Financial and institutional support are important for large-scale kelp forest restoration

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Abstract

Kelps form extensive underwater forests that underpin valuable ecosystem goods and services in temperate and polar rocky coastlines worldwide. Stressors such as ocean warming and pollution are causing regional declines of kelp forests and their associated services worldwide. Kelp forest restoration is becoming a prominent management intervention, but we have little understanding of what drives restoration success at appropriate spatial scales. This is a fundamental issue because of the typical mismatch between the scale of degradation and the scale of the intervention of these systems. Restoration guidelines commonly discuss project elements such as defining goals and metrics of success, the removal or mitigation of relevant stressors and ecological knowledge of the species, but institutional and financial support that underpins all these requirements is rarely discussed or emphasized. We begin to address this gap and review the world's largest scale kelp restoration projects, involving four countries and six kelp genera, initiated in response to different causes of decline. We argue that to restore kelp at

scale, adequate financing and institutional support are critical to overcome ecological and environmental limitations. As kelp restoration efforts progress into a future of increasing climate change, this logistical support element is likely to become even more important as innovative approaches have higher costs.

Introduction

Kelp forests (Orders Laminariales and Fucales) are ecologically and economically important coastal habitats in subtropical, temperate, and polar regions of the world (Dayton, 1985; Steneck and Johnson, 2013; Coleman and Wernberg, 2017; Wernberg et al., 2018). As prolific primary producers, kelps are vital for absorbing carbon dioxide, exuding oxygen, cycling nutrients, and sheltering hundreds of species in their canopies (Smale et al., 2013). Kelp forests are, however, under threat globally, with many populations around the world showing declines over the century (Krumhansl et al., 2016). While records of kelp declines date back to the early 1900s in Japan (Fujita, 2010) and 1940s in California (Wilson and North, 1983), kelp restoration only commenced in the 1960s (Wilson and North, 1983) and continued to emerge at a slow but steady rate until the turn of the millennium, when the number of restoration projects increased in many places around the world (Eger et al., 2020).

The field of kelp forest restoration is, however, still in its infancy and requires substantial research and application to enable restoration at scales matching those of degradation or loss. As with other restoration endeavours, once a group establishes the evidence of decline and desire to intervene (Layton et al., 2020), evaluating and achieving success require several subsequent steps (Figure 1). These steps are discussed elsewhere (Underwood, 1996; Hobbs and Harris, 2001; Gann et al., 2019), but briefly involve (1) defining clear goals and criteria to evaluate success, which then allows the (2) design and (3) implementation of the project, and of (4) monitoring and evaluation programs to determine if the defined performance criteria are met. If criteria are not met, these previous steps allow (5) identifying reasons for failure and (6) adaptive management to remediate the project to meet goals (Figure 1). While these steps are generally agreed on as best practice, the finances and institutions that underpin them are rarely discussed.

The first action step is mitigation, and when possible, removal of the initial cause of degradation (McDonald et al., 2016; Gann et al., 2019). The causes of kelp population declines are complex and involve many stressors, including ocean warming, overgrazing, habitat destruction, pollution, and overfishing (Steneck et al., 2002; Reed et al., 2006a; Vergés et al., 2014; Wernberg et al., 2018). The elimination of these threats can involve culling grazers (North, 1978; Fujita, 2010; Tracey et al., 2015), adding hard substrate where kelp was lost, offsetting in other habitats adjacent to degraded reefs if stressors are not addressed (see California example below) (Carlisle et al., 1964), remediating water quality (Driskell et al., 2001), or a combination of each – all of which require substantial resources. If there is a source population of kelp nearby to supply propagules, these actions may be enough to achieve restoration success (Reed et al., 2004; Foster and Schiel, 2010). In other cases, projects require additive actions when, the system has changed in such a way that prevents kelp recolonization (Coleman et al., 2008) or where the scale of impact is such that local propagule supply is insufficient (North, 1978; Campbell et al., 2014). These involve the re-introduction of reproductive material or donor plants into degraded areas via seeding or transplanting to create new, self-sustainable populations (Carney et al., 2005; Campbell et al., 2014; Westermeier et al., 2016; Verdura et al., 2018) and require additional resources to those needed for mitigation.

As restorationists continue to seek solutions to ecological problems and as interest in kelp restoration increases (Eger et al., 2020; Layton et al., 2020), it is important that we determine the role that financing or institutional support play in restoring ecosystems at large scales. Indeed, despite their likely significant role in the steps above, the Society for Ecological Restoration guidelines (Gann et al., 2019) make no mention of these potential factors. In this paper, we examine the role of financial and institutional support in four large scale kelp restoration projects from around the globe. We determined the projects that set the largest spatial scale goals by querying the results of a kelp restoration database which contained multi-language published and unpublished records of kelp restoration projects from 1957 to 2020 (Eger et al., 2020). The selected projects are in California (USA), Norway, Korea, and Japan, span six genera, use transplants, seeding, herbivore removal, and artificial reef deployment to restore kelp, and required restoration due to water pollution, herbivore grazing, and urban development (Figure 2).

Large-scale restoration projects

Wheeler North Reef, Southern California, USA

Discharge of cooling water from the San Onofre Nuclear Generating Station (SONGS) in southern California reduced local water quality and caused the loss of 73 ha of giant kelp *Macrocystis pyrifera* and associated biota. To offset the damage caused by these ongoing impacts, the state of California required the utility company that owned SONGS to: (1) construct an artificial reef on a nearby sand bottom, large enough to replace the kelp forest destroyed by SONGS' operations, and (2) provide funding for independent monitoring to ensure that the artificial reef meets established biological and physical performance standards used to measure restoration success. These performance standards include absolute criteria that require the artificial reef to sustain minimum levels of kelp area, fish standing stock and reef bottom coverage, and relative criteria that require the abundance, diversity and ecological functions of the artificial reef to be comparable to natural reefs in the region. Practitioners built the SONGS artificial reef, named "Wheeler North Reef", in three phases. The first phase was a five-year experiment involving the construction of 9 ha reef in 1999 that tested the efficacy of different reef designs and materials in meeting the performance standards used to measure restoration success (Reed et al., 2004, 2006b, 2006c). The monitoring results from this first phase were used to inform the design of the second phase: an additional 62 ha of reef to compensate for the ongoing loss of kelp forest resources. Ten years of additional monitoring of Phases 1 and 2 showed that abundance of giant kelp, abundance and diversity of reef biota and associated ecological functions at Wheeler North Reef were similar to those at nearby natural reefs, but also that the artificial reef was too small to sustain the required area of kelp and tonnage of reef fish standing stock (Schroeter et al., 2018). To remediate this size deficiency, the third phase of the project (2019-2020) added 85 ha of quarry rock reef covering ~45% of the seafloor. The resulting 156 ha Wheeler North Reef (273,081 metric tons of quarry rock) extends along 7km of coast and is one of the world's largest man-made rocky reefs. Cost estimates of the construction and monitoring of Phases 1 and 2 is tens of millions of USD, with monitoring costing ~ $1 million USD/year while the estimated construction costs for Phase 3 are between $17.62 - $27.89 million (USD, 2010, Edison, 2017).

Urchin culling, Northern Norway

During the 1970s, population expansions of sea urchins (*Strongylocentrotus droebachiensis*) formed grazing fronts that transformed approximately 900,000 ha of kelp forest along the northern coast of Norway into persistent urchin barrens (Norderhaug and Christie, 2009). Based on reports of successful chemical removal of urchins with quicklime (CaO) in Canadian and Californian waters (Bernstein and Welsford, 1982), restoration efforts to remove urchins using quicklime started with a pilot project in 2011 in Porsanger Fjord through a collaboration between local authorities, research institutions, and an industrial partner. These groups first tested urchin removal with quicklime at the target area and assessed any unintended environmental impacts. The pilot project (year 1) lead to the return of macroalgae and kelp cover, and the method was then scaled up in Porsanger in year 2 (~30 ha) and replicated in nearby Hammerfest over an area of ~80 ha in 2017 (Strand et al., 2020). These efforts resulted in the return of *Saccharina latissima* and *Alaria esculenta* and increases in faunal biodiversity. Estimated costs of employing the quicklime over 100 ha is $130,000 (USD, 2010) but the Norwegian Research Council provided additional financial support for pilot projects, monitoring, and research between 2011 and 2017.

Marine Afforestation Program, Korea

Several different stressors have caused kelp declines in Korea. On the east coast of the peninsula, sea urchin grazing is the major factor that has resulted in the loss of *Sargassum spp*., *Undaria pinnatifida*, and *Saccharina spp*., whereas urchins are absent and coastal development and habitat loss have caused declines of *Ecklonia spp*., *Sargassum spp*., and *U. pinnatifida* on the south coast and off the island of Jeju. These deforested areas started to rapidly spread in the 1990s and small scale restoration efforts first began in 2002 (Choi et al., 2003).

The size of these projects was small until 2009, when the government established a national research fund for kelp restoration, first managed by the National Institute of Fisheries Science (NIFS) and later by the Korea Fisheries Resource Agency (FIRA). The project also partnered with Sungkyunkwan University and Pukyong National University to study the status of kelp beds, urchin barrens, and develop restoration techniques. The scope of the fund is considerable: it aims to create 54,000 ha of kelp forest (including all species above) (Park et al., 2019) by the year 2030 and hopes to enhance fisheries resources in Korea.

The project currently focuses on deploying artificial reefs in areas with low urchin density (Jeon et al., 2015) and combining them with juvenile kelp transplants, seeding (spore bags), urchin removal, and subsequent monitoring. As of 2018, approximately 18,000 ha of concrete reef and transplants were deployed (Park et al., 2019) with a survival rate of ~50% (Jeon 2019, personal communication). Artificial reefs were originally used because the agency believed that transplanting kelp onto rock covered by crustose coralline algae would limit success, but new methods are being developed to deploy transplants onto the rocky reefs. Their final goal involves restoration at 260 locations and a budget of $267 million (USD, 2010) for the years 2015-2030.

Transplants, Shizuoka Prefecture, Japan

Increased turbidity and browsing by herbivores caused the decline of 8,000 ha of *Ecklonia cava.* and *Eisenia nipponica* beds in Hainan, Japan between 1985-2000. As a result, the wild *Eisenia* and abalone fisheries closed and interest in renewing these resources soon followed (Unno and Hasegawa, 2010). The Shizuoka Prefectural Government started initial restoration efforts in 1999 by first transplanting small concrete blocks into natural *Ecklonia* beds in the nearby Izu Peninsula to accumulate sporophytes, the blocks were then relocated to Hainan area, the target site. Initially, this was successful, but within three years herbivorous fish (e.g. *Siganus fuscescens*) grazed the transplants. A second attempt involved increasing the area restored and the number of transplants. Different sectors of society supported this second attempt, with the local fishery cooperative, the municipal, prefectural, and national governments providing logistical support and financial resources. The project ran between 2002-2010, with a budget of $5.21 million (USD, 2010). Instead of translocating blocks, *Ecklonia* sporophytes were mass cultured using a deep-sea water circulation system and attached to 2,162 concrete blocks, which were then placed onto rocky reef. In addition, the governing bodies paid local fishermen to remove herbivorous fish using gill and set nets. Following continued efforts, monitoring by video towing shows the project has restored approximately 870 ha of kelp habitat as of 2018 and fisheries cooperatives are now considering the re-opening of the abalone fishery.

Project Commonalities

Subtidal coastal restoration is an expensive enterprise, with costs reported to be in the thousands to millions of dollars (USD, 2010) per hectare (Bayraktarov et al., 2016). Restoring kelp forests is no exception and actions such as urchin culling, kelp cultivation and outplanting, and reef building are time and resource intensive. As a result, large budgets in the four projects are unobtainable by many organizations that may otherwise have the information required for restoration. Thus, once a group obtains the ecological knowledge required to plan restoration (Figure 1), access to the necessary resources, such as personnel, equipment, technologies, and seeding materials, may in fact be the key factor restricting success at scale. Even though the cost of restoration should decline as techniques become more developed and we achieve economies of scale, substantial financing will be a key element of any future large-scale restoration project. For these projects, the planning, monitoring, modifications and maintenance are additional costs over the cost of restoration (Figure 1). We find that these four projects share large amounts of funding, long project duration, and strong institutional support. Project finances ranged from $5 to $267 million USD (2010 $), areal extents spanned 110 – 18,000 hectares, the minimum time spent on a project was six years with the others spanning two decades, and a multidisciplinary team with established partners from universities, industry, and government agencies worked on each project.

The planning process

Because each project was well financed and had an extended operational timeline, there were thorough planning processes for each action. These resources and timescales allowed the projects to use a multi-step, adaptive approach to restoration and smaller pilot projects preceded the large-scale effort. These pilot projects allowed the managers to test the science and methodology, then change their approach based on the results. For example, the urchin culling efforts in Norway repeatedly tested the impacts and efficacy of their quicklime approach before investing further resources and scaling the project up. Though planning steps represent a small part of the overall budget, they are important to ensure groups use a good framework for restoration (Figure 1).

Monitoring and maintenance

As with planning, monitoring and maintenance require substantial resources. The monitoring process is essential to determine if a project is achieving its stated goals or having any unintended consequences. Not only is monitoring important, but it should occur over an extended duration as many populations take several years to establish and even longer for a full ecosystem to return (Carter et al., 1985; Tegner et al., 1997). Short term monitoring projects may thus fail to 'capture' the full outcomes of the project. Monitoring typically costs more than planning but less than maintenance or installation (Figure 1). The Wheeler North Reef is a strong example; despite high kelp recruitment on the reef within 9 months, the biomass fluctuated over the years and it is still working towards achieving the legally mandated offset value, some 12 years after the major installation.

Moreover, maintenance or adaptive management are only feasible if active monitoring occurs. For instance, longer term projects can maintain restoration sites and help reduce other stressors such as overgrazing by sea urchins (House et al., 2018) or supplement lost outplanted material caused by disturbances (North, 1978). Failing to do so can result in the failure of the project and wasted resources. For example, the initial transplants in the Shizuoka prefecture survived in the short term, but they disappeared due to an unanticipated stressor: herbivorous fish. By adapting and employing the local fisheries cooperative to help reduce the stressor and outplanting additional material, the project achieved a much larger area restored. Adaptive management can be vital to the success of a project and may often be the most expensive step (Figure 1).

Institutional support and project motivations

It can be beneficial to have groups from different sectors involved in the restoration process to help reduce individual costs per group and draw on different areas of expertise (Gann et al., 2019). All four projects were the result of multiple collaborations between different stakeholders from academia to government to industry. Government participation was the one common element across the four projects, suggesting that working with relevant government agencies can help achieve restoration at meaningful scales. Having a government body involved can lend legitimacy to the project (Van Tatenhove, 2011), provide legal backing (Lausche and Burhenne-Guilmin, 2011) and secure sustained funding (Waldron et al., 2013). These qualities are well demonstrated by the FIRA project in Korea, which as a government body, is halfway through a 21-year project that spans 10s of thousands of hectares and costs hundreds of millions of dollars. That level of coordination, financing, and commitment is exceptionally rare in restoration and likely would not have been achievable by non-government groups or agencies.

Because the cost of restoration is so high, groups require significant motivators to invest the necessary resources. Legal mandates or financial incentives are two strong such motivators and some projects may not be completed without them (Akhtar-Khavari and Richardson, 2019). The legal pathway is well demonstrated in the Wheeler North Reef restoration project; the utility company was legally required to offset habitat losses from the operation of their commercial activities. Alternately, the projects in Japan and Korea restored their ecosystems because of a desire to enhance declining fisheries resources, significant contributors to their economies. Lastly and though not demonstrated here, there are several emerging businesses that seek to merge restoration with profits linked to environmental offsets and this pairing of ecological restoration with financial and-or social license gain could be a key step in taking kelp restoration to a large scale. As societies consider different avenues for large scale restoration, these sorts of legal and financial considerations are going to be important motivators to ensure organizations invest the required resources.

Conclusions

Besides the acknowledged importance of having clear goals, the removal or mitigation of relevant stressors and ecological understanding of factors that can prevent/promote recovery, financial and institutional support of kelp restoration projects appear to be critical to enable kelp restoration at relevant scales. Such support is crucial at most, if not all, steps of the process (Figure 1), including planning, implementation, long-term monitoring and adaptive management. Encouragingly, we show that with the appropriate financial and institutional support, kelp restoration, in a wide range of conditions, is achievable at large scales. As restoration projects, kelp or otherwise, continue to attempt to restore ecosystems at large and meaningful scales, we argue that financial and institutional support are vital to help achieve these goals. These considerations will become more important in the future as ocean ecosystems change and we require new solutions to adapt (Coleman and Goold, 2019; Wood et al., 2019).

Author contributions

AE, AV, DR, PS, and EM conceived the idea for the manuscript. AE and EM led the writing. CWF and HC wrote the Norway section, MH and DF wrote the Japan section, JHK and CGC wrote the Korea section, DR wrote the California section, AE, AV, MC, MMP, PS and EM wrote the first draft. All authors provided comments, edited, and approved the full manuscript for submission.

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Figure Legends

Figure 1: Flow chart of best-practice steps involved in restoration projects. Dollar signs indicate the relative costs of each step.

Figure 2: Location, size, and costs of the four large scale kelp restoration case studies. All costs are reported in USD for the year 2010.

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Figures

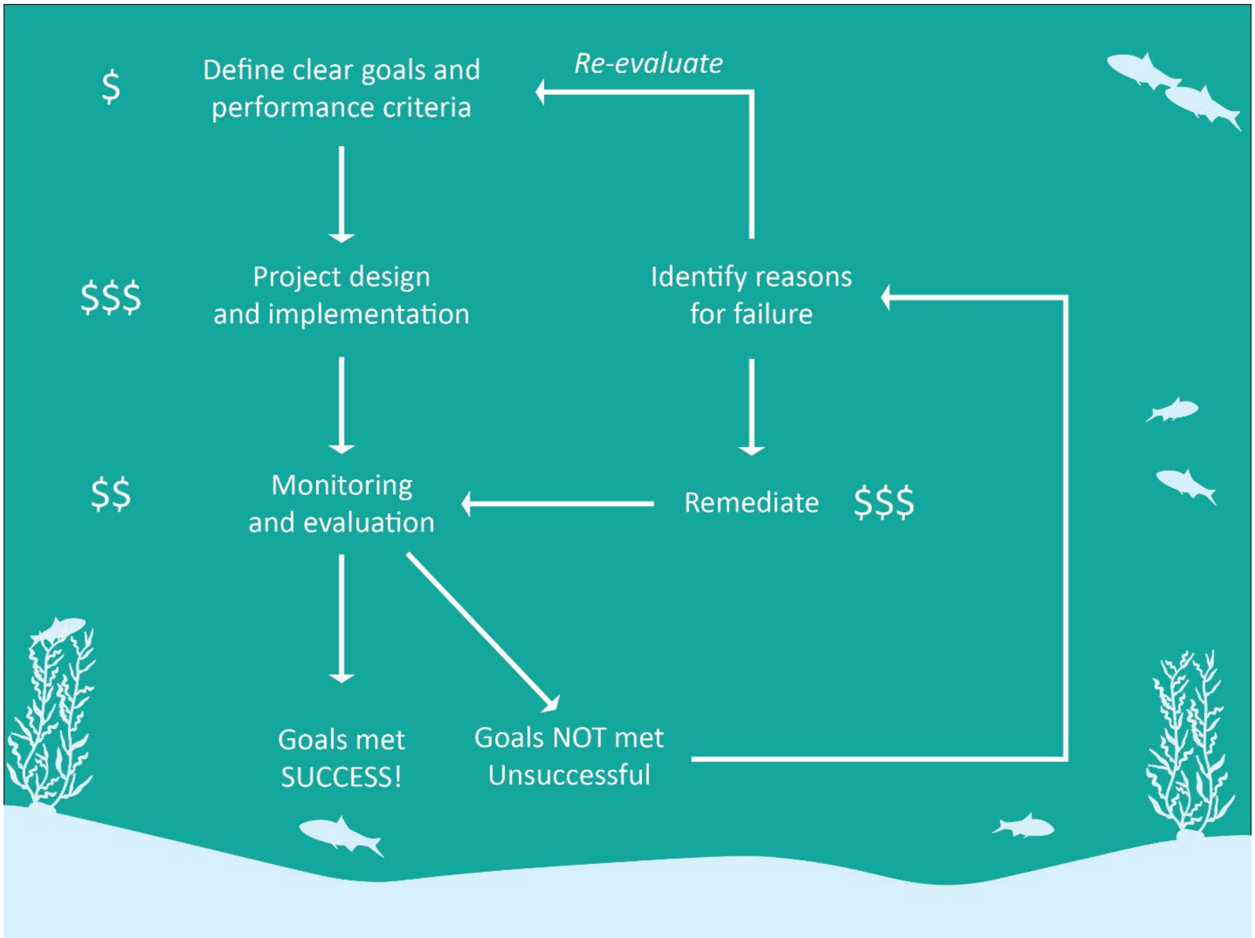

Figure 1: Flow chart of best-practice steps involved in restoration projects. Dollar signs indicate the relative costs of each step.

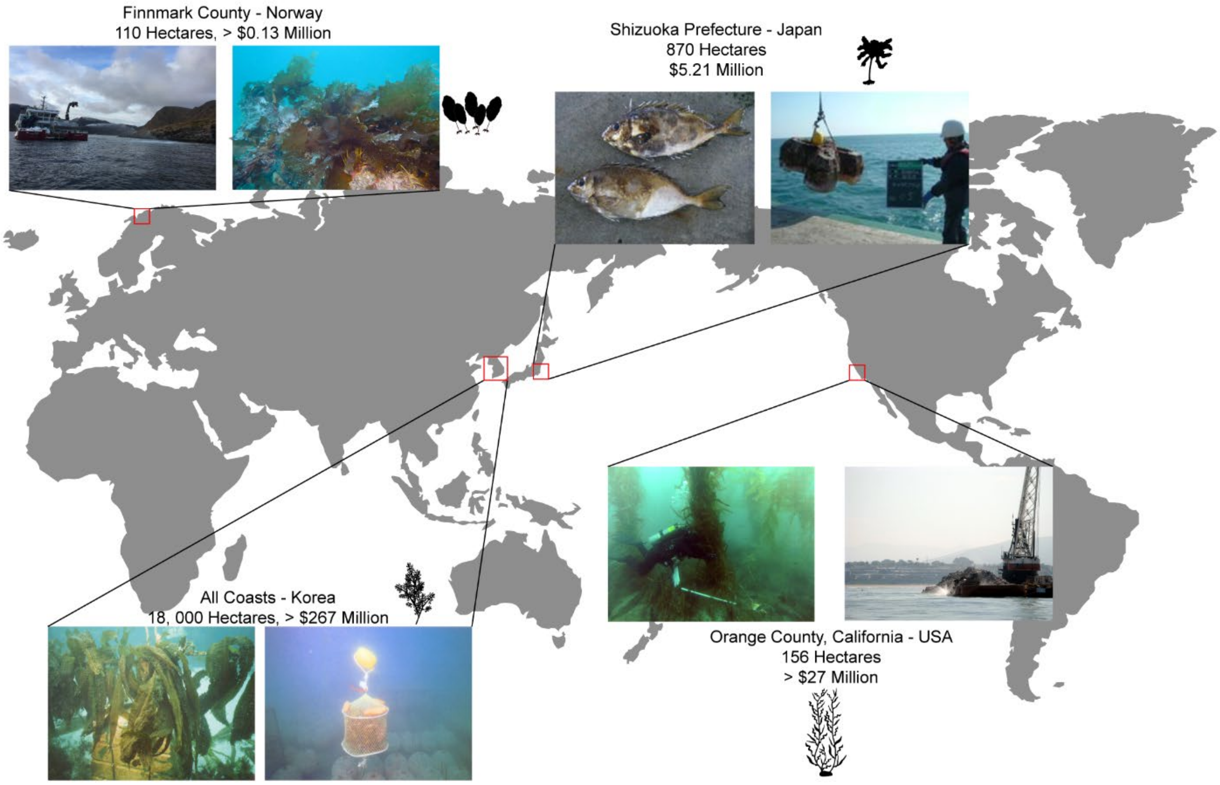

Figure 2: Location, size, and costs of the four large scale kelp restoration case studies. All costs are reflected in USD for the year 2010.