatment efficiency was probably less dependent on temperature than the quicklime particle size and bottom topography. As such, habitats rich in refuges must probably be treated several times. In those instances, we anticipate that repeated treatments should be spaced two to three weeks apart to fully evaluate the effect of the previous treatment. The required reduction in urchin density to facilitate kelp recovery will depend on urchin species, temperature, timing between quicklime treatments, and kelp sporeling settlement, among much else. All these factors must probably be decided for each region in question.

We have only developed and scaled the method of applying quicklime from the surface (Fig. 1), which is most efficient in shallow areas. A more precise and efficient method of applying the smaller (more effective) quicklime particles and at greater depths remains a major challenge for research and development. Ultimately, the overall method is not fully developed and still considered a work in progress, although the industry indicates an eventual treatment cost ~US$1/m^2.

Barrens in Norwegian waters are typically completely dominated by urchins, and thus little collateral damage to other wildlife will occur during quickliming treatment. However, barrens elsewhere can be populated with valuable and potentially vulnerable species like abalone. No toxic residuals are produced during treatment. Indeed, the main concern of environmental authorities is non-target mortality, and so they will currently only sanction use of quicklime in scientific studies.

Figure 2 In habitats rich in refuges, quicklime will still cause high sea urchin mortalities on the surface; however, chances are that unaffected individuals will also emerge from underneath and keep the habitat barren. The pictures show an untreated habitat (top) and the same habitat a few days after treatment (bottom). Photos provided by the authors

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PROJECT 9

Marine Forests Restoration in the Mediterranean Sea

Authors: Annalisa Falace, Sara Kaleb, Saul Ciriaco

KEY TAKEAWAYS

- Cultivation of the reproductive apices of *Cystoseira* in mesocosms, followed by outplanting into MPAs (where stressors were reduced), proved to be a cost-effective means of restoration, with high survival and growth of seedlings in culture and survival of thalli in the field.
- Although climate change makes restoration urgent, it also limits its feasibility, as both natural and restored populations face the same threats (e.g., thermal anomalies, storm surges).

THE PROJECT

The European Community funded project ROC-POPLife (Promoting biodiversity enhancement by Restoration Of *Cystoseira* POPulations – 2017/2021) aimed to test outplanting techniques to trigger the restoration of *Cystoseira* habitat in two marine protected areas (MPAs). The target areas were the intertidal fringe in the Cinque Terre MPA (Liguria) and the subtidal (3–5m depth) in the Miramare MPA (Northern Adriatic). Two neighboring MPAs were selected as seed donor sites (i.e., Strunjan in the Adriatic Sea, Portofino in Liguria). The major causes of *Cystoseira* loss in the Miramare MPA since 2000 have been related to habitat modification and overgrazing by sea urchins, while in the Cinque Terre MPA the losses were due to high sediment loads from excavation activities in the first half of the 20th century. These threats were no longer active at the start of the project. Human activity regulations have been implemented in both receiving and donor MPAs. These areas are also monitored for water quality and other threats. Researchers from the Universities of Trieste and Genoa have been actively involved in the restoration and cultivation activities, as well as the MPAs' technical staff for the outplanting and monitoring phases.

The specific project objectives were to: 1) restore the *Cystoseira* canopy along a 1,000 m coastline in each of the two receiving MPAs through the development of sustainable and effective protocols; 2) raise awareness among citizens and key groups about the value of and threats to marine forests; and 3) assess the feasibility and promote the replicability and transferability of algal restoration to other MPAs in the Mediterranean Sea. Project monitoring was conducted both during *ex situ* cultivation in the mesocosms (i.e., seedling survival, density, growth) and after outplanting in the field (i.e., survival, percent cover, growth, reproduction). In the mesocosms, fertile apices collected from donor populations thalli were placed directly on clay tiles (5 cm ø) with a hole in the center, then screwed directly onto rocks in the intertidal or on suitable restoration units deployed on the seabed in the subtidal. The technique proved to be fast and efficient.

Communication strategies were tailored to different target groups: 1) awareness raising activities for school children, the general public, and tourists to induce positive behavior towards marine forests and the environment; 2) stakeholder engagement with authorities, decision makers, users of ecosystem services such as fishermen, the tourism industry, and others at local- to Mediterranean-scale to stimulate active participation in biodiversity management and conservation; and 3) networking with EU-funded projects, MPA networks and practitioners, and scientists to develop a shared vision and conscientious approach to the ecological and socio-economic values of *Cystoseira* forests. These efforts aimed to promote relevant strategies/initiatives, partnerships, and preparations for future investments in the restoration of the Mediterranean.

LESSONS LEARNED

This project has demonstrated that: 1) removal of fertile apices for seeding has no effect on donor sites, as *Cystoseira* has high reproductive potential; 2) improved species-specific cultivation protocols (i.e., light, temperature, nutrients, antibiotics) maximize seedling survival and growth and support attainment of "refugium" size in a shorter time while reducing costs and reducing vulnerability of early stages in the field (e.g. consumption and bulldozing of meso- and micro-grazers); 3) transport of early life stages from the nursery to the receiving site, which may be at a great distance, is feasible without adverse effects on juvenile fitness; 4) the screw-fastening technique increases the efficiency of substrate placement in the field, is resistant to displacement by hydrodynamism, and avoids the unsightly effects of using epoxy putty; 5) coupling cultivation in mesocosms with a transition phase in the field (e.g., floating structures) prior to outplanting on the rocky reef mitigates low early-stage survival rates in the field (i.e., due to storms and other random weather events) but is still cost-effective as it avoids time-consuming and expensive nursery grow-out and long-term maintenance.

To some extent, biological, environmental as well as logistical challenges (e.g., grazing, hydrodynamism, remote rearing, and donor sites) have been overcome, and lessons learned can help guide the selection of "best" sites and protocols for restoration. Importantly, while climate change makes restoration urgent, it also limits its feasibility. Both natural and restored populations face the same threats (e.g., thermal anomalies, storm surges). Therefore, understanding how climate can affect the physiology and phenology of *Cystoseira* species and their thermal tolerance is critical to successful restoration efforts. Early warning networks against extreme events could allow collection of spores that can be grown under controlled conditions and used for outplanting, or selection for lineages with higher plasticity to temperature extremes. http://www.rocpoplife.eu/

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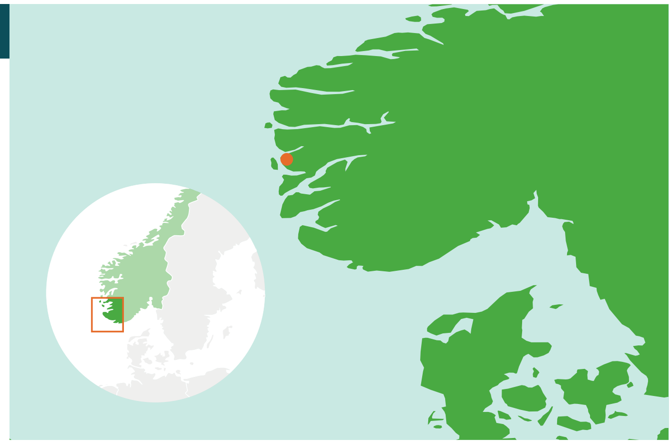
Figure 1 Attaching clay tiles onto seabed. Photos provided by the authors.

PROJECT 10



Green Gravel Trials in Norway

Authors: Karen Filbee-Dexter, Stein Fredriksen, Thomas Wernberg

KEY TAKEAWAYS

- Green gravel trials have demonstrated the effectiveness of the method to seed small areas of degraded turf reefs with kelp.
- The addition of substrates to degraded reefs dominated by turf algae can promote restoration success by overcoming turf growth that prevents natural recruitment.

BACKROUND

'Green gravel' is a restoration method that aims to allow young kelps to be seeded over large areas without extensive scuba diving. The goal of green gravel is to develop a way to reseed turf reefs, where little to no available rock surface remains for natural recruitment. This technique was developed in Skagerrak in southern Norway, a region that had experienced widespread loss of kelp. Kelp loss occurred in the region around 2000-2002, followed by a corresponding increase in dominance by turf algae (Moy and Christie, 2012). These declines have been associated with warming temperatures, in particular marine heatwaves, as well as local eutrophication (Filbee-Dexter et al., 2020). The turfs trap and accumulate substantial amounts of sediment that can prevent recruitment and germination of kelp (Burek et al., 2018; Pessarrodona et al., 2021).

THE PROJECT

Restoration trials using green gravel are still in an academic phase. Green gravel was tested at five degraded turf reefs within 20 km of Flødevigen in small plots (1 m^2). Trial sites were selected from long-term monitoring sites area surrounding the research station, where kelp was historically present but where the reefs are now turf-dominated (>90% cover) (Fredriksen et al. 2020).

The green gravel was produced from fertile wild sourced parents collected in Autumn from remnant forests at 5-10 m depth 1-15 km away from test sites. Spore solutions were added to seawater and poured over clean gravel in raceways (Fredriksen et al., 2020). The water flow was reduced in the beginning until spores had settled and attached to the rock. After two weeks, water flow was increased and left running for a period of two to three months. The gravel was then transported in trays and transplanted to sites by divers. The monitoring of these sites was done by divers revisiting the plots three times in the first year of deployment, measuring mortality, the size of the kelp growing on the gravel, and whether any have attached to the underlying rock or turf.

The kelp grew well at three of the five sites, with individuals overgrowing the gravel and attaching to the underlying reef. At 85 days after out-planting, 53% of the gravel retained kelp. After four months, 18% of the gravel with an attached kelp had overgrown the rock and attached to the underlying turf (7%) or rock reef (11%). The most degraded site with the densest turf had 100% mortality of green gravel, even in turf clearings. This was likely a combination of poor water quality and smothering by the dense turfs.

Additional pilot studies and trials in the same area were involved in the development of green gravel and provided some important insights to the conditions under which this tool worked. We found that seasonal timing of deployment was an important factor. Gravel deployed in spring did not succeed, likely because the kelps were outcompeted by other seaweeds that are rapidly growing during this time. Outplanting in winter when turf algae was minimal had the best success. The green gravel worked at both 3 m and 8 m depth and had similar success when deployed from the surface or placed on the seafloor by divers. Surface deployment was more difficult to rigorously monitor as the gravel tended to scatter, so divers were used for many of the experimental trials. To date the total area restored is < 10 m^2.

The main people involved in the project are researchers and technicians from the Institute of Marine Research (IMR), working at the Flødevigen Research Station in the Benthic Communities Group. IMR is funded by the Norwegian government, and the restoration project was funded internally as a priority development area within the Benthic Communities Group. The local government is involved in the project through the development of the tool and the permitting process and have also shown interest in expanding this work to a Marine Protected Area (Raet National Park).

Costs are mainly for the hours spent by the researchers, boat, and laboratory fees. The cost of materials was (7 US$ /m^2). We estimated that 116 kg green gravel would be enough to restore 314 m^2 reef [5 granite gravel /m^2 @ ~75 g per gravel]. Producing this quantity of green gravel required 1.5 m^2 wet laboratory tanks, 40 hours of laboratory time for culturing and maintaining tanks. Equipment, fuel and materials (but not including facilities, vessel rentals, and bench fees) were approximately $500 USD. Using hourly rates of 30 USD h^{-1}, this totals 6.75 USD per m^{-2}

LESSONS LEARNED

The timing for putting gravel into the sea, state of the reef, and reduction of stressors are important for success. In some areas there remains the need to mitigate drivers of kelp loss (e.g., sea urchins, warming temperature) before restoration can be successful. In Norway, this tool was developed for a farmed kelp species and deployed on protected or semi-exposed reefs. In wave exposed sites, small gravel often does not stay on the reef. It is likely that other substrata, such as larger rocks or lines that can wrap on structures or be attached to the reef, will be more suitable seeding tools in these places. Deeper deployments have also worked for small gravel in wave-exposed locations in Portugal.

One main outcome of this work is that these seeding techniques are now being trialed in other regions and systems via the Green Gravel Action Group (www.greengravel.org). This group currently consists of 10 projects/regions in various stages of development.

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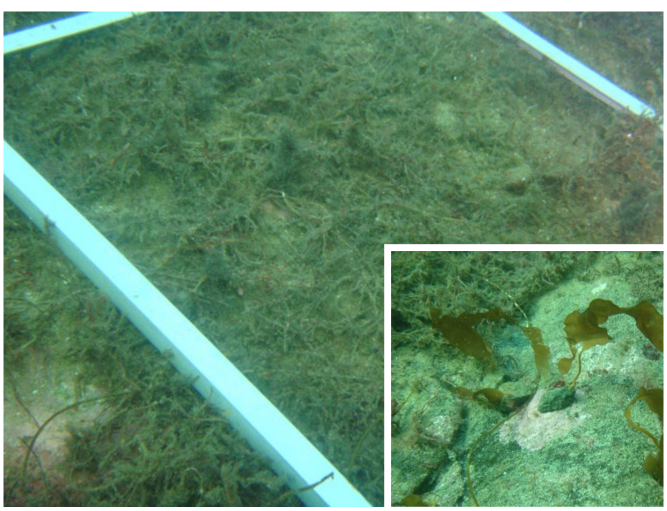


Figure 1 Quadrat with turf before clearing. Inset: Same area cleaned with gravel seeded with kelp. © Stein Fredriken

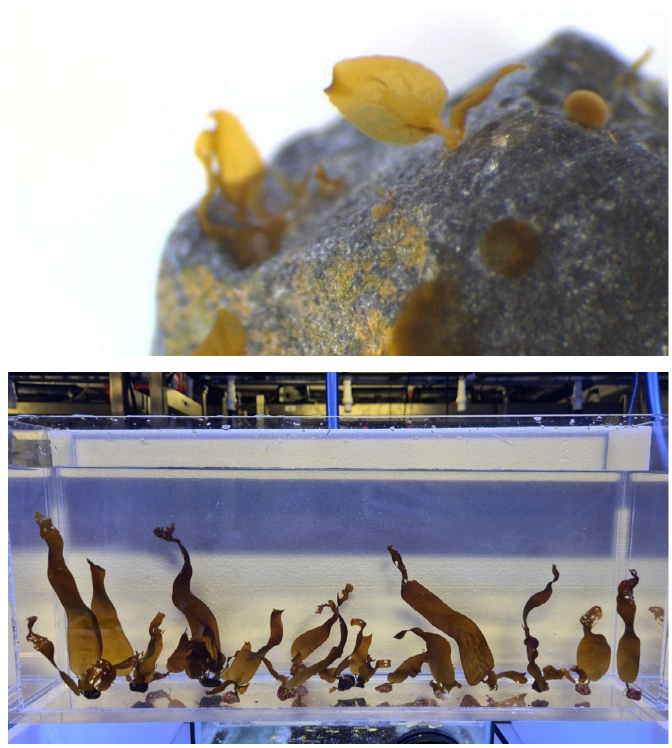
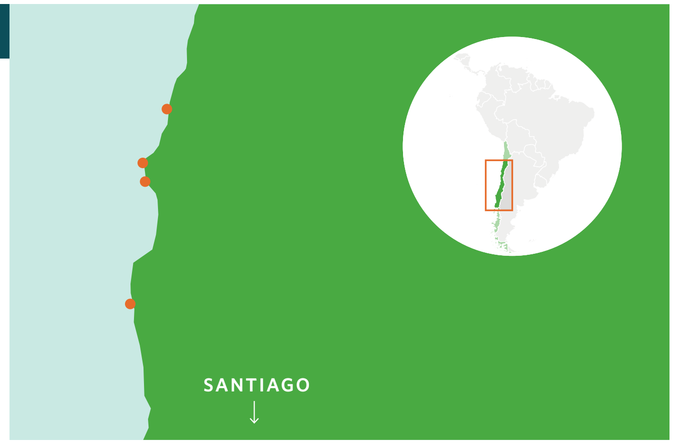


Figure 2 Small stage of kelp *Ecklonia radiata* from Australia trials of green gravel. © Nahlah Alsuwaiyan, Mason Sullivan

PROJECT 11

Using Chimeric Kelps to Restore Part of the Chilean Coast

Authors: Alejandra V. González, F. Tala, Julio A. Vásquez, B. Santelices



KEY TAKEAWAYS

- Selected breeding, production, and outplanting of chimeras improved survivorship and genetic diversity relative to homogeneous plants.
- These methods could support local adaptation and a genetic rescue of populations, especially those with a high level of inbreeding.

BACKGROUND

Along the Chilean coast, kelp harvesting is the main benthic fishery, reaching 280,000 tons/year (Anuario SERNAPESCA 2019), with 75% the harvest consisting of *Lessonia* spp. (*L. berteroana*, *L. spicata* & *L. rabeculate*). Chile provides 10% of the global raw material for seaweed chemical compounds (FAO 2012, Buschmann et al. 2014). Given the enormous harvesting pressure, these resources have become overharvested and subject to high levels of illegal harvesting (SERNAPESCA. 2019). This has affected kelp forest biodiversity and associated fisheries, and also other ecosystem services (e.g., nutrient cycling). Lower kelp forest biomass also causes declines in the kelp fishers' economic income and quality of life.

The Chilean government has created sustainability strategies in management areas (i.e., territorial usage rights for fisheries, Vásquez et al. 2014) and implemented harvesting bans, with the aim to encourage kelp recovery and cultivation (Law N°20.925). The scaled cultivation and restoration of *L. berteroana* and *L. spicata* is poorly understood, however, and there have only been unsuccessful attempts to cultivate or enhance settlement via spores or juveniles.

In this context, there was opportunity to combine a natural process with technological knowledge to generate protocols for the cultivation of high-growth multi-species chimeras of *L. berteroana* and *L. spicata,* as a method to improve the effectiveness of planting efforts and the restoration of local rocky coastal ecosystems (González et al. 2014, Rodríguez et al 2014, González & Santelices 2016, Araujo & Faugeron 2016).

THE PROJECT

Here we selected strains of *Lessonia spicata and L. berteroana* for cultivation and to build chimeras to increase fitness, resilience capabilities, and aid efforts to restore kelp and ecosystem services. For each population, we selectively bred the kelp in laboratory conditions to identify individuals with high growth rates and to develop cultures to allow outplanting of the same populations to avoid translocations of native genotypes. For each population, we also selected sporophytes to build multi-species individuals or 'chimeras' using a patented methodology to obtain chimeric individuals (Patent #2017-1827, PCT/CL2018/050053) and improve survival, growth, and genetic diversity in kelp species (González et al. 2014, Rodríguez et al 2014, González & Santelices 2016, Araujo & Faugeron 2016). For ethical and biosecurity considerations, we combined only those genotypes native to each population/site.

These chimeric individuals are formed when two genetically distinct conspecific individuals fuse together to generate a single entity, while still retaining two complete sets of genetic material (this differs from a hybrid, where two individuals contribute only half their genetic material towards the creation of the single individual). Chimera production in the laboratory allows the production of juveniles with a combination of performance and character traits, including improved survival, growth, and genetic diversity (Patent WO2019010588). We therefore found that restoration using these chimeras is more successful than using juveniles that were monospecific. Chimera production also improves biomass yields in the laboratory, hatchery, and the field. The larger size and greater morphological complexity can increase the area available for invertebrate habitat, photosynthesis, and CO_2 capture, and maximizes population sustainability and resilience. At the same time, the increased genetic diversity promotes more robust and resilient plants and helps overcome inbreeding depression due to monoculture, harvesting pressures, and ocean warming (González et al. 2020, González et al. 2021).

Transplanting of the kelp chimeras on the intertidal rocky habitat was successful with some techniques. The chimeras showed higher adherence and survival than previous restoration efforts. (Fig. 1) Of the survivors from the restored areas, at least half of them were chimeras. Once kelps were established in the field, chimeras increased the local populations' genetic diversity (~5 times greater), together with increased survival rates (1–3 times greater), biomass (~1.5 times greater), and morphological complexity or number of stipes (7-10 times more), all relative to monospecific individuals. Chimeras also showed higher levels of photosynthetic pigments compared to monospecific individuals and higher richness and abundance of associated invertebrate communities.

The cost of the project was US $355,118, provided by FONDEF ID17I10080 (US$ 276,065); U. Chile & UCN (US$77,388); and a private company (US$1,665).

LESSONS LEARNED

- Outplanting occurred during spring and summer, but the highest survival rates were observed from plantings in early spring. This likely aligns with natural patterns of recruitment, since spore production/release of *Lessonia* spp. in Chile peaks in autumn-winter.
- Various planting substrates were trialed, including metal plate, Vexar netting, adhesive-back Velcro, AlgaeRibbon, and two-part resin-quartz natural substrate analogue. After two months, only the Vexar netting, AlgaeRibbon, and Velcro has surviving kelp, and after six months, survivors only remained on the AlgaeRibbon and Velcro (and at similar densities).
- Different attachment methods were also trialed using the Vexar netting. All stainless-steel anchor-bolts lasted throughout the six-month trial period at both exposed and sheltered locations. Underwater epoxy lasted for three months at both locations, but 60% were lost within the first month at the exposed location (c.f. 30% losses at the sheltered location). However, all substrates attached using cyanoacrylate Seachem Reef Glue were lost at both locations within one month.
- Chimeras were more robust to pressure from herbivores and demonstrated increased survival while creating similar chemical cues and habitat for biodiversity.
- We are further refining our methods to generate chimeric plants with greater resilience to changes in water temperature so that the restoration of intertidal forests also considers future conditions such as climate change.

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Figure 1 Each row, left to right from top: Chimeric individuals of *Lessonia spicata* in the laboratory and installed in the field for intertidal restoration trials. (a) Details of holdfast from chimera. (b) Substrate with chimeras, one month after installation. Juveniles reached between 10-15 cm long. (c) Three months after substrate installation, with numerous chimeras reaching 25-30 cm in length. (d) Five months after installation, chimera formed an intertidal belt of juveniles (data obtained from FONDEF IDeA ID17I10080). Photos provided by the authors.

APPENDIX

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Here we provide further detail for those wishing to create a spore or gametophyte culture. The process is described for *Laminaria and Saccharina species in the Atlantic Ocean and Ecklonia in Western Australia. The specifics will vary by species and region. Further reading on culturing is available in other documentation* **(section A.4)**

A.1 ISOLATING THE SORI

Once you have the kelp containing the sori, you will work to isolate the tissue from the rest of the plant following the steps below.

Isolating the sorus tissue

Work to minimize contamination and fouling of the sorus tissue

- Avoid using fouled tissue overgrown with epiphytes (throw it away)
- Wear gloves
- Work with your sorus tissue away from your culture area

Identify and isolate sorus tissue

- Identify the sorus tissue on your blades
- Use a knife or razor blade to cut out the sorus from the rest of the blade
- Set tissue aside, keep cool and moist
- Remove excess fouling with a blade or scraper if materials permit. Throw away if excessively fouled
  - » Take care in the scraping as you may damage the sorus
  - » If no fouling, you may not need to scrape

Clean tissue

- Remove kelp mucus and other debris by firmly wiping the tissue with a paper towel
- Wipe until dry, do not reuse paper towel between tissues

Disinfect tissue

- Create a 3% iodine solution
  - » May be done in a beaker, bucket, or tub
- Carefully immerse the sorus tissue for ~30 seconds
  - » Use tweezers
  - » Avoid using other disinfectants (bleach, peroxide, alcohol)
- Rinse the tissue using chilled, filtered sea water
  - » Rinse until no color from the iodine remains
- Dry using a clean paper towel
  - » Rub gently and use a new piece of paper towel for each tissue

Tissue storage

- Place tissue in dry paper towel (or newspaper), with multiple pieces on the top and bottom
- Do not let sorus pieces touch
- Refrigerate at 10°C for 12–24 hours (or what is optimal for the species)
  - » Ensure correct temperature is maintained
  - » If no refrigeration is available, store in a low light, cool, dry place

A.2 SPAWNING THE SORUS

While the sori are chilling, you can prepare the receptacle for the spore release. A beaker is a useful piece of equipment to use for creating the spore solution, but any clean container will work. It is also best practice to use chilled clean seawater (similar in temperature to the seawater the plant was sourced from). If you are creating a gametophyte suspension you can also add nutrients to promote spore growth. All temperatures and nutrient concentrations below are presented as general guidelines and may need to be modified for specific species. If you wish, you can use only chilled seawater.

Culturing beaker

- Create a mixture of (the ratio provided below is specific for *Laminaria digitata* and *Saccharina latissima*):
  - » 1000 mL chilled seawater (sea temperature)—autoclave to sterilize optional
  - » 9 mL PES—Provasoli's Enriched Seawater (PES) culture nutrients—optional
  - » 0.8 mL germanium dioxide—optional for gametophytes
  - » 0.9 mL vitamins (optional)

Adding sorus

- Add sori to the beaker
  - » Cut into smaller pieces if necessary
  - » Pieces should be entirely submerged
  - » Use multiple or larger beakers/containers to avoid over crowding
  - » Aim for > 20 pieces from different individuals to ensure genetic diversity
  - » Keep records of species used and trial conditions
  - » Occasionally stir the sori with a sterile stirrer or swirl the beaker
- Spawning
  - » You may be able to see a cloudy plume form in the beaker when spawning occurs (if not visible by eye, it is also possible to observe spawning by dropping 1-2 drops of the solution on a microscope slide and using microscope)
  - » This process may take over an hour
  - » Try to keep the temperature cool (somewhat species specific, but cooler is often better)
- Calculate stock density (optional)
  - » Acquire materials (Microscope, hemocytometer, pipettes, cleaning materials)
  - » See other materials for calculating stock density
  - » Aim to achieve stocking densities of > 100,000 spores/ mL

A.3 CREATING A GAMETOPHYTE SOLUTION

Below are the key points from the cultivation protocol created for farming *Laminaria digitata* in Ireland. As before, the specifics (temperatures, wavelengths, durations) are reference points and will likely change based on species and region.

A.3.1 Creation of gametophyte cultures

- Gametophyte cultures can be developed from the spore suspensions and maintained for extended periods to increase their volume through vegetative growth under red light and adequate nutrient and temperature conditions.
- To start the process, add further sterilised seawater to the spore suspension to fill the vessel and add sufficient nutrient medium for the volume of culture used.
- Disperse the nutrients throughout the culture by swirling the vessel.
- To enhance growth the developing culture can be aerated by inserting a pre-sterilised glass tube into the culture vessel connected to an air-supply via tubing and an air filter.
- The vegetative development of the gametophytes requires the installation of either single or double strip lighting, such as T5 Lindas, with fluorescent bulbs in a moisture-proof housing that emit relatively low levels of heat.

- The gametophytes need to be maintained at this life stage and this stasis can be achieved by exposing to them to red light or storing the male and female gametophytes separately (they need to be manually separated using tweezers and a dissecting scope). The light units need to be covered in red cellophane to create the required red-light conditions necessary to maintain propagules in their gametophyte stage and allow for vegetative growth. Red (660 nm) hydroponic grow lamps also work.
- The light intensity (PAR) needs to be measured with a meter calibrated in μmol m^{-2} s^{-1} aiming for a range of 15-20 μmol m^{-2} s^{-1} at the surface of the glassware.
- The light source needs to be fitted with a time switch set to long days; 16 to 24 hours of light per day are sufficient.
- The cultures should be kept at a constant temperature similar to natural seawater temperatures.

A.3.2 Maintenance of gametophyte cultures

- To increase the volume of the gametophyte cultures over the next 3 to 6 months, cultures need to be kept in motion via constant air supply and the nutrient medium needs to be exchanged every 10 to 14 days.
- To maintain the cultures without growth the medium can be changed every 2-3 months and aeration and motion is not required.
- Keep a constant temperature around ambient seawater for the maintenance of gametophyte cultures during vegetative growth.

Note on contamination: In general, once a culture is contaminated it can take a lot of time to get it clean again. You should take a clean portion of the sample and move it into a new clean culture often. Ciliates and nematodes can be impossible to remove, and it is often better to throw away cultures where these are present.

A.3.3 Induction of reproduction

- Before the maintained gametophyte cultures can be used for seeding and development of sporophyte cultures, reproduction must be induced.
- Refresh the nutrient medium in the culture flasks to ensure that sufficient levels are available for sporophyte development.
- Cover the fluorescent lighting with blue cellophane to trigger sporophyte development.
- If measurable, optimal irradiance at the surface of the glassware is 15-20 μmol m^{-2} s^{-1} but values outside this range may also work.
- Set the time switch to equal light and dark periods, i.e., 12:12 hours of light to dark.
- Keep the temperature as before and provide continued aeration of the cultures.
- Maintain the culture flask(s) in these conditions until reproductive structures can be observed under a microscope.
    - » These will either be the developing unfertilized eggs still attached to the female gametophyte, or the fertilized egg/ developing sporophyte.
    - » The reproductive state of the culture is assessed by following egg development, as it is much more difficult to observe the smaller male reproductive structures.
- Once many reproductive structures are observed you can prepare the culture to add to the substrate. Substrates may be seeded by mixing the gametophyte solution and the vector in the same container or by creating a spray to apply to the vector.

A.4 FURTHER READING

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