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REVIEW

Global patterns and regional insights into kelp forest protection, restoration, and stewardship

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Abstract

Kelp forests are among the most extensive and productive coastal ecosystems, yet they remain underrepresented in global conservation policy despite widespread declines driven by interacting global- (i.e., ocean warming, marine heatwaves) to local-scale stressors. At the same time, kelp conservation and restoration efforts are expanding rapidly across regions, but measures of success and syntheses tend to primarily focus on ecological conditions and trends, not on conservation and restoration actions. To fill this gap, we developed a comparative global dataset of kelp conservation initiatives based on expert-derived regional narratives from 209 participants spanning 35 regions with kelp forests. We applied a structured presence–absence scoring framework across six domains: conservation actions, restoration approaches, governance actors, conservation objectives, social dimensions, and funding structures, supplemented by regional expert knowledge to enable cross-regional comparison. Across regions, conservation was characterised by strong emphasis on monitoring (86% of regions), multi-actor governance (scientific institutions 94%, government agencies 86%), and protecting existing forests (66%), while active restoration was undertaken in half of the regions. Social engagement (66%) and links to fisheries and livelihoods (69%) were widespread, whereas explicit climate adaptation objectives were less common (17%). We identify a set of conservation profiles that describe how kelp forest conservation is advancing in different ecological and governance contexts worldwide. These findings highlight that scaling kelp conservation is as dependent on the social, financial, institutional, and policy systems that govern implementation, as it is on ecological knowledge and technical capacity. By bridging regional knowledge with global analysis, this study provides a framework for aligning locally grounded conservation action with global biodiversity targets.

Keywords Conservation · Marine · MPA · Spatial management · Macroalgae · Social-ecological systems · Governance · Phaeophyceae

Introduction

Kelp forests, composed of habitat-forming brown macroalgae of the orders Laminariales, Fucales, Tilopteridales, and Desmarestiales (Wernberg and Filbee-Dexter 2019; Eger et al. 2024a), are dynamic ecosystems that occur across at least one-third of the world's coastlines, often dominating temperate and polar rocky reefs (Jayathilake and Costello 2021). These coastal ecosystems underpin human experiences across continents (Teagle et al. 2017; Thurstan et al. 2018; Lee et al. 2021), support high biodiversity from epibiota (fauna and flora) to megafauna (Steneck et al. 2002; Smale et al. 2013; Teagle et al. 2017), and shape the biophysical characteristics of coastal waters (Castorani et al. 2018; Lamy et al. 2020). As a result, they are foundational to ecosystem functioning and human well-being across their distribution.

Kelp forests have experienced widespread declines over the past 100–150 years, with declines in the majority of regions where multiyear datasets were available (Wilson and North 1983; Cavanaugh et al. 2019; Berry et al. 2021; Wernberg et al. 2024; Smale et al. 2025). Ocean warming and marine heatwaves are recognized as dominant drivers, often interacting with other pressures including overgrazing, invasive species, coastal development, pollution, and overharvesting (Krumhansl et al. 2016; United Nations Environment Programme 2023; Verdura et al. 2023). In some regions, these interacting stressors have triggered large-scale regime shifts and near-complete loss of kelp ecosystems (Christie et al. 2019; Rogers-Bennett and Catton 2019; Butler et al. 2020).

In contrast to other coastal ecosystems, kelp forests remain underrepresented in international and national conservation policy frameworks (Valckenaere et al. 2023; Techera et al. 2024). This gap has contributed to fragmented management approaches, uneven investment, and limited coordination across jurisdictions (Vergés et al. 2020; United Nations Environment Programme 2023). Although global initiatives such as the Kunming–Montreal Global Biodiversity Framework (Convention on Biological Diversity 2022), Global Assessment Report on Biodiversity and Ecosystem Services (IPBES 2019) and UN Decade for Ocean Science (Claudet et al. 2020) have elevated the importance of marine ecosystem protection, explicit targets, indicators, and implementation trajectories for kelp forests remain largely undefined (United Nations Environment Programme 2023; Arafeh-Dalmau et al. 2024).

At the same time, the restoration and protection of kelp forests (together, kelp conservation) is expanding in practice. Restoration projects, monitoring programmes, policy initiatives, and community-led stewardship efforts are emerging across diverse ecological and governance contexts (Eger et al. 2022b; Filbee-Dexter et al. 2022; Miller et al. 2022; Wood et al. 2024). However, these efforts are often discussed independently, and there is limited synthesis of how conservation is being implemented across regions, which actors are involved, and which mechanisms enable or constrain progress.

The Kelp Forest Challenge (Eger et al. 2024a) represents a global effort to address this gap by coordinating actions to protect three million hectares and restore one million hectares of kelp forests. The initiative emphasizes the integration of traditional and local knowledge, regional governance, and global coordination. Yet achieving these ambitions requires a clearer understanding of how kelp conservation is currently structured and operating across regions, including the diversity of approaches, enabling conditions, and barriers to implementation.

Existing global assessments have quantified trends in kelp extent (Krumhansl et al. 2016), identified major stressors (Wernberg et al. 2019), and evaluated ecosystem services (Bennett et al. 2016; Blamey and Bolton 2018; Hynes et al. 2021; Carnell et al. 2025) and conservation benchmarks (Eger et al. 2024c; Arafeh-Dalmau et al. 2025). However, there remains a critical gap in comparative, regionally grounded analyses that connect ecological knowledge with social systems, implementation trajectories, and on-the-ground conservation practice.

Here, we address this gap by developing a global comparative dataset of kelp conservation systems based on expert-derived regional narratives and expert validated classifications. Drawing on contributions from 209 participants across 35 kelp forest regions, we synthesize how conservation is currently being implemented, including the actions taken, actors involved, objectives pursued, and social and funding contexts shaping these efforts. We apply a structured presence–absence scoring framework to these regional narratives, supplemented where necessary by regional expert knowledge, to enable cross-regional comparison and identify recurring patterns in conservation approaches.

Using this framework we create a synthesis that describes how kelp forest conservation is advancing under different ecological, governance, and socio-economic conditions. These themes provide a basis for understanding the mechanisms that enable conservation at scale and offer insights for aligning regional actions with global biodiversity targets while maintaining sensitivity to local context. As a result, this approach bridges the gap between global conservation ambition and the realities of regional implementation.

Methods

Study design and data collection

We gathered information for this study through the 2nd Kelp Forest Summit, held across two in-person meetings and online consultations (Fig. 1).

The first meeting took place prior to the 25th International Seaweed Symposium (ISS) on 4th May 2025 in Victoria (British Columbia, Canada) and included an online participation option, and the second occurred prior to the 14th International Temperate Reefs Symposium (ITRS) on 30th June 2025 in Brest (Brittany, France).

Workshops were advertised through conference websites, the Kelp Forest Alliance (KFA) mailing list (~900 subscribers), and social media platforms (LinkedIn and Instagram). Participation was open to individuals from all countries and sectors engaged in kelp forest conservation, including scientists, conservation practitioners, policymakers, Indigenous and local community representatives, and artists involved in kelp-related initiatives. To improve geographic representation, we invited additional contributors from underrepresented regions to participate in the regional synthesis process after the workshops.

In total, 209 individuals from 30 countries contributed to the workshops and subsequent synthesis (Fig. 2). Participants represented a range of professional backgrounds, including universities (53%), NGOs (14%), research institutes (14%), businesses (9%), and a further 10% affiliated with government agencies, community groups, the arts, or with no formal institutional affiliation (Fig. 3).

Workshops were structured using a combination of plenary sessions and region-specific breakout groups. In breakout sessions, participants collaborated within pre-defined

Fig. 1 Outline of the steps to gather information, write regional overviews, and score the regions to inform this paper

geographic regions to develop a shared account of kelp forest conservation activities and contexts. Each group responded to a common set of guiding questions (Appendix 1) designed to capture key conservation developments, enabling conditions that had accelerated action, opportunities for advancing conservation, and core messages about the importance of kelp forests.

Regional synthesis and dataset construction

Participants were organized into 35 region-specific groups representing kelp forest systems globally. We defined regions based on geographic proximity, relevant governance jurisdictions (state or national), and the availability of regional expertise, rather than strictly ecological boundaries, to better align with conservation decision-making and policy processes (see Fig. 2 for boundaries).

After the workshops, contributors prepared long-form written responses. Regional co-authors then collaboratively synthesised and edited these into concise summaries of approximately 500–800 words.

Across regions, we structured the summaries around four common themes:

- key conservation developments;
- opportunities for advancing kelp forest conservation;
- enabling conditions that have accelerated action; and
- a key message about kelp forest importance

The finalized regional narratives (Appendix 2) constitute the primary information for this study and will also be made publicly available through the KFA website (https://kelpforestalliance.com/regions).

Participation levels varied across regions (1–34 contributors per region), reflecting geographic biases associated with conference locations, author networks, and broader accessibility constraints related to international participation.

The primary unit of analysis was the region (n = 35), with each region represented by a single synthesised narrative. Regional boundaries were defined prior to analysis and were not modified during scoring. No weighting was applied to account for variation in the number of contributors per region.

Scoring framework

To enable cross-regional comparison, we developed a structured presence–absence scoring framework capturing key dimensions of kelp forest conservation systems. The framework was designed to reflect elements considered important for characterising conservation implementation and outcomes, informed by both existing literature (Leslie 2005; Roff 2013; Earll 2018) and the content of the regional narratives (Eger et al. 2022b).

The framework comprised six primary domains:

1. **Conservation actions**, including marine protected areas, harvest management, monitoring programmes, community stewardship, and government policy initiatives.
2. **Restoration approaches**, including urchin removal, kelp seeding or transplantation, artificial substrates, hybrid approaches, and cases where no restoration activities were reported.
3. **Future conservation objectives**, including protection, restoration, monitoring, climate adaptation, and multi-objective initiatives.
4. **Human dimensions**, including Indigenous and local community participation or leadership, links to liveli-

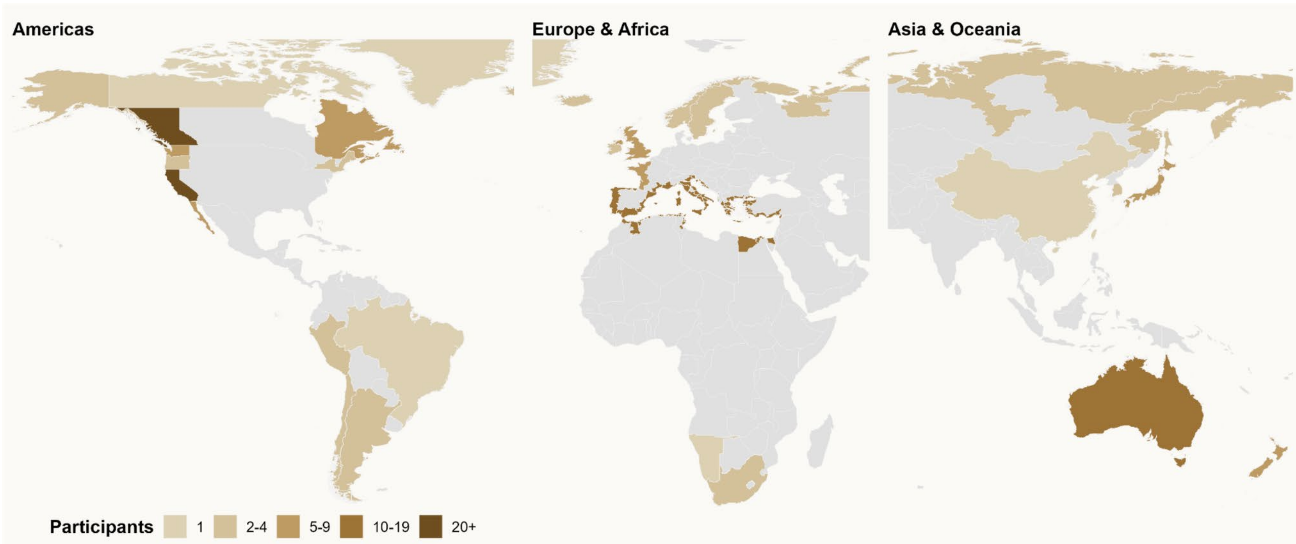

Fig. 2 Map of the regional expertise of the participants, shaded by the number of participants from each region. Darker shades indicate more participants, lighter shades indicate fewer, and grey indicates no participants

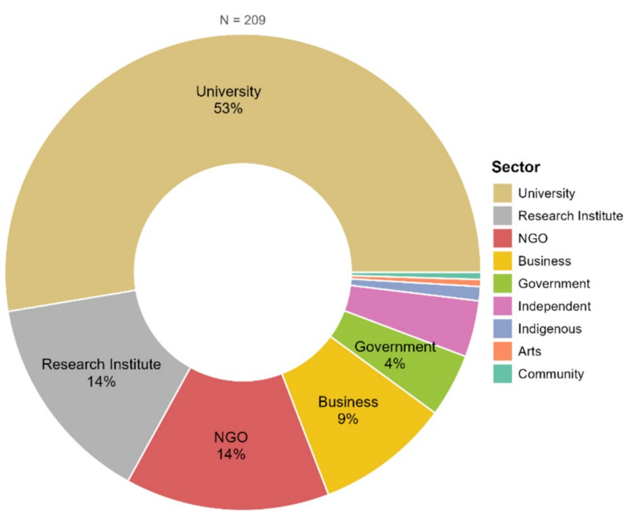

Fig. 3 Primary institutional affiliations of project participants

hoods, public engagement, stakeholder conflict, and cultural values.

5. **Actors involved**, including Indigenous organizations, government agencies, NGOs, universities or research institutions, community organizations, and private-sector actors.
6. **Funding and support**, including public funding, NGO or charitable funding, research grants, private-sector funding, mixed funding sources, and reported funding limitations.

Each domain included 4–6 non-mutually exclusive categories (none in restoration actions is an exception and is mutually exclusive). A detailed codebook, including definitions, is provided in Appendix 3.

Scoring process

Ultimately, we recorded each category as present (1) or absent (0) using information from the regional narratives, which allowed high-level comparisons across diverse socio–ecological contexts. We acknowledge that the binary scores only indicate whether elements are present, not how strongly or successfully they are being implemented (see limitations).

To start, the lead author conducted an initial filtering and only considered a category present when the regional narrative explicitly described it. Then, co-authors and regional contributors reviewed and adjusted the initial filtering through an iterative process to confirm the presence of categories despite their absence from the written summaries.

This process involved multiple rounds of refinement to ensure consistent application of category definitions across regions and alignment with the codebook. Where relevant, contributors applied their regional expertise to verify coded classifications and correct apparent omissions in the written summaries. The author team resolved ambiguities in category assignment through discussion. We did not conduct a formal inter-coder reliability analysis. The resulting dataset therefore represents regional classifications informed by both written narratives and contributor expertise. This approach reduced false absences arising from incomplete or uneven regional summaries.

Data analysis

We limited the analysis to descriptive summaries of the coded classifications. For each category, we calculated the proportion of regions in which it was present, providing a comparative overview of conservation actions, actors, objectives, and enabling conditions across regions.

Identification of conservation themes

To interpret cross-regional patterns, we developed a set of conservation themes representing recurring governance, capacity, and intervention patterns.

We identified these themes through a qualitative and interpretive synthesis of the region-level coded classifications and the underlying regional narratives. Specifically, we identified recurring combinations of characteristics, such as dominant actors, types of interventions, and enabling conditions, that appeared across multiple regions.

Conservation themes are not mutually exclusive, and individual regions may exhibit characteristics of multiple themes. Accordingly, the themes are presented as illustrative constructs to support comparative interpretation rather than discrete empirical groupings. We identified the following themes:

1. Indigenous-led and rights-based stewardship
2. Science and monitoring infrastructure
3. State-programmatic scaling
4. Market- and tenure-driven governance
5. Remote and data-limited frontier systems
6. Crisis-frontline and regime-shift systems
7. Blue-economy and mariculture
8. Public-facing conservation action

Limitations

This study is based on regional summaries and expert-validated classifications rather than standardized survey instruments and therefore reflects qualitative perspectives that may vary in depth and emphasis across regions. Participation was uneven across regions (1–34 contributors per region), which themselves varied significantly in size and scope (a state versus a country versus a conglomerate of areas) and both factors may influence the level of detail captured. Because classifications were informed in part by contributor knowledge beyond the written narratives, the dataset is not fully reproducible from the narrative text alone.

The use of binary presence–absence scoring simplifies complex conservation systems and does not capture differences in scale, intensity, timing, or effectiveness of interventions. Scoring was first conducted by a single primary coder and consistency was improved through iterative review and group validation.

Finally, the conservation themes presented are interpretive and derived from qualitative synthesis and should be understood as analytical frameworks rather than statistically derived classifications.

Results

Global patterns in kelp forest conservation

Across the 35 regions analysed, region-level classifications indicate that kelp forest conservation most emphasised monitoring, multi-actor governance, and mixed conservation objectives, with more limited and uneven application of restoration interventions (Figs. 4, 5, 6).

Regions such as Japan, South Korea, Australia, Aotearoa New Zealand, and parts of North America (e.g., Washington and California) exhibited high diversity of conservation actions, including multiple restoration approaches alongside monitoring (e.g., Reef Life Survey), policy development (e.g., Washington State's bull kelp recovery plan), and community engagement (e.g., Operation Crayweed). These regions also showed strong participation from multiple actor groups and diverse funding structures.

In contrast, several regions, including Arctic and sub-Arctic systems (e.g., Greenland, High Arctic, West Bering Sea, Canada), Iceland, Argentina were characterized by conservation actions largely consisting of monitoring and enforcement mechanisms, with limited intervention or absence of active restoration.

Other regions, including Chile, Peru, and parts of Europe, showed intermediate profiles, combining governance and monitoring with selective restoration approaches and strong connections to fisheries and resource use.

Monitoring was the most consistently reported conservation action, present in 86% of regions, followed by community stewardship (61%), policy planning (57%), and marine protected areas (54%). Harvest management (where needed) was reported in 43% of regions. In contrast, active restoration approaches were less widespread (49% of regions), and included kelp seeding (46%), urchin removal (29%), and transplantation (31%), while substrate deployment (20%) and future-oriented or experimental approaches (20%) were relatively less common. Notably, 51% of regions reported no active restoration activities, indicating that restoration is absent, emergent, or not currently considered necessary in many systems (Fig. 4).

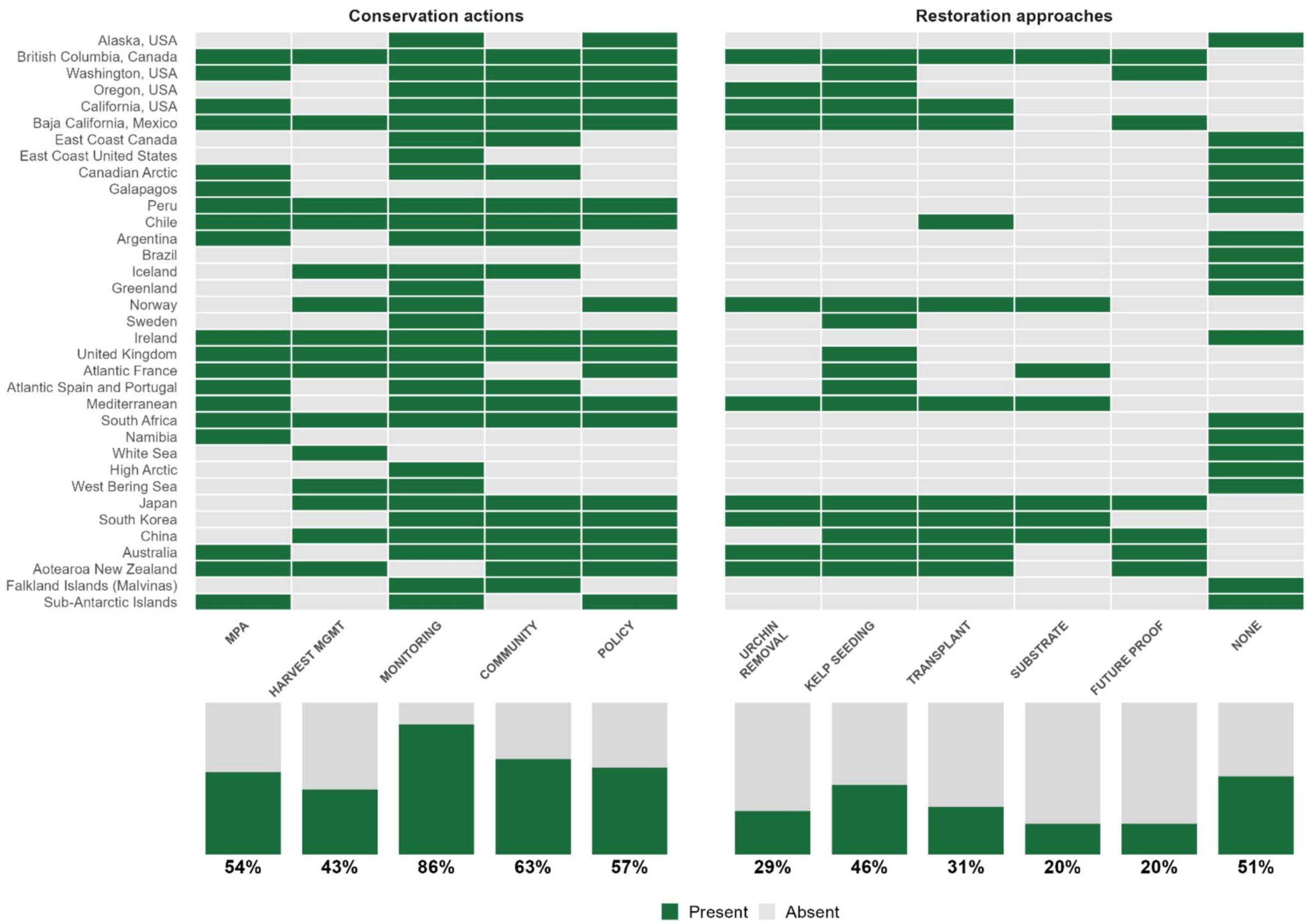

Fig. 4 Presence and absence of conservation and restoration actions across regions (n = 35), with global prevalence

Conservation objectives

Conservation objectives were frequently multi-dimensional, with regions pursuing combinations of protection, restoration, and monitoring goals. Monitoring ecological change was the most common objective, reported in 80% of regions, followed by protection of existing kelp forests (66%) and restoration of degraded systems (40%). Explicit climate adaptation objectives were less frequently reported (17%), suggesting that adaptation framing was not prominently represented across regions (Fig. 5).

Human dimensions

Social and human dimensions were widely represented across regions. Public engagement, including outreach, citizen science, and education, was reported in 66% of regions, associations between kelp ecosystems and fisheries or livelihoods were reported in 69% of regions, while harvest dependence on kelp itself was reported across 40% of regions.

Cultural values were identified in 62% of regions, whereas Indigenous participation or leadership was reported in 29% of regions (Fig. 5).

Actors and governance structures

Kelp forest conservation involved a diverse set of actors, with scientific institutions (94%) and government agencies (86%) being the most reported. Non-government organizations (57%) and community groups (66%) were also widely involved, while industry or private-sector (e.g., aquaculture operations) participation was reported in 51% of regions (Fig. 6).

Most regions exhibited multi-actor governance systems, with overlapping roles across institutions. However, the composition of actors varied considerably, with some regions dominated by government–science partnerships

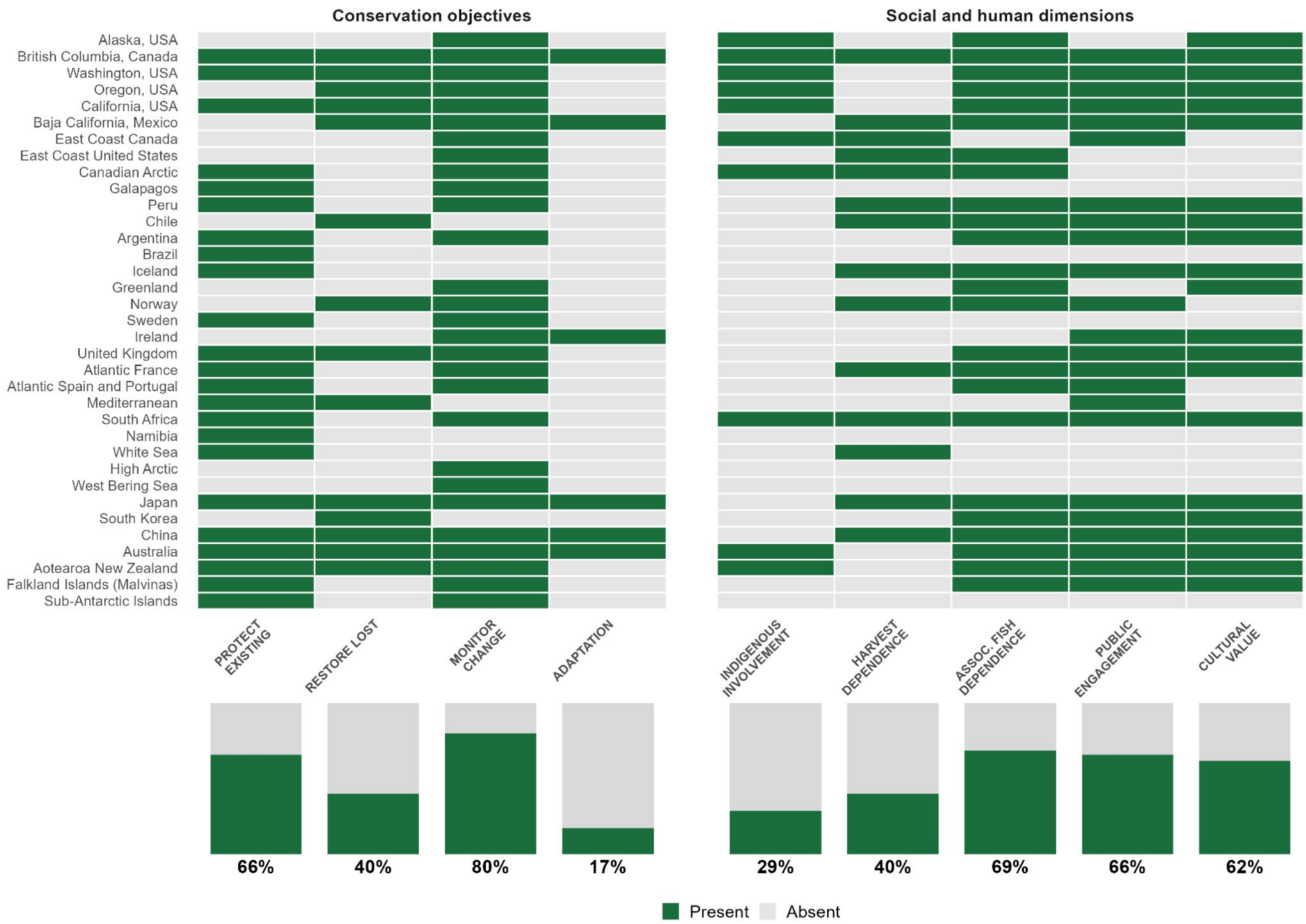

Fig. 5 Presence and absence of different conservation objectives and human dimensions of kelp forests across regions (n = 35)

and others incorporating stronger roles for communities and industry.

Funding and support

Funding for kelp conservation was typically diversified across multiple sources. Public funding (66%) and research funding (80%) were the most reported sources, followed by private-sector funding (51%) and NGO funding (43%). Many regions reported mixed funding structures, combining multiple funding streams (Fig. 6).

These patterns indicate recurring combinations of actions, actors, and enabling conditions across regions, which informed the interpretive conservation themes described below.

General discussion

Global momentum for kelp conservation

This global assessment highlights the growing prominence of kelp forest conservation across 35 regions. While the state of conservation is uneven across regions (Eger et al. 2024c; Arafeh-Dalmau et al. 2025), initiatives now span 6 continents and increasingly combine ecological research, governance reform, economic development, and community engagement. Many areas have advanced beyond pilot studies to coordinated strategies supported by policy frameworks, Indigenous and local governance, and public participation. This expansion parallels global biodiversity commitments and agendas yet maintains a unique bottom-up approach, rooted in place-based knowledge systems.

Across regions, kelp forests were consistently framed as socio-ecological systems involving diverse conservation actions, objectives, restoration methods, funding structures, rightsholders and sectoral interests. At the same time, each region was shaped by distinct ecological, economic, and sociocultural pressures that influenced how kelp conservation was implemented in practice.

Conservation profiles

To connect place-based regional insights to a coherent global narrative that accounts for local specificity, we describe

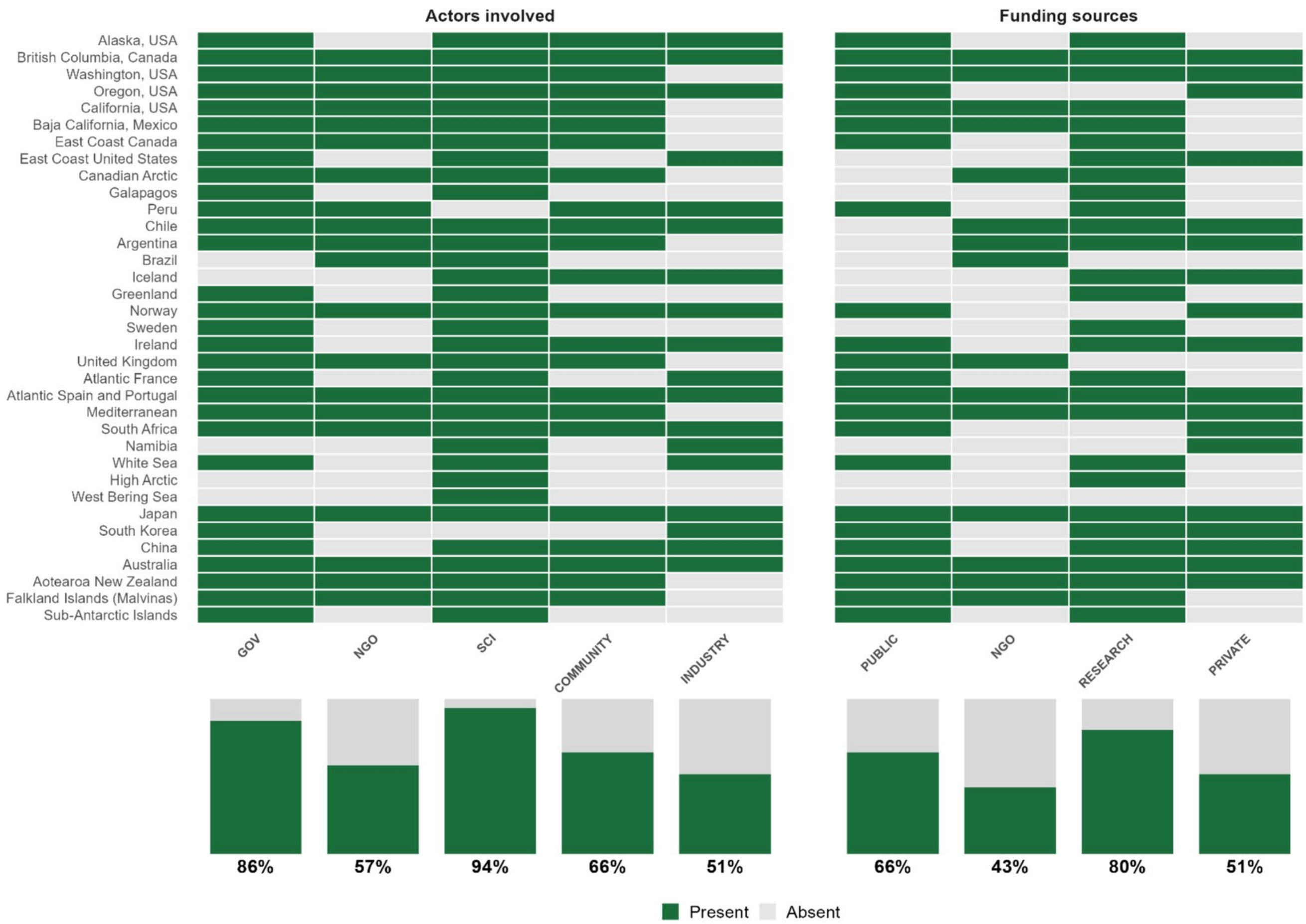

Fig. 6 Presence and absence of the actors involved and funding sources for kelp forest conservation in each region (n = 35). Gov = government, Sci = science and academic institutions

eight themes that capture how conservation is currently advancing or stalling. These themes are interpretive rather than mutually exclusive, and some regions span more than one theme. Their purpose is to make the regional synthesis more comparable and transferable by foregrounding recurring mechanisms, such as participation, knowledge base, institutional support, policy frameworks, remoteness, and crisis dynamics.

Indigenous-led and rights-based stewardship

Across several regions, kelp conservation is anchored in Indigenous rights, stewardship obligations, and co-production of knowledge (Kobluk et al. 2021; Lee et al. 2021; Gutzmann et al. 2026). In these contexts, kelp forests are not only habitats or service providers but living cultural seascapes (Thurstan et al. 2018). These anchor points suggest that kelp forests should be valued as key parts of a social-ecological landscape and not just drivers for economic or material benefit, which can replicate climate and carbon coloniality (Carlson 2024). These conservation philosophies also call for greater respect and reciprocity when it comes to managing, restoring, or stewarding kelp forests (Kirkness and Barnhardt 1991).

Examples in the regional narratives include co-stewardship arrangements and Indigenous leadership in identifying priorities, implementing monitoring, and shaping restoration delivery. In British Columbia (Lee et al. 2021; Gutzmann et al. 2026) and the U.S. Pacific Northwest (Naar et al. 2020), Indigenous governance and advocacy are repeatedly described as central to mobilising community support and restoration priorities, while in Aotearoa New Zealand, mātauranga Māori (Māori knowledge systems, including traditional knowledge, values, and worldviews) and kaitiakitanga (the Māori concept of guardianship, stewardship, and protection of the environment) are positioned as guiding principles for restoration (in review). In Chile and Mexico, both Indigenous and local peoples are involved in tenure-based small-scale fisheries (e.g., TURFs). These right-based systems show how local management can sustain kelp forests and associated resources through stewardship, access control, and long-term incentives for resource users (Micheli et al. 2024; Pérez-Matus et al. 2025), see Sect. 4.

These examples begin to illustrate that, when appropriate, treating Indigenous and rights-based governance as central to conservation can help achieve ecological (e.g., healthier seascapes) and social outcomes (e.g., community connection and economic prosperity) (Wong et al. 2020). To be effective, these beliefs and values need to be embedded in policy design, financing mechanisms, monitoring programmes, and project delivery, rather than appended as consultation (Boyd and Lorefice 2018). Where this integration is weak, participation barriers (permitting complexity, inequitable access to funding, and underrepresentation in international forums) can slow progress despite strong local interest.

These dynamics are not specific to kelp forests and indeed these patterns are repeated where Indigenous people hold clear governance roles within marine planning processes (Bennett et al. 2022; Strand et al. 2022). Though the term Indigenous Peoples has no single definition, we refer to the United Nations definition (Daes 2008) and acknowledge that Indigenous management of kelp forests is most relevant to countries and regions with histories of colonization (e.g., the Americas or Australasia).

Science and monitoring infrastructure

A second theme is characterised by long-term monitoring, standardised datasets, and a connected science-to-management pipeline (Likens 2010; Selig et al. 2014; Claudet et al. 2020). These regions are often able to define baselines, quantify change, test methods, and evaluate management actions, thereby reducing uncertainty for decision-makers and funders. In practice, monitoring provides implementation capacity by directly supporting decision-making and informing policy (Hughes et al. 2017).

Long term monitoring programs have been created for different reasons but provide the same output, consistent and reliable ecological data. Two programs in California LTER (Bell et al. 2021), PISCO (Menge et al. 2019) were created by universities and have been used as foundation for scientific research. The citizen science program Reef Check (McHugh and Abbott 2019) is also used in university research but grounds its work more in community engagement. Japan provides a different example through its long-running Monitoring Site 1000 programme (Terada et al. 2021). This program was started in 2003 and is intended to give warning signs for ecological change and support environmental management. Kelp forests are just one of the ecosystems monitored in this program. Regardless of origin, each monitoring programme provides standardised methodologies, multi-year data, and a consolidated access point. This evidence makes it easier to justify regulatory change and sustained investment.

However, the regional sections also highlighted a recurring tension within this theme: strong evidence does not automatically translate into action (Biber 2011). We can make the argument that government led monitoring programs are more likely to result in management changes as there is an integrated pathway from data collection and analysis through interpretation, decision-making, and action (e.g., 1000 sites in Japan). When monitoring is led by NGOs or universities, greater effort and interest from government is needed to move from data to action. These patterns can result in regions that are "data-rich but action-constrained" (Saunders et al. 2022). This highlights the value of coupling monitoring investment with enabling conditions, clear permitting, stable finance, community engagement, and decision triggers that translate monitoring into management actions (Bell-James et al. 2023).

State-programmatic scaling

A third, less common theme involves state-led targets, stable budget lines, and standardised operating models that support implementation beyond small pilots. The clearest examples of this approach are Japan and South Korea, which have institutionalised restoration and protection through plans, monitoring requirements, and delivery agencies capable of multi-year coordination.

The South Korean national marine forest programme includes multi-decadal planning horizons, explicit area targets, and post-intervention monitoring requirements (Lee 2019). In response to extensive degradation of the marine environment from overfishing, coastal development, and ocean warming, The Sea Forest programme in Korea aims to restore 54,000 hectares of kelp forests between 2009 and 2030, and to have reportedly placed 30,000 hectares of reef under restoration (Hwang et al. 2026).

The marine environment in Japan faces similar issues as Korea and has a structured restoration programme. Restoration in Japan is structured through two frameworks: first was the Isoyake Taisaku Guidelines (2009, 2015, 2021) and second, the Fisheries Multiple-function Demonstration Project (FMDP), which provided guidance and funding for large-scale kelp forest restoration, with implementation largely led by prefectural governments and fisheries cooperatives. These programmes supported fishing cooperatives and NGOs with co-funded financing, technical expertise, and interventions such as herbivore control, kelp transplantation, and habitat improvement to ultimately restore ~ 100 ha of seaweed forest (Sekine 2015; Eger et al. 2022b). Japan is the only country to include kelp forests in its nationally determined contribution under the Paris Agreement (Paris Agreement 2015). Making this link enabled the government to increase restoration efforts, with blue carbon credits traded by entities approved by the government, resulting in the restoration of approximately 170 ha of kelp habitat (Kuwae et al. 2025).

While not as advanced, other regions are making progress towards systematic management plans for kelp forests, for example Norway is developing its kelp forest initiatives and management plan (Verbeek et al. 2021; Norderhaug et al. 2025). In response to legislation, Washington State developed their own kelp management plan that includes 6 goals and 65 research and policy actions including strategy for an area-based target, monitoring, Indigenous stewardship, and active restoration (Calloway et al. 2020; Berry et al. 2023). Academics, with some support from the Canadian government, have created a blueprint for assessing the national blue carbon capacity (i.e., regional export and sequestration potential) of kelp forests, representing a step towards accurate carbon accounting for their national kelp forests (McHenry et al. 2025). Conservation listings can also support funding for restoration. For example, Australia classified the "Giant Kelp Marine Forests of South East Australia" as endangered under the Environment Protection and Biodiversity Conservation Act (McLeod et al. 2018), which has helped secure funding for local restoration efforts.

Market- and tenure-driven governance

In Japan, Norway, Chile, Mexico, and France kelp conservation is closely coupled with harvesting, fisheries tenure, and rights-based management systems (Fujita 2011; McCay et al. 2014; Frangoudes and Garineaud 2015; Steen et al. 2016; Westermeier et al. 2019). Coupling wild kelp forests with harvesting programmes creates both opportunity and risk. As local communities harvest kelp and benefit from sustainable kelp populations, there is the potential for increased stewardship and care for the ecosystems (Berque and Matsuda 2013; Gelcich et al. 2017). Conversely, harvesting wild kelp places an additional stressor on the population and overharvest can lead to population collapse, with low harvest rates potentially detrimental if additional stressors are present (Carranza et al. 2024). As the demand for alginates is growing (Kang et al. 2023), wild harvest pressure on kelp forests may be expected to increase in the future.

Chile and Mexico illustrate a tenure-linked theme where TURFs/AMERBs (Territorial Use Rights for Fisheries/Áreas de Manejo y Explotación de Recursos Bentónicos) and fisher associations shape kelp outcomes and can function as de facto spatial protections which can sometimes enhance ecological recovery (Micheli et al. 2024; Pérez-Matus et al. 2025). The narrative in Peru similarly emphasises how industrial demand for kelp biomass, while an important economic opportunity, increases concern of overexploitation and elevates the need for monitoring and preventive governance (Cevallos et al. 2024). In Atlantic France, there is a shift from damaging extraction methods towards spatially managed harvesting, which may reduce habitat impacts while still facilitating economic activity (Garineaud 2019). While economic kelp production is dominated by aquaculture (Buschmann et al. 2017), these industries are often reliant on wild populations for spore supply. As a result, aquaculture is at least partially dependent on wild populations and local harvest. Whether these industries are sustainable depends on whether governance embeds ecological safeguards (e.g., harvest controls, spatial protections, monitoring, and enforcement) and whether incentives support long-term ecosystem function rather than short-term extraction.

Remote and data-limited frontier systems

A substantial proportion of the kelp forest biome occurs in remote areas with low human populations, limited direct anthropogenic stressors, and sparse scientific information. Regions such as Alaska, Canada (the Arctic, portions of the East and West coast), Greenland, Iceland, Russian Arctic, Southern South America, or the Sub-Antarctic Islands provide valuable reference systems as they host more pristine kelp forests with lower levels of degradation. While these kelp forests are currently considered relatively healthy, they still face pressures from rising sea temperatures, increased vessel traffic, sediment laden run-off, and potentially invasive species (Goldsmit et al. 2021; Bringloe et al. 2022; Timmer et al. 2026). In these instances, the remoteness of these regions poses a risk as the capacity for monitoring and conservation is limited by their geography and sparse human populations. As such, conservation in these regions is currently focused on monitoring and documenting changes or protecting kelp forests as a preventive measure.

While unified by their remote geographies, there are still persistent differences in establishing monitoring programs in these regions. Greenland and the Canadian Arctic have large uninhabited coastlines with limited direct anthropogenic pressure, few active conservation projects, and limited knowledge of kelp state and drivers of change (Wegeberg et al. 2025). In the Russian Arctic and West Bering Sea (NIR Foundation 2020; Evseeva et al. 2024), there is also sparse monitoring and major information gaps, but small-scale kelp harvesting industries persist in the Russian White and Barents Sea (Northwest Territorial Administration of Rosrybolovstvo 2022). In contrast, the Falkland Islands and sub-Antarctic narratives describe relatively intact systems where remoteness combines with an active interest in marine management and monitoring innovation such as remote sensing and eDNA (Mora-Soto et al. 2020; Houskeeper et al. 2022; van der Grient et al. 2023). Alaska similarly pairs remoteness with more national scale monitoring programs such as ShoreZone (Hollarsmith et al. 2024) alongside smaller regional scale efforts (Alaska Ocean Observing System 2022).

Crisis-frontline and regime-shift systems

Several regions have lost kelp across vast scales and crossed ecological tipping points (e.g., persistent urchin barrens, intensified fish herbivory or elevated thermal stress). As a result, these regions must now consider how to manage the dynamics of the new ecological regime (Ling et al. 2009; Boada et al. 2017; Kumagai et al. 2024). In these contexts, conservation must balance urgency with realism: preventing further loss, protecting refugia, and determining if interventions can break reinforcing feedback.

Tasmania in Australia, Northern California, and Baja California are examples of regions where kelp systems have collapsed (Arafeh-Dalmau et al. 2019; Rogers-Bennett and Catton 2019), but also where solution orientated research and actions are underway. These regions are running intensive experimentations with restoration (Zertuche-González et al. 2022; Dawkins et al. 2024; Grebner et al. 2025) and climate-adaptation tools including propagule banking and stress-tolerance approaches (Layton and Johnson 2021; Veenhof et al. 2021), alongside community-based actions (McHugh and Abbott 2019; Eger et al. 2022a; Bauer et al. 2026).

A core implication is that crisis-frontline regions require climate-smart conservation framing (Wood et al. 2024; Arafeh-Dalmau et al. 2025). Interventions should explicitly incorporate warming projections (Assis et al. 2024), refugia identification, and adaptive monitoring, and should avoid assuming that historical baselines can be universally reinstated on short timelines (Johnson et al. 2017). Where regime shifts have occurred, "success" may need to be defined as staged recovery (reducing barrens extent, rebuilding seed supply, restoring partial canopy function) rather than immediate full ecosystem reinstation.

Blue-economy and mariculture

Several regions also demonstrated the potential to link kelp forest conservation with aquaculture, blue-economy development, and emerging finance mechanisms (e.g., blue carbon or biodiversity markets). This approach to conservation can broaden constituencies and diversify funding, but it also introduces risks if economic incentives outpace ecological evidence or governance safeguards (Evans et al. 2023).

Kelp farming is a key entry point in several contexts. In Alaska, interest in mariculture is associated with mapping and identifying wild kelp resources and supporting producers through permitting and research programmes. On the east coast of the USA, kelp farming is positioned as a major mechanism for public and policy engagement, alongside culturing techniques that reduce pressure on wild sourcing. It is worth noting that Japan and Korea are among two of the largest kelp farming nations in the world (Nayar and Bott 2014) and have the largest area of kelp forest area under restoration (Eger et al. 2024c). We suppose that this connection has not only motivated conservation but also that the expertise from farming has been applied to conservation (Lee 2019).

In Japan, blue carbon accounting and credit mechanisms are positioned as one explicit driver of restoration and conservation momentum (Nishihara et al. 2025), while scientists still emphasise the need to quantify uncertainty and maintain robust monitoring, verification, and public engagement. South Korea is similarly aligned, with the government working to integrate programmatic restoration efforts with blue carbon credits and increasing private-sector participation, further embedding finance in conservation outcomes.

These regions demonstrate that blue-economy mechanisms are conditional accelerators and not stand-alone conservation solutions. When linked to strong monitoring, credible baselines, and ecological safeguards, they can stabilise finance and increase buy-in for kelp conservation/restoration. Where safeguards are weak, they can incentivise premature scaling, overstated claims or misaligned outcomes. Integrating monitoring requirements and transparent reporting into finance-linked projects is therefore essential.

Public-facing conservation action

Across multiple regions, kelp conservation gains traction when it becomes visible and tangible beyond specialist communities, reflecting a broader shift from expert-driven conservation toward models that engage public constituencies as participants, advocates, and co-producers of knowledge. In these instances, visibility helps shape social licence, gains political attention, and ultimately increases capacity for action.

Narrative outputs such as festivals (KelpFest!, California Seaweed Festival, Kelp Day in Baja California, Seaweed Gardens, exhibitions (Aquarium of the Pacific, Monterey Bay Aquarium, Natural History Museum of London, Enosima-suizokukan in Japan, Two Oceans Aquarium in South Africa), and accessible data platforms and public facing digital resources (kelpforestalliance.com, artsandculture.google.com/project/invisible-forest, bullkelp.info), are central mechanisms through which this shift operates. These methods are accessible and expand constituencies, diversify participation pathways, and in some cases contribute monitoring data at relatively low cost, thereby linking engagement with evidence generation (e.g., Reef Life Survey, Reef Check, MasKelp, Zooniverse.org, iNaturalist, Observation.org, Mexico's women diver citizen science group—Las Sirenas).

Regional examples illustrate how these dynamics translate into practice. In the United Kingdom, increased public engagement through public facing reports (Blue Marine Foundation 2025) documentaries, livestreams, and citizen science initiatives (e.g. SeaSearch, Capturing our Coast, Big Seaweed Search) is associated with growing support for kelp conservation and a reinforcing cycle of visibility, funding, and action. The experience in Washington State, USA shows how building profile for kelp conservation, and co-developing management plans with local Tribes contributed to the official naming of bull kelp as the state marine forest. France highlights the role of citizen reporting platforms, diver observations, and public exhibitions in elevating kelp forests within national discourse while generating usable datasets. In Mexico participatory science across sectors has supported the establishment of a National Restoration Plan for Giant Kelp. In the Mediterranean, bottom-up campaigns, particularly those centred on storytelling and crowdfunding, position marine forests as a public and political priority. Documentary-driven (South Africa – My Octopus Teacher, Australia – White Rock, California – Sequoias of the Sea) exposure has reframed kelp from a relatively overlooked habitat into a widely recognised cultural symbol, enabling broader valuation and engagement which ultimately can lead to action.

A consistent implication across these cases such as Operation Crayweed (Australia), SeaForester (Portugal), or SeaChange (South Africa) is that communication and engagement can be core components of conservation systems. Effective approaches tend to integrate credible science with locally resonant narratives and accessible participation mechanisms, allowing conservation to scale socially alongside institutions and policy.

Connecting local action to global targets

The Kelp Forest Challenge, led by the Kelp Forest Alliance, was established in 2023 as a grassroots mission with the ambitious goal of protecting three million hectares and restoring one million hectares of kelp forests globally by 2040 (Eger et al. 2024a). Although numerous restoration projects are underway, global progress sits around 2% of the target, with the vast majority of progress made in South Korea (Eger et al. 2024c). Some regions, such as Norway (Norderhaug et al. 2025), California, Washington State, Chile, and Australia, are developing or have developed management plans for kelp forests which can be integrated into country wide reporting on global targets. These plans and their associated communities of practice provide an excellent opportunity to connect science to policy and advance meaningful action towards the Kelp Forest Challenge.

The proliferation of initiatives shows promise while stressing the need for coordinated actions to realize global change. Regional networks such as the Kelp Node (British Columbia and Washington State), NKELPA (Canada), EPaK (Northeastern Pacific), Blue Benguela Partnership (Southern Africa), MedGardens (Mediterranean), and global platforms such as the Kelp Forest Alliance provide important vehicles for coordination but require further development. Future efforts could build on the regional groupings presented here to co-develop report cards built on a baseline set of indicators, including ecological (e.g., hectares restored and protected, canopy extent, herbivore density, biodiversity indices), social (e.g., measures of community participation, demographic composition of participants and decision-makers), and governance (policies, funding, legislative engagement). Standardised but flexible frameworks can preserve local context while unified reporting (Eger et al. 2024b) allows aggregation into global assessments. Such baseline assessments can then help guide what conservation actions, targets and outcomes might be needed in each region.

Once regional priorities are identified, interested parties must still work to ensure they are enacted. In other words, science is needed to understand baselines and inform objectives but is not enough on its own to achieve the desired outcomes. One pathway for achieving this change is by linking to relevant policies to bolster implementation. Indeed, several adjacent policies related to climate adaptation, fisheries management, Indigenous rights, and blue carbon markets, can help secure government interest and further elevate kelp forests within regional, national, and international conservation agendas.

Conclusion

Kelp forest conservation is moving from scattered local effort to an increasingly connected global agenda, but this transition remains incomplete and highly uneven. Across 35 regions, we find that conservation is not progressing through a single dominant model, but through multiple themes shaped by different combinations of ecological threat, governance capacity, social legitimacy, funding structures, and implementation readiness. This diversity is a defining feature of how kelp conservation operates in practice under diverse local contexts.

At the same time, several common patterns emerge. Monitoring has become the foundation of conservation activities in many regions, multi-actor governance is now the norm rather than the exception, and public, research, and private funding are increasingly converging around kelp systems. Yet active restoration remains patchy, climate adaptation remains under-explicit, and many regions still lack the regulatory, financial, and institutional conditions needed to move from pilot efforts to durable programmes. The central challenge is therefore no longer simply recognising the value of kelp forests; it is building the systems that can consistently protect, restore, and govern kelp forests at larger scales.

Our comparative synthesis shows that scaling kelp conservation depends on more than better techniques. Scaling up will require systems shifts in how conservation is legitimised, financed, authorised, and communicated. Regions that are making the greatest progress are not only generating ecological knowledge, but also embedding kelp into policy, public awareness and engagement, strengthening public constituencies, aligning incentives, and creating pathways for implementation. Where those conditions are absent, even strong science and local commitment can remain limited to small-scale projects.

The Kelp Forest Challenge provides an important global framework for accelerating action, but global ambition will succeed only if it is matched by regionally and locally grounded implementation. The next phase of kelp conservation should focus on building comparable yet flexible reporting systems, linking area-based targets to ecological function, public policy, and social participation, and embedding kelp forests within global biodiversity, fisheries, and climate agendas. The regional assessments of kelp conservation status here can provide a geographic delineation for how future information is gathered and how action or management is coordinated. Regionally coherent frameworks are needed to connect local action with coordinated, scalable, and enduring global marine forest conservation.

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Declarations

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