Accelerating North Coast Kelp Recovery

Interim Report
OPC Project: R/HCEOPC-45

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Executive Summary

In under a decade, 96% of bull kelp habitat has been lost along 350 km of coastline on the north coast of California. One of the most rapid and extensive losses of underwater forests to date was the result of an unprecedented combination of multiple stressors, including the loss of top predators (sea otters and sea stars) and an increase in frequency of warm water events. Across this region, kelp forest habitat largely transitioned to urchin barrens leaving a wake of ramifications including the continued peril of red abalone, multiple federal fishery disasters (e.g. salmon, red sea urchin) and loss of culture and identity for a community deeply rooted in the health of these invaluable underwater forests.

Part of the 4% remaining kelp refugia on the North Coast was, for many years, at the mouth of the Big River estuary (Portuguese Beach) in Mendocino Bay, just beneath the town itself. While this location withstood the great losses of kelp from 2014-2019, it began to show signs of deforestation in 2022. One year later, *91%* of bull kelp refugia habitat was lost across the ~15 acre cove. The decline of health in this iconic forest was detected by local divers, beachgoers, scientists, fishers and stewards who have a deep connection to this place and catalyzed a call to action. We know from the global community of practice that protecting a kelp forest before it disappears should always be the first priority when considering restoration interventions. In Summer 2023, the state of California launched the second round of the Accelerating Kelp Research Program (AKRP) funding, providing us and our community an opportunity to protect and expand this threatened kelp forest, using novel and innovative approaches.

This Interim Report describes our first year (Year 1, 2024) to recover a recently degraded bull kelp forest at Big River, Mendocino County under the AKRP. Here we report on our first year results of testing and deploying a strategic combination of kelp recovery solutions and providing community participation opportunities to build stewardship connections that exceeds the lifespan of this award. This project additionally includes a one-acre kelp restoration study at nearby Albion Cove led by the same Objective 1 project team (The Nature Conservancy, Moss Landing Marine Laboratories, Sonoma State University, Reef Check, California Sea Urchin Commission, and California Department of Fish and Wildlife) proposed as match to the funding award. The project has three objectives that each intentionally address ecological, economic and social considerations that are paramount to understanding the potential for scaled and accelerated kelp recovery. The approach is a multidimensional collaboration that builds on years of kelp restoration activities, while also incorporating the ideas, experiences and musings of those who live on and with the ocean.

Our program strives to align and combine what would be individual efforts to reach a shared goal: Restore kelp. And lots of it. **Objective 1** aims to recover five acres of degraded kelp forest habitat. Knowledge gained from grazer suppression and kelp enhancement activities will directly inform the scalability of kelp recovery, document the drivers of restoration success, and engage the local sea urchin fishery. This work will directly contribute to California's Kelp Restoration and Management Plan (KRMP). Additionally, kelp restoration outcomes will support the 30 x 30 initiatives both domestically and globally through the Kelp Forest Challenge which aims to protect and restore 4 million ha of forest by 2040. **Objective 2** addresses information gaps by developing predictive models to optimize restoration, quantify the effects of urchin harvest and impacts to the fishery, and provide guidance for climate readiness and the blue economy. Furthermore, we aim to develop an understanding of urchin demographics at restoration sites, to eliminate any waste, and secure both food and non-food uses. **Objective 3** will provide socio-economic value by

creating a local trained workforce in restoration, an emerging and relevant field. The objective also seeks to engage the community and include broader perspectives through experience and art, ensuring California's coastal communities are represented in coastal ecosystem recovery, policy, and management discussions.

Key outcomes of the work to date include:

Objective 1

- 15 commercial urchin divers spent > 600 hours underwater and strategically harvested 54,870 lbs (27.4 tons) of purple urchin from two locations: Albion and Big River
- For the first time in a kelp restoration scenario, a scalable pathway to market was developed with the California Department of Fish and Wildlife and allowed us to utilize and market urchin harvested for the project for food and non-food purposes
- Grazer suppression at 'kelp edges' likely contributed to protected and expanded remnant refugia at Big River; there was a 172% increase in canopy coverage since Fall 2023 and emergent kelp became reproductive
- We closed the life cycle of bull kelp in lab allowing us to reliably culture various life stages for kelp enhancement activities, year-round
- Novel ARKEV (Array to Recover Kelp Ecosystem Vegetation) units at two field sites created invaluable young-of -the-year rockfish habitat. Within two months of outplanting, bull kelp on ARKEVs became reproductive and released trillions of spores

Objective 2

- Echino engineered marble stone has shown promise that an urchin-based marble engineered stone product could be supplied to architects and designers as a building material for the eco-friendly furniture and green building materials market in the construction industry
- Prototypes have been advanced to demonstrate the marketability of urchin-derived biomaterials, specifically for the luxury design market. At the same time, Primitives Biodesign calculated the volume of urchin that could be absorbed by their product production, their target market capture, and the resulting impact on the urchin population

Objective 3

- Local opportunities were created to build local knowledge and bolster workforce development
- KelpFest! reached over 1,500 people and elevated other ways of knowing kelp ecosystems. This work was shared in real time, with over 30 presentations and multiple media appearances reaching over 144,000 viewers, to accelerate the pace of learning and make work visible
- 19 students were supported through this project via this program and matching infrastructure
- The Mysterious World of Bull Kelp website was endorsed by the UN Decade of Change and continued to expand webstory content and reach to new audiences

The Nature Conservancy is excited to be collaborating with multiple private, academic, nonprofit, and community stewards to execute the work under this AKRP award. Because of these collaborations, our Year 1 (2024) has been tremendously successful. We are thrilled to report on those results here and look forward to working with The Ocean Protection Council, California Sea Grant, and California Department of Fish and Wildlife to ensure we utilize the learning outcomes from Year 1 to continue to improve the overall projects into Year 2 and beyond.

Introduction

Kelp serves as both an organism and a habitat. Canopy forming kelps (Brown alga in the Order Laminariales) are considered a foundational species prevalent in temperate nearshore marine environments, spanning approximately one-third of the globe (Eger et al. 2022, Eger et al. 2024). When individual kelps aggregate, they become a forest and provide essential food and shelter for a myriad of ecologically and economically significant species. Collectively, these macroalgae support thousands of associated organisms. Bull kelp (*Nereocystis luetkeana*) is an annual species and the predominant canopy-forming kelp along the rocky reefs of the northern California coast. Beneath the canopy of bull kelp, this region also hosts over seven species of stipitate and understory kelps (*Laminaria setchelli, Laminaria sinclarii, Laminaria spp., Pterygophora californica, Egregia menziesii, Costaria costata, Alaria marginata, Dictyoneurum californicum*) and well over 30 species of other brown (order Phaeophyceae, Laminariales), red (order: Corallinales, Gigartinales, Bangiales, Rhodymeniales and many others), and green (order: Ulvales) macroalgae.

In under a decade, kelp forest canopy in Sonoma and Mendocino counties declined by over 96%, leading to significant consequences, such as federal fisheries disasters, legacy dive shop closures, and the loss of an ecosystem highly valued by a coastal community deeply rooted in kelp. The 'era of great loss' from 2014-2019 was due in part to multiple stressor events such as poor oceanographic conditions (e.g., El Niño, Marine Heatwaves), the absence of key marine predators due to hunting and disease, and changes in species interactions contributed to these rapid and extensive losses. Of particular importance, while 96% of kelp has been lost, roughly 4% remains. These extant patches of resilient forest, which have withstood the great loss beginning in 2014, are vulnerable to collapse but have garnered much attention and admiration from local communities.

Although kelp forests generally exhibit a high degree of interannual variability statewide, this unprecedented contraction in the abundance and diversity of kelp ecosystems necessitates an approach that protects and expands the remaining refugia and biodiversity (grazer suppression) but also conducts additional restoration techniques in areas devoid of vegetation to expand upon (grazer suppression + kelp enhancement). A mosaic of solutions for kelp recovery is essential to revitalize biodiversity, the economy, and workforce opportunities. Furthermore, there are multiple ways of knowing and stewarding these threatened ecosystems spanning both above and below the sea surface. Global case studies emphasize that sustained governmental support, leadership and community involvement are imperative to ensure kelp recovery success and advance our understanding (Kelp Forest Alliance, State of the World's Kelp Forests Report). Our work builds on previous investments from the Ocean Protection Council (Ward, McHugh, Elsmore et al 2022), 2020 Kelp Recovery Research Program (Caselle et al. 2023, Gaylord et al 2023; Graham and Hamilton 2023), and congruent investments from The Nature Conservancy (TNC), and others. Thus, in the true spirit of scaling and accelerating kelp recovery, we have launched an ambitious kelp recovery approach yet to be tested in bull kelp systems of northern California.

Goals

Our project advances an integrated and scalable approach to kelp restoration at a recently deforested location by:

- implementing a strategic sequence of restoration and protection techniques (grazer suppression and kelp enhancement) to stimulate kelp recovery
- investigating urchin fishery adaptation and its implications for kelp restoration and blue economy opportunities
- creating community participation methods to increase the likelihood of restoration success

Objectives

1. Implement a strategic sequence of techniques to optimize kelp restoration success at Big River, expanding kelp ecosystem recovery to larger scales
    a. *Target a reduction in urchin density at or below threshold of < 2 urchins/m2*
    b. *Target ≥ 60% urchin transition from destructive to normal grazing and ≥ 40% increase in bull kelp canopy following kelp enhancement*

2. Investigate urchin fishery adaptation to effectively direct kelp restoration efforts and to evaluate blue economy opportunities in purple urchin removal
    a. *Understand kelp forest and red urchin fishery feedbacks to guide urchin harvest for guarding remnant forests*
    b. *Assess historical and future capacity for red urchin diver adaptation in response to the collapse of the red urchin fishery*
    c. *Create a framework to assess downstream economic opportunity for various market uses of purple urchins*

3. Ensure long-term kelp restoration success and stewardship by providing opportunities for the local community through experience and art
    a. *Provide internships for local divers to build diver workforce capacity and engage previously underrepresented groups in monitoring and restoration*
    b. *Develop a series of tangible and replicable art/science products and events to engage and communicate project goals and outcomes*

Ultimately, the transformative aspects of this research are centered around refining highly scalable, robust, and climate-ready restoration techniques through a coordinated community-based approach that ensures restoration is ecologically, socially, and economically viable throughout California and beyond.

Objective 1

To implement a strategic sequence of techniques to optimize kelp restoration success in year one, our team deployed grazer suppression via commercial hand harvest targeting a reduction in urchin density at or below threshold of < 2 urchins/m^2 (objective 1a). In addition, we deployed kelp enhancement practices (kelp outplanting via ARKEV modules and drift kelp deployment) to provide an additional source of spores for the system and satiate remnant urchins to encourage their transition from destructive to normal grazing, thereby allowing new kelp growth (objective 1b). In 2024, these kelp recovery techniques were deployed at two sites: Albion Cove (hereafter Albion) and Big River. Here we describe site selection, and the strategic sequence of techniques used to accelerate kelp recovery.

Study Locations

At the core of our work, our project aims to restore and protect five acres of kelp ecosystem at a recently deforested site, Big River (in Mendocino), and continue testing novel techniques in a one-acre area at Albion (Table 1). For a site to be considered for restoration under the framework of this project, it first needed to be identified as an area devoid of kelp, have urchin barrens present, and fall below historical lows for kelp abundance. This was determined by aerial and subtidal data, as well as oral history. Additional factors were prioritized according to the following primary criteria: extant kelp patches, natural barriers, logistical factors, social desire, and community interest.

Our team collectively has been conducting kelp restoration-related ecosystem aerial and subtidal monitoring at Albion and Big River since at least 2020, which has been supported through multiple state and other investments. Further, pilot kelp enhancement work has been tested at both Albion (Graham and Hamilton, 2023) and Big River (Gaylord et al 2022). Targeted urchin harvest has been underway at Albion since 2021 (Ward, McHugh, Elsmore et al., 2022). Here we attempt to consolidate the various knowledge, research, experiences, and lessons learned at the two kelp restoration sites in Mendocino that supported efforts pursued in 2024.

Site	Deforestation detected	Restoration start	Targeted restoration area (acre)	Depth (m)
Albion	2015	2021	1	0-11
Big River	2023	2024	5	0-17

Table 1: Restoration site details including site names, deforestation dates, locations, area of urchin removal effort, and depth range

Selection and Description

Albion

Although not directly supported by this AKRP award, working at Albion was a necessity in 2024 due to kelp enhancement permitting setbacks, which required strategic reprioritization by the project team. We have therefore included Albion in reporting work completed through the AKRP award. Further, this site has been used to match our scaled efforts at Big River and is included in this reporting for visibility and contextual framing.

Albion became deforested in 2015 and has remained largely devoid of kelp and in an urchin barren state since (**Fig. 1-2, Table 1**). A small patch of kelp refugia has persisted at Albion in shore of the restoration site (**Fig. 1**) and pilot efforts to protect and defend it have been underway since 2021

(Ward, McHugh, Elsmore et al., 2022, Graham and Hamilton, 2023, Karm et al. *in prep*) through state and TNC investments. A comprehensive description of site selection and work at Albion from 2020-2022 can be found in Ward, McHugh, Elsmore et al., (2022), and Graham and Hamilton, (2023).

Annual kelp status has been captured since 2020 by TNC, along with partners at Hakai, UCLA and WHOI. They established a long-term monitoring site at Albion, capturing kelp canopy throughout the cove at a 3 cm resolution scale- the finest resolution available to detect small patches of kelp refugia (Saccomanno et al. 2023). To contextualize the subtidal environment, Reef Check established a long-term monitoring site at Albion to monitor the subtidal environment by establishing n=6, 30 x 2m swath style surveys (**Fig. 2-3**). Aerial, subtidal, and oral history data sets contributed to our restoration approach in 2024 (**Fig. 1-3**).

When looking at the long-term subtidal data at Albion (**Fig. 2-3**), it is important to note that these six transects span areas both inside and outside of the targeted 1-acre restoration location to get a larger sitewide view, while more targeted restoration plot surveys were also conducted (Karm et al. *in prep*). Figure 2 displays urchin densities before and after the restoration start (July 2021) where a significant drop in densities is seen due to targeted commercial urchin harvest. Some kelp recovery has been observed (**Fig. 1-3**), yet benthic responses are still being described (Appendix: **Fig. 39**).

Albion from Above and Below, pre-2024 field season

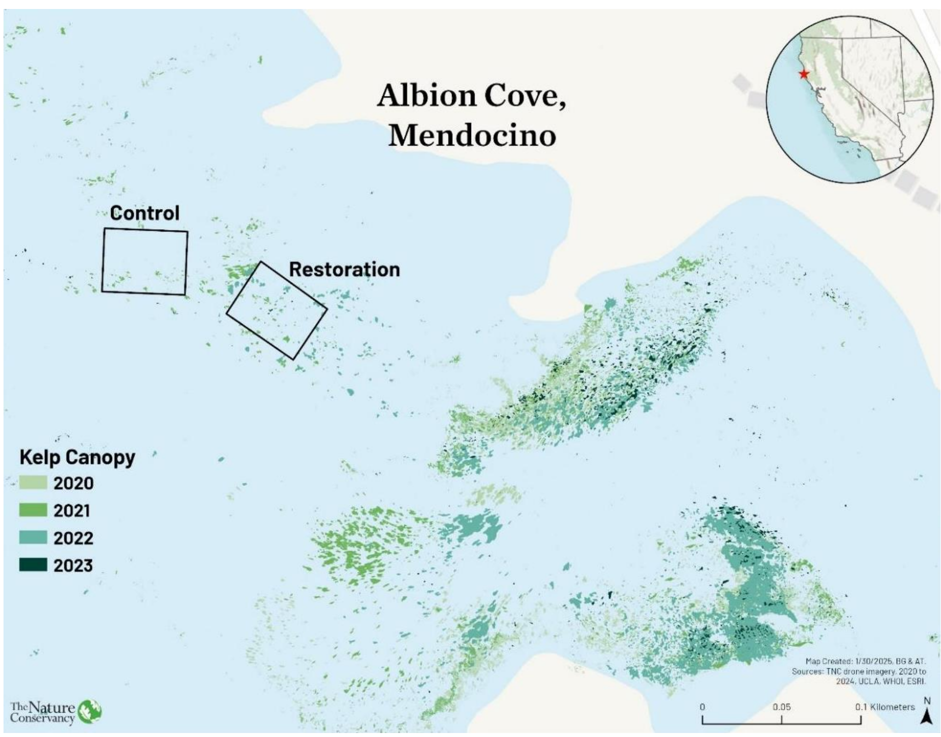


Fig. 1. Site map of Albion showing 3cm resolution kelp canopy data 2020-2023 to aerially contextualize kelp status from above. Previous kelp restoration efforts, started in 2021, are designated by the control and restoration plots (black boxes) on the map.

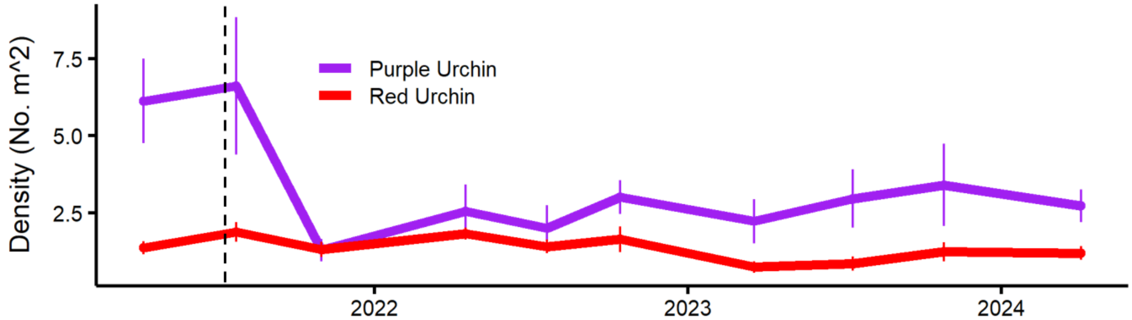


Fig. 2. Long-term ecosystem monitoring data showing red and purple sea urchin mean density ± SE Spring 2020-2024 at Albion. Dotted line designates the restoration start date (July 2021).

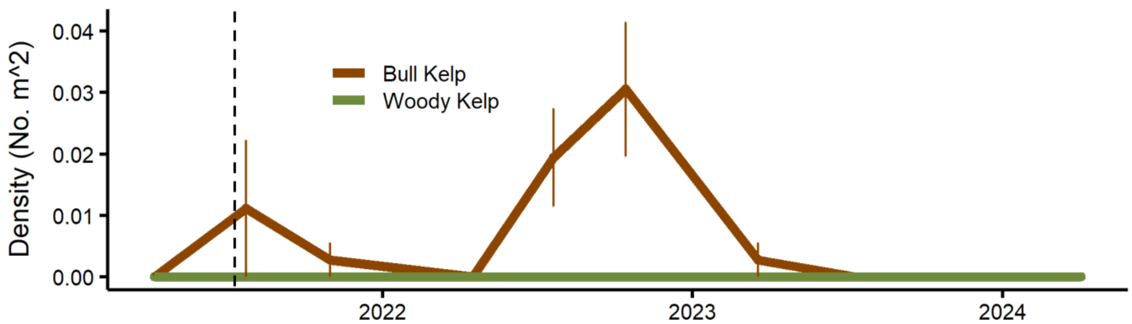


Fig. 3. Long-term ecosystem monitoring data at Albion showing Bull kelp (*Nereocystis luetkeana*) and Woody kelp (also 'winged kelp', *Pterygophora californica*) mean density ± SE Spring 2021-2024 at Albion. Dotted line designates the restoration start date (July 2021).

Big River

Collectively, our team has been monitoring Big River since 2007, and testing and developing kelp restoration techniques at Big River since 2020 (Gaylord et al. 2022, Ricart et al. 2025 *in Review*). A comprehensive description of kelp restoration technique testing work at Big River from 2020-2022 can be found in Gaylord et al., (2022), a product of the OPC/SeaGrant 2020-2023 Kelp Recovery Research Program. From the same 2020-2023 Kelp Recovery Research Program, Caselle et al., (2023) developed a guide to prioritizing site selection for kelp restoration in California using spatio-temporal models of kelp dynamics (Giraldo-Ospina, Bell, Carr et al. 2023, Giraldo-Ospina et al. 2025). Using this model, multiple sites in the Mendocino County region with a designated "high" priority classification were identified. Specifically, project partners focused on high priority sites that had historically stable kelp beds that resisted the marine heatwave but currently have a low proportion of kelp relative to historic means.

Project leadership also referred to the Sonoma-Mendocino Bull Kelp Recovery Plan to align priorities for siting regionally and referenced the Kelp Restoration Guidebook (Eger, Layton, McHugh et al. 2022) and global community of practice highlighted by the Kelp Forest Alliance for best practices in site selection. Our site selection process utilized a Strategic Decision Making (SDM) approach by incorporating a spatio-temporal model, high resolution kelp canopy data, subtidal observations, site accessibility considerations, and community interest, all within the prioritization framework previously established (Gleason, Caselle, Heady et al. 2021). Selecting a site where we could effectively protect and expand remnant kelp was a top priority (Eger, McHugh, Eddy et al. 2024).

Similar to Albion, to capture kelp status from "above", a long-term monitoring site was established at Big River to capture kelp canopy throughout the cove at a 3cm resolution scale and is now maintained by TNC (**Fig. 4**). To contextualize the benthic environment, we used a long-term monitoring site at Big River established in 2007 by Reef Check (as part of the Marine Protected Area monitoring initiative) to characterize the subtidal environment (n=6, 30 x 2m swath style surveys) (**Fig. 5-6**).

Despite Big River being one of the most persistent kelp refugia sites in the region (OPC Item 5), beginning in 2022, kelp canopy habitat contraction was detected (**Fig. 4, Table 1**). This result was captured unfolding in real time aerially and subtidally by community observation and through multiple data streams collected by this project team. Aerial imagery from September 2022 to 2023 showed an incredible 91% reduction in kelp canopy, adding to the growing urgency for bold and strategic restoration at this location (**Fig. 4**). Subtidally, while sea urchin density remained stable at the site from 2007-2014, slight increases were seen in ecosystem monitoring data from 2015-2020 (**Fig 5**). However, beginning in 2022, a drastic increase in density was observed and continued through April 2024 (**Fig. 5**). Further, as part of the OPC/SeaGrant 2020-2023 Kelp Recovery Research Program, a purple urchin front was observed decimating nearly all of the macroalgal beds at Big River, which included significant losses to the remnant bull kelp forest (Gaylord et al. 2022).

In Summer 2023, the project team brought together multiple knowledge streams, including current aerial and subtidal data on kelp canopy and purple urchin density respectively, at Big River (**Fig. 5**). Yet, by Spring 2024, purple urchin densities further escalated; at this time the mean purple urchin density was 10.4 ± 2.7 urchins/m^2, well above densities detected in Fall 2023 (**Fig. 5**). This significant and rapid increase in purple urchin density intensified the severity of urchin barren formation and restoration execution at Big River. Kelp density was variable throughout 2007-2024, yet a decrease in density coincided with the urchin density increase in 2022 (**Fig. 6**). Using recommendations from products described above, and the onset of recent deforestation, TNC and partners identified Big River, Mendocino County, as the preferred site to perform restoration.

The five-acre restoration site at Big River location spans the intertidal area down to ~17 meters depth with rocky reef and some sand channels throughout (**Table 1**). While the restoration footprint (urchin harvest and kelp enhancement) is taking place across 5 acres, over 15 acres of kelp habitat is being protected and expanded upon within the cove. While species abundance and biodiversity has decreased within the urchin barren area, within the remnant kelp forest, Big River remains a biodiversity hotspot. Of interest, > 20 species of seaweed have been documented at this site, along with two species of abalone, >10 species of fish and numerous invertebrates, marine mammals and birds. Protecting any existing remnant kelp patches at this site is a focal priority to prevent further degradation by urchin encroachment, as well as providing a source of spores for recovery and future kelp expansion. The restoration site at Big River is also predicted to be ideal for kelp enhancement due to the protected nature of the site behind the Mendocino Headland and the generally slow currents at the site, which will likely retain kelp detritus and spores. The Big River location is highly visible and valued by the community, indicating significant community interest in kelp protection and expansion at this location.

Big River from Above and Below, pre-2024 field season (restoration)

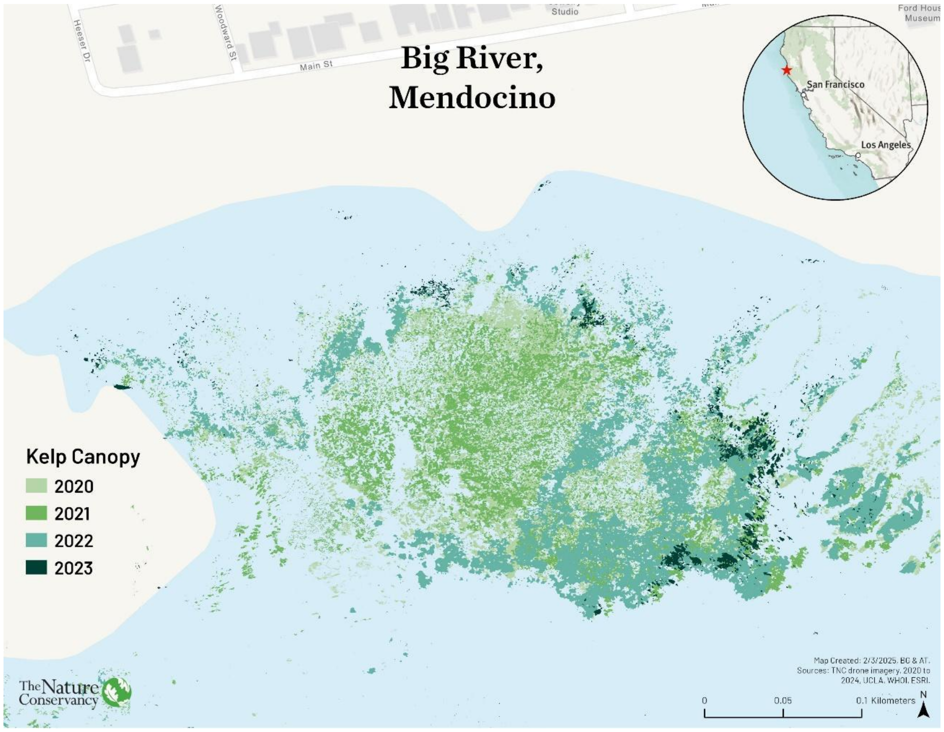


Fig. 4. Site map of Big River showing 3cm resolution kelp canopy data 2020-2023 to aerially contextualize kelp status from above sea surface. Kelp canopy area is designated by color. Kelp canopy was measured at 13,683m^2 vertical alignment in 2020, 12,348m^2 in 2021, 11,672m^2 in 2022, and 1,211m^2 in 2023.

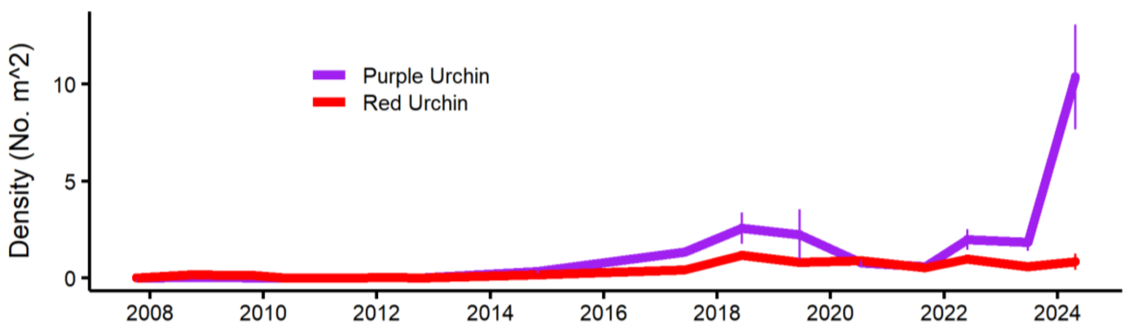


Fig. 5. Long-term subtidal ecosystem monitoring data showing red and purple sea urchin mean density ± SE 2007- Spring 2024 (prior to restoration start) at Big River.

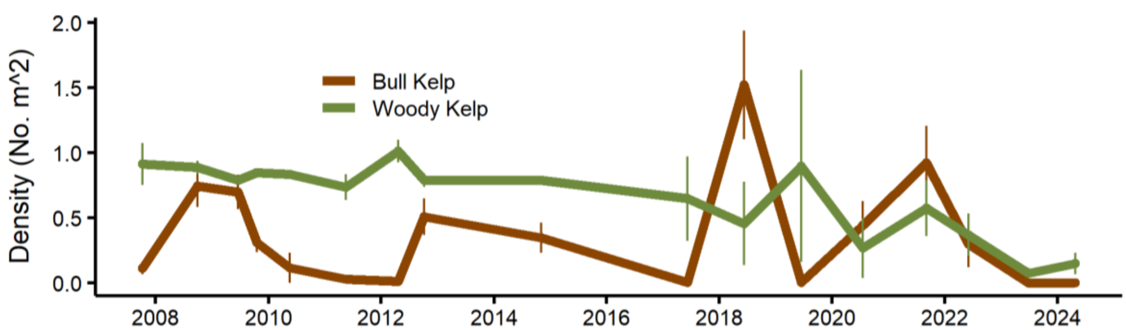


Fig. 6. Long-term subtidal ecosystem monitoring data showing brown macroalgae mean density ± SE 2007- Spring 2024 (prior to restoration start) at Big River.

Design

Albion
Utilizing the established site infrastructure from the 2021-2023 experiments (Ward, McHugh, Elsmore et al., 2022, Graham and Hamilton, 2023, Karm et al. *in prep*), we continued urchin removal efforts and tested the effects of grazer density and two kelp enhancement techniques (soral bags and ARKEVs) on kelp recruitment and growth. The two replicate 1800 m^2 plots were fabricated for an array of permanent transects, of which existing bolts were used to attach ARKEV units in Trial 1 (see kelp enhancement section) (**Fig. 7**). In 2024, kelp was only outplanted in the restoration (sea urchin removal) plot, but both plots were monitored to determine lag effects from previous year's restoration efforts (see Appendix: **Fig. 39**).

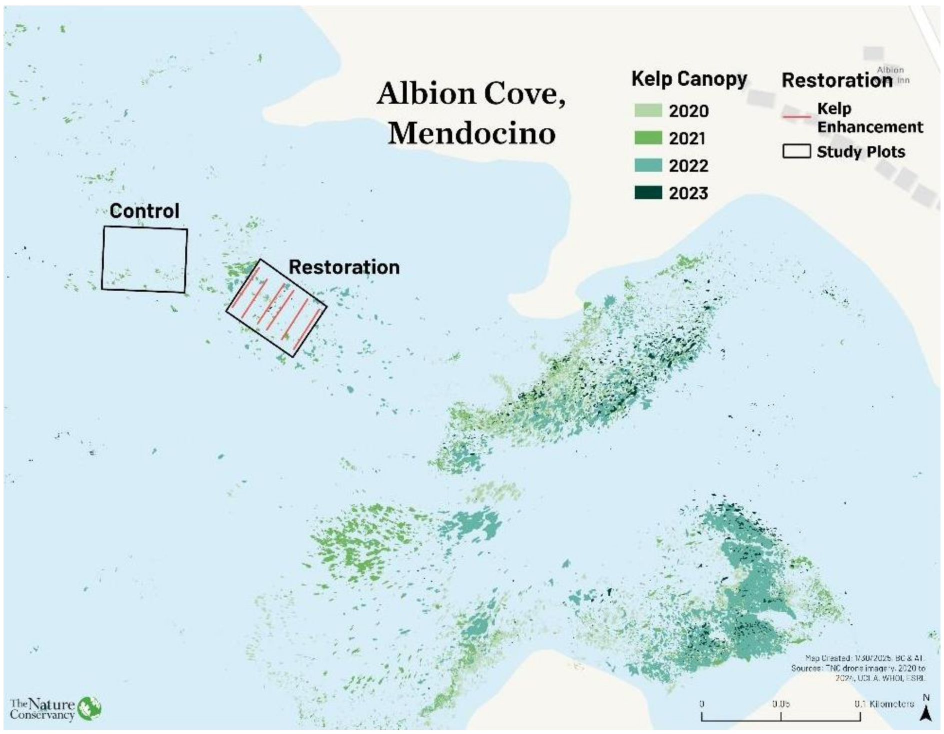


Fig. 7. Site map for kelp restoration at Albion Cove, Mendocino. Kelp canopy area designated by color. Control (no sea urchin removal) and restoration (sea urchin removal plots) are labeled. Kelp enhancement areas designated by orange lines. While in previous experiments kelp enhancement lines were used in both study plots, ARKEVs were only deployed in the restoration plot in 2024.

Big River
At Big River, 50m x 50m "blocks" were overlayed across 3cm resolution kelp canopy maps to strategically focus ecosystem monitoring, urchin grazer suppression, and kelp enhancement efforts (**Fig. 8**). Centroid coordinates were calculated for each block to facilitate site access by various partners. Blocks 9 and 10, characterized as an urchin barren, were further divided into n=20 25m x 10 m kelp enhancement study plots. In year 1, grazer suppression was strategically focused on n=12 of the 22 blocks and not all blocks were completely serviced to yield <2 urchins/m^2.

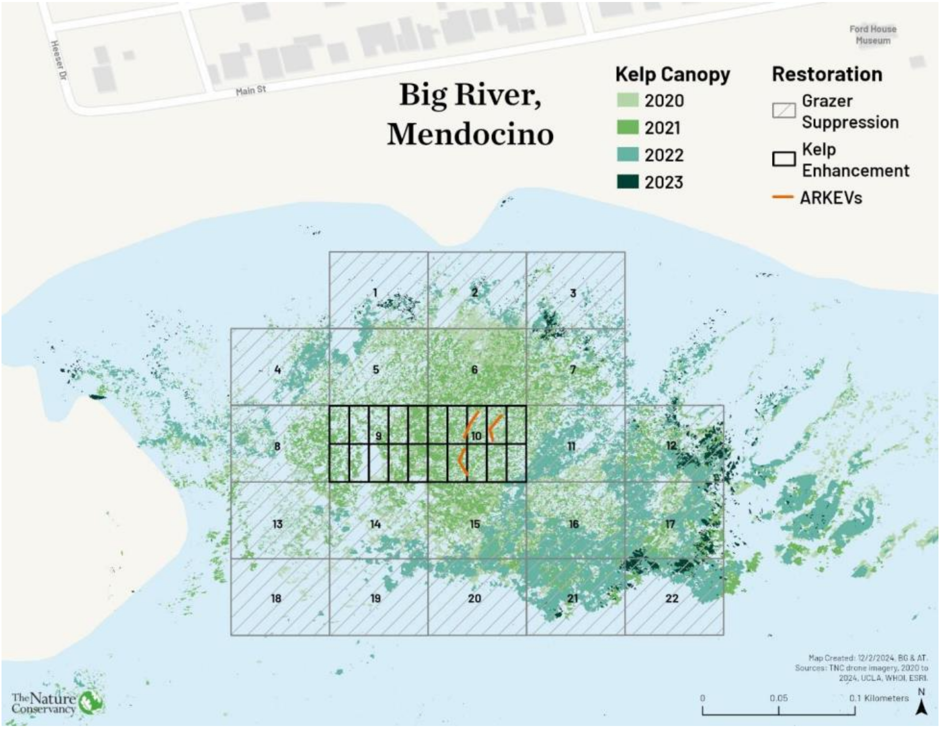


Fig. 8. Site map for kelp restoration efforts at Big River, Mendocino. Kelp canopy area is designated by color and year. Grazer suppression blocks are numbered to facilitate coordination, kelp enhancement activities occurred in blocks 9 and 10, and ARKEV unit are designated by orange lines.

Objective 1a

Methods

This section describes the methodological approach to conducting and understanding the outcomes of grazer suppression for kelp forest restoration in four sections: (1) Commercial Hand Harvest, (2) Targeted Surveys at Kelp Edges, (3) Long-Term Ecosystem Monitoring Surveys, and (4) Dockside Monitoring.

Commercial Hand Harvest

In 2024, commercial sea urchin divers conducted hand harvest of purple sea urchins at Albion and Big River, with all catches landed at facilities in Noyo Harbor. Each site featured a unique spatial design tailored to its specific dynamics and restoration footprint.

The harvesting approach was collaboratively developed by the project team. Representatives from the California Sea Urchin Commission (Big River) and Reef Check (Albion) were selected to serve as Harvest Coordinators, who then communicated with commercial sea urchin divers and processors for the execution of harvest for restoration and Project PI for project management. Commercial sea urchin divers were required to coordinate with Harvest Coordinators before each dive day to determine the targeted urchin removal areas aimed at promoting kelp regrowth. Post-dive, commercial sea urchin divers had to report back to the Harvest Coordinators after a maximum of four hours underwater to offload their catch and complete the necessary landing documents and datasheets. Additionally, divers were responsible for ensuring that processing facilities were prepared to receive the urchins by coordinating with them on the morning of the removals. Reef Check and California Sea Urchin Commission operated as a ‘fish buyer’ via a fish receivers license issued by Pacific States Marine Fishery Commission and with management by California

Department of Fish and Wildlife. Reef Check holds a receivers license and California Sea Urchin Commission utilized processors (Ocean Fresh, Pacific Rim, and Zephyr Seafoods) who held active receivers licenses.

Upon offloading at the docks, divers submitted a photo of their completed datasheet to the Harvest Coordinators and left their completed datasheet to be picked up by their coordinator. Harvest coordinators then uploaded the datasheet to google drive, and the original was kept as a backup paper copy. These datasheets contained critical information for guiding daily urchin removal efforts, including the location and total area worked, habitat and urchin behavior observations, total poundage landed, and the processing facility where the urchins were delivered. Although qualitative, these datasheets are valuable to understand the condition of the area serviced and if continued efforts are needed or if a dive team should move to a new location.

Although urchin harvesting was encouraged year-round, adverse ocean conditions shortened the season, allowing for more intensive harvesting during favorable weather months at both Albion and Big River. The average daily landings of purple urchins were influenced by factors such as urchin density, size structure, and the number of commercial underwater harvesters per team. Diver team efficiency also varied. This study outlines our approach to grazer suppression, focusing on the location and cadence of harvests, landings, urchin morphometrics, and the subtidal response in urchin densities to these suppression efforts.

Albion

At Albion, a targeted approach was employed to harvest purple sea urchins from a one-acre restoration (treatment) area, conducted twice per month throughout the year; this approach was established in 2023 and has remained consistent through 2024 (**Fig. 7**). The restoration area was designated within a workable area adjacent to an extant kelp patch. A replicate one-acre control plot was established to the west of the restoration area and remained unperturbed to serve as a grazer control. Following coordination with the Harvest Coordinator, commercial sea urchin divers anchored at a consistent location (approximately 39.228817, -123.775133) and utilized an expanding circle method for harvesting. This strategy ensured that the area designated for kelp enhancement was regularly serviced and monitored, with efforts concentrated on critical habitat zones. In 2024, commercial sea urchin divers spent 19 days (76 underwater hours) harvesting at Albion. Two vessels and four divers participated and collectively harvested 8,737 lbs of purple sea urchin (**Table 2**).

Big River

Utilizing the best available data and knowledge, the project team identified specific areas within Big River where grazer suppression was essential to achieve the desired project outcomes. Given budget and time constraints, the focus was placed on the kelp edges and the center of the site where kelp enhancement activities were underway, rather than the entire site. The primary goal was to protect and expand the remnant kelp forest by concentrating urchin harvest efforts in blocks where kelp was still present (**Table 3**). Our previous efforts have found that the average number of purple urchins harvested is largely contingent on factors such as urchin density and size structure. As such, in 2023, our program budgeted for n= 65 days in year 1 (2024) and n= 24 days in year 2 (2025) based on best- available knowledge of size structure and urchin densities (Smith, McHugh, and Grime 2024, *in prep*, **Fig. 5**).

Long-term Ecosystem Monitoring

To contextualize site-wide response to restoration and the subtidal environment, seasonal long-term monitoring surveys at both Big River and Albion build upon existing datasets (**Fig. 2-3** and **5-6**). Ecologically and economically valued species were quantified using n=6, 30 x 2m swath style surveys. A full description of Reef Check Subtidal Monitoring protocols that were conducted can be found in the Reef Check California Instruction Manual.

Targeted Surveys at Kelp Edges

At Big River, while long-term ecosystem monitoring surveys are valuable to provide a site-wide perspective of the site response to kelp restoration interventions, transect locations were fixed to the design established in 2007. Therefore, the project team additionally conducted more targeted surveys along the northernmost kelp margin (**Fig. 8**: blocks 5-6 and 9-10), an edge of an existing bull kelp bed near the restoration site to further understand the influence of grazer suppression on kelp edges. This area received significant effort for grazer suppression (**Table 3**), aligning with the high priority of protecting and expanding existing kelp forests, making these additional surveys particularly valuable. Project team members from Sonoma State University and Moss Landing Marine Laboratories conducted these targeted surveys at Kelp Edges using methods consistent with the ecosystem monitoring surveys previously described including 30 x 2m swath style surveys for fish abundance and 1 m^2 quadrats (n=3) quantifying abundance of invertebrates and algae per transect. Further, to gain an understanding of kelp bed protection and expansion, TNC and partners conducted kelp canopy surveys to further visualize kelp health and status. Flight paths for kelp canopy mapping maintained consistent to contribute to the ongoing dataset **(Fig 1 and Fig 4)** (Saccomanno et al 2023).

Dockside Monitoring

As purple urchins were landed for restoration via hand harvest by commercial sea urchin divers, we randomly subsampled landed urchins from the Big River restoration area via dockside monitoring protocols (Ward, McHugh, Elsmore et al., 2022). Interns from the CSU COAST program (TNC match) and objective 3a led in the execution and collection of this dataset. Metrics including the location of harvest within the site (block), and individual morphometrics such as diameter, wet weight, and gonad weight were collected to quantify restoration success over time. Results for Albion will be included in the final report.

Although dockside monitoring is not supported by this AKRP award, understanding urchin morphometrics and health is instrumental to develop the potential market pathways for food and non-food uses for sea urchin. Of importance, it is also a key focus for this work as we work to develop a circular restorative practice and encourage the whole use of organisms extracted from the ocean. In addition to urchin barrens having systemic ecological implications, there are also significant economic impacts on sea urchin fisheries (Rogers-Bennett and Catton 2019) and for-substance harvesters. Urchins are harvested for their gonads ("uni"), yet in barrens, urchin gonads are often underdeveloped due to a lack of macroalgal food sources (Grime et al. 2023). Historically, the red sea urchin fishery was one of the largest fisheries in California by annual tonnage (NMFS 2018), but losses in kelp since 2015-16 warm water events have resulted in collapse of the fishery in certain locations such as northern California.

In 2024, a portion of urchin harvested became food for people and were used for non-food uses as well. With the California Department of Fish and Wildlife (CDFW), we developed a pathway to market commercially viable urchin, for food and non-food markets, and have these funds cycle back into the restoration project to sustain efforts long-term. Urchin harvest for restoration is conducted through standard commercial urchin licenses, and through this pathway, landed catch should be utilized for food or non-food purposes to reduce wanton waste. As such (and further expressed in Objective 2), in year 1 this project aimed to develop a holistic restoration process by which purple urchins harvested for restoration could further enable positive feedback to the restoration program and kelp recovery. Establishing this pathway was necessary as most of the current urchin fleets' current activities are restoration focused. Prior to this, processors were not able to utilize "restoration-caught" urchins (landed under award funds) to sell as a food product due to the risk of "double-dipping". In this new established approach, marketable urchin would be purchased on a separate fish ticket, and the payment would be made to the project to support more kelp restoration.

In our program, where we strategically harvest by blocks (**Table 2-3**), we created an opportunity to have processors on standby to sort through catch and select those with viable gonad health. Processors could then sustain these long-term market demands and put a sales return percentage back into a restoration fund to further restoration efforts at the site. The dockside monitoring work described here helps to articulate urchin health by block and strategically guide and focus urchin harvest for kelp recovery, reducing wanton waste and further developing purple urchin food markets.

Results

Here we convey the preliminary results of grazer suppression in four sections: (1) Commercial Hand Harvest, (2) Targeted Surveys at Kelp Edges, (3) Long-Term Ecosystem Monitoring Surveys, and (4) Dockside Monitoring from the first year of this project. A full assessment of the effects of our efforts will require monitoring throughout multiple years of restoration.

Commercial Hand Harvest

Urchin harvest by commercial urchin divers commenced on May 26, 2024, and continued through October 22, 2024, with a total of 56 days spent. In year 1, five vessels and 15 divers participated, collectively harvesting over 23 tons (46,133 lbs) of purple sea urchins for restoration across five acres at Big River (**Table 2**). Further, to gain a spatial understanding of the urchin harvest, effort and pounds removed were documented by block (**Table 3**). Commercial sea urchin divers targeted kelp edges and adaptively planned their work around the tides and visibility. As such, on some days, if a dive team deployed on a location and came upon bad visibility or poor conditions, they would often ascend, move the vessel to a more workable location and resume harvest.

In addition to harvesting urchins for restoration, commercial sea urchin divers were encouraged to harvest commercially from Big River, especially as urchins caught from kelp edges were likely to yield a commercially viable product. In total, 4,186 lbs of purple sea urchins were commercially harvested from Big River, further alleviating the restoration urchin harvest budget (**Table 2**).

	Restoration			Commercial
	Purple Urchin (lbs.)	Harvest Days	Underwater Hours	Purple and Red Urchin (lbs.)
Big River	46,133	56	550	4,186
Albion	8,737	19	76	-
Total	54,870	75	626	4,186
Total Urchin Harvest	**59,056 lbs (29.5 tons)**			

Table 2: Total 2024 urchin landings, harvest days, and underwater hours for Albion and Big River.

Block	# harvest days	Purple urchin harvest (lbs)
4	4	4,041
5	12	12,165
6	8	6,795
7	8	6,004
8	2	1,815
10	4	2,580
12	2	1,722
13	3	1,465
14	3	2,035
15	2	1,317
17	5	3,666
4, 8	2	2,073
7, 9	1	455
TOTAL	**56**	**46,133**

Table 3: Total 2024 effort and lbs/block (restoration only) at Big River. It should be noted that on two occasions, the landed catch was not separated by block and combined.

Long-Term Ecosystem Monitoring

These preliminary results describe the subtidal response to restoration at Albion and Big River at a "sitewide scale". Aerial long-term monitoring responses are described in the "Targeted Surveys at Kelp Edges" section below.

Albion

As a response to grazer suppression of purple sea urchins, subtidal ecosystem monitoring surveys demonstrated divers were able to keep purple sea urchin density at the restoration site close to 2 urchins/m^2 (**Fig. 9**). Ecosystem monitoring at Albion covers an area larger than the removal plot where urchins were harvested in 2023 and 2024 to characterize densities in the cove following larger scale urchin removals in 2021. Purple urchin density remained fairly stable for two years and in spring 2024, urchin densities were 2.7 ± 0.5 urchins/m^2. In Fall 2024, urchin densities had increased to 5 ± 1.1 urchins/m^2. Increases in urchin density were likely in areas where removal efforts had ceased and small urchins had recruited.

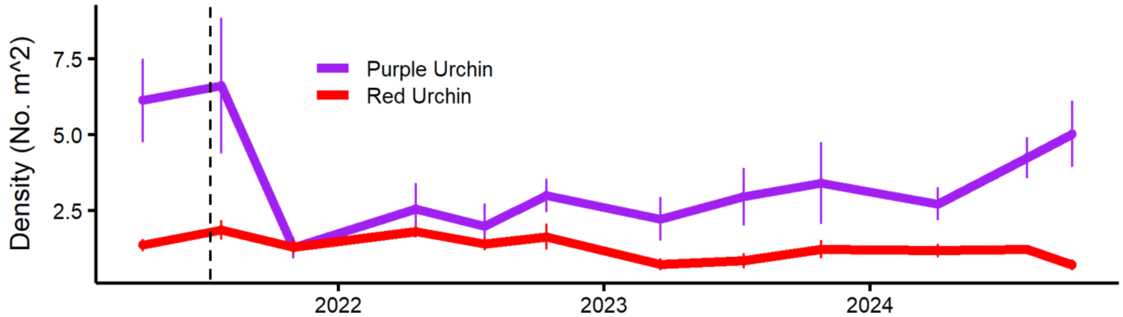


Fig. 9. Long-term ecosystem monitoring data at Albion showing red and purple sea urchin mean density ± SE from Spring 2023 - Fall 2024 throughout multiple years of restoration efforts starting in July 2021 (dotted line).

Although not included here, in final reporting, we will include size-frequency demographics of urchin remaining on the benthos and small-scale urchin density surveys from within the removal plot. Together this will allow for a detailed analysis of where urchin densities increased and if recruitment or movement of large urchins played a role in increasing their density. Additionally, kelp density has been variable throughout in the earlier years but remained at or near zero in 2023-24, even with low urchin densities (**Fig. 10**).

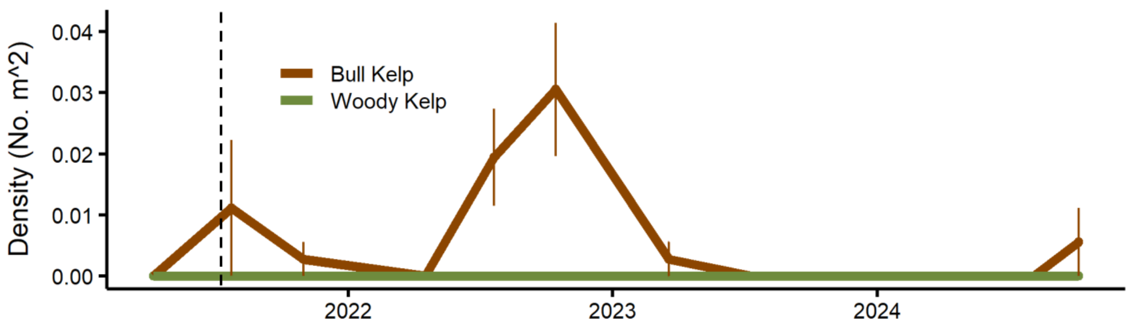


Fig. 10. Long-term ecosystem monitoring data at Albion showing brown macroalgae mean density ± SE from Spring 2023 - Fall 2024 throughout multiple years of restoration efforts starting in July 2021 (dotted line).

Big River

In Spring 2024, prior to the start of restoration activities, Reef Check staff and volunteers performed seasonal ecosystem monitoring at their permanent long-term monitoring site at Big River. Across six 30m x 2m transects, the mean purple urchin density was 10.4 ± 2.7 urchins/m^2, well above the proposed density of 2 urchins/m^2 (**Fig. 11**). Grazer suppression began on May 26, 2024 and continued through October 22, 2024. Ecosystem monitoring of the same six transects revealed a decrease in urchin density to 4.6 ± 2.4 urchins/m^2 in Summer 2024 and 3.3 ± 2.2 urchins/m^2 in Fall 2024 (**Fig. 11**). Kelp density was variable at the monitoring site, likely due to the seasonal effects of when monitoring was conducted (**Fig. 12**). Throughout this time, 4,024 lbs of urchins were removed from Block 4 (**Table 3**), which overlaps with the fixed transects.

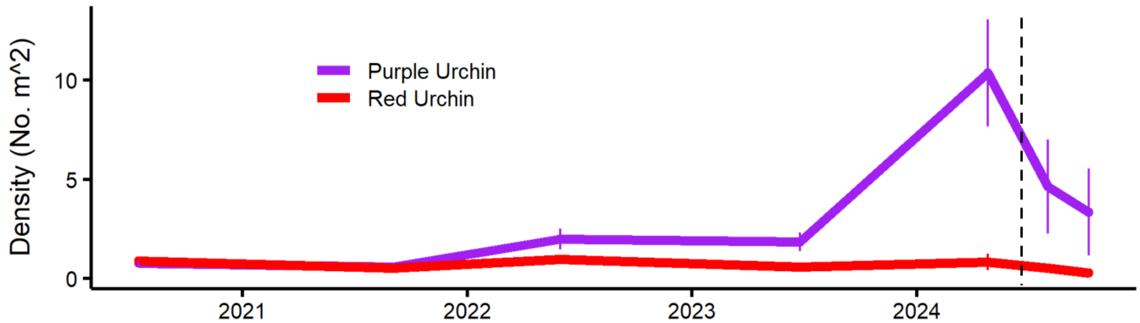


Fig. 11. Long-term ecosystem monitoring data showing red and purple sea urchin mean density ± SE 2020-2024 at Big River. Dashed line represents the restoration start date (May 2024).

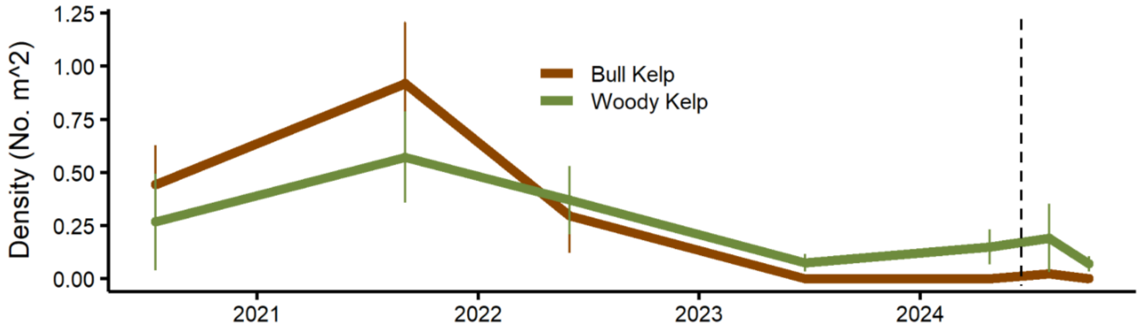


Fig. 12. Long-term ecosystem monitoring data showing brown macroalgae mean density ± SE 2020-2024 at Big River site. Dashed line represents the restoration start date (June 2024).

Targeted Surveys at Kelp Edges

These preliminary results describe location-specific responses to urchin harvest at the kelp edges where the "protect and expand" approach was deployed at Big River. Both subtidal and aerial datasets were used to describe these results. The following figures illustrate the changes in indicator species densities observed before and after purple urchin removal in these areas in year 1. These are preliminary figures and results and require further visualizations and analysis. All analyses, unless otherwise stated, are nonparametric t-tests.

Purple and Red Urchins

These time periods correspond to surveys conducted before and after the initiation of purple urchin removals in the northern kelp margin sites. Interestingly, we observed significantly more purple urchins after the removal efforts began ($p<0.005$; **Fig. 13a**). One possible explanation for this increase is that small recruits (<1 cm), while initially cryptic, could have become increasingly noticeable as they proliferated throughout the field season. Additionally, the rise in observed counts could stem from divers becoming more adept at identifying these smaller individuals over time. Alternatively, the increase might be attributed to a large-scale encroachment of purple urchins into the area, underscoring the critical need for continued grazer suppression efforts. In contrast, there was no significant change in red urchin densities between the two time periods (**Fig. 13b**).

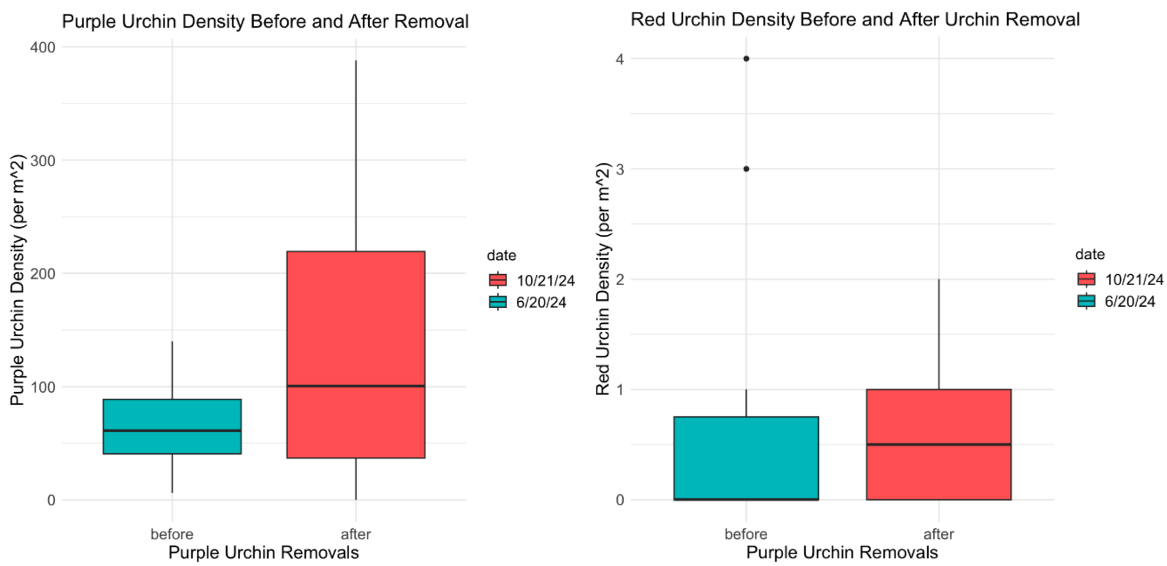


Fig. 13. Mean purple (13a) and red (13b) urchin densities at the kelp margin before and after concentrated urchin removals.

Abalone and Sea Stars

We observed consistently low densities of abalone (**Fig. 14a**) and sea stars (**Fig. 14b**) throughout the study, with no significant changes observed before or after the purple urchin removals.

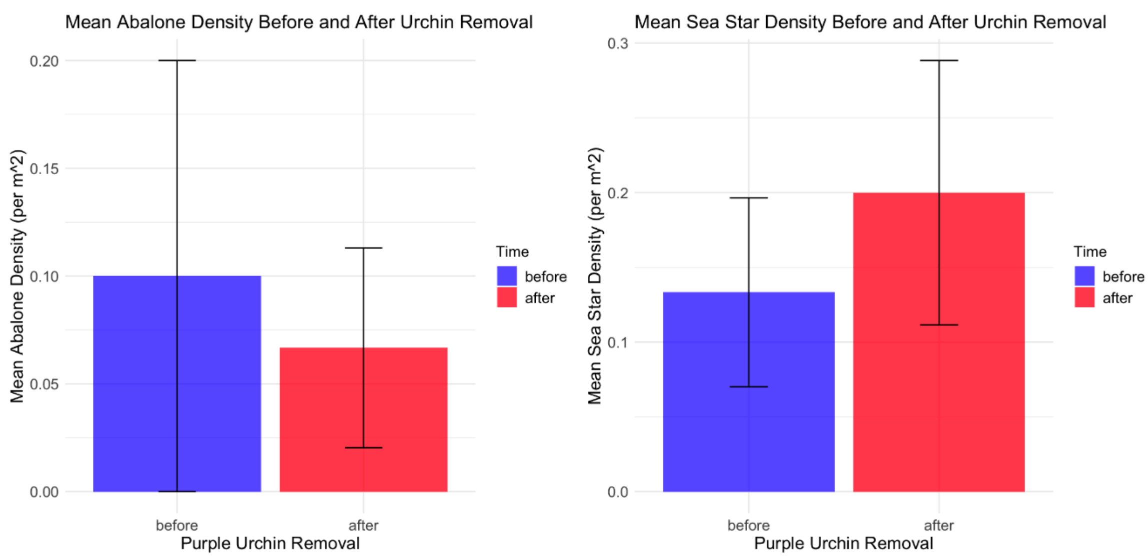
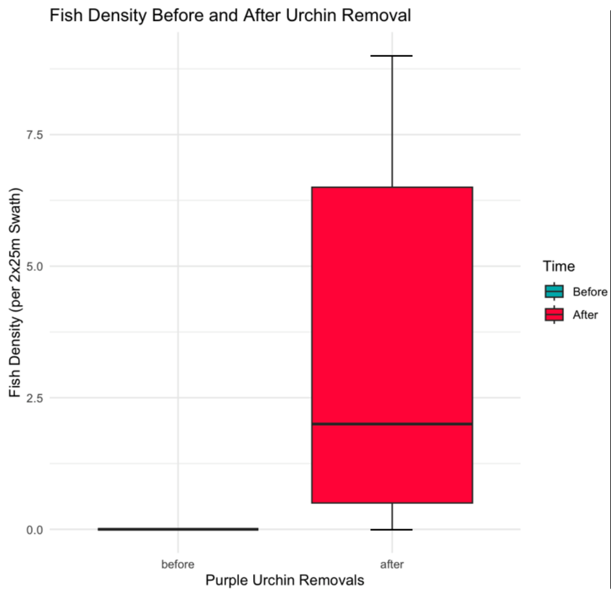


Fig. 14. Mean abalone (14a) and sea star (14b) densities at the kelp margin before and after concentrated urchin removals.

Fish

We observed a significant increase in fish abundance at the kelp margin following the initiation of purple urchin removals (**Fig. 15**). This kelp growth and presence coincides with recruitment season. Fish species observed in kelp margin include 7 species of young – of – the -year rockfish (Black, Blue, Kelp, Gopher, Black and Yellow, Boccaccio, and Copper) and adult kelp greenlings, lingcod, cabezon, wolf eel, black perch, striped perch, among others.



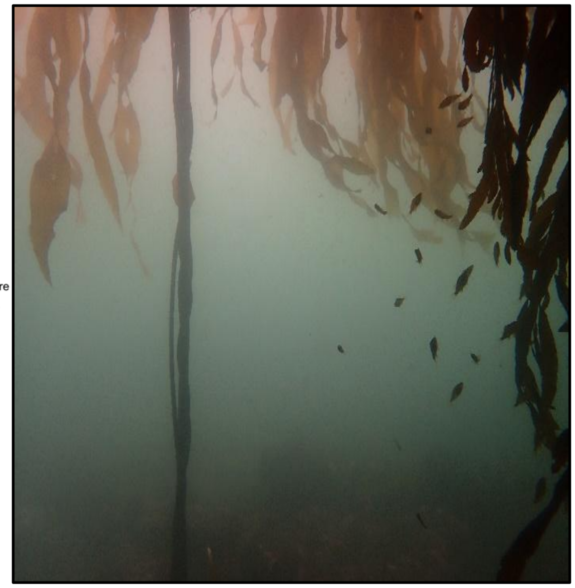


Fig. 15. Fish densities at the kelp margin before and after urchin removals (left). Young-of-the-year rockfish (Kelp-Gopher-Black and Yellow complex) in kelp margin and newly created habitat following grazer suppression (right). Photo by Tristin Anoush McHugh.

Laminariales

When we assessed bull kelp density at the margin, we documented the presence of the different life stages. We observed Laminariales (an Order of brown alga that includes all of the kelps) recruits, which refers to kelp recruitment that could not be clearly identified as bull kelp. Although there was no statistical difference between the time points—likely due to few kelp recruits observed—a positive trend was apparent. We only observed Laminariales recruits during the later time period, after purple urchin removals had been initiated, despite higher overall purple urchin densities within the margin (**Fig. 16**). This trend might also be influenced by the natural life history phases of bull kelp.

While we did not detect any significant differences, we further visualized the trend plotting Laminariales recruit densities against purple urchin densities. Although there were only two sections with Laminariales recruits, those sections correlated to lower purple urchin densities (**Fig. 17**). These findings emphasize the importance of reducing urchin densities through continued grazer suppression efforts.

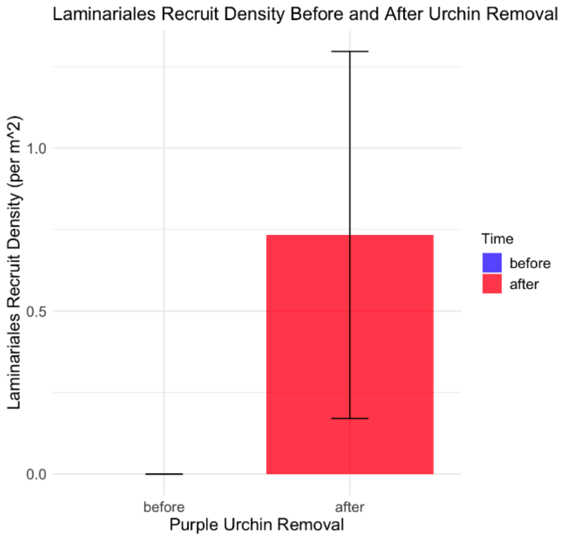


Fig. 16. Mean Laminariales recruitment densities at the kelp margin before and after concentrated urchin removals (left). Laminariales recruits emerging on rocks at kelp edge 1.5 months following urchin harvest (note: purple urchins exhibiting passive behavior) (right).

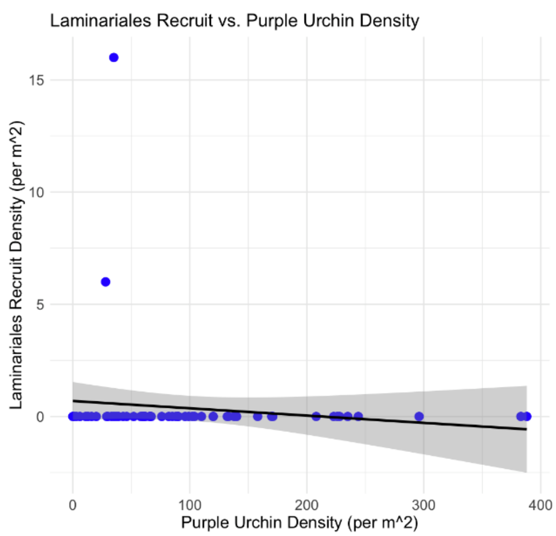


Fig. 17. Laminariales recruit density by purple urchin density within the kelp margin.

Bull Kelp

In addition to the Laminariales recruits, we also observed adult bull kelp at the kelp margin. We saw no significant differences between bull kelp density between the time periods when observing this edge subtidally (**Fig. 18**). It is important to note that any differences in adult bull kelp due to grazer suppression would most likely be visible in the following 2025 field season reiterating that continued surveys in this area are necessary. Additionally, our efforts to suppress grazers did protect and expand remaining forests at Big River as can be observed in the aerial kelp canopy imagery (**Fig. 19**). From 2023 to 2024 drone surveys, a 172% increase was measured in kelp canopy coverage. Additionally, bull kelp that emerged in areas post-urchin harvest were observed to grow from juvenile to reproductive adult in under two months (**Fig. 20**).

Fig. 18. Mean bull kelp densities at the kelp margin before and after concentrated urchin removals (right). Diver swimming through recently emerged bull kelp at the kelp edge two months after initial urchin harvest (right). Photo by Tristin Anoush McHugh.

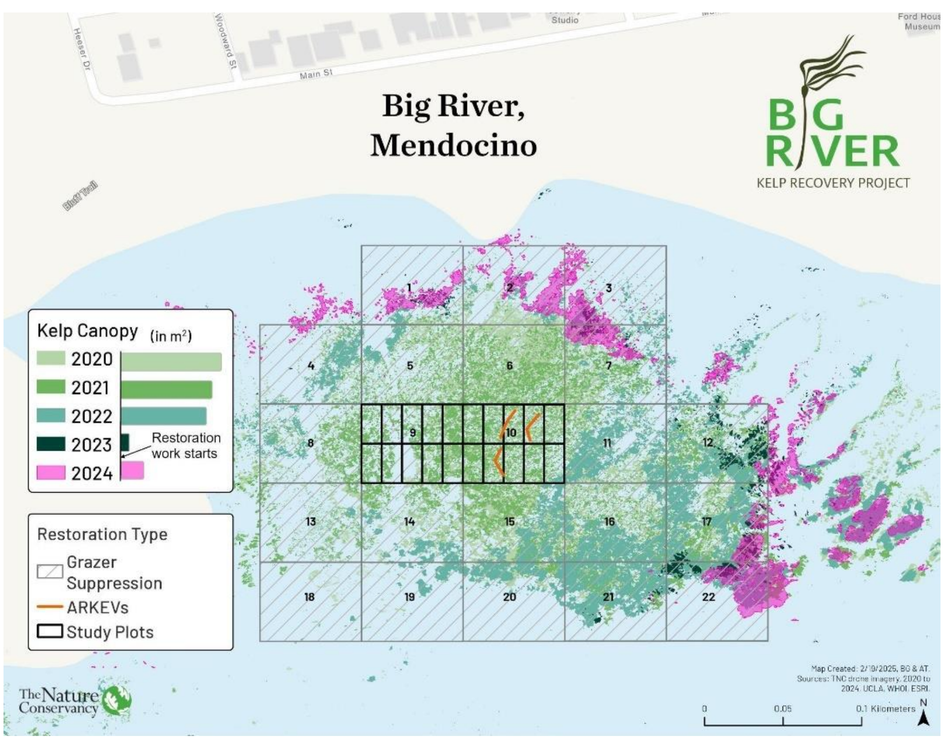


Fig. 19. Site map for kelp restoration efforts at Big River, Mendocino modified from previous figure to include Fall 2024 kelp canopy information. Kelp canopy area is designated by color. Kelp canopy was measured at 13,683m^2 in 2020, 12,348m^2 in 2021, 11,672m^2 in 2022, 1,211m^2 in 2023, and 3,299m^2 in 2024. Kelp enhancement activities occurred in blocks 9 and 10, and ARKEV units are designated by orange lines.

Fig. 20. Diver pointing to juvenile kelp (left) emerging 2 months following urchin harvest, and sorus tissue from a reproductive kelp (right) from kelp edge 3 months following urchin harvest.

Dockside Monitoring

Of urchins landed for restoration (**Table 2**) over 2,400 urchins were analyzed dockside at processor facilities in Noyo Harbor to characterize urchin size frequency, morphometrics, disease presence, and gut content. A preliminary analysis of urchin morphometrics generally showed that urchins had a higher gonad weight at test diameter relationship when kelp was present than in those collected from areas devoid of kelp canopies (**Fig. 21**). While larger mean urchin test diameters typically coincide with healthy kelp forests due to increased food availability, we found no relationship in test diameter size to kelp canopy coverage at the site, nor among blocks (**Fig. 22**). All data was promptly shared with the CSUC as it was collected and analyzed. This data was especially useful throughout 2024 to inform adaptive management of the project and further identify opportunities for strategic harvest for food and non-food uses of urchins. For example, in the food market, purple urchin test size needs to be $\geq$ 5.72 cm (2.25 in.) so that the urchin can be processed with ease and hold large enough pieces of uni to create profit (whereas uni is more efficiently processed from red sea urchins, which need to be $\geq$ 8.89cm (3.5 in.)). In terms of healthy gonad weight ratios, roughly three purple urchins equal one red sea urchin. The same harvest size for purple sea urchins is desired for urchin ranching.

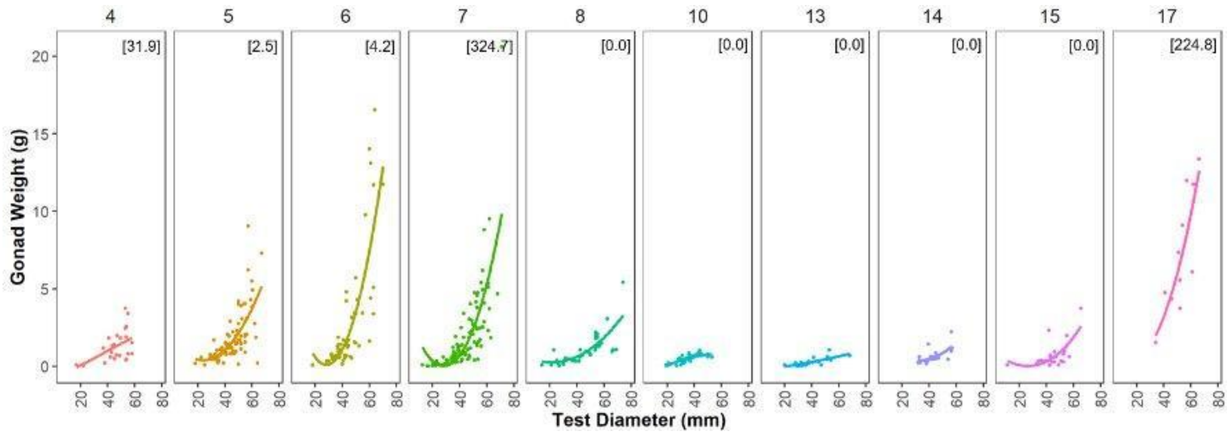


Fig. 21. The relationship between gonad weight and test diameter size per block of purple urchins collected June-September 2024. Brackets [ ] signify September 2024 kelp surface area (m^2). Blocks with canopy presence generally had a higher gonad weight at test diameter relationship than those devoid of kelp canopies.

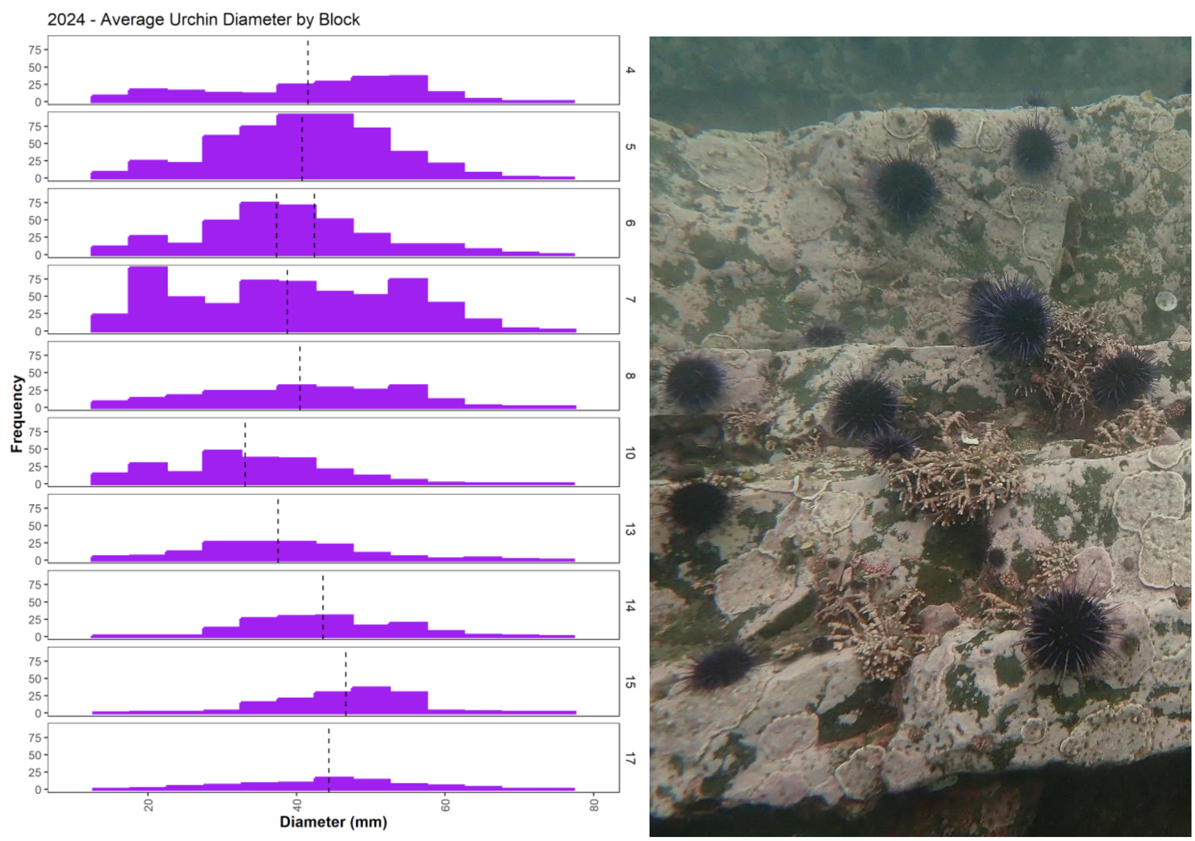


Fig. 22. Purple urchin test diameter (mm) size distribution for urchins collected between June-September 2024 (left). Purple urchins at Big River demonstrating a range of sizes (right). Photo by Tristin Anoush McHugh.

Discussion and Outcomes

Assessing the response of the kelp forest community to urchin harvest will take another year and more analysis to articulate. We conducted subtidal and aerial monitoring surveys in addition to tracking urchin harvester effort and pounds of urchin removed across the two sites to better understand how urchin harvest would influence kelp forest recovery.

At Albion, a total of 3 tons of purple urchin were harvested from the targeted 1-acre location during hand harvest conducted approximately twice a month. Ecosystem monitoring showed a slight increase in urchin densities in 2024 in the wider area of the cove, likely driven by an increase in densities surrounding the targeted 1-acre plot where removals had ceased. Anecdotally, drift algae was observed at Albion and changes in urchin behavioral responses (aggregation on drift or passive feeding) might affect their distribution and could influence new kelp growth even with elevated urchin densities. This observation helps challenge the preconceived notion of 2 urchin/m^2 being a target threshold to allow for kelp recovery.

At Big River in 2024, we sought to try a new approach to tackle a 5-acre area; we spatially designed the site to allow us to visualize effort (lbs urchin harvested and number of days/block) and strategically focused direct urchin harvest to the kelp edges. In year 1, 24 tons of purple sea urchin were harvested throughout the site, while predominantly focusing on kelp edges. Long-term ecosystem monitoring surveys detected a decrease of purple urchin from 10.4 ± 2.7 urchins/m^2 to 3.3 ± 2.2 urchins/m^2. Further, efforts to target the kelp edge allowed for the protection and expansion of remnant kelp forests (**Fig. 19**). Targeted grazer suppression likely contributed to a 172% increase in kelp forest canopy cover at the Big River location that was in peril from complete decimation the year prior (**Fig. 19**). By focusing harvest on kelp edges, we were able to alleviate pressure and protect extant kelp patches further allowing them to stabilize and expand. Bull kelp was observed to be reproductive at kelp edges likely releasing trillions of spores into the environment.

Prior to bull kelp emerging at kelp edges, we observed "primary succession" of red, green, and brown opportunistic seaweeds (**Fig. 23**). For example, in Block 4 a variety of seaweeds emerged as early as one month following urchin harvest (video: [pre-urchin removal]() and [1 month post urchin removal]()). Consistent visits to the kelp edge and photo evidence allowed us to capture the succession of primary producers in the forest and further elevate these critical microhabitats as biodiversity hotspots beyond the canopy-forming bull kelp (**Fig. 20**). Even in these early stages of restoration, stabilizing these kelp edges has proven critical for maintaining biodiversity of various indicator species, including invertebrate and fish complexes within the kelp margin.

Importantly, although we saw some year 1 successes in reducing urchin densities sitewide (**Fig. 9**) and some kelp canopy protection and expansion along the kelp edges (**Fig. 19**), we must emphasize that areas further away from extant kelp struggled to recover even with urchin harvest. Ongoing monitoring will be necessary to understand potential encroachment which may have led to increased purple urchin counts after removals have been initiated, as well as to determine how this year's restoration efforts may impact these areas. The areas that responded best to urchin harvest were those within close proximity to an extant kelp edge (~20m) as it is suspected that spillover spores and detrital material curbed urchin from actively consuming new kelp. In referencing the kelp canopy map (**Fig. 19**), the centroid of kelp loss is at the center of the site, and furthest from kelp patches. As such, our team deployed our first year of kelp enhancement efforts (outplanting and drift) to accelerate kelp recovery, and these efforts are later described in the "Kelp Enhancement".

Fig. 23. Primary succession of red and green algae one month following targeted urchin harvest at the kelp edges.

Objective 1b

Kelp Enhancement

In 2024, our team focused on accelerating vegetative recovery at Albion and Big River. This study encompassed both land and sea-based activities, including on-land aquaculture and outplanting. Our approach to conduct kelp enhancement for restoration included the following activities:

1. Aquaculture: Sustaining multiple cohorts of bull kelp year-round via "tumble culture" at on-land facilities, for both Albion and Big River and at various life stages.
2. Outplanting:
    a. *ARKEVs***:** Utilizing aquaculture-derived juvenile sporophytes, by splicing them into novel ARKEV (Array to Recovery Kelp Ecosystem Vegetation) modules, and deploying them at study locations. These efforts were developed to create year 1 kelp canopy habitat while allowing these outplanted individuals to reach reproductive capacity and release spores into the environment.
    b. *Drift:* Conducting studies to enhance drift utilizing aquaculture derived kelp biomass. These efforts were aimed at satiating urchins and deterring them from consuming new kelp recruits, thereby promoting a sustainable kelp ecosystem.

Methods

This section describes the methodological approach to conducting and understanding the outcomes of kelp enhancement for kelp forest restoration in three sections: 1) Aquaculture, 2) ARKEV (outplanting), and 3) Drift (outplanting). This study encompassed both land and sea-based activities, including on-land aquaculture and outplanting *in situ*. All techniques were tested at Albion before implementing the kelp enhancement activities at Big River due to permitting delays.

Aquaculture

Over the last year, our team maintained multiple generations of bull kelp at all life history stages from Albion and Big River in Mendocino, California for both short and long-term use at both the shore lab and the main lab facilities at Moss Landing Marine Laboratories (MLML). At the shore lab facility, we maintained multiple Albion soral bank cultures in 600-gallon tanks. We utilized smaller

40-gallon tanks to grow out multiple cohorts of F2 juvenile sporophytes for splicing onto the ARKEV modules. Pilot studies evaluating the development of spliced sporophytes into twisted lines were conducted in 100-gallon trough tanks.

In the MLML aquarium room, we modified two water tables as a semi- recirculating system with filtered, chilled seawater and full spectrum LED strip lights with a range of intensities from ~20-100 umol (**Fig. 24**). We used the table with side mounted lights to expand the whole sporophyte tumble culture capacity using 4 modified 15 L carboys and the top-lit table for experimentation as well as expanding the space available for inoculations. The top-lit table was initially covered with cleaned substrates and sea urchin tests and then inoculated to grow out sporophytes for the first round of ARKEV kelps. Crushed sea urchin tests were used as a potential novel substrate for kelp recruitment and a potential way to recycle material from urchin harvest for further restoration efforts. We also began a pilot study investigating the effects of light and nutrients on microscopic stages. Utilizing our findings, we would be able to define more precise protocols to cultivate microscopic stages at specific light and nutrient concentrations for either arresting development or achieving rapid growth to macroscopic stages. To this end, red and white light cultures were maintained for gametophyte and small sporophyte cultures. Small petri dish cultures were maintained in incubators in the cold room to establish a bank of microscopic stages that could be readily available for grow-out and experimentation.

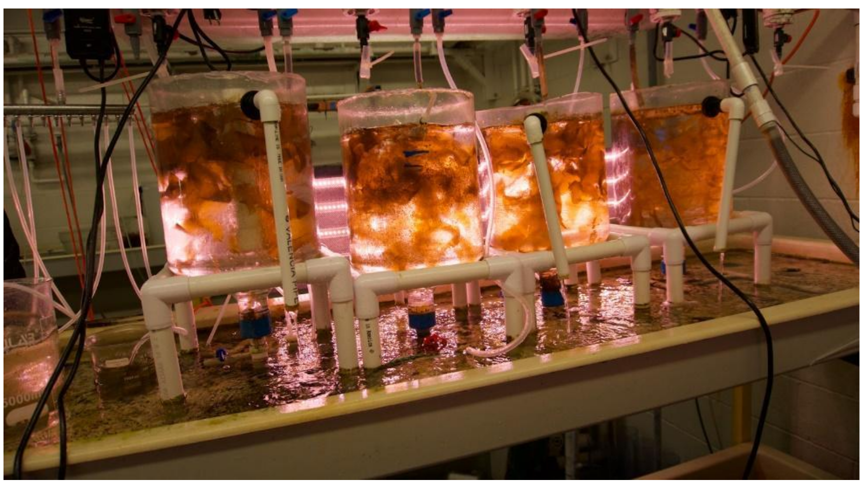


Fig. 24. Tumble culture of juvenile bull kelp in the aquarium room.

On September 20, 2024, we established cultures harvested from the reproductive kelp on the Albion ARKEV pilot deployments. On October 21, 2024, we collected and isolated cultures from reproductive kelp on the Big River ARKEV pilot deployments. We used Big River spores to inoculate 2 new 135 L tanks that were outfitted with adjustable spectrum core-lit lights that were fabricated in-house (**Fig. 25**). We were also able to inoculate a set of twine cultures with Big River spores to be grown-out at the Sunken Seaweeds farm in Humboldt for use as drift kelp deployments. We also isolated Albion ARKEV spores to establish cultures for experimentation and seed bank stock for future grow out. Additionally, we expanded into six 300-gallon tanks and conducted a pilot study comparing growth of tumble-cultured bull kelp crowns versus individual blades (**Fig. 25**).

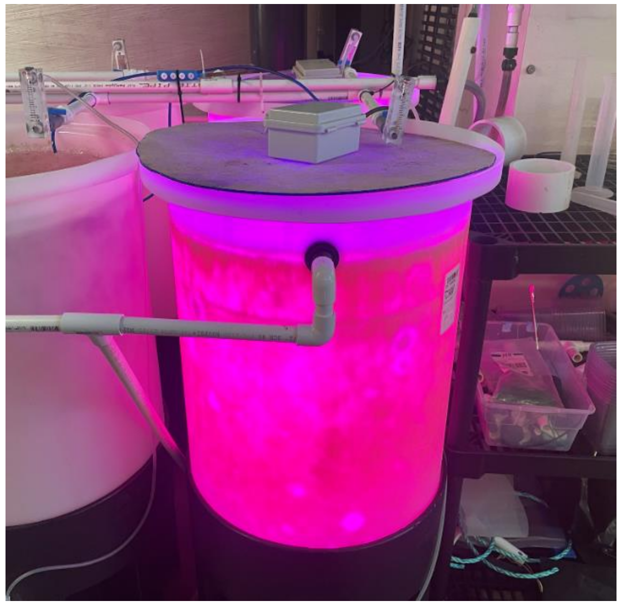


Fig. 25. Core-lit tumble culture with adjustable lights.

Tumbling crowns have historically been a means to complete the bull kelp life history and define distinct individuals for harvesting sori to outplant or establish new cultures. Needing to increase kelp biomass production for both drift deployments and soral outplants, we hypothesized that tumbling blades would be more space efficient than tumbling crowns, as crowns grow entangled with each other at larger sizes. After determining that individual blades grew significantly faster than blades attached to crowned kelp (**Fig. 26**), we conducted an additional pilot study investigating the effects of light levels on vegetative growth and soral production using single blade tumble culture. Understanding what conditions promote or inhibit soral production would allow us to have distinct tanks for either vegetative or reproductive kelp biomass. In addition, in 2024, we purchased and installed four 1000-gallon tanks which were installed at the shore lab facility to increase the capacity for growing bull kelp biomass, primarily for the purpose of drift enhancement (**Fig. 27**). We fabricated each tank for bottom-supplied air using the system-wide air supply, flow through sand-filtered seawater, and partially submerged the tanks in the ground for accessibility.

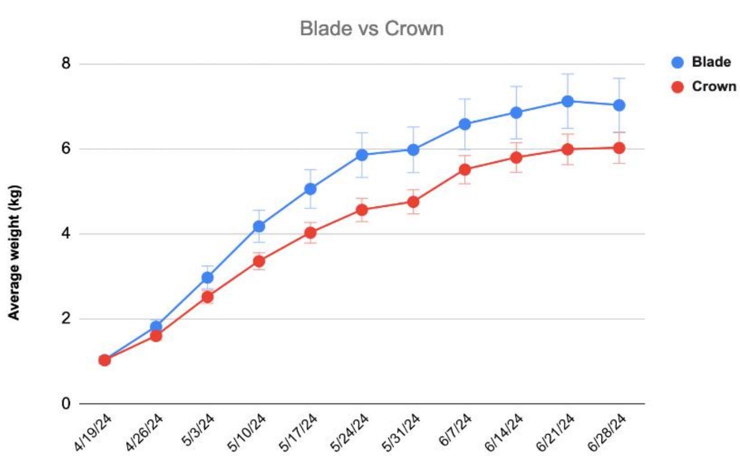


Fig. 26. Preliminary figure showing average change in biomass (weight in kg) of blades vs. crowns over time.

Fig. 27. New 1000-gallon bull kelp tanks for drift enhancement production at Moss Landing Marine Laboratories.

Outplanting

ARKEV (Array to Recover Kelp Ecosystem Vegetation)

Trial 1 - Albion Cove

Due to initial permitting limitations the deployment of prototype ARKEVs with cinderblock bases were not possible (see permitting timeline section, **Fig. 28**). We deployed the first set of ARKEV pilot modules (n=6 type A, **Fig. 28**) at Albion on 04/29/2024 using the existing eye bolt infrastructure left over from previous field seasons. The shackles at the bases of the ARKEVs were connected to two eye bolts that were each ~2.5 m away from the ARKEV. The first set ARKEV modules had two sets of 1 m lines each with 8-9 individuals for a total of 16-18 kelps per module (**Fig. 29**). Each module contained a line with kelp that was spliced in the lab 2 weeks prior to deployment along with a line of kelp that were spliced on the dock immediately prior to deployment.

We transported pre-spliced lines either between seawater-soaked towels or in sealed bags with seawater to understand which was more effective for minimizing transport-induced mortality. Both were transported in coolers with gel ice to keep cool. Free floating sporophytes that were spliced on the dock prior to deployment were kept in a sealed bag with seawater. We tagged all the spliced lines with numbered and colored bird bands to help identify line type, splice type (pre-spliced versus dock spliced), along with the transport method. Due to seizing wire and eye bolt failure, 4 of the initial 6 ARKEV modules were lost after two months, rendering the results of the transport method pilot inconclusive, however, dock-spliced individuals survived and grew rapidly. A good portion of the materials from the two lost ARKEVs were recovered by local-based TNC partners as they washed to shore.

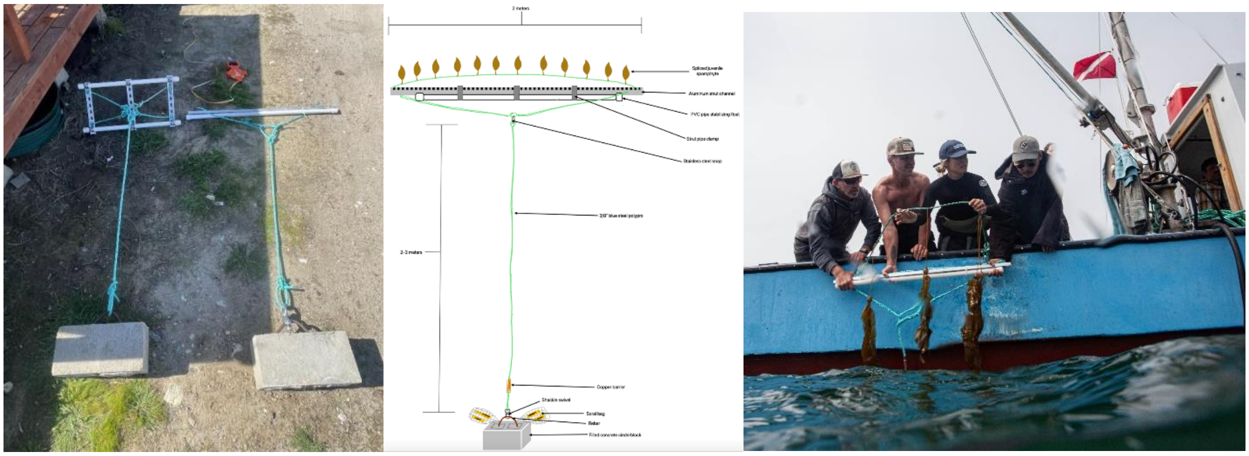


Fig. 28. Examples of two ARKEV module designs: Left- ARKEV module prototype A. Right- ARKEV module prototype B (left). Example prototype diagram of ARKEV units deployed (note: no soral bags used in 2024 (middle)). Project team dropping deploying ARKEV unit with splice sporophytes from boat (right). Photos by: Bennett Bugbee (left), Andrew Kim (middle), and Abbey Dias (right).

Fig. 29. Spliced kelp on a line ready for outplanting to an ARKEV module. Photos by: Bennett Bugbee

Trial 2 - Albion Cove

We deployed the second set of ARKEV pilot modules (n=6 type B, **Fig. 28**) at Albion on May 24, 2024 utilizing a single line of 7-8 individuals all of which were spliced immediately prior to outplanting. Modules were initially outplanted using the same methodology as the first set of ARKEVs using two lengths of ~3 m line to connect the shackle to two eye bolts ~2.5 m either side of the ARKEV. Shackles were reinforced using seizing wire and zip ties. On June 19, 2024, our team conducted a reconnaissance dive to check on ARKEVs deployed three weeks prior. To account for lost individuals on the second set of ARKEVs, due to warm water and poor growing conditions, we replenished the sporophytes via SCUBA.

Trial 3 - Big River

Despite significant challenges in permitting (see permitting timeline section in "Challenges") and subsequently holding and maintaining sporophytes in a lab culture setting longer than ideally anticipated, on July 18, 2024 we were able to scale outplanting efforts from Albion to Big River. Our team was able to deploy 9 ARKEV modules (type B, **Fig. 28**) directly off F/V Cindy Lynn, working with commercial sea urchin diver and co-PI Grant Downie, with no modifications to the design other than using an 80 lb concrete-urchin cinderblock as a weighted base (versus the eye-bolt shackle used in Albion). The cinder block allowed for easy deployment from the vessel as the ARKEVs were tactfully released from the starboard side of FV Cindy Lynn by four researchers (**Fig. 28**). Each module contained a single line of 3-4 sporophytes that were spliced on the boat immediately prior to deployment, and only 2 sporophytes across the 9 modules became dislodged during deployment. Due to warm water and poor growing conditions for juvenile kelps in mid-July and grazing/decorating by kelp crabs that reduced survivorship, sporophytes were replenished twice thereafter at Big River by splicing in new individuals via SCUBA on August 14 and August 22, 2024.

Drift Enhancement

Drift enhancement outplanting activities were first implemented at Albion on July 9, 2024, at both the restoration and control areas using Albion bull kelp crowns grown at the Moss Landing Marine Laboratories shore lab facility. We combined drift deployments with a grazer assay bar containing pre-weighed sections of lab grown Albion bull kelp blade tissue, which was deployed for 24 hours, to aid in quantifying grazer consumption rates with and without the presence of drift kelp (**Fig. 30**). Six grazer assay bars were deployed at the restoration and control areas respectively, half of which were deployed with 3 kg of non-reproductive bull kelp drift sourced from Moss Landing Marine Laboratories Albion soral bank tanks. After 24 hours, we retrieved the grazer assay bars and weighed the remaining bull kelp tissue. The second drift enhancement pilot experiment was conducted at Big River on August 20, 2024. We deployed three distinct 20 kg drift supplements directly under ARKEV units 3, 6, and 9 representing the northwestern, southern, and northeastern most ARKEV units at the site. Non-reproductive bull kelp drift was again sourced from Moss Landing Marine Laboratories Albion soral bank tanks. We deployed grazer assay bars (n=9) next to each ARKEV unit pairing three with the 20 kg drift and six without drift at increasing distances from a deployed patch of drift. After 24 hours, we retrieved the grazer assay bars and weighed remaining kelp to quantify grazing.

Additionally, we deployed two rounds of GoPro camera traps set on a time lapse capturing one still image every 30 seconds for about 1.5-2 hours or until battery ran out, at each drift deployment to capture grazer movement behavior in response to the drift supplement. This footage has yet to be analyzed.

Fig. 30. Example of a grazing assay bar with pre-weighed kelp blades at Albion (left) and Big River (right). Photos by: Bennett Bugbee and Tristin Anoush McHugh

Results and Analysis

Here we describe the results and analysis of kelp enhancement outplanting activities via ARKEV and Drift using Aquaculture derived material and the associated fish recruitment.

Outplanting

ARKEV

At both Big River and Albion, ARKEVs were ultimately successful at growing kelp from ~10cm sporophytes to reproductive adults.

At Albion, ARKEV units from the first deployment had kelp survive for 4-5 months of which kelp was reproductive for 2-3 of those months (**Fig. 31**). No units were lost from the second set of ARKEV deployments (type B), however kelp growth and survivorship was lower than the early season deployments, requiring a kelp supplementation via SCUBA. No units were lost once ARKEVs were moved onto concrete bases and modules showed no signs of movement for the duration of the outplanting season. We noticed a strong pulse of fish recruitment with early introduction of the ARKEVs and spliced kelp which prompted additional surveys to attempt to quantify fish abundance associated with the ARKEV modules. Not including the ARKEVs lost to mechanical failure, we had approximately 40% survivorship of spliced sporophytes at Albion after two months (**Fig. 32a**). At the time of harvest, 14 individuals remained on two initial ARKEVs and had been reproducing on site for at least 3 months.

Spliced sporophyte stipes at Albion grew from an average 8.5 +/- 0.59 (mean +/- SE hereinafter) cm at the time of outplanting to 176.6 +/- 22.4 cm in two months, at which individuals were reproductive (**Fig. 32b**). After we moved Albion ARKEVs to cinderblocks, we observed further stipe growth to 387.9 +/- 33.1 cm at the time of harvest (**Fig. 32b-33**). The longest stipe length was 465 cm (**Fig. 32b**). Each individual had on average 54.1 +/- 8.8 blades of which 26.8 +/- 4.8 bore sori. The maximum number of blades and reproductive blades across individuals was 99 and 56 respectively. Based on an individual synchronously releasing all mature sori every 4-6 days, we estimate that, on average, an individual is releasing 133.9 to 200.9 sori per month.
To quantify fertility, we conducted spore releases for all reproductive individuals harvested from Albion on September 9, 2024. Three sori were randomly selected from each reproductive individual

and had a 1 cm^2 section of tissue cut out and placed in autoclaved seawater for two hours, each in a distinct beaker for spore release. Spore densities were quantified at one hour and two hours post release and spore release densities ranged from 20,000 to 1,250,000 spores per ml after 1 hour. These estimates are highly preliminary, suggesting an average of ~150,000 spores released per cm^2 of soral area. Given an estimated average of 72cm^2 per sori, we estimate ~$1.1x10^7$ spores on average per sorus when induced to release following desiccation. When combined with the average number of sori per individual at harvest (~30 sori) we can estimate an average of $3.2x10^8$ spores released per individual every ~5 days, meaning the 14 remaining individuals were releasing an estimated ~4.5 trillion spores every 5 days. Given the ~90 days the kelp spent being reproductive, we can estimate a total of 82 trillion spores released this year across the site. Further analyses are yet to be conducted but will continue over the course of this study.

Visualizing ARKEV performance over time:

- Initial ARKEV deployment: https://youtu.be/xzxZeYWknlc
- 1 month post outplanting: https://youtu.be/a4Z08HWC90k
- 1.5 months post outplanting: https://youtu.be/BpVrySz_tjY
- 2.5 months post outplanting: https://youtu.be/lGO-0m3l5Xw

Fig. 31. ARKEV images at Albion on May 24, 2024 (Photos by: Patrick Webster // @underwaterpat).

At Big River, most ARKEV modules structurally performed well in the field, and we successfully retrieved all modules at the end of the season working with co-PI Downie. Due to the delays in outplanting and initial issues with grazers on the ARKEV modules, initial kelp survivorship was low, necessitating multiple kelp supplements via SCUBA to get individuals to survive and grow. Following the August 22, 2024, kelp supplement, we were able to see more ARKEV modules with kelp surviving and growing. Due to the temporally late success of kelp outplants at the site, only a few of the modules produced reproductive individuals prior to retrieval (2-3 months post-deployment).

Big River spliced sporophytes showed significantly lower survivorship compared to Albion due to the combined effects of increased ocean temperatures at the time of outplanting and a prolonged time spent in culture both emanating from previously described permitting delays (**Fig. 32a**). In addition, we observed increased grazing pressure at Big River including kelp crabs cutting the stipes of our spliced sporophytes. However, the sporophyte replenishment on August 22, 2024, showed increased survivorship following decreased ocean temperatures and individuals selected from a newer crop with 33% of those individuals surviving for the subsequent two-month outplanting period (**Fig. 32a**). At the time of harvest October 21, 2024, 9 individuals remained on site, 5 of which were reproductive.

In the two months following deployment, spliced sporophyte stipes grew from ~10 cm to 220.4 +/- 53 cm at which individuals were at or near the surface (**Fig. 32b)**. The largest individual grew to 525 cm total stipe length. The most blades and reproductive blades were borne by the same individual at 79 and 37 respectively. On average, Big River individuals produced 40.2 +/- 5 blades of which 11 +/- 4.5 were reproductive. Based on an individual synchronously releasing all mature sori every 4-6 days, we estimate that on average, individuals at Big River were releasing 55 to 82.5 sori per month. Quantification of fertility using spore releases was not performed for the Big River outplants.

Mature kelp on ARKEV at Big River Oct 21, 2024:

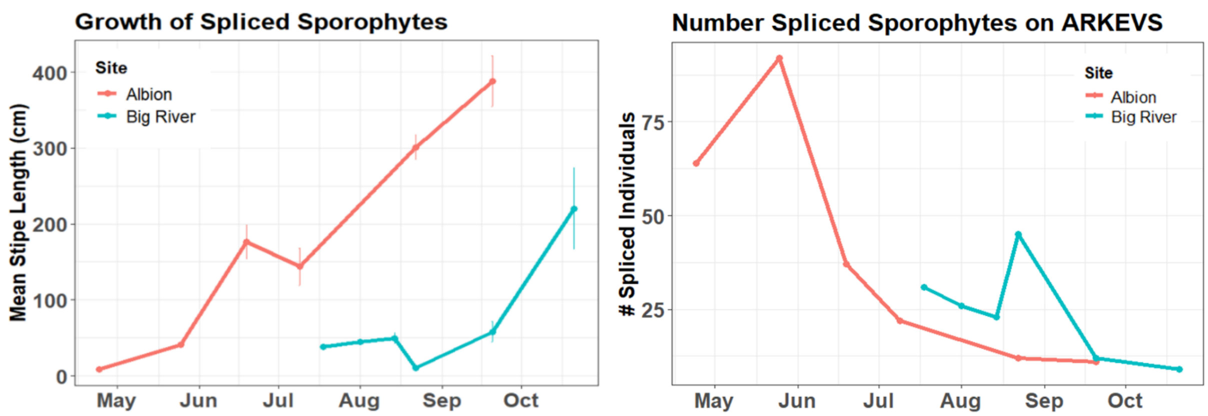


Fig. 32. Survivorship (a) and growth (b) of bull kelp on ARKEVs at Albion and Big River in 2024.

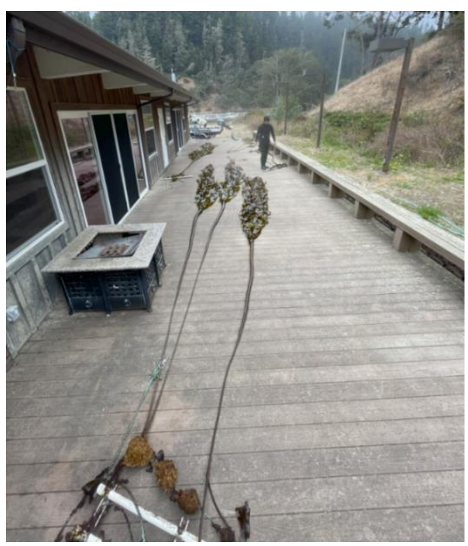


Fig. 33. Kelp growth on an ARKEV from Albion by late September 2024. Photo by: Bennett Bugbee

At Albion, there was a trend in increased fish abundance with the introduction of habitat via ARKEVs. Following an observed initial pulse of juvenile YOY rockfish, surveys were conducted to quantify fish abundance relative to the ARKEV units at Big River. The recruitment signal was not as strong as it was anecdotally at Albion, which is likely due to Albion ARKEVs being deployed earlier in the year when rockfish recruitment is generally higher. However, there was a trend of more fish observed within a 1 m radius around the Big River ARKEVs for the three months surveys were conducted (**Fig. 34**). Fish species observed close to the ARKEVs include a variety of rockfish species juvenile/adult blue rockfish (*Sebastes mystinus*), black rockfish (*Sebastes melanops*), olive rockfish (*Sebastes serranoides*), young of the year rockfish complexes (KGBC - kelp rockfish (*Sebastes atrovirens*), gopher rockfish (*Sebastes carnatus*), black/yellow rockfish (*Sebastes chrysomelas*), copper rockfish (*Sebastes caurinus*) and OYT - olive rockfish and yellowtail rockfish (*Sebastes flavidus*), and clingfish spp. Further experimentation is in preparation by project team (SSU Master's student) to disentangle whether the increased fish abundance is due to the introduction of kelp biomass, the structure of the ARKEV, or both.

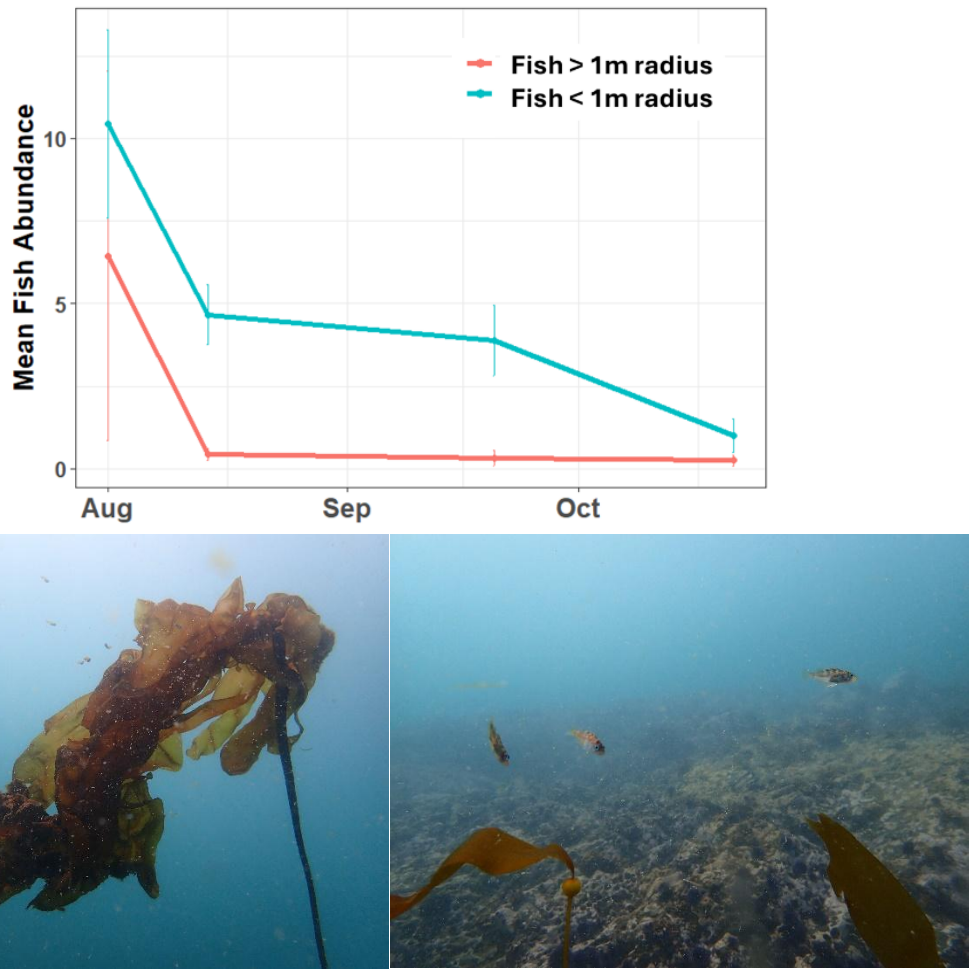


Fig. 34. Rockfish recruitment on and off ARKEV modules at Big River (top). YOY rockfish in kelp on ARKEV modules (bottom). Photos by: Tristin Anoush McHugh

Drift Enhancement

We observed a significant difference in the grazer assay kelp weight from the time of deployment to retrieval ($p<0.0001$), among drift treatments ($p<0.0001$), and the interaction of deployment time and drift treatments ($p<0.0001$). The addition of drift kelp, even in small quantities, significantly reduced kelp consumption on the grazing assays across a range of grazer densities. Initial pilot studies at the Albion control and restoration sites, utilizing 2 kg drift additions, saw approximately

4x decrease in kelp consumption on the grazer assay when paired with drift (**Fig. 35**). Grazers consumed approximately 8 kg of kelp on the assays when drift was absent, translating to 84-93% loss of kelp biomass. In the presence of drift, grazers consumed roughly 2 kg of kelp on the assay, approximately 20-30% of kelp biomass. We observed a similar pattern at Big River, where 100% of the grazer assay kelp was consumed when drift was absent, compared to only 29% when drift was present (**Fig. 35**). In addition, urchins appeared to be attracted to drift kelp additions within 5 meters of the deployment site (**Fig. 36a**) and large urchins (**Fig. 36b**), in particular, migrated to the deployment site in less than 24 hours to feed on drift kelp. These results suggest that drift enhancement effectively shifts or distracts sea urchin behavior for short periods (≤24 hours).

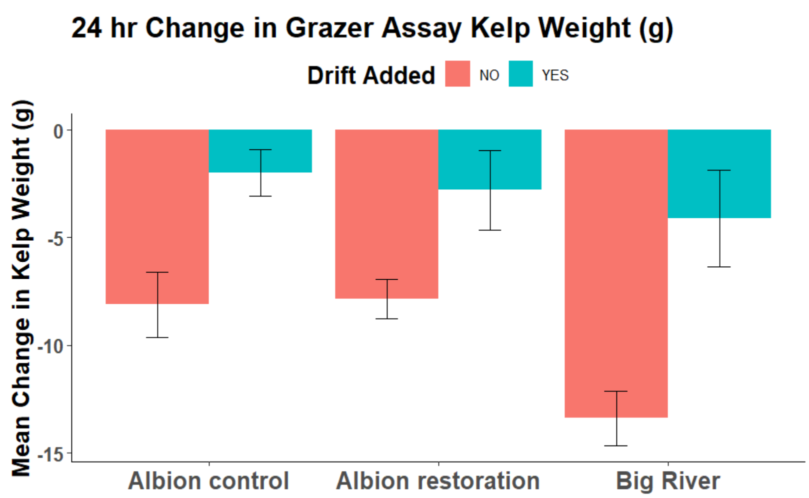


Fig. 35. Bull kelp consumption in grazing assays in the presence or absence of drift.

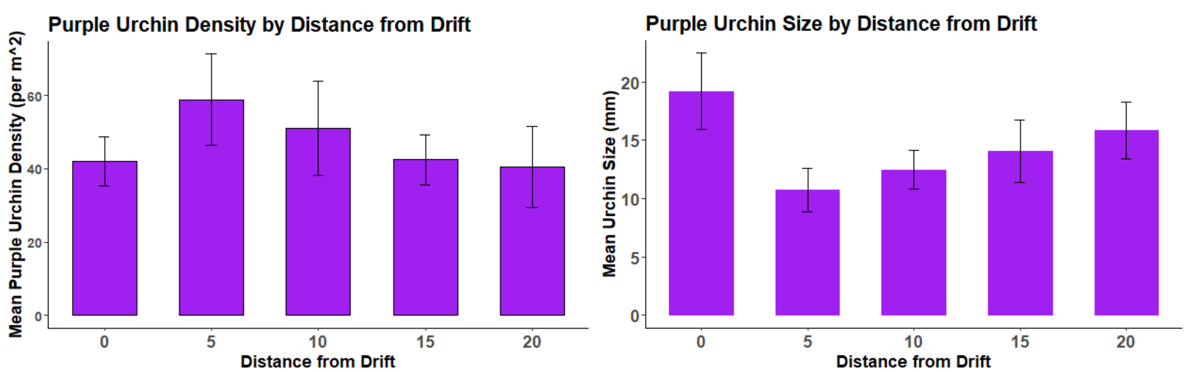


Fig. 36. Urchin density (a) and size at increasing distances from the drift kelp (b) deployment at Big River.

Discussion and Outcomes

ARKEV

The outplanting results at Albion and Big River suggest that outplanting earlier in the calendar year will facilitate increased survivorship and growth of kelp. At Albion, survivorship was predominantly affected by mechanical failure of modified ARKEV deployments due to permitting delays. However, favorable upwelling conditions typical of spring in the northeastern Pacific yielded substantial growth and rapid canopy formation. The subsequent months presented continuous spore output from surviving individuals until sporophytes were harvested. The later outplanting in the summer months at Big River substantiate the results from Albion as the majority of individuals outplanted in July and August did not persist due to elevated ocean temperatures. However, subsequent sporophyte replenishments following a reduction in ocean temperatures facilitated increased survivorship and a late season canopy formation. Unfortunately, only a few individuals became reproductive limiting the reproductive output of ARKEV sporophytes. This result suggests that temperature is a driving factor in initial ARKEV sporophyte survivorship, further highlighting the importance of outplanting early in the calendar year. In year 2 of this study (2025), we plan to deploy ARKEVs in April.

To summarize, the Albion ARKEVs demonstrated strong growth and reproduction potential despite initial mechanical failures, with spliced sporophytes achieving substantial stipe lengths, producing sori, and supporting increased fish abundance due to early deployment and favorable conditions. At Big River, ARKEVs faced challenges from delayed outplanting, elevated ocean temperatures, and grazing pressure, resulting in lower survivorship and comparatively lower reproductive output, though later replenishments showed improved performance under cooler conditions. Overall, the results of 2024 ARKEV pilots highlight the immediate benefit of splicing sporophytes as a restoration technique, bypassing highly susceptible microscopic stages, thus yielding rapid growth to canopy and reproductivity. In addition, emphasizing the importance of early-season deployment to maximize survivorship and growth, as well as reinforcing the need to address permitting delays and environmental challenges for long-term restoration will be instrumental to success.

Drift Enhancement

Adding detritus into the environment may be one tool used to satiate and transition urchins in a barren from active and destructive feeding to normal and passive feeding. This is an especially important concept to consider at a location where recent deforestation has taken place, and restoration is underway to harvest and transition urchin behavior. Observing the same response in grazer behavior between a recently deforested site (Big River), a long-standing barren (Albion control), and an area of active grazer suppression (Albion restoration) demonstrates that the urchins in these systems are still exhibiting active, voracious, and destructive grazing behavior. Next year, we have increased tank infrastructure and are hopeful to partner with a commercial bull kelp farm, Sunken Seaweed, to grow our seed stock and produce more biomass than we had available in 2024.

Conclusion: Year 1 Response to Restoration

In 2024 we conducted grazer suppression (commercial hand harvest) and kelp enhancement efforts (outplanting via ARKEV and drift) at Big River and Albion. The integration of on-land aquaculture, sea-based outplanting, and grazer suppression has shown promising results in accelerating vegetative recovery at Big River. Further studies are needed to optimize these methods and ensure long-term sustainability. In year 2, we plan to continue urchin harvest at kelp edges and the center of the site where the kelp enhancement outplants are. We also plan to deploy urchin traps to aggregate urchins and allow for urchin harvest to occur on days where divers may not get in the water due to low visibility or poor ocean conditions. Additionally, we plan to deploy more ARKEVs and drift algae to vegetate the system, while continuing various ecosystem monitoring methods to quantify response to restoration.

Objective 2

Objectives 2a and 2b

To understand kelp forest and red urchin fishery feedbacks to guide urchin harvest for guarding remnant forests (2a) and assess historical and future capacity for red urchin diver adaptation in response to the collapse of the red urchin fishery (2b), our efforts have been focused on obtaining access to essential data privately held by the California Department of Fish and Wildlife. To date, we have achieved the following steps:

1. CDFW has agreed to share key confidential datasets that will enable us to evaluate objectives 2a and 2b of the OPC-SeaGrant funded research
2. UC Davis and Monterey Bay Aquarium (MBA) initiated data security preparation following the protocols set by CDFW for receiving confidential data
3. UC Davis and Monterey Bay Aquarium established a contract agreement facilitating pass through of data from UCD to MBA
4. Monterey Bay Aquarium initiated internal data security protocols mirroring those of UCD, in preparation to receive data following transmission from CDFW to UCD

A final necessary step (before restricted data is shared) is for IT staff at UC Davis to affirm that data security controls required by CDFW are met (NIST 800-53). This affirmation has proven more difficult to achieve than originally expected. To date, this has led to a delay in working with the data of approximately 6 months. As of February 24, 2025, the draft security plan was sent to UC Davis' Chief Information Security Officer for their review. After data is transmitted from CDFW to UCD, UCD and MBA will coordinate data access and sharing under the already established MBA-UCD contract.

Objective 2c

For the last several years, TNC has been advancing ambitious work to identify market-based solutions that will dramatically reduce the cost of urchin removals for kelp restoration in California and incentivize harvest of this problematic and overabundant species. Purple urchins have been identified as an abundant resource for biominerals and compounds. Between Sonoma and Mendocino, there are 206 miles of coastline with over 1.5 billion pounds of urchin. While seafood applications for addressing the problem of overabundance of urchins and high cost of removals exist, not all urchins at a given restoration site can meet the minimum size requirements for urchin ranching for seafood. The development of urchin-based materials can offer an additional market-driver for commercial urchin divers to conduct a comprehensive and profitable harvest-facilitating kelp forest recovery.

With dockside data and urchin demographic information acquired from urchins landed for restoration, we have been working to create a framework to assess downstream economic opportunity for various market uses of purple urchins. With these data we hope to visualize economic opportunity as we categorize urchin by size: $\leq$ 5.72 cm (2.25 in.) diameter as non-food and $\geq$ 5.72 cm (2.25 in.) diameter as food. For example, using the size criteria above and the urchin demographic data from dockside monitoring, we aim to develop a framework that allows us to understand X% is of viable size for food markets and Y% for non-food markets at a given restoration site.

Non-food market development
Through an initial scoping of several possible applications of urchin shells as input into materials, Echino engineered marble stone was selected for further research. This is due to its high technology-readiness level, alignment with urchin removal targets, and market opportunity. Further studies were conducted to examine preliminary technical, economic, and environmental viability of urchin-based engineered marble.

Research has shown promise that an urchin-based marble engineered stone product could be supplied to architects and designers as a building material for the eco-friendly furniture and green building materials market in the construction industry. Until this time, no such uses have existed for non-food applications of purple sea urchins. Further research into purple sea urchin engineered marble composition, applications, and their performance could unlock the key to deploying market-based solutions for urchin harvest and kelp restoration. These demonstrate greater promise even than their seafood counterparts.

Opportunities in the blue economy within these market-based solutions support regional workforce development. Additionally, new innovations are being created for environmentally friendly, low-carbon materials in the green building materials industry. Over the last year, Primitives Biodesign has advanced prototypes to demonstrate the marketability of urchin-derived biomaterials, specifically for the luxury design market. At the same time, they have calculated the volume of urchin that could be absorbed by their product production, their target market capture, and the resulting impact on the urchin population.

For next steps in advancing this work, urchin-based products, such as biominerals and engineered stone materials, exploration must be taken closer to commercial scales. The next phases of this work will move product development towards the thousand-pound scale and increase conversion of urchin inputs from 2% to 17%. It will also uncover potential performance and processing discrepancies that arise from an increased processing scale that could impede on application success and adoption in the green construction industry.

Successful outcomes of this work will include increasing the conversion capability of restoration purple urchins into biominerals and engineered stone from the current 2% to at least 10%. An engineered marble sample, with a minimum size of 3' x 3', will be produced and examined, receiving stakeholder approval based on conventional industry standards. Additionally, material characterization data will show performance outcomes across all metrics, comparable to commercially available natural and engineered building materials. Based on these findings, a detailed technical roadmap will outline the viability of specific built environment use cases in the near, mid, and long term.

Food market development
At this moment, we are donating some of the food-grade sized purple urchin for urchin ranching pilot studies led by local partners in Noyo Harbor including California SeaGrant, the City of Fort Bragg and the Noyo Center for Marine Science.

Objective 3

Objective 3 aimed to ensure long-term kelp restoration success and stewardship by providing opportunities for the local community through experience and art. We provided internships for local divers to build diver workforce capacity and engaged groups that traditionally have not been exposed to these work opportunities (objective 3a). We also began developing a series of tangible and replicable art/science products and events to engage and communicate project goals and outcomes (objective 3b). Below we describe the work that was accomplished in year 1.

Objective 3a

Kelp Forest Restoration Internship

Through this award, we offered a paid internship opportunity with Reef Check, which supported three early-career individuals to gain invaluable experience through this collaborative restoration project. While this internship preferred those with SCUBA certifications, they were not required, allowing an increased diversity of applicants and focus on recruiting local talent. The team made the decision to allow for non-diving interns to engage local community members who expressed interest in restoration and be involved in activities that occur topside, in addition to those underwater activities exclusive only to divers. This was preferred over only hiring divers from outside of the community, as it allowed for the hiring of local residents which helped to strengthen local connection and visibility to kelp recovery efforts while building capacity where restoration is taking place.

Two of the 3 individuals hired were non-diving and one intern was a diver. The one diving intern is a local diver currently attending CalPoly Humboldt. She went through the annual Reef Check training course and assisted on multiple restoration surveys. The other two interns were not dive certified but were invaluable in both the collection of urchin morphometric data, as well as data entry. Both are from Fort Bragg, and despite having no dive experience, expressed that these intern experiences were transformative in their personal and professional development. All three interns actively participated in the daily activities of the restoration program alongside TNC's CSU COAST interns, resulting in a highly collaborative and organized internship program in Fort Bragg led by Annie Bauer-Civiello of Reef Check and lead PI.

In addition to these ongoing tasks during the field season, two interns took their engagement with restoration practice and research further. One is scheduled to obtain her Open Water scuba certification, and one was able to attend the Western Society of Naturalists (WSN) meeting in Portland, where she experienced how data collected during field work is presented to the scientific community to advance our understanding of restoration practices.

Looking ahead to next year's internships, we are hoping to continue offering internships to divers and non-diving community members, thereby offering the broadest opportunities for engagement to the local level in restoration activities.

Long-term Ecosystem Monitoring

Reef Check staff (2), volunteers (6) and intern (1) monitored Reef Check's long-term monitoring site at Big River (Portuguese Beach) and Albion seasonally in April, August, and October of 2024.

Results from this effort are described in Objective 1 as these data contributed to the contextualization of the subtidal environment of Big River and Albion. See Figures throughout.

Objective 3b

To reach the broader community and provide a gateway to our Objective 1 work, our team worked to develop multimedia products and events that showcased efforts to recover kelp. For Objective 3b, there are eight total products to complete by the end of this award. Below we describe the completed products following the conclusion of year 1.

North Coast KelpFest!

The first North Coast KelpFest! was held from mid-May to mid-June 2024, bringing art, science, food and film together to tell the story of kelp forests on California's north coast. Through a month-long series of events, communities from across Northern California were invited to the Mendocino coast to learn about and celebrate the ocean's forests and connect with coastal ecosystems and culture in a meaningful way. The combination of innovative art + science, ocean-oriented and kelp-inspired events hosted through KelpFest! engaged the hearts and minds of people of all ages and backgrounds– there was something for everyone. These events significantly contributed to the outreach and communication of our in-water kelp recovery work at Big River and Albion.

As part of objective 3b, we held a Kelp Demonstration Day where the Objective 1 project team (Reef Check, Sonoma State, Moss Landing, California Sea Urchin Commission and TNC) students and staff attended KelpFest! and presented its citizen science diving program and opportunities for engagement in kelp restoration during tabling events and during discussions with the public. To create a tangible experience, mock survey transects, face painting, ARKEV modules, and more were set up for visitors, both children and adults alike. In addition to the project team, other colleagues from the City of Fort Bragg, OPC, SeaGrant, Kashia Band of Pomo Indians, the Fort Ross Conservancy and MPA Collaborative Network participated as well. The KelpFest! Demo Day and our project was featured on PBS Terra with over 140,000 views to date, as well as in a number of other local media, providing tremendous visibility into our work.

Planning
Planning and execution of the inaugural KelpFest! event took place over a multi-month period involving several community leaders and organizations, led by the Above/Below directors as a part of the Big River Project team.

This included:
- Formation of Steering Committee which included: Mendocino Art Center, Noyo Center for Marine Science, Xa Kako Dile, Mendocino Film Festival, MendoParks, Visit Mendocino, Word of Mouth Magazine and Lemon Fresh Design
- Steering committee members participated in monthly meetings, subcommittee meetings for event planning, design and production of printed posters, postcards, flyers, magazine ads and website development
- Distribution of materials and promotions of month-long celebration of kelp on the North Coast of California as well as coordination of media outreach and social media promotions
- Coordination of the Opening Event for KelpFest! including food planning with local chefs integrating sustainable foods from the sea, speaker program planning, Tribal dancers, design

of event program, solicitation of donations from local wineries and breweries and an event photographer to document the opening event on May 18th

- ❖ Curation of the Kelp! Art Exhibit at the Mendocino Art Center and coordination of artists work on display. The art exhibit ran the entire month of KelpFest!
- ❖ Coordination of three art/science workshops related to the Kelp Recovery work at the Big River site, including fabric dying with urchins, ceramic glazes with urchin tests and cyanotype printing from seaweed specimens harvested locally
- ❖ Coordination with the Mendocino Film Festival for the Kelp! Film Program and panel discussion to follow.
- ❖ Coordination with the Noyo Marine Center Field Station on multiple science-oriented events including low tide walks, science socials, kelp presentations and speaker panels
- ❖ Coordination with the TNC project team on the Kelp Recovery Demonstration Day, and other organizations tabling at Big River Beach on May 26th
- ❖ Coordination with MAC board members and the City of Fort Bragg for volunteers to work events throughout KelpFest!
- ❖ Management of event participation through Eventbrite together with local community groups
- ❖ Solicitation of funding for promotions through the Community Foundation of Mendocino

Execution

- ❖ Final organization, coordination, and hosting of 16 individual art, science, food, and film events and workshops from May 18th –June 17th in Mendocino and Fort Bragg
- ❖ Final print production and distribution of posters, flyers, postcards and event programs.
- ❖ Media outreach, coordination, and interviews
- ❖ Coordination of event photography and media coverage
- ❖ Final Steering Committee wrap session post-festival to share lessons learned and discuss possible improvements for 2025 KelpFest!
- ❖ Final updates to the website with images from KelpFest!, press coverage, and website analytics
- ❖ Survey of event participants through Eventbrite
- ❖ Preparation of metrics and financial summary for KelpFest! events. Preparation of reports to funders for KelpFest! grants

Visual Record and Communications Design

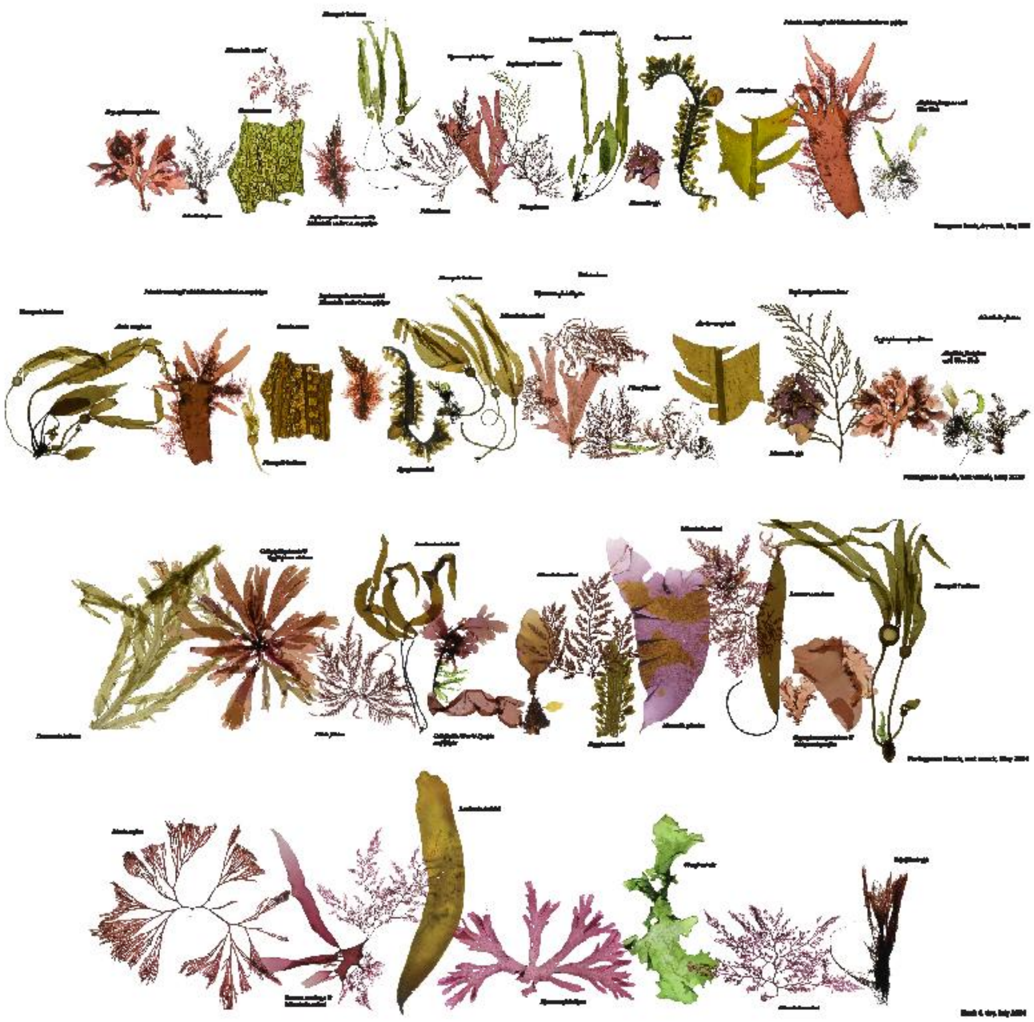
A visual record of seaweed biodiversity from the restoration site, together with the design of project communications, will make the process and outcomes of this kelp recovery work more accessible to more people. Outcomes from this first year include:

- ❖ Initial work on the visual record of Seaweed Biodiversity & Design including collection and scanning of seaweed specimens from Big River from April-June (Spring Record) (**Fig. 37-38**)
- ❖ Development of visual record of Seaweed Biodiversity & Urchin including collection and scanning of specimens from Recovery Site July-Sept (**Fig. 37-38**)
- ❖ Final scans and file processing of Visual Record including PDF files of six composite images or "posters" with identifiers plus 38-40 individual scans of individual specimens (**Fig. 37**)
- ❖ Completion of research and presentation of comparable community engagement campaigns for restoration projects to inform additional Community Engagement strategies for Big River Project

- ❖ Design of project branding and communication materials including naming & branding for Big River Kelp Recovery Project; design of the presentation & report template, and concepts for signage and merchandise
- ❖ Final design and production of project communications including Powerpoint template, Report template, Big River Project web page, and Style Guide
- ❖ Development of Big River team presentation to California Seaweed Festival in Humboldt Oct 18-20. Coordination with the team for production of final PPT content. Distribution of materials and presentation at Seaweed Festival
- ❖ Additional research and exploration of community engagement initiatives including initial meetings for North Coast KelpFest! 2025 and half day training of Mendo/Sonoma State Parks Interpretive team and PORTS program leads

More of this product will be showcased in the final report. However, we have been using the templates and logos for this interim report as well as presentations made to program leads and to the public.

Visual Record



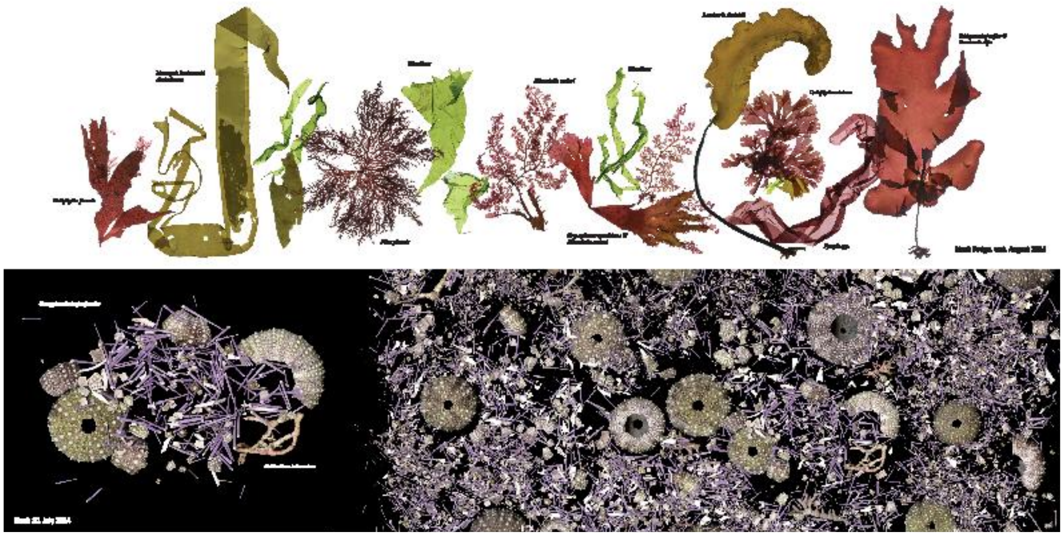
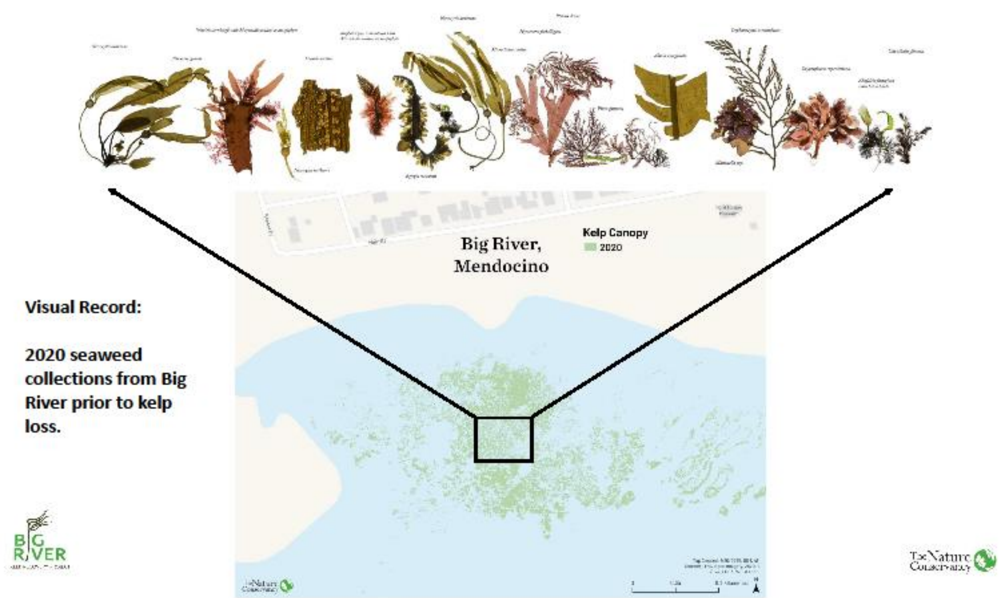


Fig. 37. Visual record of Seaweed Biodiversity & Design including scans of seaweed specimens and urchins collected from Big River before, during, and after restoration.



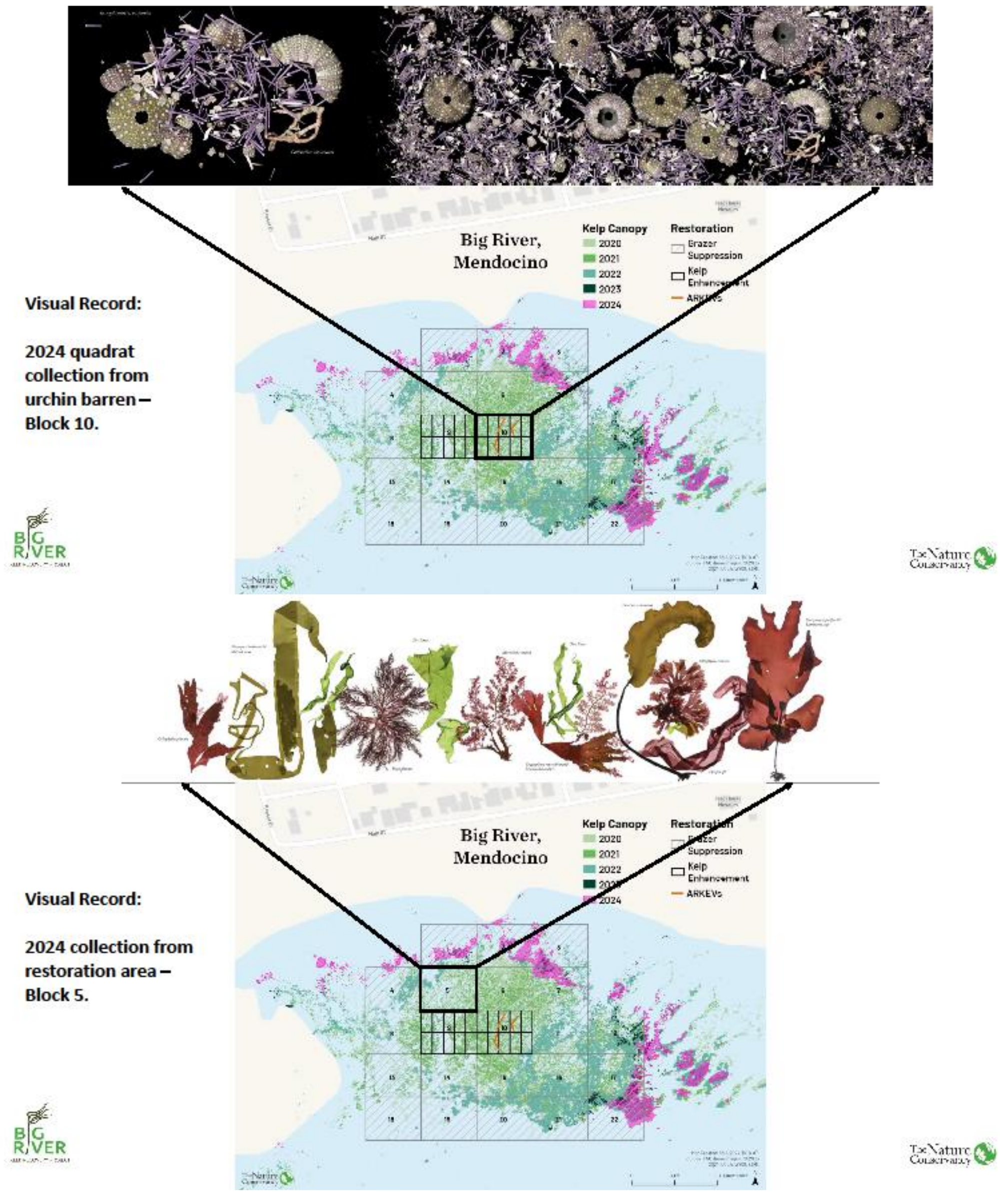


Fig. 38. Preliminary results of combining visual records of biodiversity to visualize kelp restoration success. Algae collected in 2020 before kelp loss at the site (top). Urchins collected from the same area as 2020 after urchin barren formation (middle). Algae collected in 2024 following grazer suppression (bottom).

Webstory and United Nations adoption

A new restoration section was added this fall to *The Mysterious World of Bull Kelp* webstory (https://bullkelp.info/restoration) to bring together best practices for kelp recovery and aquaculture techniques related to both restoration and farming across the North Pacific Coast. One bull kelp restoration or aquaculture project was featured from each bioregion. Just as varying environmental conditions for bull kelp health are described on the regional story pages of this site, the same is true of restoration efforts: each is unique, necessitating different strategies for helping restore or maintain kelp forest resilience. These case studies will facilitate learning and communication across regions.

The Big River Kelp Recovery Project is highlighted as the "Mendocino" case study on the webstory (https://bullkelp.info/case-studies/big-river-kelp-recovery-project). This page will serve as the project's landing page which will include up to date information about the restoration strategies and outcomes, as well as relevant links including this report.
The Mysterious World of Bull Kelp was published in November 2023 and launched at the California Seaweed Festival and the Western Society of Naturalists. Promotions and outreach continued throughout 2024 to help build the kelp network and movement coastwide. The webstory also received endorsement from the United Nations Decade of Ocean Science for Sustainable Development and the LH Tiffany Award from the Phycological Society of America in 2024. As of January 2025, the webstory has recorded over 22,000 visitors.

Challenges

The Challenges section addresses the obstacles encountered during the project, detailing their nature and impact. These challenges were meticulously documented through regular monitoring and feedback mechanisms. By analyzing these issues, we aim to adaptively manage and enhance the project's effectiveness in future iterations.

Project Management

- *Delays in distribution of Prime Award language and full funding*- this delayed all TNC x subawardee grant execution and shifted timelines for project execution. We received the Prime award language to review a month after it was originally anticipated. This was impactful on our program in two primary ways: 1) we could not begin work on this award with partners until subawards were executed (6 subawardees), and 2) bull kelp is an annual species, and therefore, restoration success is largely dictated by a strategic sequence of events that begin in early spring when weather is most ideal to begin work. For example, springtime outplanting is the ideal window of opportunity to outplant from lab to field and this is the ideal time to begin urchin harvest with commercial divers.

Objective 1

- *Kelp Outplanting (ARKEVs) permitting delays*- the SCP required for kelp enhancement and testing of ARKEVs was delayed, as well as unforeseen approvals from Coastal Commission and State Lands Commission. Although we had submitted all permits during application for this program and consulted on the use of these tools, ARKEVs were flagged to need further approval beyond CDFW. This significantly delayed the kelp outplanting component of our work and required us to test ARKEVs in two locations (Albion and Albion River).
    - SCP - Previous years' work highlighted the importance of early-season outplanting (spring) for maximizing restoration success. However, the delayed issuance of the scientific collection permit (SCP) postponed the deployment of ARKEVs requiring adjustments to our timeline and approach. With the SCP not issued until 07/08/2024, the initial deployment of the prototype ARKEV was limited to utilizing the ongoing SCP allowing outplanting of modified ARKEV units using lines and shackles connected to established eyebolts within the Albion restoration site. Whilst this did not delay outplanting at Albion, the modified ARKEV module did limit our outplanting success via mechanical failure of eyebolts and shackles. Without an

existing SCP covering Big River ouptlanting efforts, ARKEV module pilot deployments were delayed until 07/18/2024, months after our targeted outplanting date in early spring. The permitting delays for Big River resulted in low survivorship due to unfavorable oceanic conditions at the time of outplanting, limiting the success of the restoration efforts in 2024.

- ➢ Additional approvals from California State Lands and California Coastal Commission were required prior to the deployment of ARKEV modules with cinderblocks at Big River. This process took approximately three months at which point California State Lands issued a Letter of Non-Objection in lieu of requiring a land lease, and the California Coastal Commission issued a *de minimus* waiver rather than requiring a Coastal Development Permit. It should be noted that if either of those waivers were not issued, the project could have been delayed up to an additional six months and cost ~$20,000 in permit fees.

❖ *Recruitment of small purple sea urchins and increased density from Fall 2023 to Spring 2024-* (further described in Objective 1). We simply under budgeted for the number of the days allocated for urchin harvest as we proposed this project under auspices that 91% of kelp loss had occurred in one year and urchin densities had stabilized at time of proposing this project in Fall 2023 using best available data from Summer 2023 ecosystem aerial and subtidal surveys. The unexpected recruitment events challenged commercial urchin harvesters significantly in their CPUE as small urchins were tedious to harvest and resulted in low poundage of urchin harvested from the site. As such, in year 1 we prioritized hand harvest of purple urchin (in lieu of trapping) to address small urchin and strategize the sequencing of restoration techniques. We contacted OPC, SeaGrant and CDFW prior to the changing our approach. In year 2 we will plan for both commercial hand harvest and trapping to reduce purple urchin densities at Big River.

Objective 2

❖ *Developing and implementing data security protocols to meet requirements for obtaining access to restricted data from CDFW-* Ensuring that strict data security controls required by CDFW (NIST 800-53) are met has been more difficult and taken more time than expected. However, the requisite hardware is now in place and the requisite security plan is almost completed.

Objective 3

❖ *Finding local divers-* Given the applicant pool, we opted to broaden this internship scope to support non-diving interns and prioritize providing local workforce opportunities. This worked well as both interns locally were foundational to the dockside monitoring work.

❖ *Funding for the cost of implementation of KelpFest! and webstory management continues to be a challenge-* But with growing public interest and community engagement, shifts in spending priorities by local and state agencies and foundations are expected to help sustain these initiatives which in turn help to sustain the kelp recovery work of this project.

Conclusion and Key Outcomes

In conclusion, this interim report encapsulates the principal findings and key outcomes of our year 1 efforts through the AKRP program. The results offer valuable insights that enhance our comprehension of bull kelp restoration and recovery in California and outcomes are transferable throughout the state, eastern Pacific, and globally.

Objective 1

- *Over 30 tons of purple sea urchin were strategically harvested from overabundant locations in Mendocino- 15* commercial urchin divers harvested 27 tons of purple sea urchin from Big River during their initial pass through the site, and 3 tons from Albion during maintenance. On their own time, commercial divers additionally harvested 2 tons of marketable red and purple urchin from Big River, further supporting a reduction of grazers and synergy between fisheries and restoration
- *Urchin harvested for restoration were used and a pathway to market was developed-* A portion of urchin harvested became food for people and were used for non-food uses as well. With CDFW, we developed a pathway to code market commercially viable urchin, for food and non-food markets, and have these funds cycle back into the restoration project to sustain efforts long-term
- *Grazer suppression at 'kelp edges' led to kelp recovery-* targeted grazer suppression ultimately resulted in a 172% increase in kelp forest canopy cover at the Big River location that was in peril from complete decimation the year prior. By focusing harvest on kelp edges, we were able to alleviate pressure and protect extant kelp patches further allowing them to stabilize and expand
- *Regulate timing of kelp enhancement by closing the lifecycle of bull kelp-* We developed an approach to complete the life cycle of bull kelp in a lab setting allowing for precision and control in timing to outplant kelp back in the environment during the ideal season and conditions
- *Outplanted kelp grew and released trillions of spores-* We designed novel ARKEV (Array to Recover Kelp Ecosystem Vegetation) units that allowed us to out-plant bull kelp like never before in an open coast system; 10cm bull kelp plants grew to the surface of the sea (>6m!), became reproductive within two months of deployment and released millions of spores into the environment

Objective 2

- *Dockside data (urchin morphometrics)-* Data is being utilized to create a framework to assess downstream economic opportunity for various market uses of purple urchins
- *Urchin-based marble engineered prototypes-* These have been advanced to demonstrate the marketability of urchin-derived biomaterials, specifically for the luxury design market and understand the volume of urchin that could be absorbed by their product production, their target market capture, and the resulting impact on the urchin population
- *Food-grade sized urchins-* Many have been donated to urchin ranching pilot studies

Objective 3

- *Local opportunities were created to build local knowledge and workforce-* We hosted five undergraduate interns, six graduate students, and provided urchin harvest opportunities to five vessels and 14 divers, all who were intimately involved in the work mentioned above. 19 students were supported through this project via this program and matching infrastructure

- *KelpFest!* reached over 1,500 people- Over fifteen hundred people attended the month-long *KelpFest!* Event, which showcased food, art, science and film and all events warranting registration were at capacity. *KelpFest!* brought new ideas and made true meaningful connections between people who might otherwise have no way of interacting
- In late 2024, PI McHugh was asked to serve as the Community Advisor to the globally-based Kelp Forest Alliance program given her background in kelp forest restoration and the scope of the program she is leading through the AKRP award. In her role as the Kelp Forest Alliance Community Advisor, she aims to ensure that both local communities and organizations worldwide are included in international kelp forest decision-making and to leverage the global movement to strengthen conservation programs at home
- *This work was shared, in real time, to accelerate the pace of learning*- We showcased our work at international and domestic conferences, and collectively gave over 30 presentations and appearances at such venues such as: the Ocean Protection Council, the Ocean Science Trust, Legislative Staff briefings, Fishermen in the Classroom, California Seaweed Festival, *Kelpfest!*, Mendocino Beacon/Fort Bragg Advocate, PBS, Natures Archive podcast, the New York Times, and Bay Nature.The Eastern Pacific Kelp Recovery Workshop led by TNC, was attended by over 200 participants and four PIs were able to present on their AKRP Projects
- The Mysterious *World of Bull Kelp* website, was endorsed by the UN Ocean Decade, and our project was showcased as a case study among other excellent projects along the Eastern Pacific further elevating the global considerations of kelp loss and recovery

Opportunities for activity synergy

- Align “Kelp Edge” research and findings with Carr et al.
- Opportunities for kelp farming with Sunken Seaweed- biomass for kelp enhancement in Mendocino and for Tolowa Di nee nation priorities

Appendix

Albion Cove Restoration Efforts Lag Effect

In addition to outplanting the ARKEV prototypes at Albion, we leveraged previous years' restoration efforts to investigate potential lag effects of kelp outplanting. In the first year of the project (2023), we deployed both soral bags and inoculated twine within two areas: one area with urchins present (barren), and one with urchins removed (restoration site). It was crucial to maintain continued monitoring through 2024 to assess whether outplanted kelp might exhibit delayed growth or recruitment.

The sori placed in the soral bags monthly during the 2023 field season had been releasing spores, with early microscopic life history stages potentially persisting through the winter in a dormant state. Similarly, the kelp growing on the lifted inoculated twine lines had become reproductive during the 2023 season, likely increasing spore dispersal and potentially contributing to new recruitment in 2024. In 2023, the experimental infrastructure included both control and restoration sites to test the two enhancement methods (soral bags and inoculated twine). Inline controls were also used to account for natural recruitment, which might arise from grazer suppression or existing nearby kelp beds.

In 2024, while no infrastructure was deployed, we maintained continued analysis between control and enhancement sections for statistical power, although no significant differences were expected between them due to the far-reaching effects of reproductive kelp. As anticipated, we did not observe a significant difference in kelp growth between enhancement and control sections (**Fig. 39**). However, kelp abundance was significantly greater in the site where urchins had been removed compared to the barren.

This outcome highlights the potential importance of continuing restoration efforts at Albion and the importance of further monitoring to understand the benefits of continuing this combined approach for kelp restoration for long-term success.

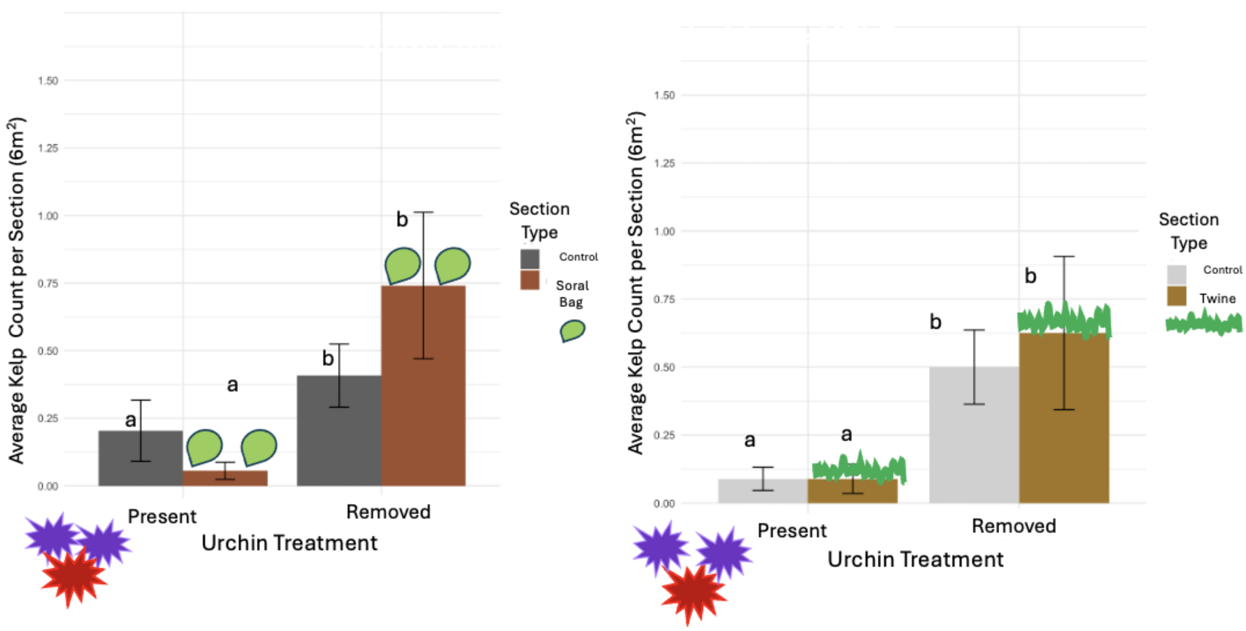


Fig. 39: Average kelp count per section by site (whether urchins were present or absent) and by treatment type (left: soral bag sections or in line control sections)(right: seeded twine sections or in line control sections).