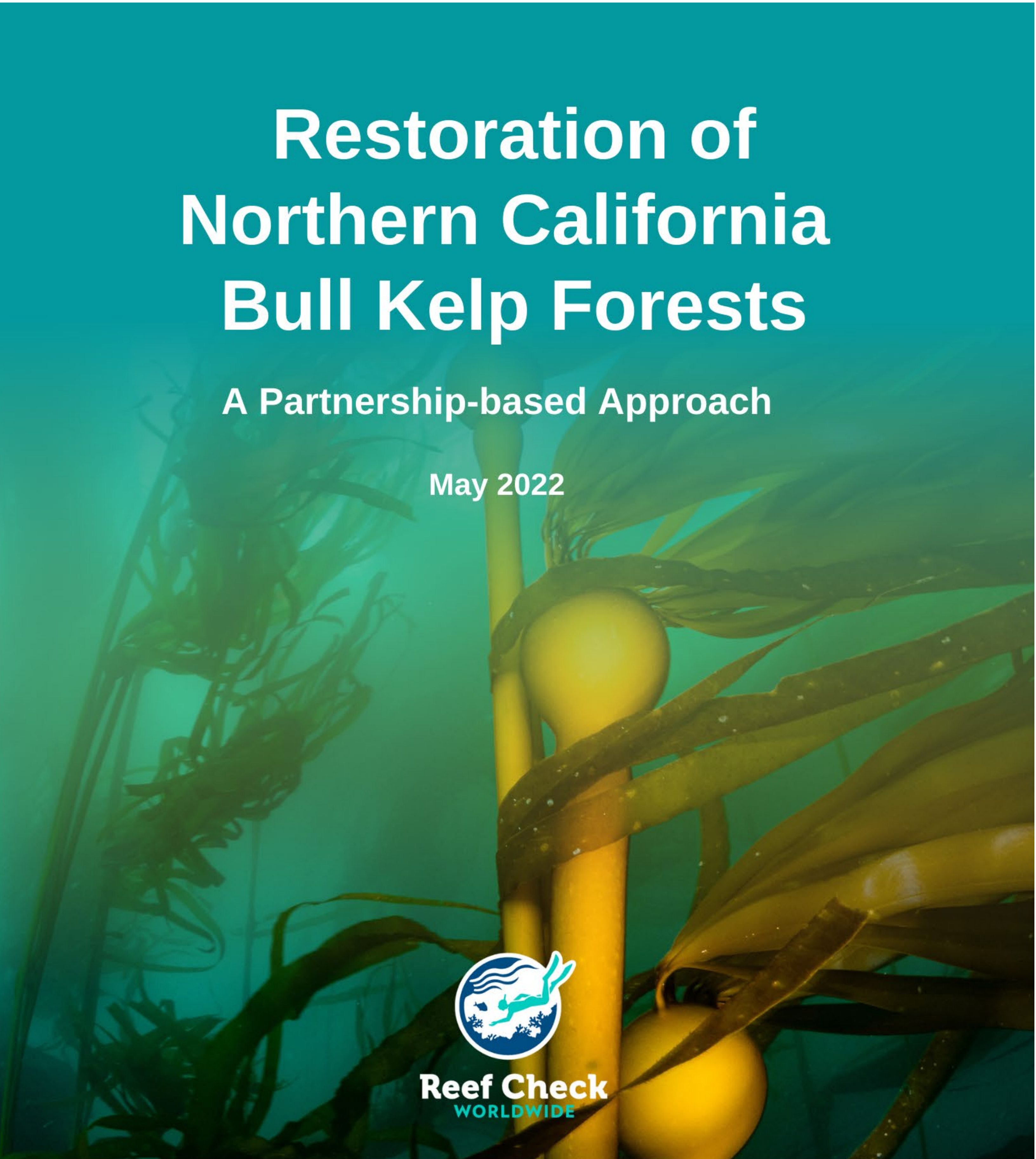
Restoration of Northern California Bull Kelp Forests

A Partnership-based Approach

May 2022



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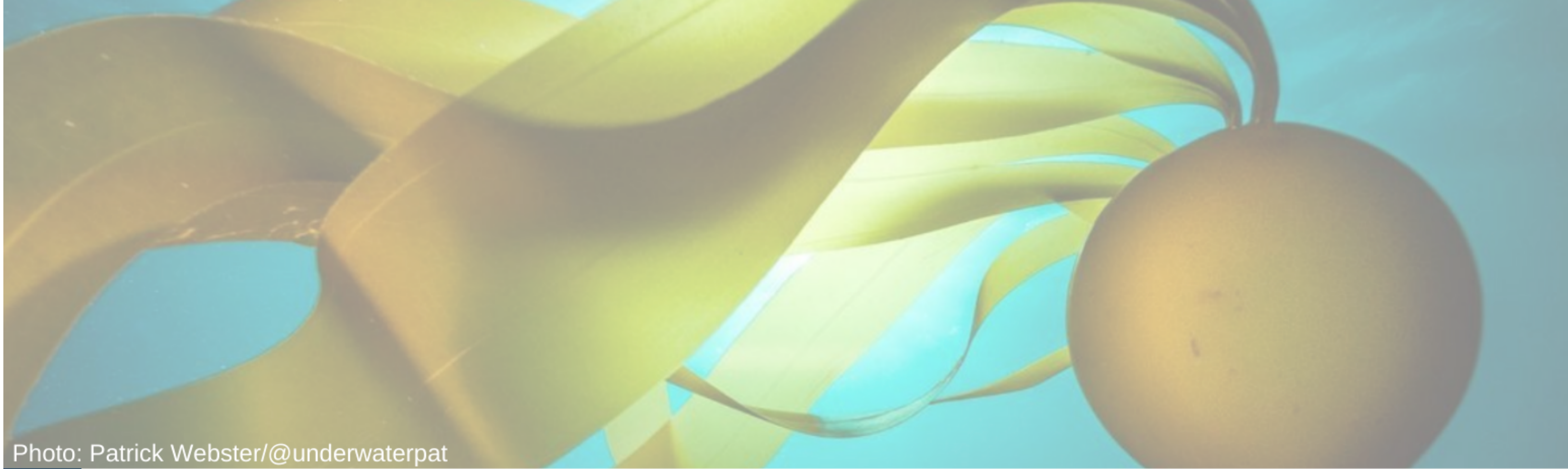
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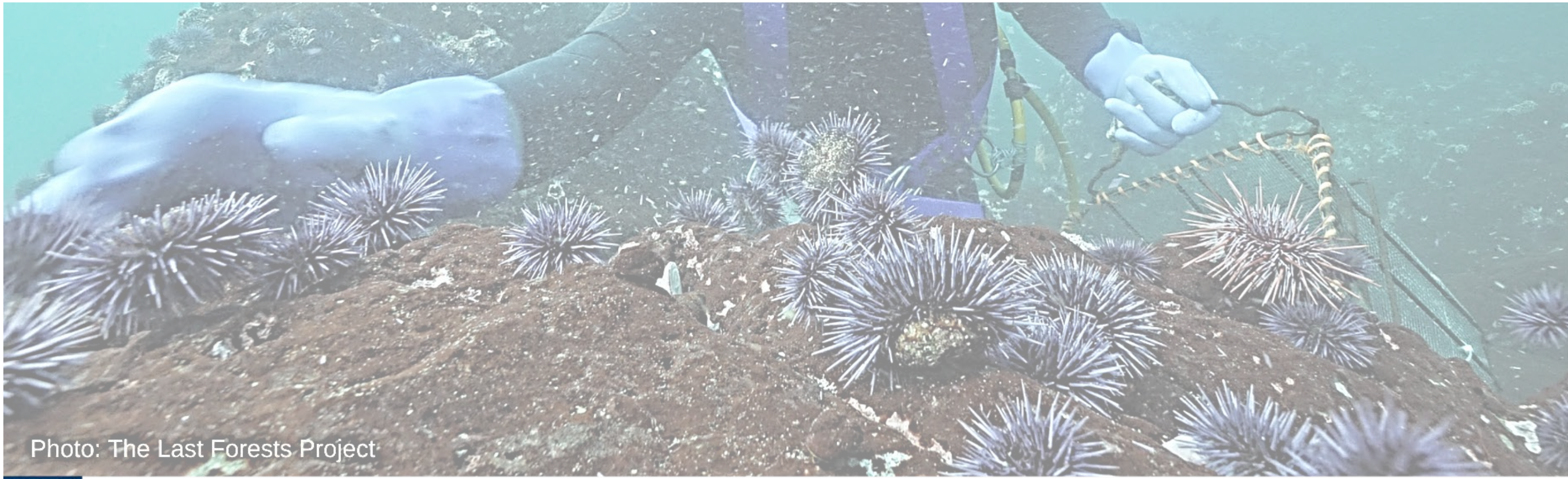

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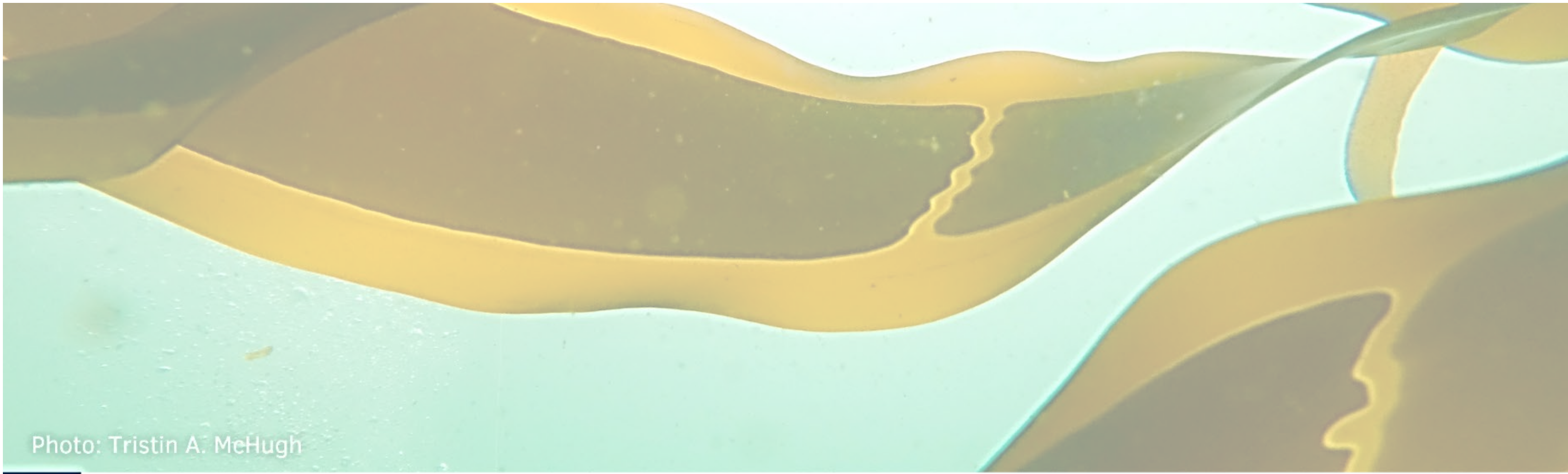

1. Executive summary

Starting in 2014 and continuing into 2021, California's North coast, in particular Sonoma and Mendocino Counties, experienced a dramatic loss of bull kelp (*Nereocystis luetkeana*) due to a combination of oceanographic and biological stressors. This loss had catastrophic impacts to the kelp forest ecosystem, as well as socio-economic impacts on the human communities that rely on the kelp forests' natural resources. These severe and prolonged impacts have elevated the protection and restoration of California's kelp forests as a top priority for state resource managers. Despite California's iconic kelp forest ecosystems being studied for decades, there is still relatively poor understanding of the efficacy, logistical feasibility, and ecological outcomes or potential risks of various kelp restoration approaches. One such approach is the reduction of grazing pressure through large-scale urchin removal by commercial divers, which hereto had not been scientifically investigated in California's bull kelp forests. To address this gap, Reef Check, was awarded $617,000 from the Ocean Protection Council to develop, test and study, in partnership with others, a novel collaborative approach for bull kelp forest ecosystem restoration: urchin removal by commercial sea urchin divers along Northern California's rugged coastline. Restoration was implemented at two sites in Mendocino County at Noyo Cove and in Albion Cove starting in July 2020 and July 2021, respectively.

This project demonstrates that commercial divers can conduct kelp forest restoration via urchin harvest, and the impacts of human intervention can be quantified. Specifically, with a frequent and coordinated initial removal effort, urchin densities can be reduced to a target threshold density of 2 urchins per square meter over spatial scales of several acres, and densities of less than 2 urchins per square meter can be maintained over time with lower relative effort and investment. Several factors affecting cost of urchin removals became evident and should be considered in future restoration projects. For example, the effort required to remove an equivalent biomass of urchins from the shallow reef zones is lower than in the deeper zones. This could lead to prioritization of removals within a given site or influence how removals might be distributed over the duration of a project. Similarly, early efforts might be focused on areas of a site where urchin densities have not yet become as high or where some kelp still remains throughout a site.

Overall, the cost of removal of urchins to reach the low density threshold (<2/m^2) was similar among the two restoration sites when corrected for the higher pay for work at Albion due to longer distance from port. This suggests that environmental differences among the sites did not play a large role in cost per acre but that distance from port and accessibility of a site can greatly increase cost of restoration. Therefore, urchin removals by commercial divers will be most effective in areas where there is already an established commercial red urchin fishing fleet (e.g., Mendocino County, Southern California), at restoration locations that are relatively close to fishing ports, and at locations where urchin incursion can reasonably be controlled to keep them low after initial removals.

One year after restoration began, kelp density at the first restoration site was significantly higher relative to an unmanipulated reference site (Figure E1) and reached about 20% of historical densities observed in Mendocino County prior to the recent kelp forest loss during Reef Check surveys prior to 2013. These findings suggest that reducing and maintaining low purple urchin (*Strongylocentrotus purpuratus*) density may contribute to bull kelp ecosystem recovery at sites along California's North coast. Continued monitoring, at least through 2022, is underway to further evaluate the ecological outcomes of kelp forest ecosystem recovery efforts. As impacts from environmental change become more prevalent, understanding the processes and opportunities for adaptation and restoration are becoming increasingly important. We demonstrated that local stakeholders can be successfully engaged to conduct restoration work, that this approach leads to co-development of knowledge and fosters collaboration that is essential for the coordination and logistics of community-based ecosystem restoration. Continued ecological monitoring spanning ecologically relevant timescales (e.g., >2 years), is essential to achieving and documenting restoration success.

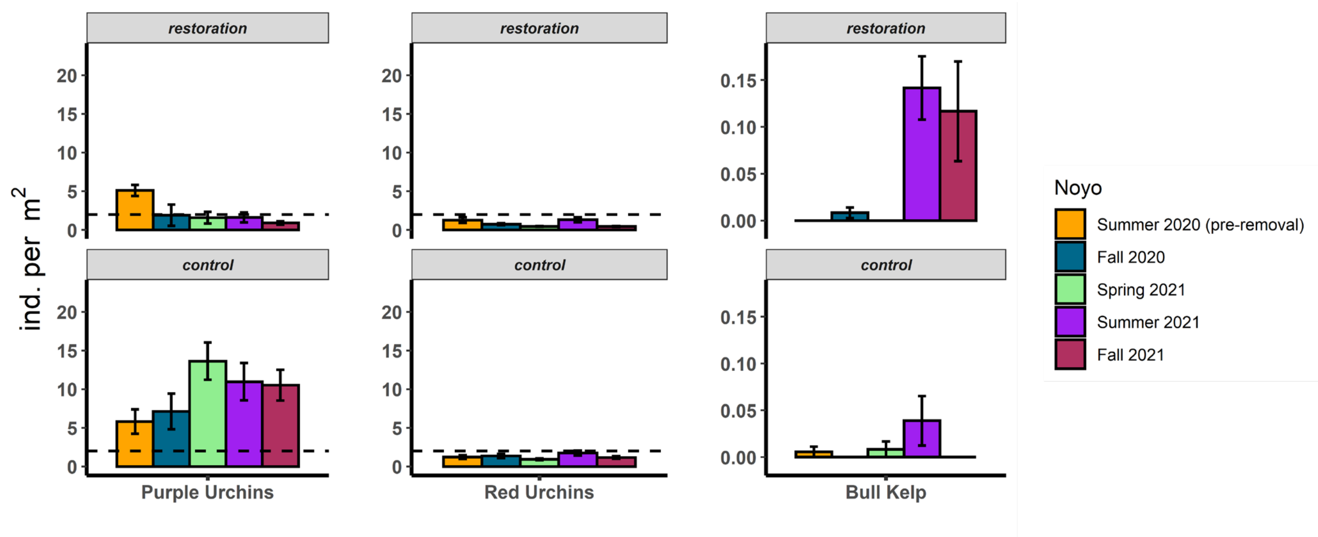

Figure E1. Densities (individuals per m^2) of purple urchins, red urchins, and bull kelp in both the restoration and control sites over the project period (Summer 2020 to Fall 2021) at Noyo. Bars indicate means ± SE.

Future work along the North coast and beyond can build upon these findings and outcomes and test implementation of similar frameworks. Working within the commercial fishing regulations made this project possible, however, developing restoration specific permitting could further facilitate stakeholder engagement and allow for broader participation in similar projects. This project was initially designed and funded for one year. It took considerably longer than this initial time frame, in part due to the COVID-19 pandemic, but mainly because of the lengthy process to organize community members and the time it takes to complete work in the ocean environment and the seasonality of this type of work in North coast. Future projects in similar environments or with similar community engagement and co-management should be designed and funded for time periods that are more compatible with the time frames of the socio-economic and ecological processes involved.

2. Introduction

Canopy-forming kelps are foundational species found in temperate marine systems across the globe, providing food and shelter for numerous ecologically and economically important species. Bull kelp (*Nereocystis luetkeana*) is the dominant canopy-forming kelp along the rocky shores of Northern California (north of the Golden Gate), supporting many recreational and commercial fisheries (e.g., rockfish, red urchin, and abalone) and holding high cultural and economic significance in the region (Springer et al. 2010, Rogers-Bennett and Catton 2019). Bull kelp forests can also serve to potentially ameliorate the impacts of ocean acidification and climate change through carbon metabolism and sequestration (Pfister et al. 2019). More than 96% of bull kelp in Sonoma and Mendocino Counties was lost between 2014 and 2020 due to a combination of ecological and oceanographic stressors linked to climate change (McPherson et al. 2021, Wernberg et al. 2021, The Nature Conservancy 2022). This unprecedented loss dramatically altered the community structure and functioning of coastal reefs, subsequently impacting local human communities and coastal economies that rely on these habitats (McHugh et al. 2018, Hohman et al. 2019, Rogers-Bennett and Catton 2019, McPherson et al. 2021).

Although kelp forests are exposed to a wide variety of stressors and kelp cover generally exhibits a high degree of interannual variability statewide, the severe loss in the past decade has been attributed to several key compounding events. In 2013, a severe outbreak of sea star wasting disease caused a cascade of species interactions and induced the functional extinction of the sunflower sea star (*Pycnopodia helianthoides*). The loss of the sunflower sea star dramatically reduced predation pressure on native purple (*Strongylocentrotus purpuratus*) and red urchins (*Mesocentrotus franciscanus*), which feed on bull kelp (Harvell et al. 2019, Gravem et al. 2021, Hamilton et al. 2021). In addition to the loss of a key urchin predator, a series of severe marine heat waves and a strong El Niño Southern Oscillation (ENSO) event in 2014-2016 and 2019, which reduced nutrient availability required for kelp growth, decreased the availability of drift kelp a key urchin diet item (Bond et al. 2015, Smale et al. 2019). These oceanographic events, likely also lead to increased urchin recruitment, often associated with warm water (Okamoto et al. 2020).

The series of oceanographic and ecological stressors is currently understood to have resulted in a behavioral shift in urchins from passive to active grazers on kelp beginning in 2013 (Smith et al. 2021), facilitating continued urchin proliferation (Harvell et al. 2019, Okamoto et al. 2020), and hindering kelp recovery (Gravem et al. 2021). This overabundance of urchins led to the prevalence of so-called ‘urchin barrens’ – areas devoid of kelp with anomalously high urchin densities (Filbee-Dexter and Scheibling 2014, Wernberg et al. 2019). Once reefs shifted from kelp forest to urchin barren, urchins often experienced prolonged periods of starvation, leading to further aggressive feeding behavior and poor urchin reproductive condition (Smith et al. 2021).

This poor reproductive condition greatly decreased the quantity and quality of red urchins that could be legally harvested, reducing the commercial landings by 60-80% and leading to near collapse of the fishery (Hohman et al. 2019, Rogers-Bennett and Okamoto 2020).

After years of widespread and persistently low kelp cover, a federal fishery disaster was declared for the region's valuable commercial red sea urchin fishery in 2015-2016. Large declines in populations of red abalone (*Haliotis rufescens*), which also feed on kelp, led to closure of California's last remaining recreational abalone fishery in 2017, a $44 million dollar industry (Rogers-Bennett and Catton 2019, Rogers-Bennett and Okamoto 2020). Although the severity of oceanographic stressors has been reduced in recent years with subsidence of marine heatwave conditions, kelp forests on the North coast are only beginning to show early signs of regrowth. In key reef habitats, persistent high densities of purple sea urchins continue to suppress kelp recovery along the California's North coast (McPherson et al. 2021), leading to compounding and prolonged stress on the fisheries and coastal communities.

Given the severe disruptions to the coastal ecosystem, economy, and coastal communities, the protection and restoration of California's kelp forests has emerged as a top priority for state resource managers and several steps have been taken (Hohman et al. 2019, California Ocean Protection Council 2021, CDFW 2021, Eger et al. 2022a). The California Department of Fish and Wildlife (CDFW), in partnership with California Sea Grant (CASG), developed the Giant Kelp and Bull Kelp Enhanced Status Report, which includes a species overview of giant kelp (*Macrocystis pyrifera*) and bull kelp, the "fishery" (i.e., kelp harvest), management and restoration, monitoring and essential fishery information, as well as future directions and needs for management of both giant and bull kelp (CDFW 2021). The state's Interim Kelp Action Plan, co-developed by OPC and CDFW, which summarizes pilot restoration and research initiatives, lists important knowledge gaps, and outlines priorities for future action, highlights the development of a kelp restoration "toolkit" - a suite of kelp restoration options available to resource managers and partners in California - as an important step toward proactive, climate-ready management of the state's kelp forest ecosystems (California Ocean Protection Council 2021). The Interim Kelp Action Plan serves as a critical, actionable roadmap to bridge the gap between now and implementation of the statewide Kelp Restoration and Management Plan, which is in its early developmental stages.

The kelp ecosystem loss along the North coast of California is not unique. Kelp forests are declining globally, and engagement from local communities are subsequently underway globally (Wernberg et al. 2019, California Ocean Protection Council 2021, Eger et al 2022a, Eger et al 2022b). In temperate reefs, reducing grazing pressure via removal of urchins has been understood to aid in kelp recovery, and lead to additional benefits to communities that rely on healthy ecosystem (Williams et al. 2021, Eger at al 2022a, Eger et al. 2022b). If urchin densities can be reduced to a level that enables reefs to shift from urchin barrens to bull kelp forests (Filbee-Dexter and Scheibling 2014, Williams et al. 2021), this could act as a valuable tool in restoring resilient bull kelp populations, and if done with community involvement and sufficient funding may simultaneously serve as a supplemental income alternative to those impacted by kelp loss (Lee et al. 2021). Despite the need for restoration, relatively few programs have taken such an approach, and documentation of their restoration successes and challenges is sparse (Williams et al. 2021, Eger et al. 2022b). It was hereto unknown if urchin removals along the North coast could successfully restore kelp habitat, and what the associated costs and outcomes would be. In addition, the challenges of conducting research and restoration along the North coast had been limited by funding, and subsequent capacity by practitioners, fishermen and scientists. In order to fill this need, the California Ocean Protection Council (OPC) funded a bull kelp restoration project along the Mendocino coast in 2020. $617,000 was granted to Reef Check (RC) to support a partnership with CDFW, the Watermen's Alliance and Noyo Center for Marine Science (NCMS). This partnership later also included collaborations with the UC Davis Bodega Marine Laboratory and The Nature Conservancy (TNC). This work addressed the following questions:

1a) Can commercial divers be coordinated to reduce urchins to target densities (< 2 urchins/m^2) and maintain this urchin density at sites along the North coast?

1b) What is the cost and effort (logistics and time investment) required to achieve and maintain this target urchin density?

2) How does kelp density change following urchin removals, compared to un-restored control sites?

By addressing these questions, the work presented herein demonstrates that kelp restoration via urchin removal could be a viable and valuable tool for effective coastal management in California, bolstering economic and ecological resilience. We were not able to compare the cost of these efforts to other restoration projects using different methods or in other regions of the state as the financial information of those projects were not available to us.

3. Methods

RC worked, in close collaboration with CDFW, OPC and commercial sea urchin divers, to develop a mechanism for commercial divers to conduct restoration via urchin harvest, with urchin processors to land and process harvested urchins, and volunteers to support sampling efforts on the docks following urchin removals. In order to participate in this project fishermen had to have a valid commercial Sea Urchin Diving permit and they are hereafter referred to as commercial divers. A Before-After Control-Impact (BACI) design was implemented to monitor restoration success from July 2020 to December 2021 (Figure 1). Ecological monitoring began prior to restoration at all four sites (two restoration sites and two associated control sites). Systematic urchin removals were then conducted, and seasonal ecological monitoring was completed at all sites to evaluate kelp recovery. Diver effort, pounds of urchins removed, urchin biometrics, and bycatch were also quantified throughout the project. Each of these processes is described in more detail below.

2.1 Commercial diver coordination

Funding for this project was used to pay commercial divers as participants for urchin removal. Initially, the project team planned to select three to four 3-4 commercial divers to participate in order to maximize the number of working days per diver. However, strong interest from the commercial diver community led to their advocacy for more participants. Therefore, CDFW, OPC and RC developed an application process to involve more fishermen from within the community. To support this engagement and gauge the interest and qualifications of divers, RC developed and circulated the Mendocino Urchin Removal Project Diver Questionnaire (Appendix A). Project managers from RC, CDFW, and OPC reviewed applications, and ultimately accepted all 16 applicants, each of whom had operations primarily based out of Noyo Harbor. All 16 applicants had experience diving for red sea urchin along the North coast, held valid commercial urchin fishing licenses and had access to registered fishing vessels; each of these criteria were necessary to participate in the restoration project.

In an effort to provide equal opportunities to all commercial divers involved at the start of the project, and following diver consensus, the total number of diver days was distributed as evenly as possible among the participants. Limitations were, however, placed on participants' consecutive working days to ensure diver safety. Implementing a predetermined number of dive-days for each commercial diver allowed divers to be more selective about what kind of ocean conditions they conducted restoration in versus competing for days. This equitable approach was taken in both Noyo Cove and Albion Cove, however, differences between these two sites arose predominantly because transit to and from Albion Cove required a 2-hour round trip by boat from Noyo Harbor. The added transit time to Albion reduced the total number of vessel operators willing to make the trip and required an increase in the daily pay rate for divers and vessel operators to compensate for travel time and costs. Ultimately, this translated into a first-come-first-serve allocation of diver days in Albion Cove; any participating vessel that was ready on a workable day was given the go ahead. Daily work was negotiated between project management and commercial divers and agreed upon at four hours of underwater urchin removal time at both sites.

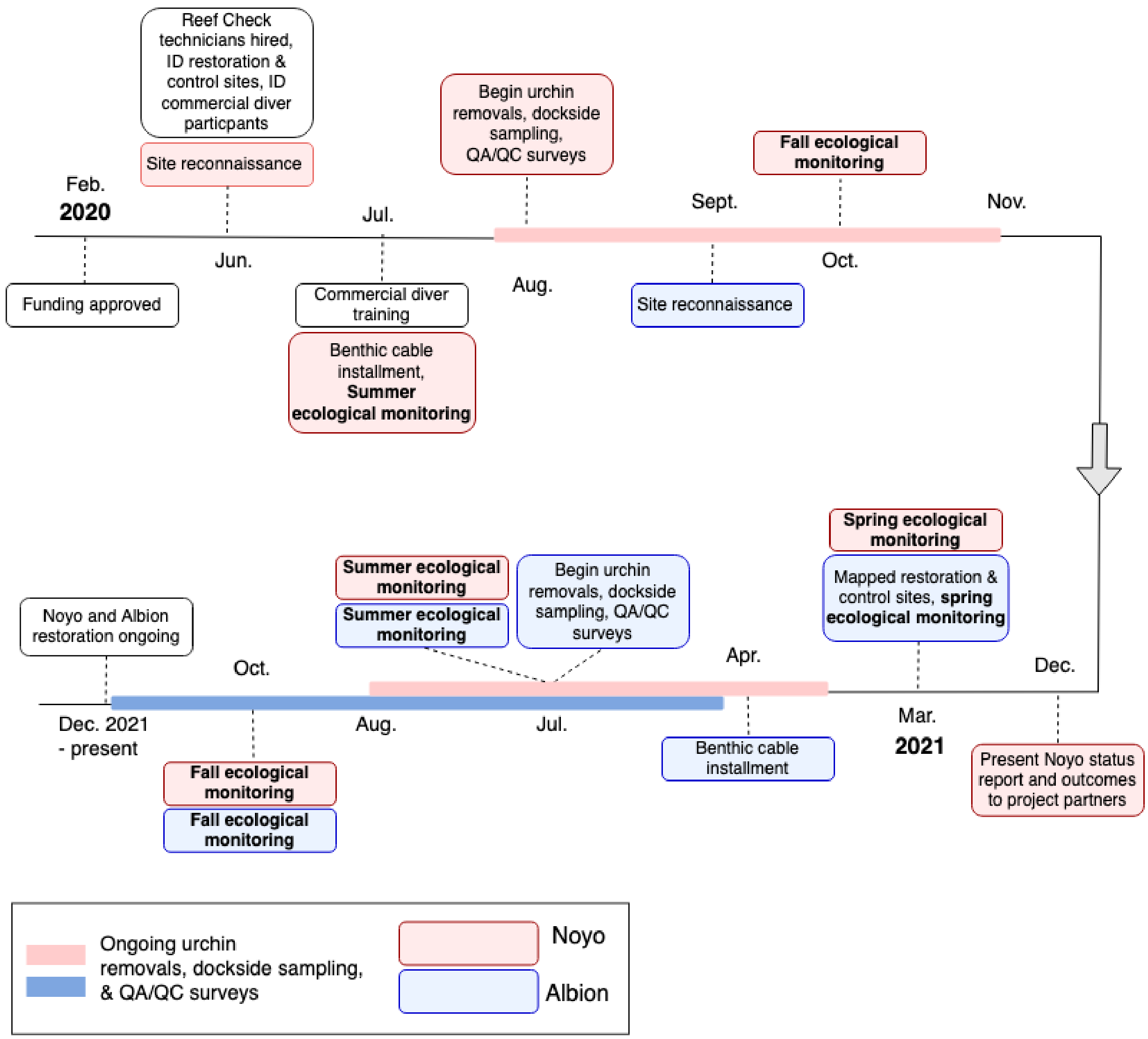

Figure 1. Timeline of activities from February 2020 – present. Key dates of monitoring and restoration activities for Noyo shown in red, and Albion in blue.

Communication between RC, CDFW, OPC, commercial divers, processors, volunteers, and additional organizational collaborators was an essential part of urchin removal. Communication between commercial divers and project management was frequent in order to coordinate removal efforts around challenging and rapidly changing weather and ocean conditions. Commercial divers were required to contact the RC project manager prior to going out on any given day to confirm with RC where urchin removals were needed and be directed to specific locations to focus removal efforts. Additionally, commercial divers were required to contact the RC project manager again after completing a maximum of four hours underwater on their return to the harbor to offload and complete the required landing documents and datasheets (see section 2.4 below, Appendix B). Commercial divers were also responsible for communicating and coordinating with the processing facilities the morning of removals to ensure processors would be present and ready to receive urchins during offload times. Once urchins were offloaded via the processors at the docks, commercial divers were required to send a photo of their completed datasheet to the RC project manager. The datasheet included key information that was used to guide urchin removal efforts on a daily basis. Specifically, it included the location and total area divers worked, notes about the habitat and urchin behavior (in cracks or out on rocks), total poundage landed at the docks, and which processing facility the landed urchins were located at.

Determining a mechanism for paying commercial divers proved to be a significant barrier because of the State's insurance requirements for contracting with outside entities. Commercial divers typically work for themselves, not as contractors, and sell their catch directly via the processors. In order to efficiently and effectively compensate commercial divers for their urchin removal efforts, RC held a Fish Receiver's License from CDFW. The Fish Receiver's License (California Code of Regulations, Title 14, Section 197), allowed RC to purchase the collected purple urchins from the commercial divers to compensate their efforts. All landed urchins were reported to CDFW through the E-tix (electronic fish ticket) system. E-Tix is a web-based form that is used to record and send landing data to CDFW via the E-Tix system, managed by the Pacific States Marine Fisheries Commission (PSMFC). Pounds of purple urchins landed were recorded and the price per pound was adjusted to reflect the agreed upon daily rate a commercial diver would earn. Rates for commercial divers differed by status as "vessel operator/diver" or "diver". The vessel operator/diver classification encompassed commercial divers that operated a vessel and also participated in diving efforts. They were paid more than the diver classification, which encompassed commercial divers that just dove on another operator's vessel. The vessel operator/diver received $600/day for work in Noyo, compared to $925/day in Albion. The "diver" rate was $500/day or $700/day, for Noyo and Albion, respectively. These pay rates totaled $1,100/day for Noyo or $1,625/day for Albion.

2.2 Selection of control and restoration sites

Site selection for restoration and control sites was determined using criteria outlined in the Sonoma-Mendocino Bull Kelp Recovery Plan (Hohman et al. 2019) and through discussions with restoration practitioners in Canada (Lynn Lee pers. comms). For a site to be considered for restoration or as a control site under the frame work of this project, it first needed to be identified as an urchin barren. An urchin barren is characterized by anomalously high density of urchins and absence of habitat forming kelp. Additional factors considered were prioritized according to the following primary criteria:

1) Extant kelp patches: Kelp patches in proximity to, but outside, existing restoration sites act as valuable spore sources to support new kelp growth within the restoration sites (Hohman et al. 2019). Additionally, these patches may have persisted through previous periods of environmental stress, suggesting a degree of potential genetic resilience. By enabling spores from these populations to settle in restoration areas, it is possible to promote populations that are more resilient to periods of future environmental stress (Schoenrock et al. 2021). High preference was therefore placed on coves where extant kelp patches were known to have persisted through recent environmental stressor events (Tristin Anoush McHugh, pers. obs. and Vienna Saccomanno pers. comms.).

2) Natural barriers: Clear site boundaries (e.g., distinct reef-sand interfaces, shoreline) can define the extent of the restoration or control areas and act as natural barriers to inhibit or eliminate urchin encroachment into the site – hereafter referred to as “choke points”. An ideal restoration site is a reef of a “manageable size” (e.g., between 5-10 acres, depending on project resources) and is a reef “island”, with choke points preventing urchin encroachment from all sides.

3) Site similarity: Similarity between restoration and control sites with comparable abiotic features such as freshwater input, substrate type (Figure S1 Appendix C), reef size, topographic complexity, and hydrodynamics was also considered. Control sites were selected in close proximity to their respective restoration sites in order to minimize environmental differences between the two.

4) Logistical factors: Given that ocean conditions along California’s North coast can be challenging and unpredictable, site accessibility and safety were also prioritized in site selection. For example, a nearby commercial harbor was required to provide overnight shelter to vessels, and to allow for offloading, weighing, processing, and disposing of urchins.

Sites protected from prevailing swells would yield more workable days for commercial divers and corresponding monitoring days for RC divers.

5) Additional factors: Sites with histories of use by commercial and recreational fishing communities who might benefit from restoration were given additional consideration. Sites with public visibility and opportunities for outreach/education and additional research were also considered.

Based on the criteria outlined above, sites along the north side of Noyo Cove and Albion Cove were selected as restoration sites, with paired control sites along the south side of Noyo Cove and Dark Gulch Cove, respectively (Figure 2,Table 1). The restoration site on the north side of Noyo Cove is hereafter referred to as "Noyo North" and the control site on the south side of Noyo Cove is referred to as "Noyo South" (Figure 2). The restoration site on the north side of Albion Cove hereafter is referred to as Albion Cove with the control site hereafter referred to as Dark Gulch (Figure 2). When referring to the paired restoration and control sites they are hereafter referenced as "Noyo" and "Albion", respectively.

Table 1. Restoration and control site names, locations, area of urchin removal effort, and depth range.

Site Name	Site Type	Date Established	Centroid Coordinates	Removal Area (acres)	Depth Range (m)
Noyo North	Restoration	July 2020	39.42794, -123.813357	8.16	0-12
Noyo South	Control	July 2020	39.42691, -123.81319	NA	0-12
Albion Cove	Restoration	July 2021	39.22830, -123.77440	6.22	0-11
Dark Gulch	Control	July 2021	39.24115, -123.77569	NA	0-11

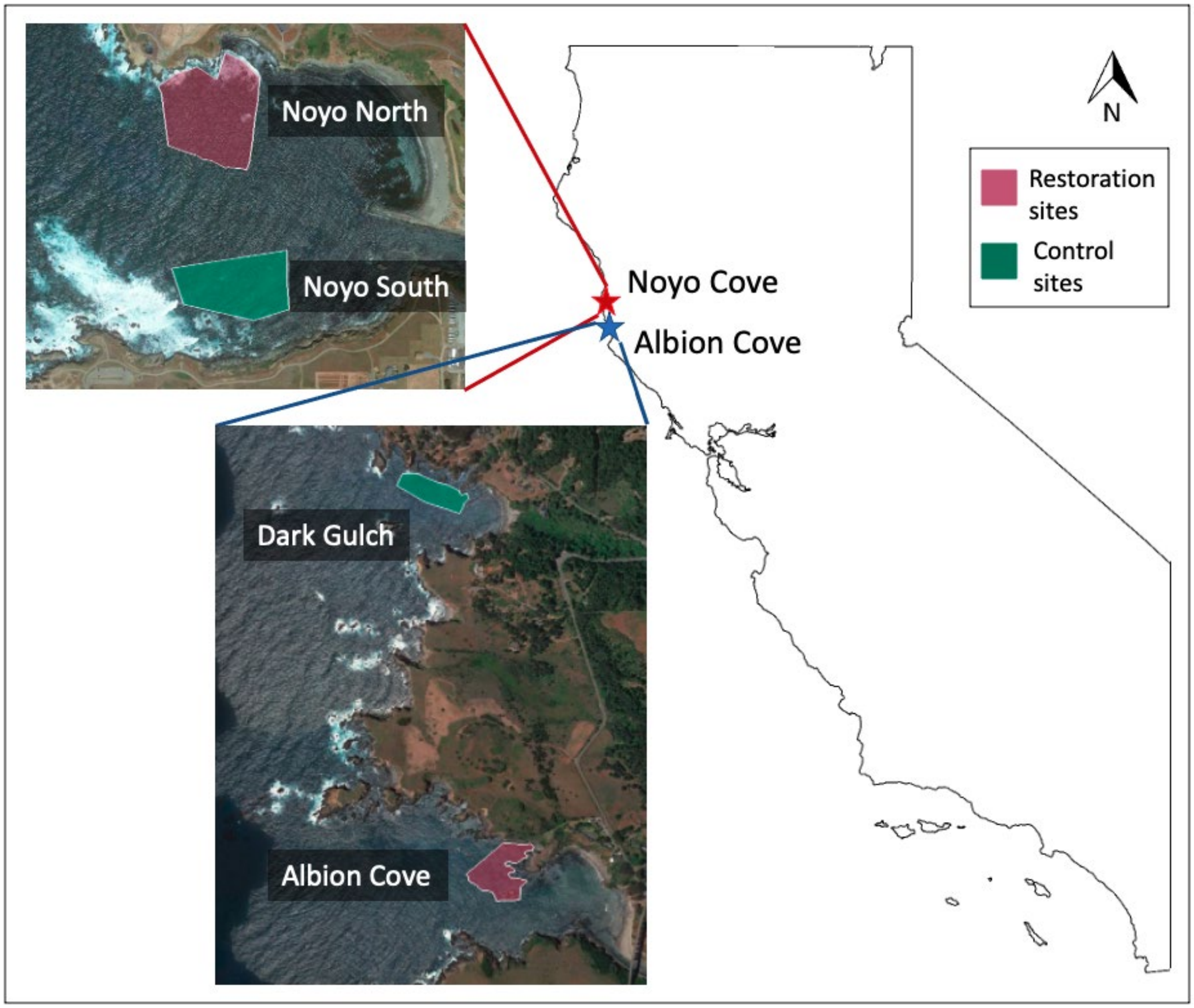

Figure 2. Bull kelp restoration via urchin removal was conducted in two coves along the Mendocino coast - Noyo Cove and Albion Cove. Restoration sites (red) were paired with control sites (green) for each cove. The Noyo and Albion restoration sites are referred to as 'Noyo North' and 'Albion Cove', respectively. The Noyo and Albion control sites are referred to as 'Noyo South' and 'Dark Gulch', respectively.

Both coves exhibited similar biotic and abiotic site characteristics. Purple urchin densities were high compared to densities historically observed at RC long-term monitoring sites in Mendocino County prior to the kelp forest decline (mean purple urchin density from 2008-2012: 0.4/m^2 ± 0.13) and bull kelp was absent or at very low density at the restoration area and control site compared to historic densities (mean bull kelp density from 2008-2012: 0.7/m^2 ± 0.2) (Freiwald and Neumann 2017). Nevertheless, both Noyo Cove and Albion Cove, had extant kelp patches that were distinct from (but nearby) the restoration areas (Figure 3c). These extant kelp patches were some of the only zones along the Mendocino coast where persistent kelp was observed in 2019 when kelp presence was at a historical low (Tristin Anoush McHugh, pers. obs.). Benthic assemblages within kelp patches prior to restoration activities were characterized by a diversity of algae and invertebrates, with relatively high densities of red abalone, bull kelp, and stalked kelp (*Pterygophora californica)*, and low densities of purple and red urchins. Both restoration sites, Noyo North and Albion Cove, had natural barriers to the north, east and south that created isolated reefs and choke points for urchin encroachment on all but their western edges (Figure 3a). Both restoration sites were bordered by sand channels that ran through the middle of the coves separating the reefs on the north and south side (Figure 3a). They also both receiving freshwater inputs from major river systems (Noyo River and Albion River), and each restoration site exhibits substrate and relief characteristics that are very similar to their respective control sites (Figure S1, Appendix C).

Figure 3. Example of a sand/reef interface from the southern boundary of the Noyo North restoration site. B) Example of an infiltration point and urchin barren, taken from the western side of the Noyo North restoration site. C) Kelps at the inshore extant kelp patch in Noyo Cove. (Photos: M. Murphy-Cannella)

2.3 Ecological monitoring

To characterize how urchin density, kelp density, and subtidal community composition changed, following urchin removals, RC staff divers conducted subtidal surveys at Noyo and Albion restoration and control sites before, during, and after restoration activities (hereafter referred to as “ecological monitoring”). The ecological monitoring surveys followed the kelp forest monitoring protocols outlined in the RC monitoring manual (Freiwald et al. 2021). At each restoration site and associated control site, six replicate 30 m by 2 m transects were conducted at a seasonal frequency (i.e., fall, spring, summer; winter excluded due to weather limitations) to employ a BACI experimental design. Surveys were arranged spatially throughout the sites using a randomly stratified sampling design, with three transects positioned within a depth range of 4.5-7.5 m and the remaining three transects positioned within a depth range of 7.5-11 m (Figure 4).

To quantify the physical characteristics of the reef, uniform point contact data (e.g., substrate, relief) were collected at 1 m intervals along each 30 m transect. Invertebrate and kelp swath surveys were conducted along 30 m long by 2 m wide transects within which all individuals included on the RC invertebrate and kelp species' lists were counted. Size frequencies of red and purple urchins were collected *in situ* using calipers and their test size was measured in 1 cm size bins. Subtidal ecological monitoring surveys for this project deviated from the RC sampling protocol in two aspects. First, the 2.5 cm minimum size threshold for counting an invertebrate was not implemented for purple and red urchins - all sizes of urchin were counted. This was to ensure urchin densities measured *in situ* reflected the full suite of sizes visible to divers. Second, complete counts of purple and red urchins were enumerated instead of the usual subsampling protocol for most transects in order to more accurately quantify urchin densities across sites where aggregations of urchins were patchy. The RC subsampling protocol was only implemented in cases with extremely high densities or rough conditions such that subsampling was necessary to complete the survey safely. The RC subsampling protocol implemented as needed was to count at least 50 individuals or to a minimum distance of 5 m whichever comes second.

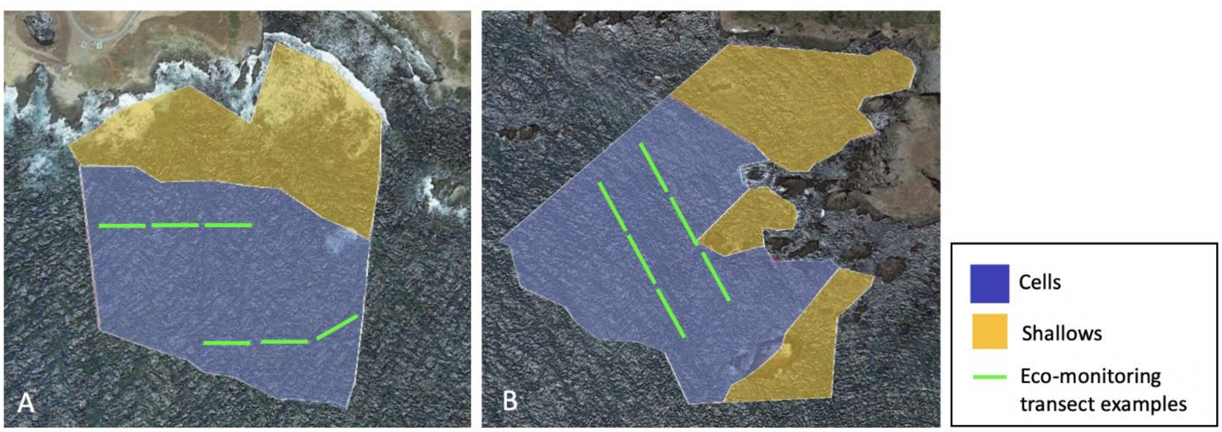

Figure 4. Panels show total restoration areas, split between the shallows (yellow) and cells (blue) in Noyo North (A) and Albion Cove (B). Examples of the six eco-monitoring transects (green) are shown in each.

2.4 Restoration: urchin removals and landings

Briefly described, purple urchin removals were conducted by establishing a grid of 100 m-long transects at parallel headings across the restoration sites. A team of two commercial divers each anchored meter tapes to benthic bolts, spaced 10 m apart, swam in the prescribed 100 m transect direction (i.e., north or south) and systematically removed purple urchins found within any of the 100 m by 10 m "cells" created by the transects. A full description of urchin removal methodologies and site set-up can be found in Appendix D. Once transects reached the shallows (Figure 4), divers used slightly different georeferencing methodologies. They placed an anchor within the assigned area, took a GPS point, and removed urchins moving outward from the anchor. The 100 m by 10 m 'cells' occupied depth ranges of 4.5-12 m, while the 'shallows' occupied depths of 0-4.5 m. Purple urchins were removed predominantly by hand picking or raking techniques, although one two-diver team employed an air lift to facilitate urchin removal (Figure 5).

Purple urchin removal efforts were divided into two phases: 1) the time period needed for divers to reach a density of 2 urchins/m^2 is the 'initial clearing phase' and 2) the time period in which this density was maintained is known as the 'maintenance phase'. In Noyo, the initial clearing phase occurred from July 24, 2020 to November 2, 2020, while the maintenance phase occurred from March 28, 2021 to August 3, 2021 (Figure 1). Maintenance phase removals will continue at Noyo throughout 2022 as needed. In Albion, the initial clearing phase within the cells occurred from July 17, 2021 to December 31, 2021. Removals within Albion's shallows had only just begun by late 2021 and is still in the initial clearing phase. While not presented here, Albion maintenance phase removals have recently begun within the 'cells' and will continue into 2022.

Quality assurance and quality control (QA/QC) surveys to monitor the progress of removals were conducted by RC staff within two weeks of urchin removal by commercial diver teams. During these surveys, RC staff established two 30 m by 2 m transects in each cell in the removal area and six 30 m by 2 m transects in the shallows to enumerate purple urchin, red urchin, and bull kelp (juvenile and adult) densities. When purple urchin densities exceeded 2/m^2, RC directed commercial divers to continue removal efforts until the 2/m^2 threshold was reached. To quantify removal effort, time was measured in "single diver days". The unit "single diver day" equates to one commercial diver conducting four hours of removal.

Immediately following urchin removals, commercial divers landed the purple urchins at one of three different processing facilities in Noyo Harbor: Pacific Rim, Zephyr, or Ocean Fresh. These facilities were responsible for offloading urchin from commercial vessels, weighing urchins, and storing urchins in bins. After urchins were landed, RC assumed responsibility for proper disposition of the urchins. Landed urchins could not be sold by RC without additional licensing from CDFW (California Code of Regulations, Title 14, Section 197). Consequently, landed purple urchins were donated to numerous interested parties to explore uses for purple urchins in a variety of ways, e.g., composting, textile dyes, pavement for drive ways.

Figure 5. A) A diver using a hand rake to remove urchin at Noyo (Photo: T. A. McHugh). B) A diver using the air lift method to remove urchins at Noyo. (Photo: M. Murphy-Cannella).

2.5 Dockside monitoring methods: urchin biometrics

A random subsample of the landed catch was collected at the processing facility by RC staff in a 5-gallon bucket to characterize urchin size frequency, morphometrics, disease presence, and unintended bycatch at each restoration site (hereafter referred to as 'dockside sampling'). RC staff and volunteers conducted dockside sampling for 44 out of 61 landings at Noyo North and 10 out of 38 landings at Albion Cove. Dockside sampling was more intensive in the first year of removals at Noyo, and then scaled back to accommodate the addition of Albion Cove as a second restoration site.

To determine if divers exhibited a size bias in their removal efforts, test diameters of purple urchins were measured with vernier calipers and the resulting size frequency distribution was compared to that of purple urchins measured by RC divers *in situ* (measured to the nearest 1 cm). Wet weights of subsampled purple urchins were measured to determine the number of urchins per pound. To determine the prevalence of blackspot disease and wasting disease among purple urchins, presence or absence of either disease was indicated for each urchin measured. Within the total subsample, anything other than purple urchins was considered bycatch, and was identified to the lowest possible taxon, enumerated, and weighed using a portable balance (+/- 0.01 g) to characterize and quantify unintended consequences of urchin removal.

Costs for urchin removals per pound and per area were calculated for the initial clearing of urchins until they reached the target density of 2 purple urchin/m^2, for maintaining urchins at this density, and for the total effort separately according to the following calculations. The total cost of removal was calculated by multiplying the number of single diver days by the average cost per single diver day (average of vessel operator/dive and diver only cost). The average cost per acre was calculated by dividing the total cost by the size of the restoration area, and the average cost per pound was estimated by dividing the total cost by the pounds landed. The total area of each restoration site is defined by the area in which removals were conducted. For the total restoration cost per acre, the cost of initial removal and the cost of maintenance was added. For Albion only the cost of initial removal metrics within the 'cells' were calculated as the maintenance within the 'cells' and initial removals within the shallows are ongoing.

2.6 Statistical Analyses

All analyses and data summaries were performed in the statistical program R (R Core Team 2021). To compare urchin densities from before and at the end of the restoration periods, between control and restoration sites, we used Welch two sample t -tests. A Welch two sample t -test was also used to compare mean urchin diameters between the shallow and deep areas at Noyo North and to compare urchin diameters measured via *in situ* sampling and dockside-sampling. This test accounts for unequal sample sizes. Because there was no significant difference between mean urchin sizes from the shallow and deep areas, sizes were pooled for additional analyses comparing *in situ* measured versus dockside measured sizes. Not enough purple urchins have been collected from the shallows in Albion Cove to evaluate size difference between cells and shallows at this site.

For comparison of dockside and *in situ* collected urchin size data, dockside data was binned in the same way that RC divers collect data in 1 cm bins. Means reported are based on the binned data. A one-way ANOVA tested for significant differences in urchin densities across sampling periods (for example at the control sites) with the sampling season/year combination as a factor. A TukeyHSD post hoc test evaluated significant differences in urchin densities sampled across the seasons. T-test results are reported below with the following notation: (test type, t(degrees of freedom) = t-statistic, p=p-value). All mean values are reported with their associate standard error (mean ± SE).

To evaluate the effectiveness of urchin removal and bull kelp recovery at Noyo, a BACI design analyzed the densities before the removals began (summer 2020) and the densities one year later (summer 2021 sampling period) at both the manipulated restoration site and the unmanipulated control site. A two-way ANOVA was used (aov function in R) with sampling season (summer 2020 vs. summer 2021), site (restoration vs. control) and their interaction as factors to implement the BACI design.

4. Results

3.1 Urchin removal diver effort

3.1.1 Noyo

Of the 16 divers who signed up for the program, 13 were active in Noyo removal efforts and dove a combined total of 119 single diver days between July 25, 2020 and August 3, 2021 (Table 2). This effort resulted in a total removal of 31,509.5 lbs. of purple urchins from the Noyo restoration site (Table 2). The majority of urchin removal occurred during the initial clearing phase of summer and fall of 2020, resulting in the removal of 26,535.5 lbs. of purple urchin over 98 single diver days (Table 2, Figure 6a). After the Fall 2020 ecological monitoring, removals continued in maintenance phase until August 3, 2021, resulting in the additional removal of 4,974 lbs of urchins across 21 single diver days (Table 2, Figure 6a). The seven vessels conducting removal efforts at Noyo landed 4,501.4 ± 1,198.6 pounds on average (± SE) over the duration of the project. The daily average per vessel was 287.5 ± 53.0 lbs., over an average of 17 ± 2.9 single diver days (Table 3). Figure 6a shows the distribution of effort over the months of restoration and how the amounts of monthly urchin removals changed as the sites reached the maintenance phase after purple urchin densities fell below 2/m^2.

Efforts among vessels varied greatly from 2 to 24 days, the average number of pounds removed also varied from 108 to 439 lbs per day (Table 3). Additionally, while divers spent a similar amount of time in the shallows (57 diver days) as the cells (62 diver days), more total urchin biomass was removed from the shallows (21,624 lbs.) than from the cells (9,885.5 lbs.) (Figure 7). As removals progressed and urchin densities decreased, the time to collect the same amount of urchins increased. Of the total cost of $65,450 at Noyo North, $31,350 (57 single diver days) were spent on the ‘shallows’ and $34,100 (62 single diver days) were spent on ‘cells.’ Based on the total pounds harvested at Noyo North, an average cost per pound of urchin harvested was estimated to be $2.07 across the entire restoration site (Table 2) with a cost of $1.45/lbs in the shallows and $3.45/lbs in the cells.

3.1.2 Albion

Of the 16 divers who signed up for the program, only three were active in Albion Cove removal efforts. Participation was lower mainly due to the additional transit time and distance. Three additional divers were approached to engage mid-project, one of whom actively participated. This resulted in four divers completing a total of 75 single diver days or 37.5 vessel days between July 17, 2021 and December 7, 2021 (Table 2, Figure 6b). A total of 13,609 lbs of purple urchins were removed from the restoration site (Table 2). Across both vessels conducting removals in Albion, the average (± SE) total pounds landed per vessel over the duration of the project was

6,804.5 ± 1,262.8, with a daily average removal per vessel of 190.7 ± 11.1 pounds over an average of 37.5 ± 8.8 single diver days per vessel (Table 3). The 75 single diver days (37.5 vessel days) cost a total of $60,937. The total pounds of urchin landed per day was lower in Albion than in Noyo, resulting in a removal cost of $4.48/lbs (Table 2). Removal in the shallows is ongoing; thus a separate cost for removals in shallows versus cells is not available for Albion (Figure 7). Similarly, the maintenance phase of removal in Albion Cove will be conducted in 2022 and therefore is not reported here (Figure 6b).

Table 2. Costs of urchin removals at both restoration sites. Costs indicate averages that are calculated separately for initial removal of urchins to the target density of $2/m^2$ and for the maintenance of that density once it was confirmed during ecological monitoring (Figure 6). '*' asterisk indicates that the Albion project cost represents the cost of initial removals only. As of December 2021, Albion was still in the initial clearing phase, thus maintenance and total costs are not reported. A single "Vessel Day" involved a vessel operator/diver and a diver.

Site	**Area (acres)**	**Restoration Phase**	**Duration**	**Lbs. landed (E-Tix)**	**Vessel days**	**Single diver days**	**Cost per Lbs.**	**Daily average cost per diver**	**Cost per acre**	**Total cost of removal**
Noyo North	8.16	Initial Clearing (2020)	3 months	26,535.5	49	98	\$2.03	\$550	\$6,605	\$53,900
		Maintenance (2021)	4 months	4,974	12	21	\$2.32	\$550	\$1,415	\$11,550
		Total		31,509.5	61	119	\$2.07	\$550	\$8,021	\$65,450
*Albion Cove	6.22	Initial Clearing (2021)	5.5 months	13,609	37.5	75	\$4.48	\$812.50	\$9,797	\$60,938

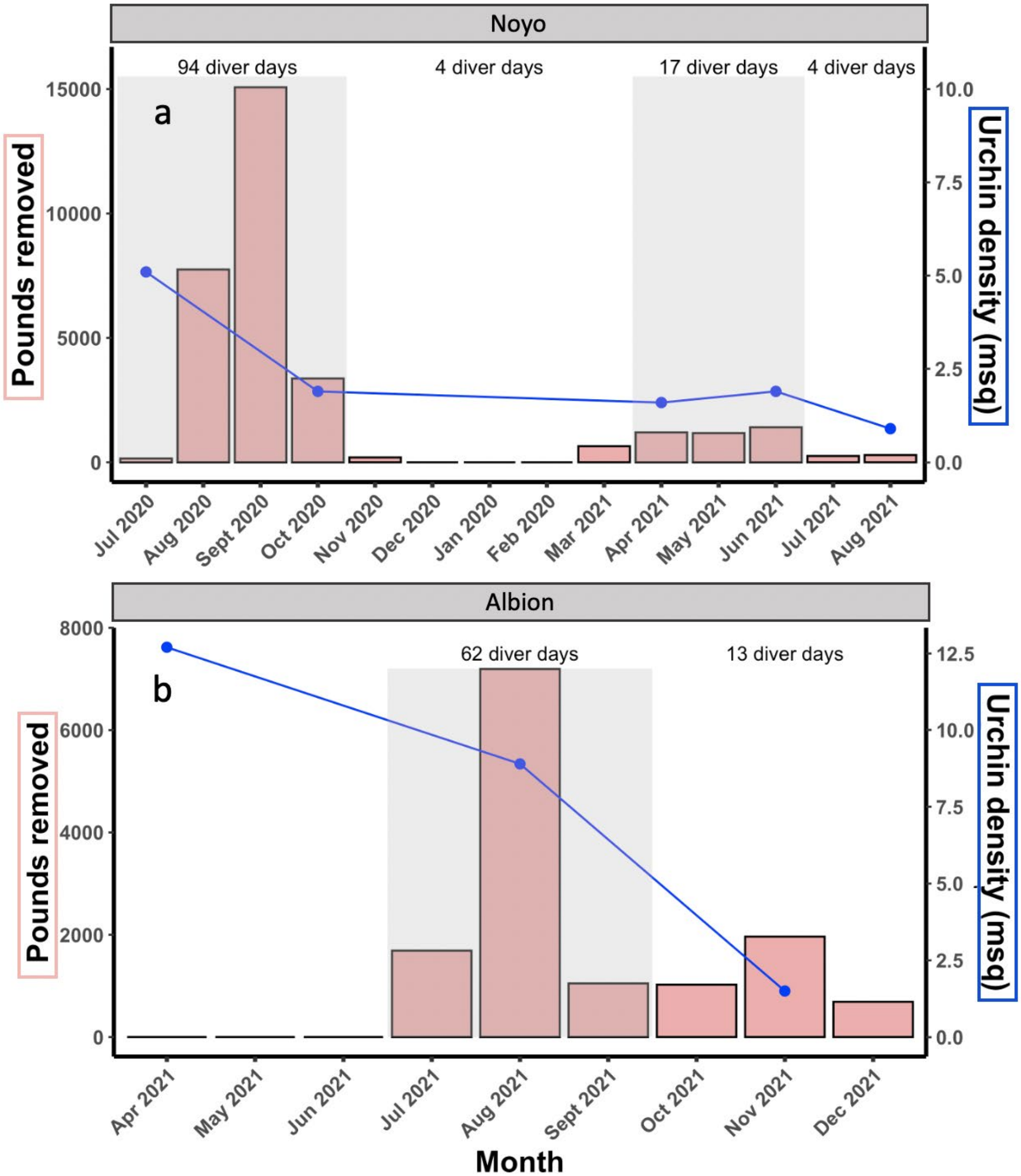

Figure 6. Diver effort (single diver days), pounds of urchins landed, and density of purple urchins (urchins/m^2) determined during the ecological monitoring periods.

Table 3. Effort of each vessel by pounds landed, single diver days, and average pounds per day for each restoration site over the duration of the project.

Site	Vessel Number	Urchin landed (lbs.)	Total single diver days	Average urchin landed per day (lbs.)
Noyo North	1	5,377	14	384.1
Noyo North	2	1,941	18	107.8
Noyo North	3	3,111	16	194.4
Noyo North	4	9,598	24	399.9
Noyo North	5	2,989.5	24	124.6
Noyo North	6	7,615	21	362.6
Noyo North	7	878	2	439
Albion Cove	1	9,167	54	169.8
Albion Cove	2	4,442	21	211.5

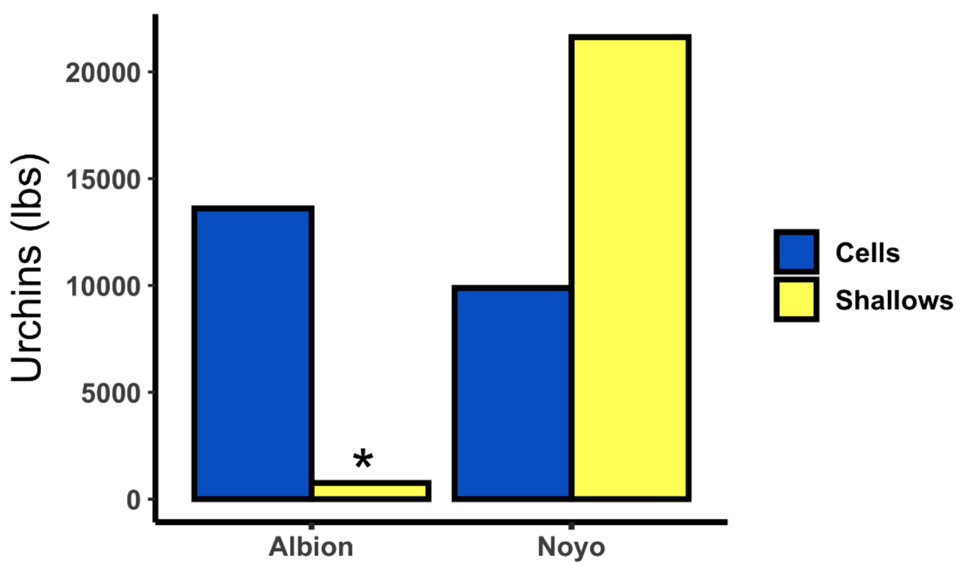

Figure 7. Total pounds removed from each restoration site in the cells (blue) and shallows (yellow). The '*' above the Albion shallows indicates that these removal efforts are still underway and are therefore not representative of the expected total project removal totals. Depth ranges for the shallows and cells are 0-4.5 m and 4.5-12 m, respectively

3.2 Urchin densities

3.2.1. Noyo

In Noyo, prior to removal (summer of 2020), mean purple urchin densities at the restoration and control sites were not significantly different from one another (Welch two sample t-test, $t(6.91) = 0.41$, $p = 0.69$), with densities of $5.1/m^2 \pm 0.70$ and $5.8/m^2 \pm 1.58$, respectively. By the fall of 2020 ecological monitoring surveys, purple urchin densities at the restoration site were reduced to $1.9/m^2 \pm 1.37$, near the target density of $2/m^2$ while the control site densities remained similar to the pre-removal densities at $7.1/m^2 \pm 2.31$ (Figure 8). These trends persisted, with continued reduction of mean urchin densities in the restoration site, sustained below $2/m^2$ for the duration of the project, and ending in average densities of $0.9/m^2 \pm 0.21$ during the ecological monitoring surveys in fall of 2021. The urchin densities in the control site remained well above the $2/m^2$ threshold and increased over the duration of the project, ending in a mean density of $10.5/m^2 \pm 1.98$ in fall of 2021 (Figure 8).

To evaluate the effect of removal efforts on urchin density at the restoration site related to the control site, we compared urchin densities at both Noyo sites (restoration and control) from the summer of 2020, before the removals began, to urchin densities in the summer of 2021, one year later, when kelp growth would be expected to be strongest given its seasonal growth cycle. This BACI analysis showed a significant interaction between time period and treatment indicating that urchin densities were successfully reduced by summer of 2021 compared to the control site (Table 4, Figure 9).

Table 4. Results of BACI analysis on purple urchin density. The 2-way ANOVA of purple urchin density at the Noyo restoration and control site in summer 2020 versus (vs.) summer 2021.

	Df	**Sum Sq**	**Mean Sq**	**F value**	**P**
Before/After (summer 2020 vs. summer 2021)	1	4.12	4.12	0.296	0.592
Treatment (control vs. restoration)	1	152.41	152.41	10.967	0.003
Before/After*Treatment	1	112.32	112.32	8.082	0.01
Residuals	20	277.95	13.9		

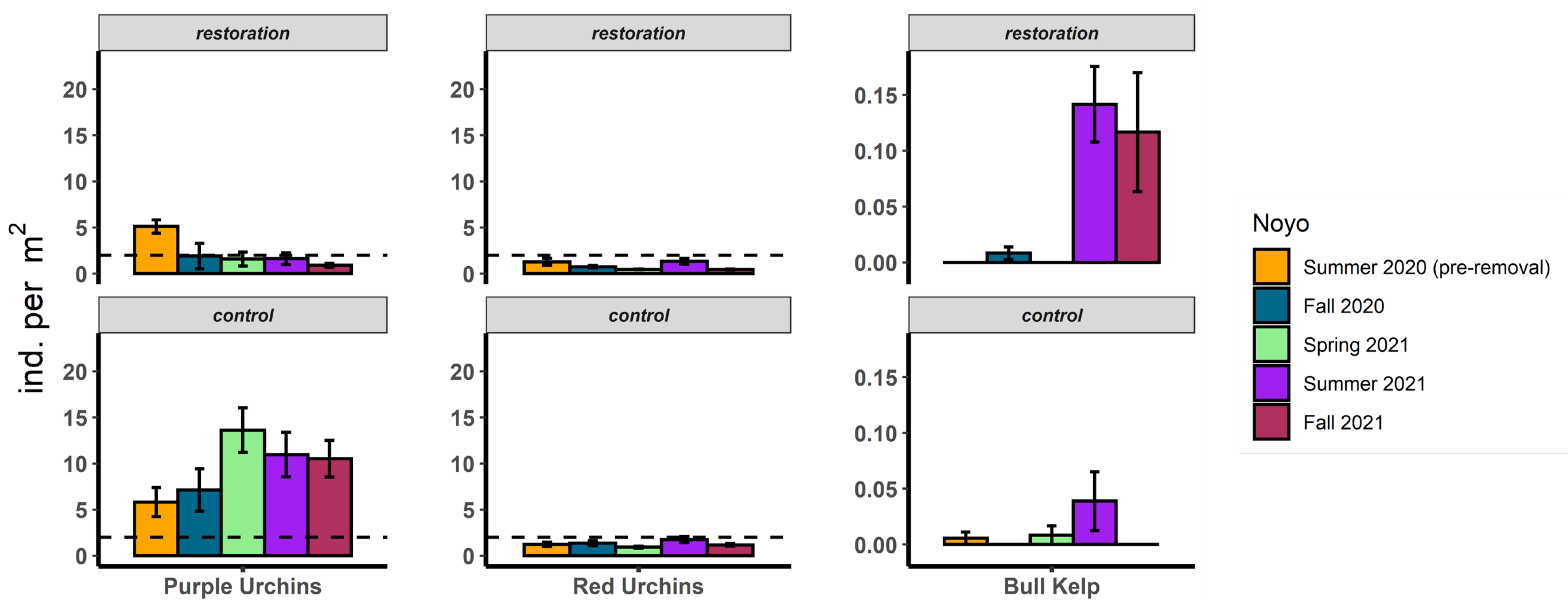

Figure 8. Densities of purple urchins, red urchins, and bull kelp in both the restoration and control sites during the seasonal ecological monitoring periods at Noyo. Bars indicate means ± SE, and the horizontal dashed lines on urchin density panels represent the 2 urchin per square meter threshold.

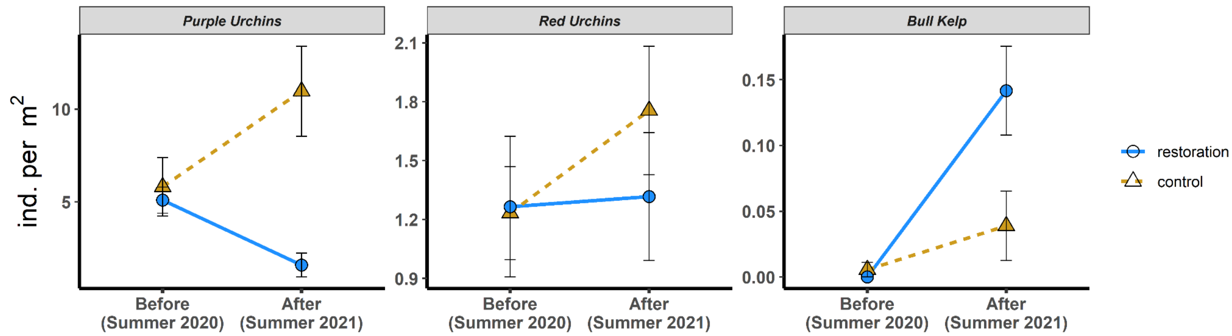

Figure 9. Interaction plots of the BACI analysis of urchins and bull kelp at Noyo. Points indicate mean density, vertical bars indicate +/- standard error of the mean. Both purple urchin and bull kelp densities show significant interaction between the control (yellow) and the restoration (blue) site from before urchin removal began in summer of 2020 to one year after removal in summer of 2021. Red urchins did not show a significant interaction among sites and season (Table 5 and 6).

Red urchin densities in the restoration (1.3/m^2 ± 0.36) and control site (1.2/m^2 ± 0.24) at Noyo were similar prior to the beginning of the restoration efforts (Welch two sample t-test, $t(8.67) = -0.07$, $p= 0.94$) (Figure 8). Red urchin densities in the restoration site demonstrated significant variability throughout the duration of the project (ANOVA, test statistic = 4.83, df = 4, $p < 0.01$) (Figure 8). Although project removal efforts may have contributed to trends in red urchin density in the restoration site, it is likely that the removal of legal sized red urchins from the restoration site by commercial divers played an additionally valuable role. Red urchin density at the control site did not change significantly over the project period (ANOVA, test statistic = 1.66, df = 4, $p = 0.2$).

A BACI analysis on the red urchin densities at the Noyo restoration versus control site over the same time period, from summer 2020 to summer 2021, did not show any significant results (Table 5). The non-significant interaction between treatment and time period shows that red urchin densities at the restoration site did not change compared to the control over the study period (Figure 9). Because red urchin densities were not systematically reduced in the same way as purple urchin densities this supports the result that changes in purple urchin density were driven by the manipulation and non-targeted urchin populations exhibited similar dynamics at the control and restoration site over the study duration.

Table 5. Results of BACI analysis on red urchin density. The 2-way ANOVA of red urchin density at the Noyo restoration and control site in summer 2020 versus (vs.) summer 2021.

	Df	**Sum Sq**	**Mean Sq**	**F value**	**P**
Before/After (summer 2020 vs. summer 2021)	1	0.493	0.4928	0.827	0.374
Treatment (control vs. restoration)	1	0.249	0.2486	0.417	0.526
Before/After*Treatment	1	0.332	0.3323	0.557	0.464
Residuals	20	277.95	13.9		

3.2.2 Albion

Similar trends in urchin density were observed in Albion. Prior to removal, mean purple urchin densities at the restoration and control sites were not significantly different from one another (Welch two sample t-test, $t(5.67) = 1.18$, $p = 0.29$), with densities of $12.1/m^2 \pm 6.29$ and $19.7/m^2 \pm 1.62$, respectively (Figure 10). After removals were conducted in summer 2021, purple urchin densities were reduced to $8.9/m^2$, with further reductions to below the target threshold density by fall of 2021 to $1.6/m^2 \pm 0.43$. The control site densities did not significantly differ from one another throughout the project period (ANOVA, test statistic = 0.26, df = 2, $p = 0.8$), and were significantly higher than the restoration site densities by fall of 2021 (Welch two sample t-test, $t(5.83) = 9.92$, $p < 0.001$) (Figure 10).

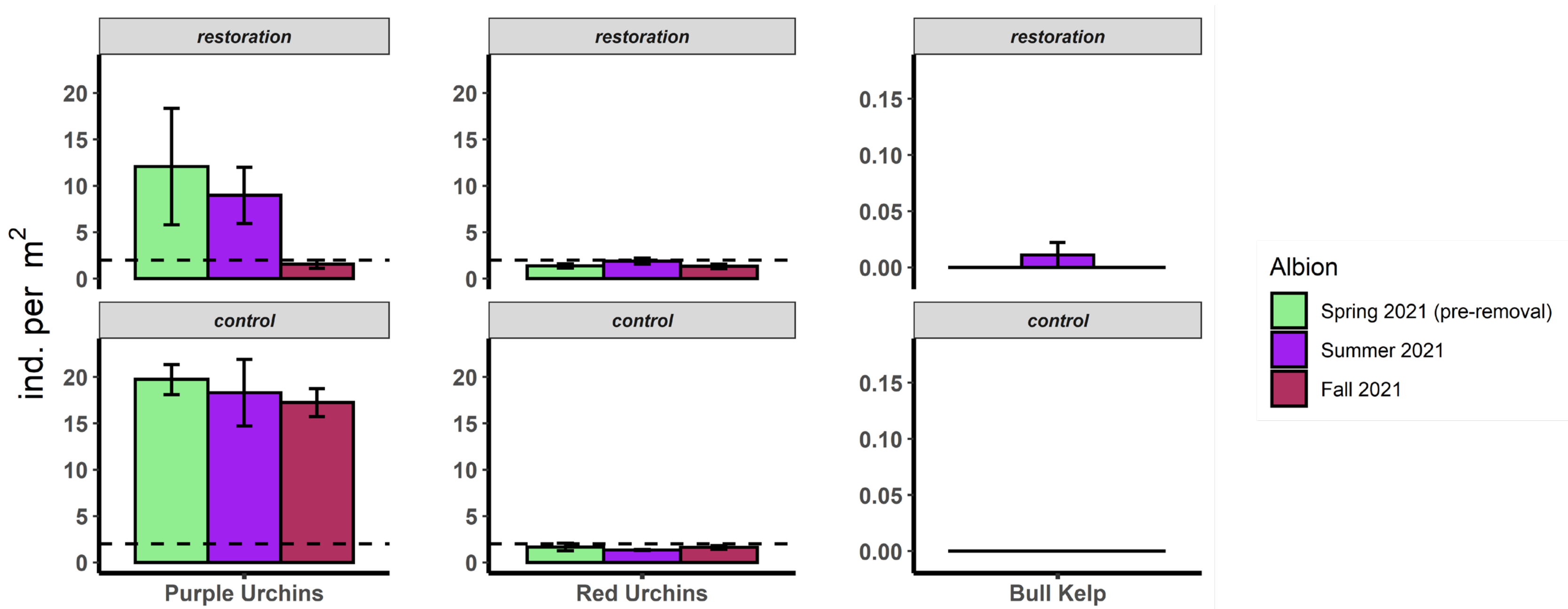

Figure 10. Densities of purple urchins, red urchins, and bull kelp in both the restoration and control sites during the seasonal ecological monitoring periods at Albion. Bars indicate means ± SE, and the horizontal dashed lines on urchin density panels represent the target threshold ($2/m^2$).

3.3 Kelp densities

3.3.1 Noyo

Prior to urchin removal at Noyo North, bull kelp was absent from the restoration site and at very low density at the control site (Figure 8). By summer of 2021 bull kelp was present at the restoration site at significantly higher densities than the control site compared to summer of 2020 as indicated by the significant interaction term in the BACI analysis (Table 6, Figure 9). The bull kelp density of $0.14/m^2 \pm 0.033$ at the restoration site in the summer of 2021 was about 20% of the historic mean bull kelp density of $0.7/m^2 \pm 0.2$ observed at RC long-term monitoring sites from 2008-2012 prior to the kelp decline in Mendocino county (for more detail on historic kelp density see RC's North Coast MPA baseline monitoring report (Freiwald and Neumann 2017)). Moreover, reproductive adult bull kelp was observed at Noyo North from spring of 2021 until November 2021 (Morgan Murphy-Cannella and Ian Norton pers. obs.). Observed kelp was very patchy during the ecological monitoring surveys conducted in fall of 2021, leading to the large error bar in Figure 8. Notably, a band of kelp running east to west starting at 20 ft of depth was clearly visible from the surface, with additional smaller patches spread along pinnacles of varying reef depths (Figure 11).

Table 6. Results of BACI analysis on bull kelp density. The 2-way ANOVA of bull kelp density at the Noyo restoration and control site in summer 2020 vs. summer 2021.

	Df	**Sum Sq**	**Mean Sq**	**F value**	**P**
Year (summer 2000 vs. summer 2021)	1	165.38	165.38	16.36	0.001
Treatment (control vs. restoration)	1	51.04	51.04	5.049	0.036
Year*Treatment	1	63.38	63.38	6.27	0.021
Residuals	20	202.17	10.11		

Figure 11. Observed kelp recruit near the transect line in September 2020 (Photo: T. A. McHugh), and bull kelp patch on the Noyo restoration site in June 2021 (Photo: M. Murphy-Cannella)

3.3.2 Albion

Although fewer timepoints of ecological monitoring data were available from Albion, due to restoration within the site still being in progress, similar trends were observed. Specifically, bull kelp was completely absent from the control site throughout the restoration period (Figure 10). In the restoration site, some small amount of new bull kelp was observed by summer of 2021 (Figure 10). Purple urchin removals in the initial clearing phase are ongoing at Albion and urchin densities only fell below the threshold of 2/m^2 after the bull kelp's growing season in 2021, therefore we did not expect any kelp growth at this site by the end of 2021. Further work in 2022 will be needed to evaluate the kelp response at this site.

3.4 Dockside data

3.4.1 Urchin size frequency and disease presence

At Noyo North, there was no significant difference in the mean size of purple urchins removed from the shallows and the cells (Welch two sample t-test, $t(3408.6) = 1.39$, $p = 0.17$) and their size distributions were very similar (Figure 12). However, the mean size of purple urchins landed and measured at the dockside (33.2mm ± 0.15) was significantly smaller than the mean urchin size measured *in situ* by RC divers (41.2mm ± 0.52; Welch two sample t-test, $t(839.4) = 14.66$, p

< 0.0001) at Noyo. Although the differences were not as pronounced in Albion Cove, mean purple urchin size landed and measured dockside (31.9mm ± 0.37) was significantly smaller than mean urchin size measured by divers *in situ* (34.3mm ± 0.72; Welch two sample t-test, $t(405.09) = 3.04$, $p = 0.003$, Figure 12). The pattern highlights that commercial divers were able to remove all size classes including small urchins that likely emerged after initial removals commenced and were therefore not sized *in situ* due to RC divers limitations to measure urchins in cracks and crevasse. At both Noyo North and Albion Cove, presence of disease was documented in <1% of all sampled urchins (combined wasting and blackspot disease).

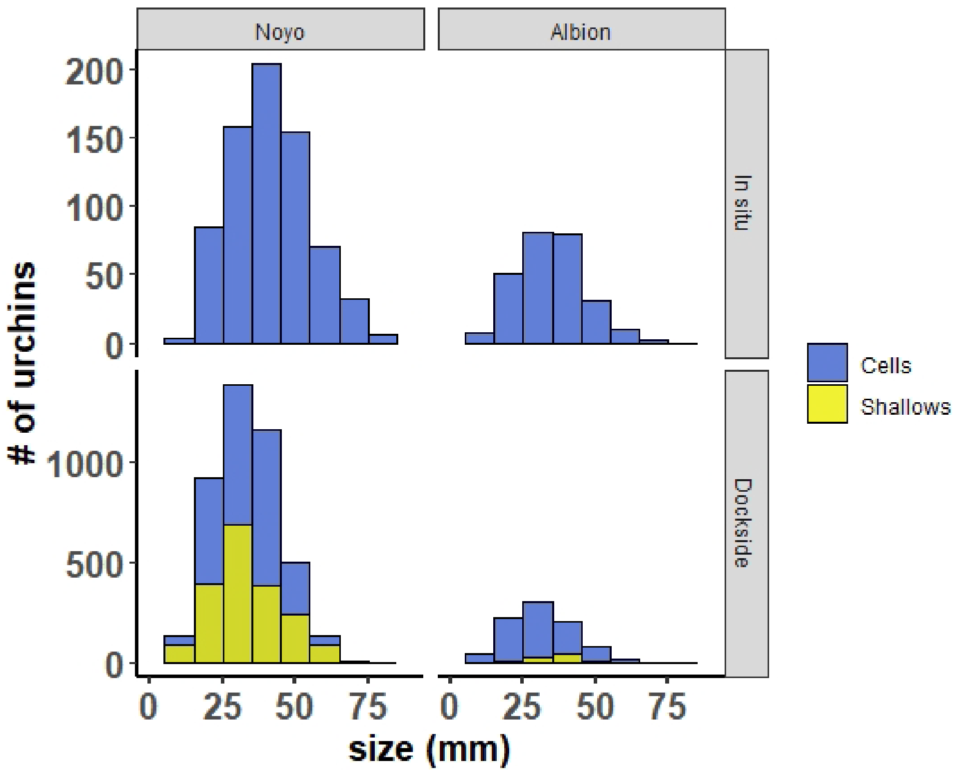

Figure 12. Purple urchin size frequency measured by *in situ* compared to measured dockside when landed from Noyo and Albion restoration sites. Urchins were collected from both the shallows (yellow) and cells (blue), while *in situ* measurements were only collected from the cells.

3.4.2 Urchin harvest bycatch

Bycatch was closely monitored during the initial removal efforts at Noyo North in order to understand the amount and species composition of bycatch that could be attributed to the restoration activities. Overall, bycatch during the removals of purple urchins using the predominant commercial removal methods (i.e., hand pick/rake) was low, representing on average, 1.3% ± 0.2 of the total biomass landed (Figure 13a). The most common taxonomic group among the bycatch was algae followed by small snails (*Tegula funebralis*) and some red urchins that were accidentally taken during purple urchin removals (Figure 13b). Algae bycatch was typically fragments of drift red algae that the urchins were eating at time of harvest or that was stuck on their spines. Abalone species are not included in the 'snails' category, and none were found as bycatch. Bycatch monitoring was scaled back in 2021 due to low percentages of bycatch documented in 2020, and in order to streamline simultaneous dockside sampling efforts across both Noyo North and Albion Cove.

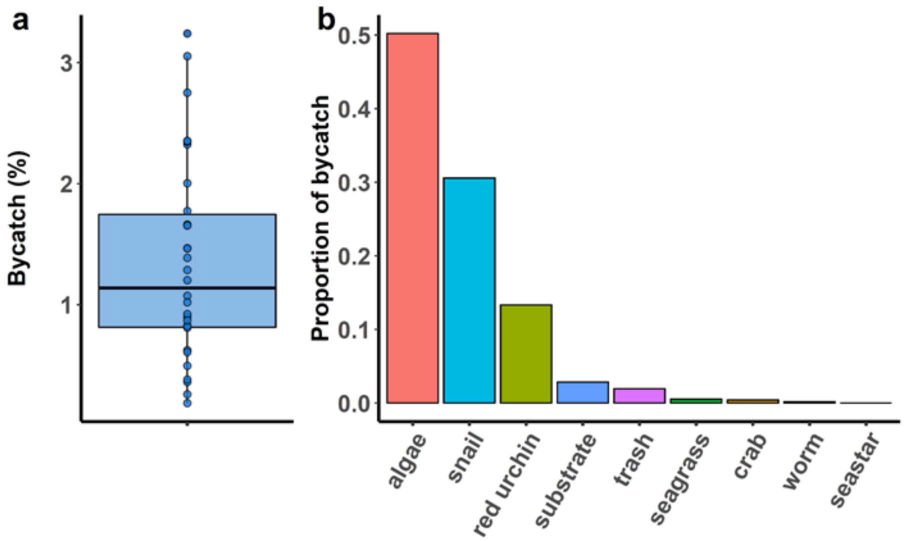

Figure 13. Bycatch collected from dockside sampling efforts from Noyo North in 2020. Values represent bycatch found with urchins collected by hand-harvest methods; A) boxplot showing total percentage of hand harvested bycatch across subsampled landings by weight, with points representing bycatch percentages for a given landing, and B) taxonomic composition of hand harvested bycatch collected from dockside sampling efforts from Noyo North.

4. Discussion

4.1 An adaptive approach to restoration: Interdisciplinary partnerships and community-engagement

Prior to the work presented herein, very few projects within the U.S. or along the North American West coast have successfully engaged those invested in and impacted by kelp forest ecosystem health in restoration efforts. Previous efforts in southern California have successfully worked with commercial divers to conduct giant kelp forest restoration (Williams et al. 2021). However, ocean conditions and accessibility, kelp forest ecology, and social and political landscapes are vastly different between Northern and Southern California, making it unclear if a similar model could be successful along the North coast. To test this, RC partnered with CDFW and OPC to develop relationships with a variety of stakeholder groups including commercial divers and processors, the Watermen’s Alliance, the NCMS and TNC with the goal of developing a community-based kelp restoration project. Ongoing dialogue with the local commercial divers led to their direct engagement in the work as they conducted the urchin removals. Although developing such community partnerships can pose challenges (see discussion of site selection and removal of red urchins below) and requires significant time and resource investment, gaining ‘buy-in’ from key stakeholders can be essential to restoration efforts and can promote local ecosystem stewardship beyond the project duration. This project was designed to answer questions with respect to the feasibility, effort and cost of engaging commercial divers in restoration activities. It demonstrated that divers can be successfully engaged and efficiently remove urchins from selected restoration sites. If this will lead to successful restoration of kelp forests remains to be seen. This project demonstrated initial kelp growth, but its timeframe did not cover enough consecutive seasons to demonstrate restoration success. More theoretical and field work is needed to define and demonstrate restoration success for northern California’s bull kelp forests.

Importantly, commercial divers had the expertise, equipment, and local knowledge that was essential to conduct urchin removals efficiently in locations that are notoriously difficult to work in. Their insight, dedication and patience to develop a robust project cannot be overstated. Partnering with commercial divers proved to be immensely beneficial and required a high level of communication and project adaptation. Commercial diver engagement provided some income during times of reduced red urchin fisheries income that helped support the fishing community and recovery of the fishery.

Given commercial divers relied on red urchins for their livelihoods, one challenge arose with commercial diver’s concerns that if red urchins were harvested as a part of restoration, this would lead to further decline of the fishery, rather than support its recovery. This concern was particularly strong at sites with high red urchin density or historically profitable fishing locations. To navigate this challenge, RC, commercial divers, and CDFW worked together to identify possible solutions. RC conducted reconnaissance dives at additional potential restoration sites to guide site selection and communicated results with CDFW and OPC, as well as commercial divers. As a result, sites with high red urchin density were avoided during the site selection process. Going through this collaborative selection process and changing one of the sites from the originally selected site (Caspar Cove) to one that was preferred by a consensus of commercial divers (Albion) greatly improved the collaborative spirit and cooperation among project partners.

Nevertheless, removal of red urchins from the selected restoration sites remained controversial. To aid in the removal of red urchin from the restoration site, commercial divers were encouraged to continue harvesting legal-size red urchins at the restoration site on their own time. They could sell these to processors as they do with all their red urchin catch. Red urchin removal using a scientific collecting permit was also explored as a mechanism of non-lethal removal of undersized red urchins through translocation. Ultimately, large-scale red urchin removal proved difficult due to logistical challenges and a seeming unwillingness of commercial divers to relocate or harvest undersized red urchins. Although these discussions took time, the communication and project adaptation generated positive working relationships between all partners and collaborators and ultimately enabled project success.

Similarly, prior to this project, it was uncertain if and how a payment structure for commercial divers could be developed. Direct contracting of their services was cost prohibitive due to the high cost of insurance required by the state and payment of a fixed price per pound would have created an incentive to harvest as many pounds of urchins per day as possible, potentially inadvertently incentivizing the selection of larger size classes and leaving smaller size classes behind. This would have been counterproductive to the need to orchestrate harvest effort regardless of total pondage landed in order to achieve even density reduction of urchins across the entire site. To ensure urchins of all sizes were removed from low and high density areas, a flexible payment rate per pound was agreed upon by project leadership, collaborators and partners as a way to implement the flat daily rate and allocate fair payment to all divers regardless of how many and what size urchins they harvested each day.

In addition to building relationships with commercial divers, this work also provided an opportunity for broader stakeholder engagement. For example, RC, NCMS, and other project partners pursued numerous public education opportunities such as virtual presentations, placing signage at the bluffs overlooking the restoration site, developing curriculum and urchin models for classroom use and an exhibit at the NCMS (Appendix E). After purple urchins were landed, community members became involved in this project through the use of harvested urchins in art projects, to develop dye or use them as compost or soil amendments. Ongoing work by project partners at The Nature Conservancy is investigating market-based applications in food and non-food sectors for harvested purple urchins to maximize the benefits from such restoration efforts. Together these activities serve as an example of the numerous benefits that can be gained by integrating community engagement in coastal restoration and management.

4.2 Implications for kelp forest restoration practices

In this North coast project, we demonstrate that commercial divers can be coordinated to reduce urchins to a target density in relatively small areas of bull kelp habitat, a valuable finding in and of itself and corroborating results from work giant kelp forest in southern California (House et al. 2017, Williams et al. 2021). In addition to demonstrating the effort required to reach the target urchin density threshold, this project further evaluates the investment required to sustain low urchin densities through time. Specifically, data on diver effort and urchin landings indicate that while a higher relative initial investment is necessary to reach the target threshold, this threshold can be maintained over time for a lower relative investment (Figure 6, Table 2). Similarly, for an equivalent biomass, the effort required to remove urchins from the shallow reef zones is lower than in the deeper zones. This difference may be due to several factors. Most likely, higher densities of urchins in the shallows (as observed by divers and researchers) lowered the overall search time for a given amount of biomass of urchins. Secondarily, additional time investment associated with higher relative rugosity and greater depth variability in the deeper zone may also have contributed to the effort difference.

Although these differences may be site specific, these findings can be highly relevant to future projects aiming to develop work plans for restoration under similar conditions, informing where efforts might be prioritized within a given site or how they might be distributed over the duration of a project. These findings also allude to the possibility that if urchin removal activities began sooner, when urchin densities have not yet become so high or some kelp remained throughout the site, the overall investment to maintain the target urchin density would be much lower. This lays a foundation for future work aiming to understand when and how to intervene, and how restoration efforts can be maximized to ensure a high likelihood of success - critical knowledge gaps identified in the Interim Kelp Action Plan (California Ocean Protection Council 2021).

Overall, the cost of removal of urchins to reach the low density threshold ($<2/m^2$) was similar among the two restoration sites when corrected for the higher pay for work at Albion. This suggests that environmental differences among the sites did not play a large role in cost per acre but that distance from port and accessibility of a site can greatly increase cost of restoration. Cost estimates presented here are based only on diver effort and rates developed in 2019, and do not include monitoring, coordination, management, and evaluation costs. Having completed this restoration three years after establishing the rates and having experienced changing cost and financial situations over the project term, we caution practitioners to consider changes in socio-economic context in cost estimates for future restoration projects. This is particularly important for projects with budgets extending years into the future and involve community participants with evolving incomes and changing community-economic contexts.

Bycatch data indicate that unintended negative consequences to the benthic community from urchin removal activities are relatively low. Half of the bycatch was drift algae attached to the urchins further reducing the amount of organisms removed from the reef as bycatch. The vast majority of commercial divers employed hand-pick methods, however, a small portion of the removals were conducted using an air lift and future work should evaluate how important a difference in bycatch between these approaches is in relation to the restoration goals achieved by the different harvest methods.

These key takeaways provide valuable insight into the potential benefits and logistical challenges of this restoration approach, building on lessons learned from restoration work on giant kelp in Southern California. As the state of California moves forward with the development of a kelp restoration toolkit, which will be a key component of the statewide Kelp Restoration and Management Plan, urchin removal by commercial divers should be considered as a viable restoration option. It is likely to be most effective in areas where there is already a commercial red urchin fishing fleet (e.g., Mendocino County, Southern California), at restoration locations that are relatively close to fishing ports, and at locations where urchin incursion can reasonably be controlled.

Organization of removal efforts, as well as robust quality control and ecological monitoring spanning ecologically relevant timescales (e.g., >2 years), are essential to achieving and documenting restoration success. Notably, this restoration method is relatively expensive, and its economic sustainability would be greatly enhanced through the development of a market for purple urchin or other market-based restoration incentives. Non-market based approaches that involve other stakeholders beyond commercial divers might also reduce cost. Restored ecosystems and restoration activities can provide recreational opportunities, enhance coastal property values and therefore create economic value other than the sale of urchins.

4.3 Implications for kelp forest recovery

Preliminary findings demonstrate that achieving and sustaining a 2/m^2 urchin threshold may lead to bull kelp recovery (Figure 8, Figure 9), as indicated by the significantly higher bull kelp densities at the Noyo site after restoration relative to the control site and before restoration (Table 6). Importantly, this density is about 20% of the density observed in Mendocino County by RC prior to the kelp decline in 2013 (Freiwald and Neumann 2017). Data that were collected by RC as part of the MPA baseline and long-term monitoring programs in this region provides this context. Without these historical data it would be difficult to evaluate the recovery success. Future surveys at other unmanipulated sites conducted as part of the MPA long-term monitoring in Mendocino County will continue to provide environmental context especially if the recently observed natural recovery of some kelp continues into the coming years.

Additionally, new patches of adult bull kelp were observed within the Noyo restoration site by the final monitoring period in fall 2021. Marine heatwave events subsided by the start of this project in 2020, and cooler ocean conditions were certainly conducive to facilitating kelp growth and recovery. Ongoing and future monitoring will further evaluate the progress of bull kelp recruitment and growth within the sites. Currently, it is unknown precisely where the bull kelp recruits at the two restoration sites originated from but given the presence of extant kelp patches near the restoration sites, it is possible that the new bull kelp resulted from spores supplied by these patches (Lipcius et al. 2008, Schoenrock et al. 2021).

Schoenrock et al. (2021) found microscopic stages of bull kelp in the biofilm on rocks in Noyo Cove in 2019. This was at a time when kelp was at its historical low and spore availability and production was hypothesized to be extremely limited. The findings of this study influenced the desire to conduct restoration at sites with extant patches of kelp (Noyo and Albion specifically) to leverage the “seed banking” potential of kelp. Microalgal forms could be a mechanism of resilience and recovery in species with complex life cycles as they rely on environmental cues to grow and subsequently reproduce. In 2020, when we began urchin removals, marine heatwave conditions naturally subsided. The combined effects of enabling ocean conditions and herbivore suppression likely supported kelp growth past the microscopic stage. This finding highlights that timing of when to do restoration is critical. Because these extant microscopic stages and small kelp patches were observed to persist through significant environmental stress events, enabling propagation of these spores could be highly beneficial in supporting resilient kelp populations.

Collaborations added significant value to the initial investment made by the state of California. Open communications from the project team with outside researchers brought new ideas and questions that could be answered. Many of the six research projects in the Kelp Recovery

Research Program, co-funded by the OPC and CASG in collaboration with CDFW, are taking advantage of the restoration activities in Noyo and Albion or are active collaborators to this program. For example, (1) genetic work on spore sourcing discussed above was conducted by collaborators (Alberto et al.); (2) gonad data from this project will be used to inform regional reproductive potential of purple urchins; (3) restoration through different techniques of outplanting bull kelp is being actively researched at the Albion restoration site in close coordination with urchin removals (Graham et al.); and (4) the effects of hydrodynamics on spore dispersal was investigated in Noyo Cove (Gaylord et al.). Similarly, future work investigating bull kelp spore dispersal could help to determine how far apart restoration sites should be from one another or from extant kelp patches to enable spore propagation (Gaylord et al. 2006, Lipcius et al. 2008, Eger et al. 2022b). Further monitoring of the restoration sites, and additional work along the North coast will greatly add to our understanding of if and how restoration responses vary between canopy-forming species and along California's coastline.

Kelp forests are fundamental to the functioning and persistence of California's rich marine biodiversity and coastal economy, yet kelp will be increasingly vulnerable in the future as ocean conditions change and disturbances such as marine heatwaves and marine disease become more frequent and more severe. As noted in state's Interim Kelp Action Plan, the state urgently requires a framework for proactive, climate-ready management of these ecosystems (California Ocean Protection Council 2021). The work presented here can contribute to that framework by offering an in-depth exploration of one restoration method and the extent to which this method can contribute to bull kelp recovery at local scales. As bull kelp recovers at restoration sites, it can contribute to wider scale recovery of kelp forest along the North coast should oceanographic and ecological conditions be favorable. If, for example, purple urchin populations were reduced by natural causes (e.g., disease) restoration sites could provide resilient populations of kelp and other species for the repopulation of nearby reefs. A network of restoration sites along the coast might create the sources for broader-scale kelp forest recovery should conditions allow. Moving forward, it will be important to explore the feasibility of scaling up this restoration method to other locations on the North coast and beyond, as well as further elucidating the specific ecological, environmental, and socio-cultural conditions under which this restoration method can be most effective across the state.

5. Recommendations

The formation of a valuable foundation for establishing a North coast restoration framework was made possible by the funding provided by the State of California, however, it only begins to demonstrate the ecological outcomes from implementing this framework. Several key recommendations for building upon this work can further advance our understanding of bull kelp restoration as a tool and help build resilience in California.

1. Establish and expand upon community-based frameworks for bull kelp restoration along the North coast

This project builds upon existing work to establish a preliminary framework for coordinating and conducting bull kelp restoration along the North coast that considers the region's complex human-ecological systems (e.g., Lee et al. 2021). The extreme ecological effects and severe economic impacts of recent ocean changes motivated the need for intervention (Hohman et al. 2019). In response, through ongoing dialogue with project partners and stakeholders, a process was developed to conduct restoration in close collaboration with those impacted most by loss of the kelp forest ecosystem services (Eger et al 2022b). By overcoming challenges arising from this community-based approach through discussions and continued engagement, this work can serve as an example for future restoration efforts. It acts as a valuable and promising starting point from which to explore further community engagement and structures for cost effective restoration by modifying compensation schemes of commercial divers or changing the timing of restoration. More broadly, this work demonstrates what can be achieved when state government agencies partner with local communities to respond to and mitigate environmental change impacts - a process which should be further developed.

Key lessons learned from this collaborative process are that commercial divers can be engaged and be a great asset to restoration due to their local knowledge and skill. Given the complexities of engaging private business owners, NGOs, government agencies and community members and integrating the suite of perspectives and priorities into this project, further work should be done to identify opportunities to make this integration easier and engage and leverage an even broader group of stakeholders. For example, exploring additional permitting pathways that facilitate responsible harvest as a mechanism for restoration activities could improve cost efficiency and streamline project implementation and expand the scope of stakeholder involvement.

2. Support long-term monitoring and maintenance of existing restoration sites

While results presented here indicate initial regrowth of some bull kelp, it is clear that given the relative paucity of data from similar restoration projects (e.g., Lee et al. 2021), continued monitoring of these sites will provide valuable insight into the outcomes and lessons learned from bull kelp restoration via urchin removal. For example, several outstanding questions remain and could be addressed by continued monitoring and research focused on pursuing questions such as “How long does bull kelp forest recovery take? Does this recovery persist? What level of maintenance (if any) is needed to ensure persistence?”. In seagrass habitats for example, monitoring is recommended for a minimum of 5 years before a restoration project is deemed successful, and longer if mid-project intervention is necessary (National Marine Fisheries Service (NMFS) 2014). The limited opportunities to collect data and the variable nature of North coast kelp forest habitats make additional evaluation of these restoration sites highly valuable.

Funding for future projects should, at a minimum, aim to span a timeframe that corresponds to the time needed for recovery (Bayraktarov et al. 2016). For instance, in the project presented herein, we anticipate at least two additional summer seasons are needed for substantial kelp growth to occur and persist. This should be monitored, and low urchin densities should be maintained (if necessary). Given recovery times are still unknown, we recommend support for research that will help in determining minimum project timeframes for future kelp restoration projects, using frameworks from other habitats such as seagrass meadows as key examples.

3. Address scientific gaps surrounding bull kelp forest restoration and ecological responses

Although this project addresses key questions regarding the implementation of bull kelp restoration, many scientific gaps remain. Future research investigating spore dispersal and the genetic lineage of restored kelp can help guide restoration efforts and provide valuable insight into the resilience of these populations. Work also remains to explore other methods of restoration and how their use might alter restoration outcomes. We demonstrate kelp regrowth solely via urchin removal. However, alternative or combined approaches such as using green gravel (Fredriksen et al. 2020), outplanting or spore sublimation might produce different results or could increase recovery speed in a system where dispersal might be limiting. It is not clear at this point what ecological state may be characterized as “recovery,” and further work is needed to explicitly define metrics of kelp forest restoration success and recovery.

Conceptual work on defining useful ecological recovery should also be implemented in order to have clear benchmarks that determine successful kelp forest restoration for future projects along the North coast, and statewide. Investigations are needed into the resilience of restored forests relative to new perturbations or constantly high urchin densities on surrounding reefs once interventions are completed. Further research is also needed to address these approaches and questions, whether from continued work on these restoration sites or additional sites elsewhere. For example, understanding at what stage of the progression from kelp forest to urchin barren an intervention is most successful and cost effective needs to be addressed by conducting more research at other sites in varying stages of barren development. Lastly, future work evaluating the social and community implications of restoration can further identify how and where we might best implement and design restoration projects. Research that addresses these gaps will be essential in improving the efficiency, likelihood, and benefits of restoration success in future work and should be supported.

Several elements of this project were built and adapted from lessons learned among kelp restoration practitioners worldwide (House et al. 2017, Lee et al. 2021, Williams et al. 2021). As such, sharing lessons learned from this bull kelp restoration project will facilitate a step forward in the global understanding of kelp restoration techniques. With relation to global connectivity and sharing lessons learned from this project with other communities facing kelp loss, this study was included as a case study in Global Kelp Restoration Guidebook led by The Nature Conservancy (Eger et al. 2022b). This project was showcased along with other projects from Australia, Gwaii Haanas, Tasmania, Korea, Japan, Southern California, Norway, Italy and Chile in the section "Restoration in Practice: Project from Around the World." As kelp forests health continue to be threatened by a changing ocean, it is increasingly important to share findings and maintain a dialogue on how to improve.

6. Conclusion

In response to the severe and persistent loss of bull kelp along California's North coast, the state supported RC, in collaboration with key agency and community partners, to develop a novel, community-oriented approach to bull kelp restoration in Mendocino County. Over the course of two years, the project team initiated restoration activities at two sites, involving participation by 16 commercial divers, three urchin processors, local volunteers, and several research institutions. From this work, we gained valuable information in understanding and developing processes that can be implemented to bolster coastal communities and their economies in the face of ocean change and restore the ecosystems that they depend on.

The primary goals of this project were to investigate whether or not North coast commercial divers could reduce urchin density to reach a target of 2 urchins per square meter at selected locations, to evaluate the effort level required to do so, and to study how this might affect bull kelp recovery. We demonstrate that, indeed, with state, community and stakeholder involvement, an effective process can be developed to engage and compensate commercial divers to conduct urchin removals for restoration. We see that with a higher initial removal effort, commercial divers can readily reach the target density and maintain this density through time with lower relative effort in the period that follows. Furthermore, early data on the kelp forest responses suggest that reaching and maintaining this urchin density threshold may lead to bull kelp recovery. Future work building on this project to better assess restoration outcomes and implement similar frameworks in other sites and regions will advance our understanding of how we might best use and invest in restoration across the State and successfully restore lost bull kelp ecosystems. The work presented here can contribute directly to the State’s development of a kelp restoration “toolkit” and, more broadly, to climate-ready management of the state’s kelp forests, directly informing the development of a statewide Kelp Restoration and Management Plan (California Ocean Protection Council 2021, CDFW 2021).

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8. Appendices

APPENDIX A. Diver Questionnaire

The following questions were used to assess the eligibility and interest of commercial divers to participate in the restoration.

Questions

1) How many years of experience do you have as a commercial urchin diver? __________
2) Do you currently have a valid commercial urchin license? ______________
3) When was the last time you dived for urchin? ____________
4) Do you own a vessel suitable for harvesting urchins? __________
5) If yes, does the vessel have a valid commercial registration? __________
6) If not, are you willing to obtain a valid commercial registration? __________
7) All participating vessels must pass the appropriate U.S. Coast Guard safety inspection for this class of watercraft. Are you willing to participate in a Coast Guard safety inspection? ____________
8) The project may require that participants have vessel and liability insurance, the cost of which can be reimbursed. Are you willing to obtain the appropriate insurance? _______
9) Divers are responsible for providing the appropriate diving and urchin removal equipment. The purpose of this project is to remove urchins of all sizes. What is the mesh size of your urchin bags? _______________
10) Have you worked on purple urchin removal projects before? If so, please estimate how many days you participated in these efforts. ______________________
11) Have you participated in any other efforts pertaining to purple urchin removal and kelp restoration, such as helping to plan or seeking funding for purple urchin removal projects or local education and outreach activities? Please describe your experience.
12) This project is currently delayed due to COVID-19 travel and work restrictions. However, we are trying to begin the project as soon as possible. What is the soonest you could be available to start work on this project? _____________
13) What is your availability like? ______________________________
14) Are you physically able to dive for 4 hours/day? __________________________
15) If you are a diver, are you willing to work on someone else's vessel? _______________
16) If you are a vessel owner, are you comfortable having non-family divers on your vessel?

APPENDIX B. Datasheets

Commercial Diver Datasheet

Commercial Diver Datasheet
Kelp Forest Restoration Project: Reef Check

Daily Assignment				
Date:		Vessel:		Time in:
Site (circle): Noyo Albion				Time Out:
DIVER 1:		DIVER 2:		Distance End (m) / area complete? (y/n)
1	BOLT: N or S	BOLT: N or S		m / Yes No
2	BOLT: N or S	BOLT: N or S		m / Yes No
3	BOLT: N or S	BOLT: N or S		m / Yes No

Dive		
Visibility:	Surge: Low Medium High	Depth Range:
Habitat (0= bare rock, 5=some algae, 10= the full kelp forest)	1 2 3 4 5	6 7 8 9 10

Circle all that apply		
Post-Dive Q's	Did you see any new/young algae growing :	Red (lettuce, lacy, leafy) Green (thin lettuce) Brown (kelps)
	Notes about algae:	
	purple urchin behavior :	Few: scattered on reef / in cracks Dense: everywhere / deep / shallow / patches
	red urchin behavior :	Few: scattered on reef / in cracks Dense: everywhere / deep / shallow / patches
	Were the red urchin you saw harvestable?:	Yes, and right now Yes, but they're not ready yet No, they're too small
	Notes about urchin:	
Draw General Area Worked:		

Post Dive- Landings	
Lbs. Landed (TOTAL):	# of totes:
Processor (circle): Ocean Fresh Pacific Rim Zephyr	
Datasheets are (circle): In grey databox given to Reef Check staff	
**Send photo of this datasheet to Morgan (circle): Completed	
NOTES/GPS:	

Contact Info: Morgan Murphy-Cannella, Program Coordinator: 760-994-5719, mmurphycannella@reefcheck.org

APPENDIX C. Site selection: substrate analysis

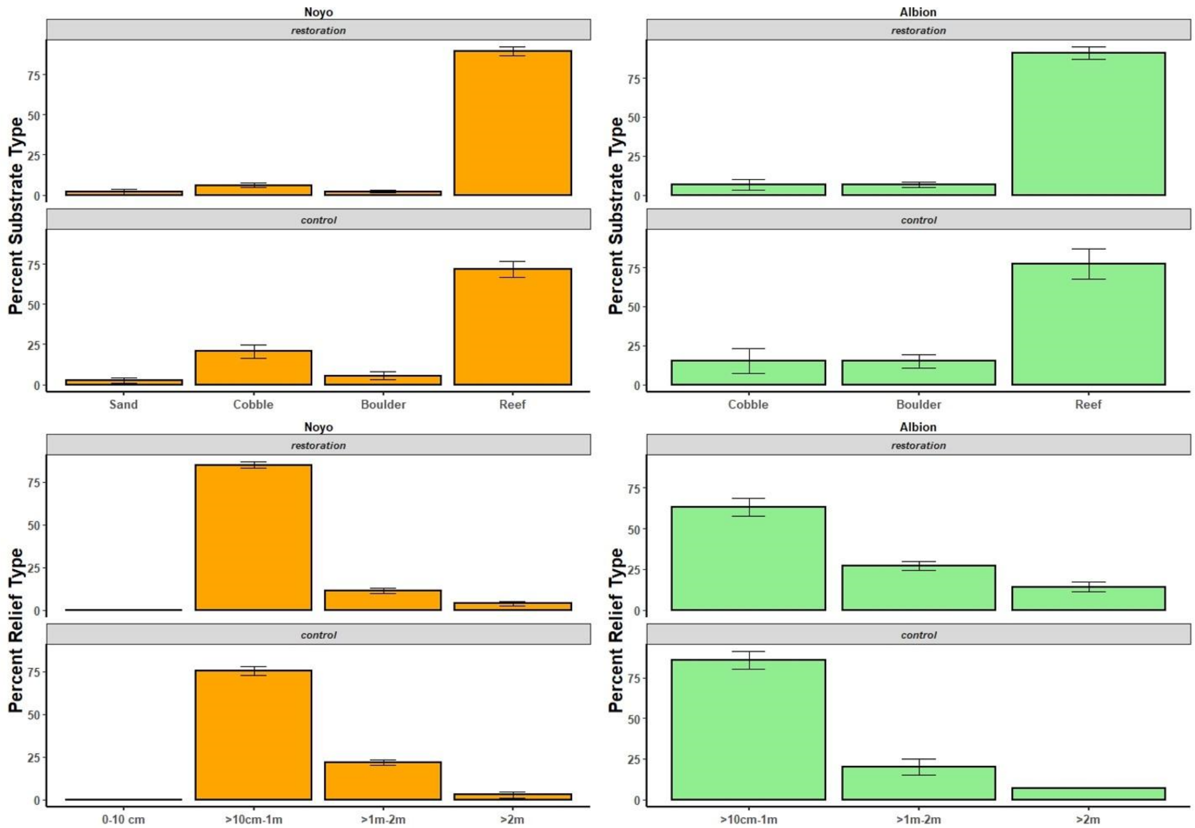

Figure S1: Substrate type (% cover) and relief level (% cover) were determined in the restoration and control sites in both Noyo (orange) and Albion (green).

To confirm that restoration and control sites were similar with respect to physical habitat, substrate and relief analyses were conducted based on diver survey. The substrate at all four sites (both restoration and control sites) consisted mostly of continuous reef (defined as grain size >1m), which characterizes between 60-80% of the sites' substrate. Cobble (0.5 cm - 15 cm) and boulders (15 cm -1 m) were the next most common substrate types, sand was rare or absent from the restoration and control sites (Figure S1). All sites were dominated by relatively low relief (10cm - 1m), with occasional observations of higher relief (more than 1 m) at all four sites.

APPENDIX D. Methods: Urchin Removals

To explicitly delineate site locations and determine site areas, the exact coordinates and directions of the sand-reef interfaces were carefully mapped using surface GPS points taken at the surface where divers indicated sand-reef interface locations before installation of the benthic lines used for coordination of monitoring and restoration. Additional site boundaries were also marked (Figure 4). To conduct restoration and QA/QC monitoring, a gridded system was designed in both sites to provide easy underwater navigation and allow for systematic urchin removal and monitoring. In each site, one 'master transect' was laid by anchoring 16 bolts (numbered 0 to 15) at 10 m intervals into the reef, running east to west near the sand-reef interface boundary (Figure S2). These bolts were then connected with lead line, and each bolt marked with PVC (Figure S3). Selected bolts were also marked with surface buoys to provide a surface visual of the master transect location. To conduct the restoration, 16 'removal transects' were run from each bolt perpendicular to the master transect, extending across the restoration sites at parallel headings (Figure S2). Each removal transect extended 100 m north (Noyo) or northeast (Albion) from the master transect before reaching the shallow areas. In Albion, some transects also extended southwest at various distances until reaching the reef-sand interface. Each commercial two-diver team was assigned specific 10 m wide removal transects to conduct (0-15) and a heading. 100 m transect tapes were connected to the assigned adjacent bolts, then reeled out along the predetermined heading, and both divers then swam back along the tapes to return to the bolt and master transect. At this point, commercial divers worked as a team to systematically remove urchin inside the 'cell' created by the two transect tapes. This process was repeated for each cell until all 16 cells were completed.

The urchin removal transect design described above partitioned the restoration sites into two distinct areas, the cells and the shallows (Figure S2). The cells were delineated by the tapes and urchins were removed using the grid system described above, while urchins in the shallows were removed opportunistically. Specifically, shallow removals were conducted by two-commercial diver teams first placing an anchor within the area and recording anchor coordinates. Urchins were removed outward from their anchor, and GPS coordinates were recorded where they ended for the day. Upon their next deployment, divers were assigned to begin removals from the previous endpoint.

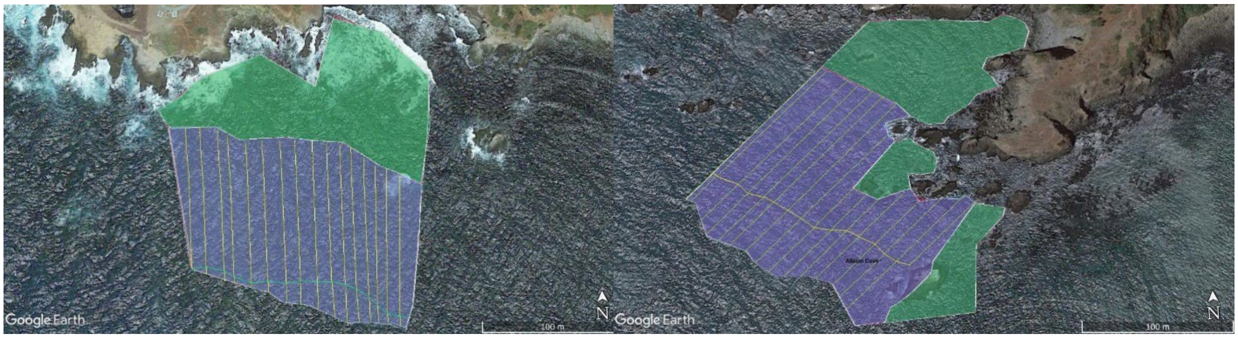

Figure S2. Map of the grid system (cells) and shallows in Noyo (panel A) and Albion (panel B). Cell areas are represented in blue and shallow areas in green.

Figure S3: A) Example of Bolt #3 with benthic line and PVC marker. The number of holes drilled into each PVC marker signify its associated bolt. B) Buoy and anchor associated with bolt #10 (Photos: M. Murphy-Cannella).

After urchin removal in the cells was complete, QA/QC surveys to monitor the progress of the commercial divers were conducted by RC staff, a method demonstrated to be effective in other kelp restoration projects (House et al. 2017). These surveys were conducted within two weeks following removal efforts to account for the behavioral responses of urchins post-clearing. QA/QC surveys were done along two 30 by 2-meter transects in each cell, each in a different depth range within the cell when feasible (approx. 35 -20 ft and 20 -15 ft). Along each transect, RC divers counted purple urchin, red urchin, and bull kelp, and collected video transects. These data were used to identify cells that needed additional removals, and divers were re-deployed into cells where densities exceeded 2 urchins per m^2. This process was repeated until an acceptable urchin density of < 2 urchins/m^2 was reached. Further QA/QC surveys were conducted to track potential increases in densities. If there was a noticeable increase in density, commercial divers were redeployed to continue urchin removals (maintenance phase).

APPENDIX E. Project Outreach, Dissemination, and Media

Noyo Center for Marine Science Virtual Webinar Series: RC staff and contractors presented the status of the restoration project and future directions for 100 attendees (Figure S4)

Figure S4: Flier for the restoration science talk that was circulated across various social media outlets.

Public Signage on Noyo Buffs: Informational posters (Figure S5) were placed on the Noyo bluffs trail above the Noyo restoration site to disseminate general project information to the public. This is a high pedestrian traffic area for many locals and tourists. Signs were not permanent and were set out daily on the bluffs during acceptable weather conditions.

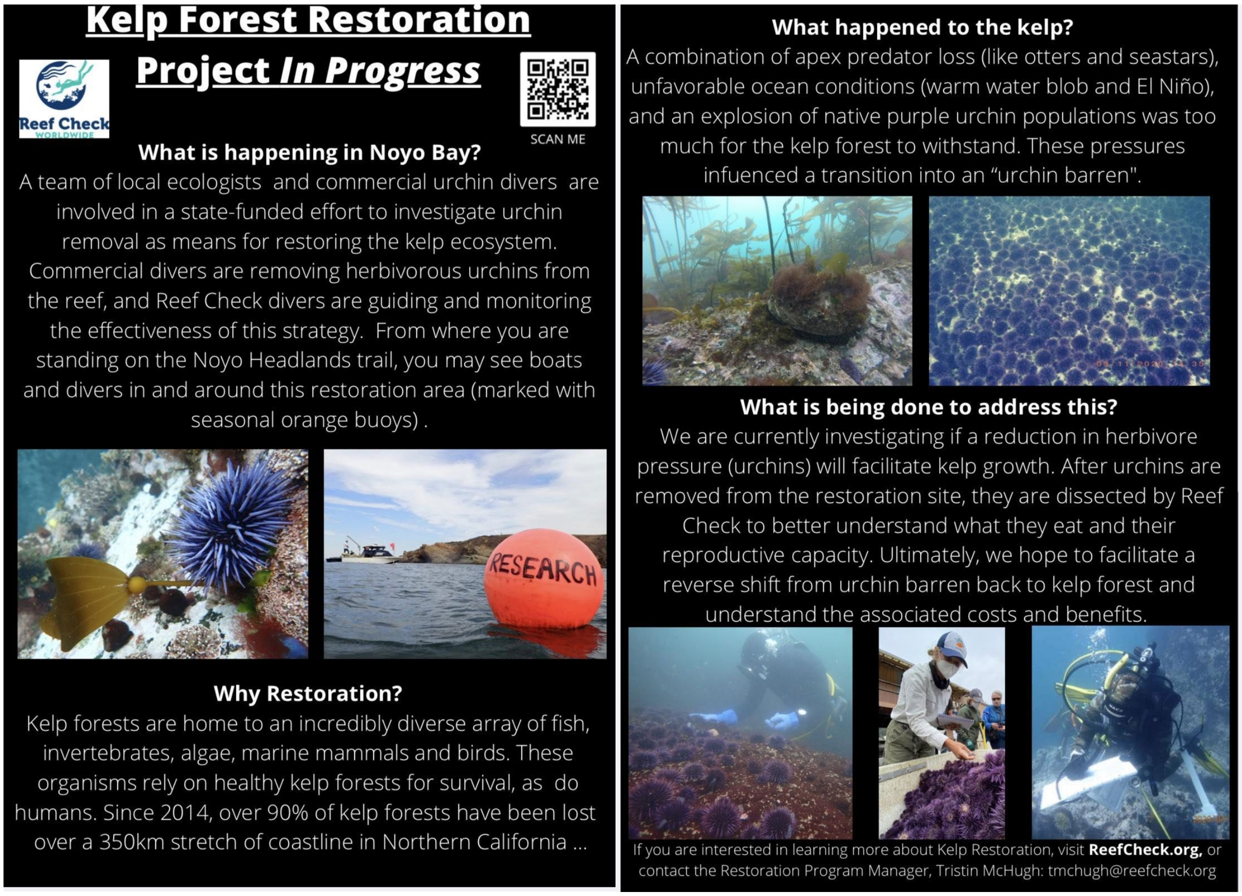

Figure S5: Signage on Noyo Bluffs

Clay urchin models and virtual education: Three 4th grade classes from Novato Unified School District participated in a virtual educational series about kelp forest ecology and kelp restoration in Mendocino. Commercial divers and RC staff engaged in virtual talks and presentations about their work in kelp restoration. Students created life sized clay models of purple urchins using dockside size frequency data. These urchins are planned to be displayed at the Noyo Center for Marine Science Discovery Center urchin barren exhibit.

Figure S6. Clay urchins made by elementary school students (Photo Credit: Anonymous parent, K. Elsmore).

Bull kelp exhibit: The Noyo Center for Marine Science constructed a bull kelp exhibit at the Discovery Center located in downtown Fort Bragg. A local artist used wood and copper to create the display, which is hung from the ceiling giving the viewer a feeling of standing inside a kelp forest.

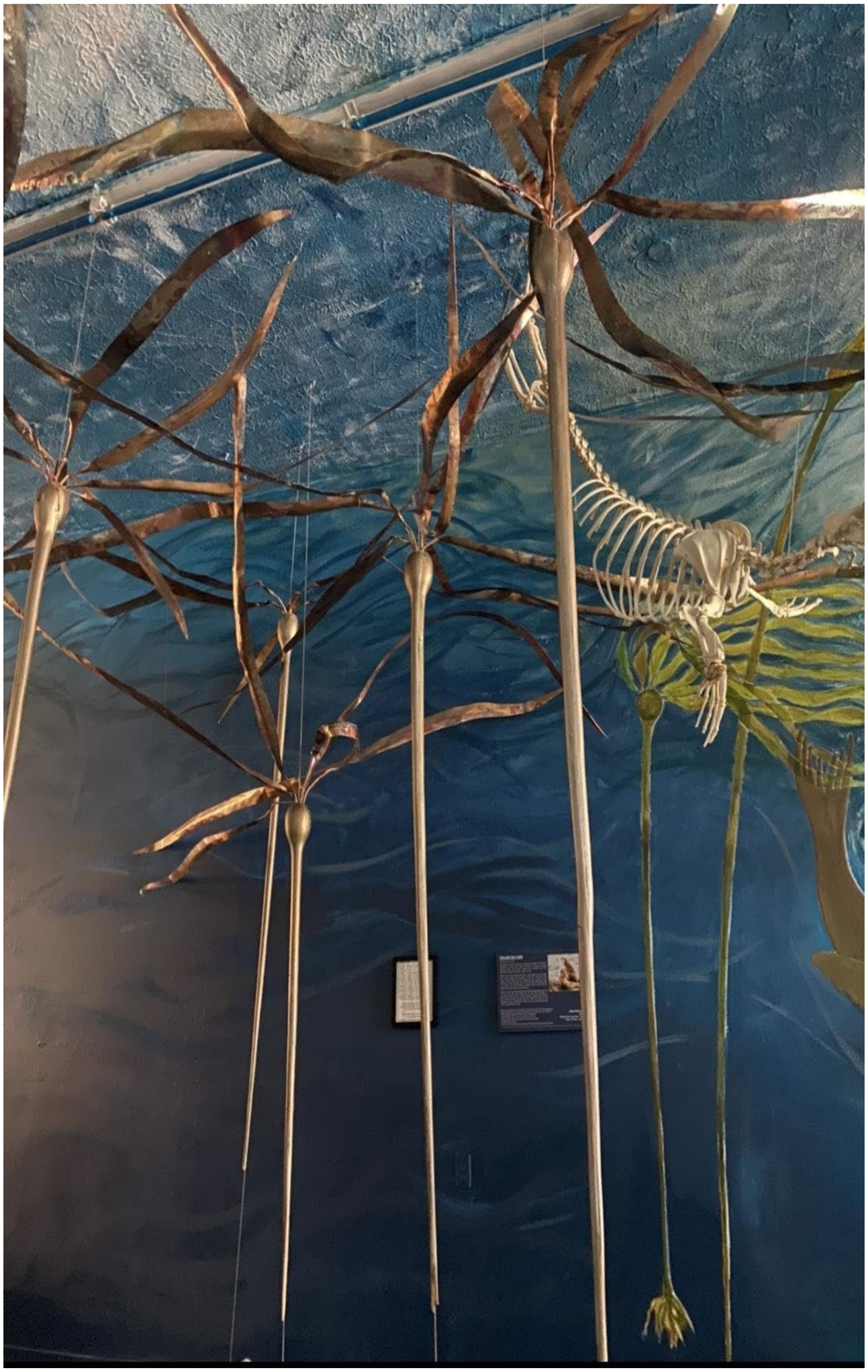

Figure S7. Bull kelp forest exhibit at Noyo Center for Marine Science.

News Articles related to the restoration project

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