KELP FOREST
ALLIANCE

STATE OF THE WORLD'S KELP FORESTS REPORT

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EGER, AARON M., MCHUGH, TRISTIN A., EDDY, NORAH, VERGÉS, ADRIANA (EDITORS).

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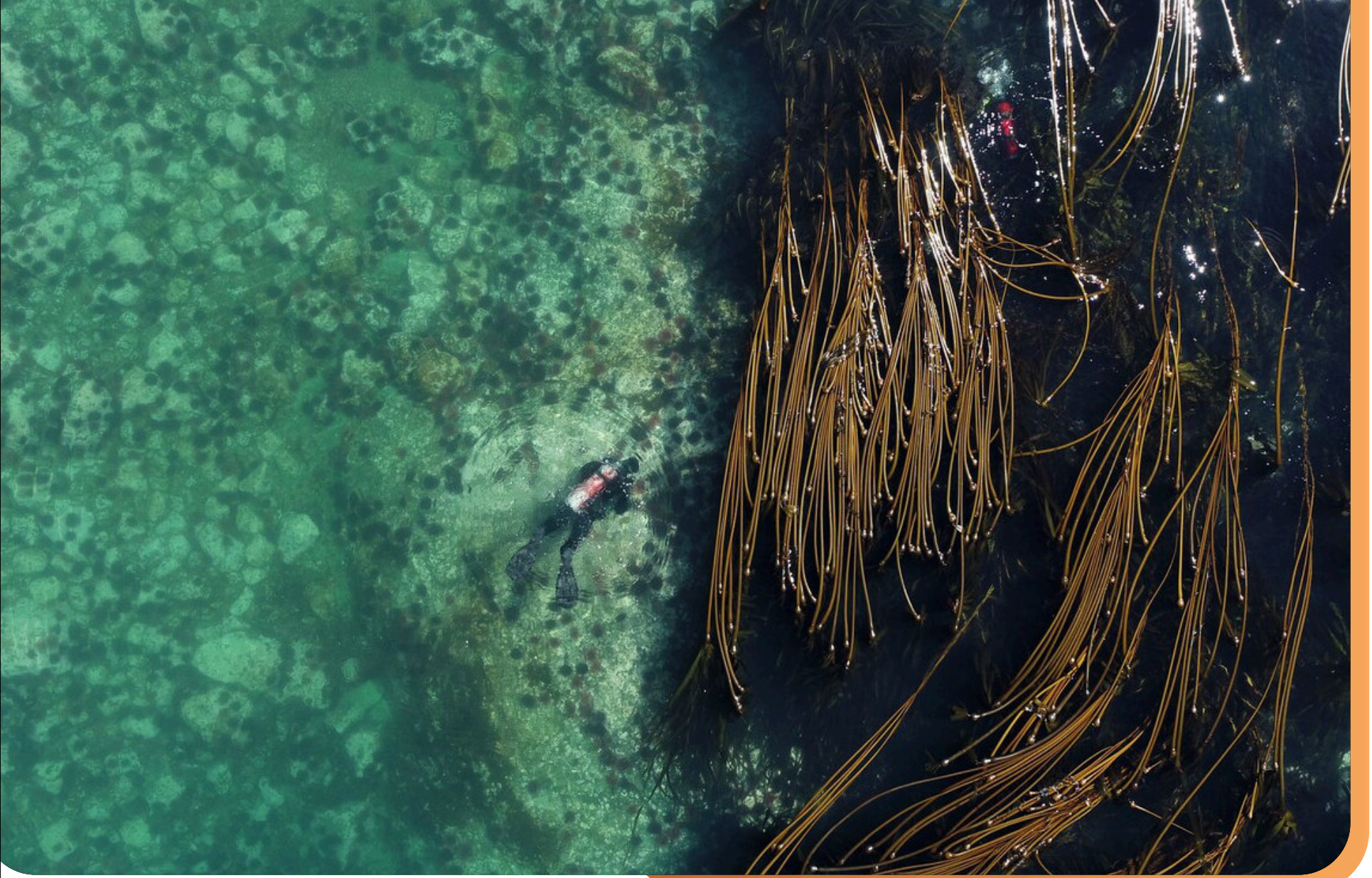

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The Nature Conservancy

UNSW SYDNEY

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Executive Summary

Kelp forests are some of the most important ecosystems on Earth, providing a wide range of benefits to both marine life and people. These underwater forests inhabit many of the world's coastlines, supporting countless species and contributing billions of dollars to the global economy. They also play a crucial role in absorbing carbon dioxide, cycling nutrients, and supporting fisheries. The economic value of these benefits is immense, estimated at over $500 billion each year. Additionally, kelp forests have the potential to help combat climate change by capturing carbon from the atmosphere and storing it in the deep ocean.

Despite their significance, kelp forests often go unnoticed in environmental policies and conservation efforts. The Kelp Forest Challenge works to ensure that kelp forests are included in nations' commitments to international agreements such as the Global Biodiversity Framework and associated 30x30 targets.

Protecting a kelp forest before it disappears should always be the first priority, and this strategy is critical for their long-term survival. While 16% of the world's kelp forests are protected, just 1.6% are in areas where activities like fishing are fully restricted. What's more, 6.8% are not classified in IUCN categories, hampering efforts to assess their conservation status. Effective conservation requires a combination of strict protection and sustainable management, and nearly all countries still need to increase their efforts to meet global conservation targets.

Efforts are being made around the world to restore kelp forests that have been lost or degraded. Countries like Japan and Korea have led the way, with government support driving successful restoration projects. Although kelp restoration is still a relatively new field, progress is being made, with ~19,000 hectares of kelp forests restored so far.

A growing global community is working to protect and restore kelp forests, with hundreds of participants from 25 countries. This community includes scientists, conservation groups, Indigenous Peoples, communities, and businesses, all working together to safeguard these vital ecosystems. Public engagement and community-driven efforts are becoming increasingly important in the fight to protect kelp forests.

There is a growing body of resources that have been developed to support kelp conservation efforts, including guidebooks, monitoring tools, and databases. These resources help people working in conservation to share knowledge and learn from each other's successes and challenges. Collaboration and information sharing are key to making sure kelp conservation efforts are as effective as possible.

Kelp forests are incredibly valuable ecosystems that play a vital role in supporting marine life, coastal economies, and even helping to fight climate change. However, they face serious threats from climate change, overfishing, and habitat destruction. Protecting and restoring these underwater forests is not only an environmental imperative but also a necessity for the well-being of communities and the planet. By working together, advancing our understanding, and committing to sustainable practices, we can ensure that kelp forests continue to thrive for generations to come.

Acknowledgement of Country

The Kelp Forest Alliance acknowledges the Gadigal people of the Eora Nation, the Traditional Custodians of the land where we are based, and we pay our respects to Elders both past and present. We also extend these respects to Indigenous people and organisations around the world. We acknowledge that all conservation works involving the traditional lands and seas of Indigenous people must be co-developed, create space for leadership, and integrate Traditional Ecological Knowledge into the decision-making process. We kindly invite any person or group to contact us to provide comments on this document and/or develop new kelp conservation programs.

Using this Report

This report brings together the best available information on the current status of kelp forest ecosystems in one location. The report can help you understand kelp forests, the benefits they provide, the threats they face, and the movement to save them. It provides the most up-to-date information at publication and will be updated as new information becomes available.

Please note the version number when citing the report or its chapters.

All data used to produce this report are **available here**.

Living in Australia, it's impossible not to recognise the vital role oceans play in our planet's health and our own lives. But our oceans are under threat.

As we face these threats, it is imperative that we evaluate the health of kelp forests and our progress towards meeting our goals.

Locally, 95% of Tasmania's Giant Kelp forests have disappeared, largely due to warming waters, creating a disastrous knock-on effect. This demands immediate attention and action.

Like many people, I was unaware of the importance and threats facing kelp forests. However, witnessing the scale of this issue firsthand has deepened our resolve. We're now dedicated to raising awareness and fostering collaboration to address this urgent national (and international) challenge.

As part of Google's Digital Future Initiative and the Kelp Forest Challenge, we've made a significant, multi-year commitment to help regrow and restore our Giant Kelp forests. This is a national issue with global consequences, and we believe technology can be a powerful ally.

We're partnering with organisations including the CSIRO, The Nature Conservancy, University of Tasmania, Great Southern Reef Foundation and the Kelp Forest Alliance to develop the first national map of Tasmania's remaining Giant Kelp forests, and we're using AI to help sequence and analyse the Giant Kelp genome, searching for the genetic keys to heat resistance. We're investing not only our technology and expertise, but also funding to build the local capacity needed for this crucial work.

As you can see, environmental restoration is not a solo endeavour. We're proud to join the long-standing and ongoing efforts of the Government, nonprofits, and the research community. To all businesses, large and small, we extend the invitation: join us.

Your contribution can take many forms. Financial or in-kind donations are invaluable, but even raising awareness among your employees, customers, and suppliers makes a difference. Every business has a unique role to play in protecting and restoring our Giant Kelp forests. Let's work together to ensure their survival for generations to come.

Mel Silva

VP and Managing Director, Google Australia

The State of the World's Kelp Forests Report is the result of collaborative efforts by many dedicated individuals and organisations. This report serves as a critical roadmap for scaling up the necessary actions and investments to protect and restore one of the planet's vital, yet often overlooked, ecosystems. As the first comprehensive assessment of kelp and its conservation actions, this report establishes a baseline for future management decisions and resource allocations in kelp conservation.

The report underscores the urgent need for increased awareness and action to conserve and restore this essential ecosystem that provides many ecosystem services, such as carbon sequestration and storage. The importance of kelp forests as a Nature-based Solution for climate change mitigation and adaptation is recognised in the Restoration Barometer. Yet, despite their significance and wide geographical distribution, these vital ecosystems remain undervalued and face serious threats from climate change and other anthropogenic influences.

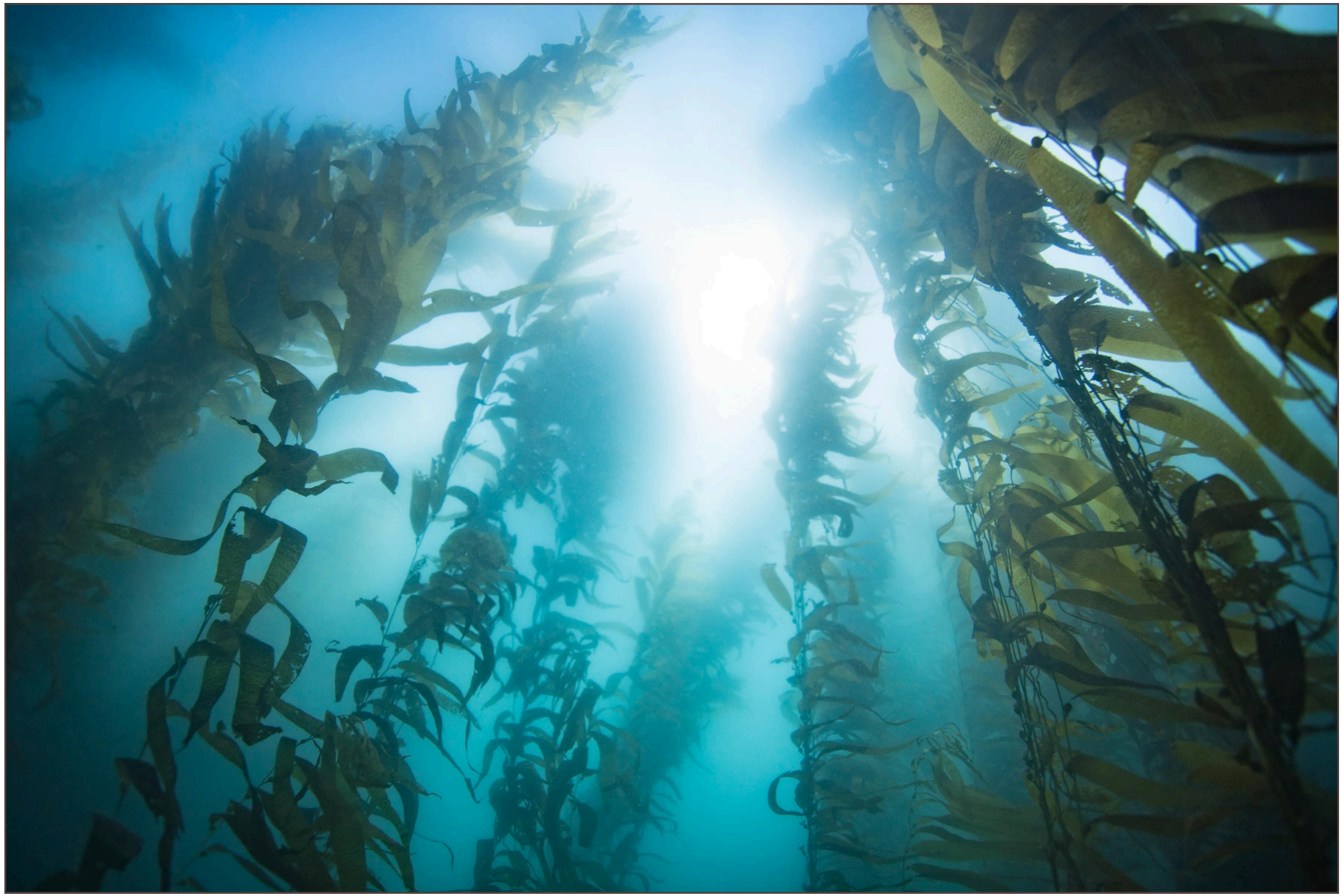
The global mission is clear: protect 3 million hectares and restore 1 million hectares of kelp forests by 2040. Launched at UNFCCC COP28 in November 2023, the Kelp Roadmap outlines actionable steps to achieve this ambitious target and serves as a baseline to guide our collective efforts.

The Kelp Forest Alliance is laying the groundwork for future kelp conservation efforts, from innovative site selection, to enhanced monitoring and policy tools. As a committed partner, and co-lead of the Marine Conservation sector of the Ocean Breakthroughs, IUCN is actively exploring the potential for a "Kelp Breakthrough" to elevate kelp restoration efforts alongside the global actions on mangroves, seagrasses, and coral reefs.

Together, through collaboration and commitment, we can ensure that kelp forests continue to thrive, contributing to a healthier ocean and planet for generations to come.

Trevor Sandwith

Director IUCN Centre for Conservation Action



I love kelp. I can usually smell it before I see it: that briny, earthy, seaweed scent that conjures childhood memories of running along the water towards piles of matted discovery. Where there is kelp, there are crabs, anemones, and, on lucky days, whales and furry ocean animals.

But it's no secret that kelp is threatened today by human activities and by a warming ocean with lower nutrients and more sea urchins. Climate change makes it more difficult for kelps to grow in the places where they have grown for all of human history, and poor water quality and harmful fishing can damage not only their structure and function but the biodiversity associated with kelp forests.

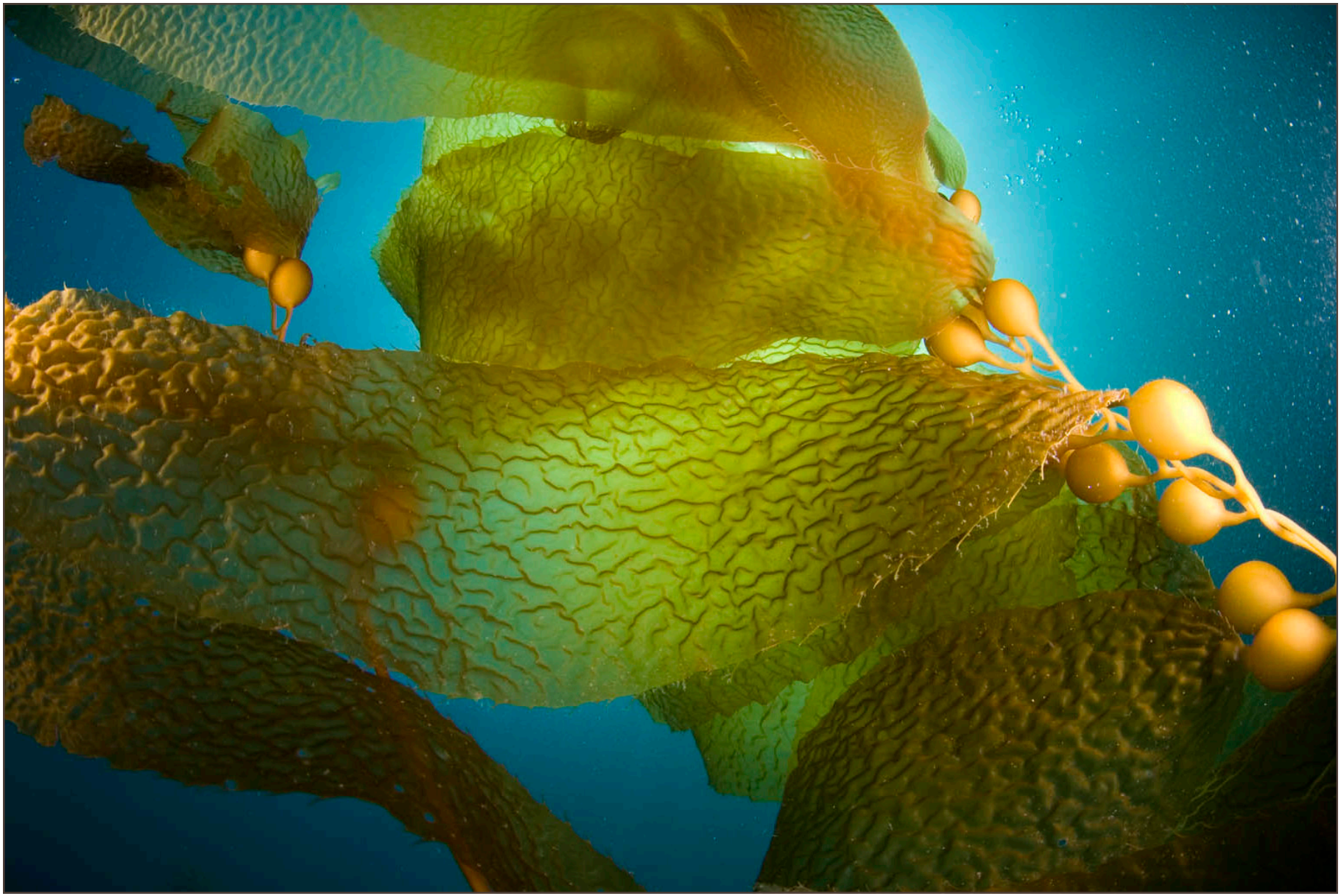
We know how important kelps are for ocean health and people too. They play a role in the identity and culture of Indigenous and coastal peoples, like the Chumash people living near the recently designated Chumash Heritage National Marine Sanctuary, who have used kelp for generations as medicine, food, and material.

Conserving kelp is going to require more than putting lines down on maps and claiming credit towards the global goals to protect 30 percent of the ocean. The threats facing kelp are as dynamic as the ocean itself and will require interventions tailored to the coastal communities nearby.

For too long, many decisions on how to manage ocean resources have been made without involving the people who have to live with those decisions, particularly Indigenous people. This is despite evidence showing that including Indigenous knowledge and values in conservation efforts leads to better outcomes for people and nature.

This report is an important step in ensuring that future generations of children can learn to love kelp and all that it supports. These data are an important tool for decision makers to help them better understand how much kelp is protected, restored, and threatened, and help us envision the path towards what we do next.

Angelo Villagomez,
Senior Fellow, Center for American Progress



1

1. Introduction

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1.1 Kelp Forests

As an ecosystem, kelp forests occupy a unique intersection.

On one hand, kelp forests grow on over one third of the world's coastlines, and over 750 million people live within 50 km of a kelp forest. These highly productive ecosystems generate 500 billion dollars of potential value each year and are some of the most productive ecosystems on the planet[1]. Thousands of animals live in or rely on a kelp forest, from iconic sea otters to treasured abalone, from the smallest snail to the largest whale. Humans, too, are inextricably tied to kelp forests and all the benefits they provide.

On the other hand, kelp forests are often overlooked or misunderstood. They are, in many places, our forgotten forests. For such important ecosystems, they are rarely defined or included in national or international policy and regulation[2]. In many countries, kelp forests receive a small (or near zero) fraction of the environmental-spending budget. This funding gap means that there are lower levels of knowledge and protection for kelp forests than there are for their land-based counterparts or even for better-known marine ecosystems like coral reefs or the deep sea.

But the tide is turning, and the number of kelp forest conservation activities (restoration, sustainable management, or protection) is increasing, as dedicated funding is becoming available. There is also an emerging consensus that kelp forests are becoming more visible to the public. This increase in kelp-based awareness and activity coincides with a growing global interest in topics such as "nature positive", "blue carbon", and "biodiversity credits". Putting all of this together means there is an opportunity to ensure that kelp forests are well represented in these emerging international initiatives as well as in the emerging social and market trends.

1.1.1 What is Kelp?

Kelp is both an organism and a habitat. As an organism, kelp is a structurally complex brown seaweed (**species list)**. However, much of the data presented are based on a subset of species: most commonly, species within the taxonomic groupings **Laminariales** and **Fucales**. Kelps are attached to the seafloor, grow vertically, create a leafy structure and canopy, produce oxygen, and cycle nutrients. Several kelp together create a kelp forest, yet notably the term 'kelp forest' does not have a strict definition. All kelps are a type of seaweed, but not all seaweeds are a type of kelp. Kelps create unique, complex, homes for animals in their blades ("leaves"), stipes ("trunks"), holdfasts ("roots"), and their very presence defines the ecosystem (Figure 1.1).

Simply put, kelp forests are the forests of the sea.

1.1.2 Distribution and Depth

Kelp forests are mostly subtidal (always under water), extending from the water's edge down to 15–25 metres: within the sunlight's reach. In particularly clear waters, they live at depths of up to 40–60 metres and, in very rare instances, all the way down to 200 metres. Kelp forests are cold-water (~0-25 °C) ecosystems and are distributed on every continent from the subtropics to the poles. The only kelp forests in the tropics are in very deep waters, and they occupy a small area[3].

1.1.3 Meet the Kelp

The many species of kelp come in many different shapes and sizes ranging from centimetres to tens of metres tall.

Canopy species: These species are over 10 metres tall from the seafloor to the surface. They have a strong holdfast gripping them to the seafloor, flexible stipes, and dense canopies that float on the surface, where they can often be seen from shore or by satellite.

Sub-Canopy species: These kelps have stiff, tree-trunk-like stipes that grow upright in the water with leaves growing from the top. They live only beneath the waves and do not break the surface.

Understory group: These kelps have big leafy branches that grow from the top of the stipe down to the seafloor. This creates a dense canopy that you have to brush aside to swim through.

Seafloor species: These kelps straddle the line between land and sea and form dense mats on the seafloor, where they are often exposed to the air at low tide.

Among these species, there are several notable species that have captured public attention, either for their ecological and economic significance or simply because of their impressive aesthetic.

Giant kelp (*Macrocystis pyrifera*) is one of the most iconic species of kelp, recognised for its dense, towering forests that are vital to marine biodiversity. It is a perennial species, present all year round, and commonly found along the Eastern Pacific from Alaska to Mexico. Further south, it is distributed across the southern coasts of Chile and Argentina, in the waters of South Africa, New Zealand, and Tasmania, and along Australia's southern coast.

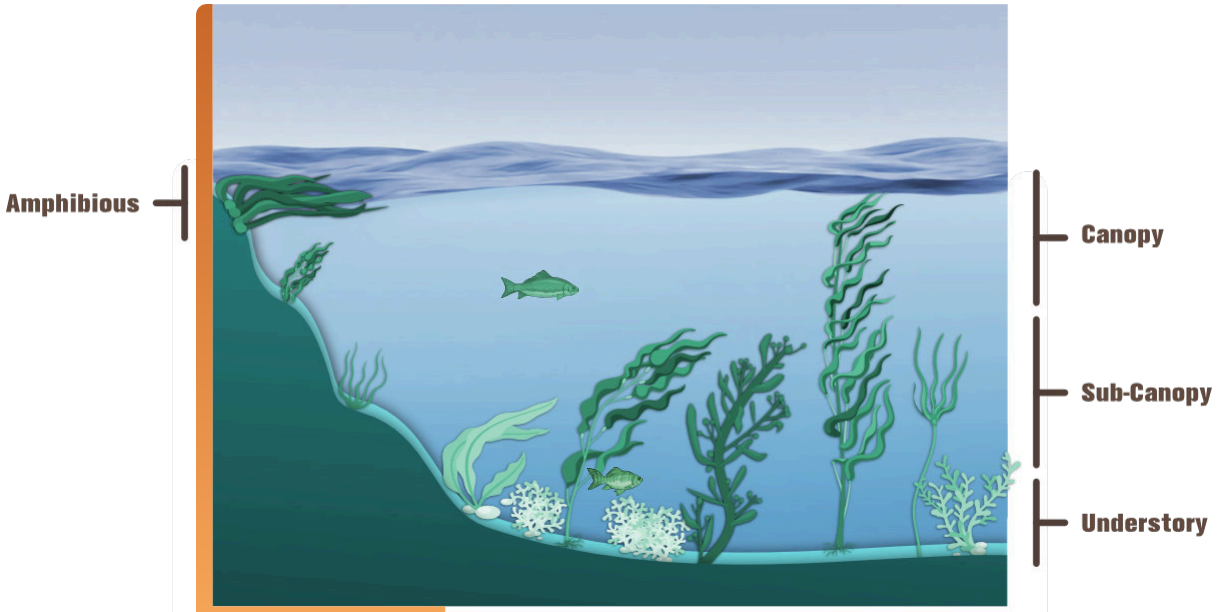


Figure 1.1
Diagram of kelp forest ecosystems (different forms)

Bull kelp (*Nereocystis luetkeana*) is found predominantly along the West Coast of North America, beginning in central California and extending to the Aleutian Archipelago. Bull kelp is an annual species with cycles of growth, reproduction, and senescence each year. It gets its common name from its bull-whip-like form and has been a highly regarded cultural component of Indigenous cultures in North America for millennia.

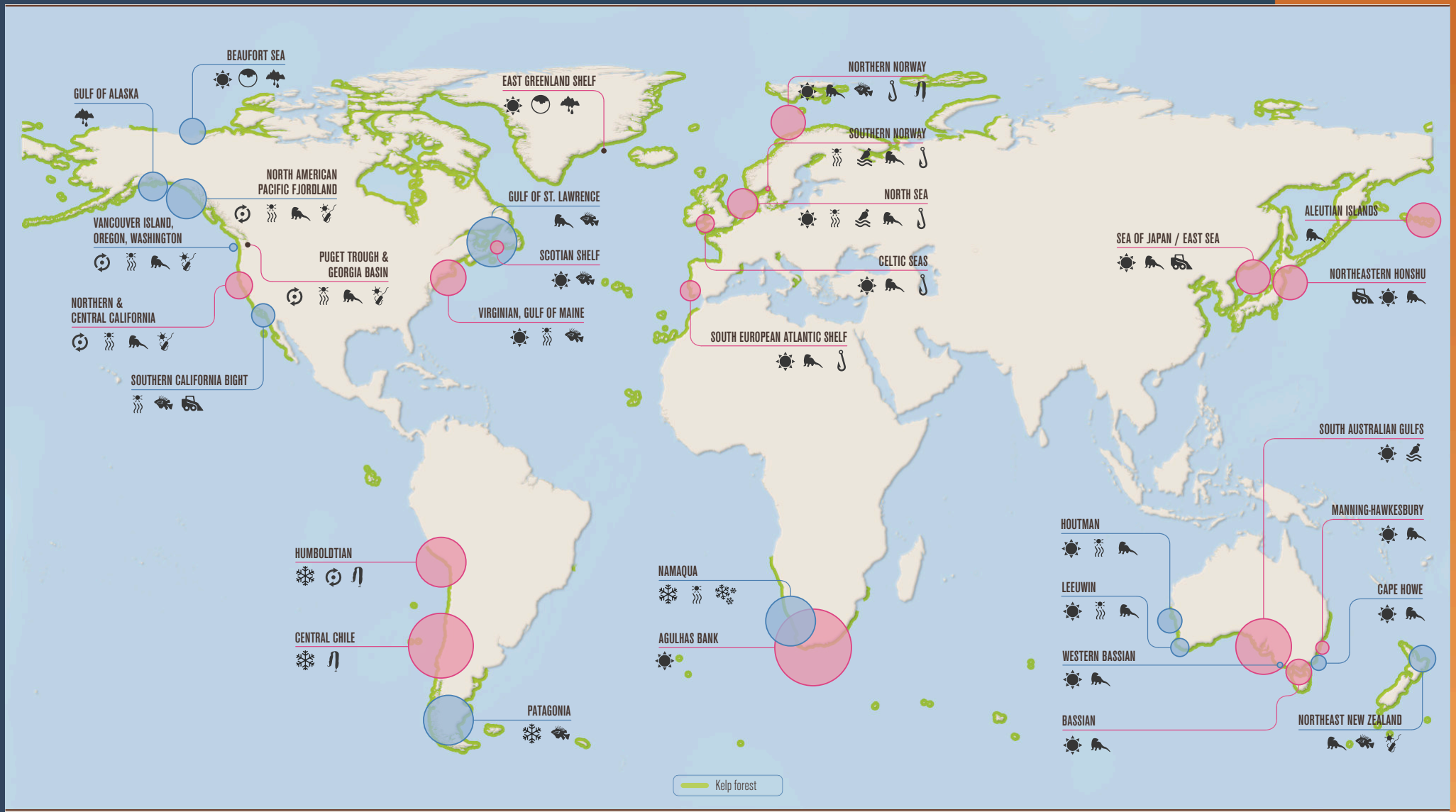
Golden kelp (*Ecklonia radiata*) forms extensive forests in the Western Pacific and is the key component of the Great Southern Reef on the southern half of Australia.

Bamboo kelp (*Ecklonia maxima*) is found only off the coast of South Africa, and sharks weave through its towering trunks. It was recently featured in the Oscar-winning documentary, My Octopus Teacher.

Laminaria and *Saccharina* are known for the big, broad leaves of many of their species. These species are well known for their use in food (known as kombu in Japan), are often grown for aquaculture, and have many important medical and chemical derivatives. They are widespread across the Pacific and North Atlantic.

Lessonia species are native to the southern Pacific Ocean. As they are often intertidal and subtidal, they provide critical connectivity habitat in coastal zones. *Lessonia* support one of the largest wild harvests of kelp on the planet.

The *Cystoseira* and *Fucus* fucoid kelps create shorter, dense meadows of kelp habitat along rocky seashores but are also found in subtidal regions.



Adapted from UNEP-Grid Arendal 2023. Data sources: Krumhansl et al (2016)

Note: Many of these data illustrated here are from before 2014, and although they represent the most comprehensive data-driven assessment of kelp trajectories to date, many of these ecosystems may have experienced changes in extent or distribution in the past decade that are not captured. (Wernberg et al. 2019). Additional data are from Gunderson et al. 2011, FIRA 2022, Japan Fisheries Agency 2023, Mora-Soto et al. 2021

Figure 1.2
Kelp Forest Stressors

1.1.4 Threats and Stressors

On average and across their distribution, kelp forests have been declining at a rate of 1.8% per year. As kelp populations are naturally variable and influenced by many different factors, the scale and direction of these changes varies widely across the globe (Figure 1.2 & Table 1)[4]. However, the overall trend is negative: long-term datasets suggest that ~60% of kelp forests have declined in their abundance[5].

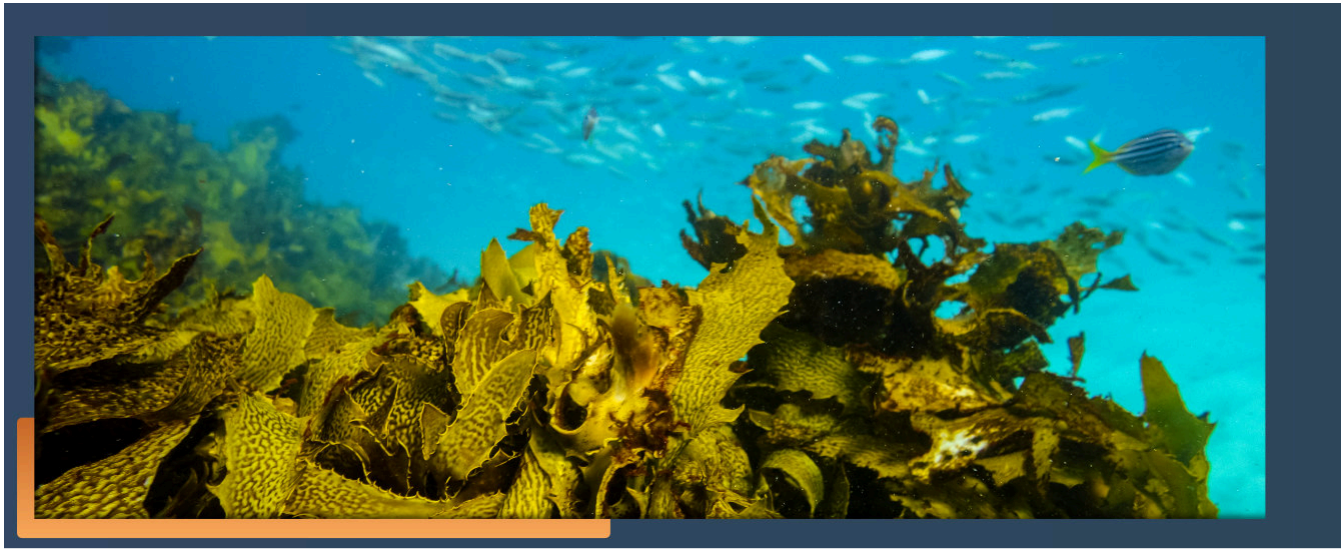
Declines are most evident at the warm range edges of kelp distribution where marine heatwaves add to regional warming and cause large-scale losses[6] . In many places, kelps in these areas are naturally replaced by more warm-adapted species of seaweed and fishes, which can limit recovery and restoration efforts[7].

In temperate, mid-latitude regions, most kelp forests are either decreasing or remaining stable, and which of these occurs often depends on how regional changes in sea temperature, e.g., warming or cooling, interact with other stressors such as kelp over-harvesting or grazing by sea urchins. Notably, these kelps have shown a better ability to persist or recover from extreme heat events compared to warmer-water populations.

Kelp populations tend to be stable or are even increasing in higher latitudes or in areas with cool population refuges, upwelling, cooling trends, or increasing cold spells[8],[9]. Elsewhere in these regions, cooler-water kelp populations are replaced by more warm-tolerant species. In these instances, there is no net loss in kelp cover, but the functioning of the community can shift considerably[10].

Though limited, the historic data suggest that Arctic kelp forests are generally stable or increasing, with limited local losses[11]. More recent surveys have also found highly abundant and previously undocumented kelp forests[12], so future warming may indeed result in an increase in Arctic kelp forests[13]. However, retreating ice may lead to increased sedimentation and salinity changes that cause these populations to decline.

Bright spots: Examples of places where kelps forests are stable and healthy.



Alaska – With cooler waters, more nutrients, and recovering food webs, the kelp forests of Alaska are faring well, and canopy kelp cover has increased in the region.

South Africa – The Great African Seaforest is made of four species of kelp, with some taxa like *Ecklonia maxima* expanding its range into cooler waters and currents that keep kelp healthy.

Patagonia – Home to the largest kelp forests on the planet, these remote waters have been protected from overfishing and pollution and rarely experience marine heatwaves. As a result, these kelp forests have been remarkably persistent over the past 200 years.

Worry spots: Examples of places that have had severe declines in kelp populations.

Tasmania – The waters around Tasmania are warming 4x faster than the global average, and giant kelp has declined steeply by 95%. As waters warm, nutrients decrease, and new sea urchin populations thrive, many solutions must be considered in the race to save these kelps.

Northern California – Perhaps the world's most famous marine heatwave, "The Blob" (2013-2015) coincided with the 2015-2016 El Niño event and marine disease outbreak which killed the sunflower star, the last remaining urchin predator in the region, subsequently reducing the bull kelp of Northern California by more than 95%.

Japan – At least 40% of Japanese kelp forests declined between 1978 and 2007. The causes of decline vary by region but include warming oceans, urbanization, and increases in sea urchins and herbivorous fish.

REGION	SUB REGION	DIRECTION OF CHANGE	KEY REFERENCES
Northeast Pacific	Southern California Bight, Baja California	Variable- Declines northern Baja California. Stable-central Baja California.	Arafeh-Dalmau et al. 2019, Cavanaugh et al. 2019, Bell et al. 2023.
	Northern California to Washington State	Variable – Washington, California, OregonDeclines - N. California, South Puget Sound	Pfister et al. 2017, McHugh et al. 2018, Hohman et al. 2019, Rogers-Bennett and Catton 2019, McPherson et al. 2021, Bell et al. 2020, Hamilton et al. 2020, Berry et al. 2021
	Western Canada	Variable, stable	Shroeder et al. 2020, Watson & Estes 2011, Starko et al. 2019, Costa et al. 2020, Mora-Soto et al. 2024
	Aleutian Islands	Declines	Estes et al. 1998
South America	Chile and Argentina	Declines – northern and centralStable – southern Chile and Argentina	Vasquez 2008, Mora-Soto et al. 2020, 2021, Friedlander et al. 2020
Northwest Atlantic	Virginian, Gulf of Maine	Declines	Feehan et al. 2019, Suskiewicz et al. 2024
	Nova Scotia, Gulf of St. Lawrence, Newfoundland	Variable, stable	Krumhansl et al. 2024, Navarez 2019
Northeast Atlantic	Southern European Atlantic Shelf, Celtic Seas, North Sea, Southern Norway	Declines – Northern and Southern Norway, Spain, Portugal, English Channel. Increases – Germany, mid-Norway	Araujo et al. 2016, Filbee-Dexter et al. 2020, Smale 2020, King et al. 2020, Christie et al. 2019
Southern Africa	Western South Africa	Variable, increases	Bolton et al. 2012, Blamey et al. 2015
	Eastern South Africa	Declines	Blamey et al. 2015
Northwest Pacific	Japan and Korea	Declines	Kirihara et al. 2006, Tanaka et al. 2012, Kang & Chung 2015, Jeon et al. 2015, Hong et al. 2021
Oceania	Western Australia - Houtman	Declines	Wernberg et al. 2013, 2016, 2020
	Leeuwin	Stable	Wernberg et al. 2013
	South Australia – South Australia Gulfs, Western Bassian, Cape Howe, Manning-Hawkesbury	Declines	Carnell and Keough 2019, Verges et al. 2016
	Tasmania	Declines	Johnson et al. 2011, Ling & Kean 2018
	New Zealand	Declines	Shears et al. 2008, Thomsen et al. 2019, Glover 2021
Arctic	Canada	Unknown	
	US – Beaufort Sea	Stable	Bonsell & Dunton 2018
	Norway (Svalbard)	Increase	Bartsch et al. 2016
	Russia	Increase	Krause-Jensen et al. 2020

Table 1.1

1.2 The Race to Help our Kelp

December 2022 marked the launch of the Kunming-Montreal Biodiversity Framework. This landmark agreement was signed by 196 countries and agreed to the effective restoration and protection of 30% of the world's ecosystems and the restoration of 30% of the world's degraded ecosystems by 2030 (often called 30x30)[14]. The agreement contains language that specifies that these gains should be representative of the ecosystems in each country's jurisdiction. As such, national targets for the protection and restoration of coastal ecosystems must be adaptive and ensure that all critical habitats are quantified and represented in these international discussions and target setting. As of 2024, countries only have six more years to achieve these targets, and it is imperative that we ensure that critical habitats such as kelp forests are included in these allocations.

February 2023 marked the launch of the **Kelp Forest Challenge**[15]. The Kelp Forest Challenge is intended to ensure that kelp forests are included in local and global marine management decisions, as previously, there were no international targets, policies, or agreements for kelp forests. The Challenge is a collaboratively developed mission to save our kelp forests around the world and is at the intersection of local projects and global initiatives such as 30x30. The Kelp Forest Challenge calls for:

1. The protection of 3 million hectares of kelp forests by 2040
2. The restoration of 1 million hectares of kelp forests by 2040
3. Increased awareness and appreciation of kelp forests
4. Increased funding to support these activities (target pending)

The Challenge provides an open, participatory, pledge-based system to incentivise kelp conservation and awareness raising. The Challenge intentionally encourages any section of society to participate, whether business, government, community, university, or individual. The Kelp Forest Challenge is hosted by the **Kelp Forest Alliance**, a global home for kelp forests that brings together people and information to help our kelp.

The Kelp Forest Challenge calls for holistic management of kelp forests, which requires a combination of strategies. These can include MPAs (marine protected areas), improved fisheries management, habitat restoration, and controlling invasive or overabundant species. This management will depend on collaborative efforts between local communities, governments, and conservation organizations, and its decisions should be grounded in scientific research, respect cultural contexts, and consider socio-economic activities to ensure sustainable and equitable outcomes for both people and marine ecosystems.

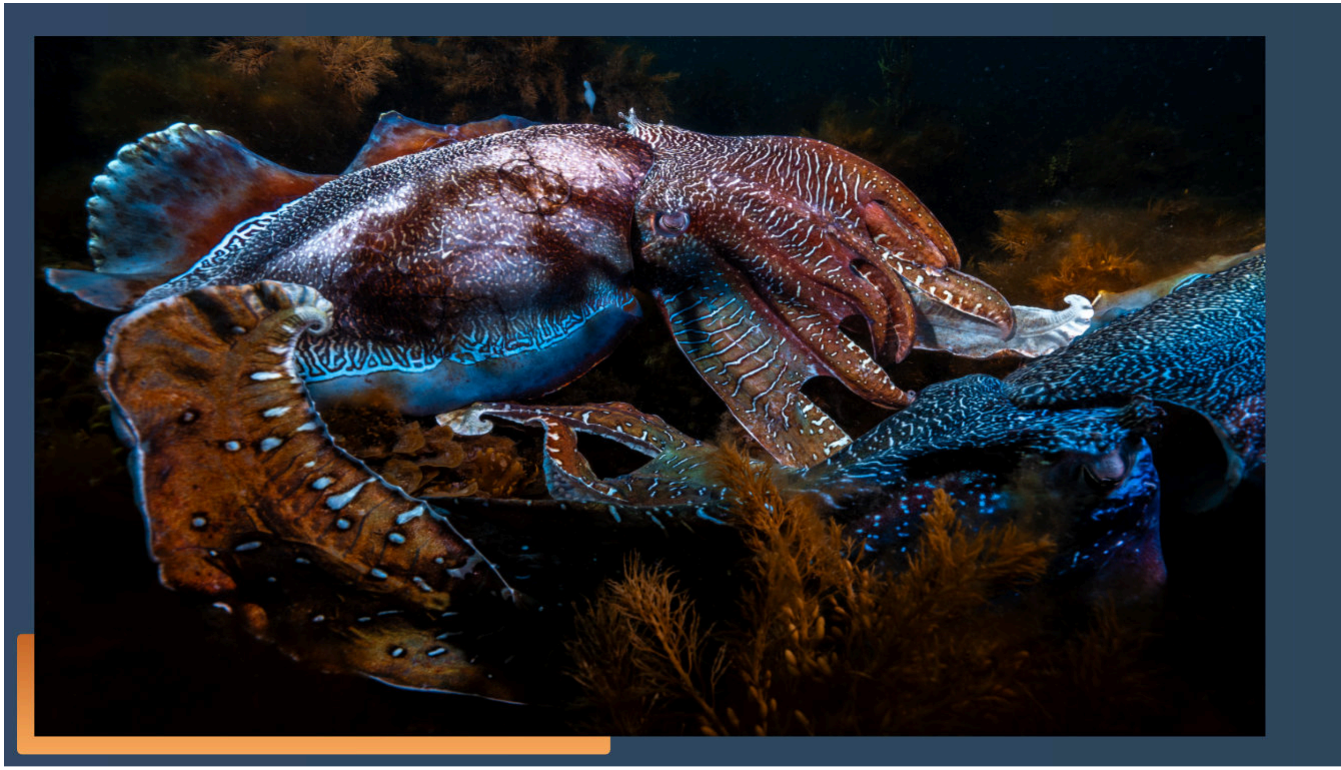
1.3 Pledge Spotlight

Although there has been much discussion about the role businesses can play in conservation, real-world examples of such support are often rare. The Kelp Forest Challenge invites a range of businesses to leverage their unique capacities and reach to support kelp forest conservation globally.

One example comes from Google Australia, which has dedicated resources, expertise, and capacity building to advance kelp forest conservation in Australia. Specifically, Google Australia has provided technical and financial support to:

- Use aerial imagery to map giant kelp forests in Southern Australia
- Complete sequencing of the giant kelp genome to understand genetic drivers of heat tolerance
- Raise awareness of kelp forests in Australia and worldwide through marketing, original content, and partner creators

Other potential pledgees are invited to consider how they too may support the Kelp Forest Challenge.



Endnotes

1 https://www.nature.com/articles/s41467-023-37385-0
2 https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2023.1235952/full
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7 https://besjournals.onlinelibrary.wiley.com/doi/10.1111/1365-2435.13310
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14 https://www.cbd.int/conferences/2021-2022/cop-15/documents
15 https://link.springer.com/article/10.1007/s10811-023-03103-y

2

2. Kelp Ecosystem Services

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2.1 Key Takeaways

1. Kelp forests provide a wide range of economic and cultural services to over 750 million people around the world.
2. The potential economic value of ecosystem services in kelp forests is over $500 billion USD per year.
3. Kelp forest fisheries (lobster, abalone, fish) generate tens of millions to billions of dollars for national economies each year.
4. Nearly 800,000 tonnes of wild kelp are harvested each year.
5. Kelp forests sequester ~32 million tonnes of CO_2 annually.

2.2 Services Provided by Kelp Forests

Kelp forests are foundation marine habitats that provide many different benefits to society. In economic terms, three key services are estimated at over 500 billion USD per year (Figure 2.1). These range from supporting fisheries to nutrient uptake to creating opportunities for recreation and spiritual fulfilment. As such, the value of kelp and what it can provide extends beyond the economic, but it is often helpful to communicate kelp's contribution to economy. The total economic value[1] of kelp forests' services is presented below, though other methods may produce different values, e.g., welfare value.

2.3 Wild Harvest

Kelp forests have directly supported coastal communities and provided food and materials to coastal communities for thousands of years. Here we define this direct provisioning from the sea as wild harvest. Across 14 countries, an estimated 600,000 tonnes of wild stocks are harvested annually (Figure 2.2). In the last five years, more than one million tonnes of wild kelp have been harvested in Chile, followed by Norway, Japan and Peru (477,352, 233,528 and 212,465 tonnes)[2].

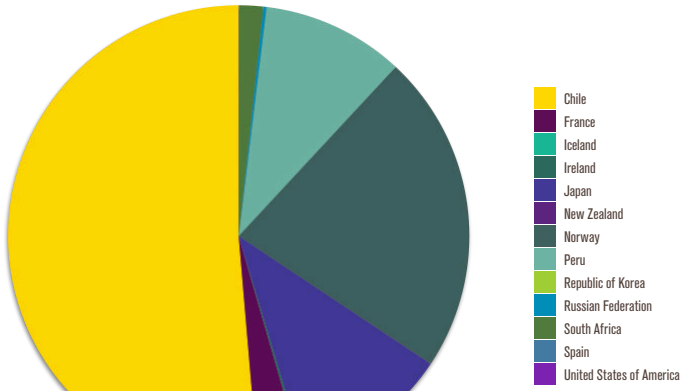

Figure 2.2
Wild Kelp Harvesting

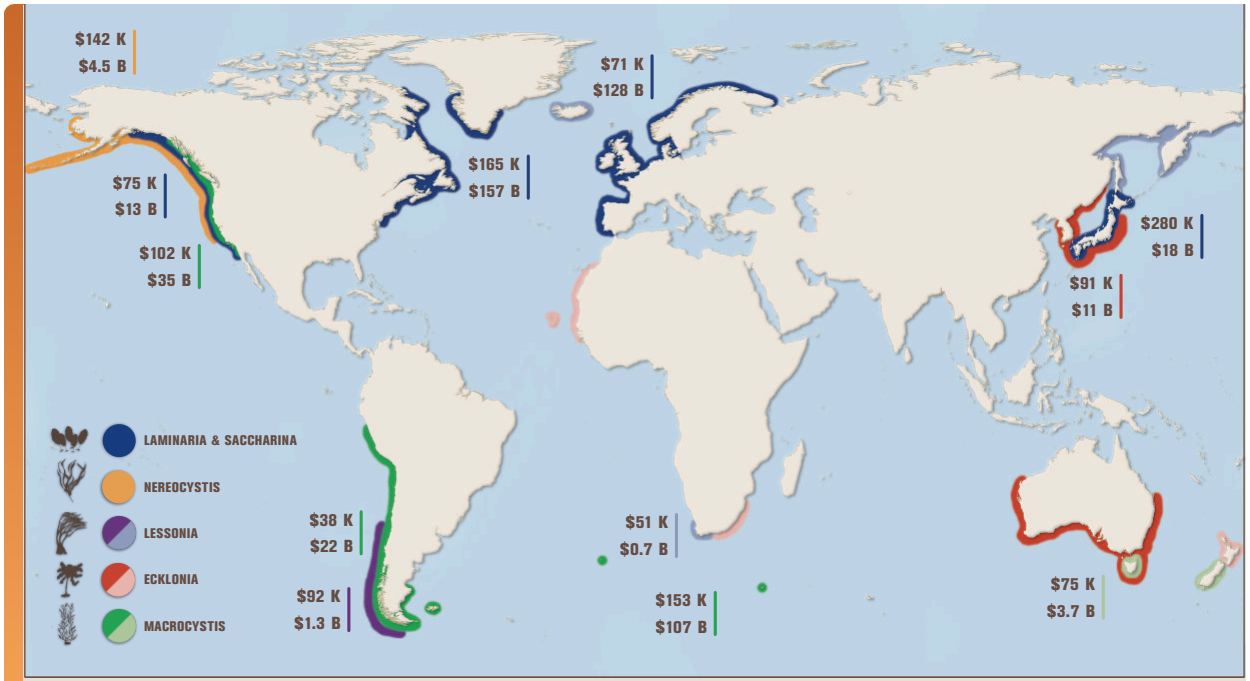

Figure 2.1
Map of Ecosystem Services

ECOSYSTEM SERVICE	KELP DESCRIPTION	KELP VALUE	SCALE
Seaweed aquaculture	Kelp aquaculture is dependent on wild kelp forests for breeding stock.	17.48 M tonnes/yr	Global
Wild harvest	Kelp (Fucales/Laminariales) harvested in 2021 across 17 countries.	0.77 M tonnes/yr[11]	Global
Wild fisheries	Fisheries relevant biomass. Key fishery species such as lobster and abalone.	2380 kg/ha/yr	Global
Nutrient absorption	Waste treatment/water purification, including nitrogen removal.	$17,608/ha/yr; Nitrogen removal - $73,800, 657 kg N/ha/yr[12]	Australia, Global
Nutrient absorption	Kelp beds deplete nitrate and phosphorus concentrations but enhance ammonium and DOC.	£2400 M/yr	UK, Global
Wave dampening	The presence of kelp may significantly affect coastal stability during storm events (modelled study).	NA	Global
Wave dampening and Current Flow	Canopy kelp forests have limited, but measurable, capacity to enhance shoreline protection from nearshore waves.	NA	Global
Nursery Habitat	Kelp forests serve as important nursery habitats for ecologically and economically valuable fish (e.g., mackerel, cod, rockfish) and invertebrates (e.g., lobster, abalone).	NA	NA
pH regulation	The chemical environment within kelp forests positively impacts calcifying organisms, acting as refugia from ocean acidification.	NA	Global
Carbon cycle	Net primary production	536 gC/m2/yr	Global
SCUBA/snorkel	Recreational divers interested in kelp monitoring and citizen science for purposes including exploration and absorption of wildlife, biodiversity, learning more about kelp ecology.	~$197.2 M/yr	Global
Traditional Ecological Knowledge related to kelp	Kelp has been documented as a food source, recreational item, tool, and material used in art across multiple traditional and Indigenous cultures.	NA	NA
Kelp ecology courses	Kelp holds high value as a source of scientific and applied research. Recreational divers interested in kelp monitoring and citizen science.	$25,957,253	Chile
Kelp arts, movies, etc	Artistic practices involving kelp (sculpture/painting), photography, and shell-stringing culturally important necklaces from species found in seaweed.	NA	NA
Habitat	Loss of kelp reduces net primary production (NPP), detrital flow, mobile invertebrate populations, fish and sessile invertebrate richness, but it increases benthic light availability, sub-canopy algae species cover and richness, and sessile invertebrate cover.	NA	NA

Table 2.1

2.4 Fisheries

Kelp forests are also critical habitats for many commercially and culturally important species, including abalone, lobsters, and fish; fish in particular being one of the major beneficiaries of kelp forests. It has been estimated that each hectare of kelp supports an average of 904 kg of harvested fish and seafood annually[3].

Lobster and abalone are the most valuable fisheries in several countries. Approximately 3,060 tonnes of abalone and rock lobster are harvested annually in South Africa, with an estimated economic value of US$ 299.3 million per year. In total, 38 species with economic value linked to kelp forests are found in South Africa[4]. In Australia, approximately 9,199 tonnes of rock lobster and 3,614 tonnes of abalone are harvested annually, generating an estimated US$ 512.6 million per year[5].

In addition, fisheries associated with kelp forests are also significant in other countries. In the USA, there are at least nine fisheries with economic value associated with kelp forests[6]. Seven fisheries in the UK are linked to kelp forests, with the rocky lobster fishery generating an estimated US$ 38.4 million per year[7]. In Spain, 32 species are fished in kelp forest areas, with an estimated annual revenue of approximately US$ 18 million[8].

2.5 Carbon Removal

Kelps have very high carbon-fixation rates, an extensive distribution, and are increasingly being viewed as a tool for carbon dioxide removal to help mitigate climate change. Kelp forests were recently shown to transfer significant quantities of carbon to the deep ocean, where it can remain sequestered for >100 years[9]. These estimates suggest that a metre squared of kelp forest may sequester between 5 to 30 grams of carbon in the deep ocean every year. Globally, kelp forests are thought to sequester 8.6 million tonnes (range of 2.6 - 14.7) of carbon every year (32 million tonnes of CO_2), with forests in Australia, the USA, New Zealand, Chile, and Peru having the greatest sequestration potential.

These estimates show that it is feasible—albeit technically complex—to link management actions such as protection and restoration to specific amounts of CO2 sequestered from the atmosphere. If done correctly, these methods can provide the basis for carbon credits in kelp forest ecosystems. It is important to stress that preventing the loss of kelp forests is the most cost-effective strategy to avoid losing their carbon removal capacity, as well as safeguarding the numerous other benefits they provide[10].

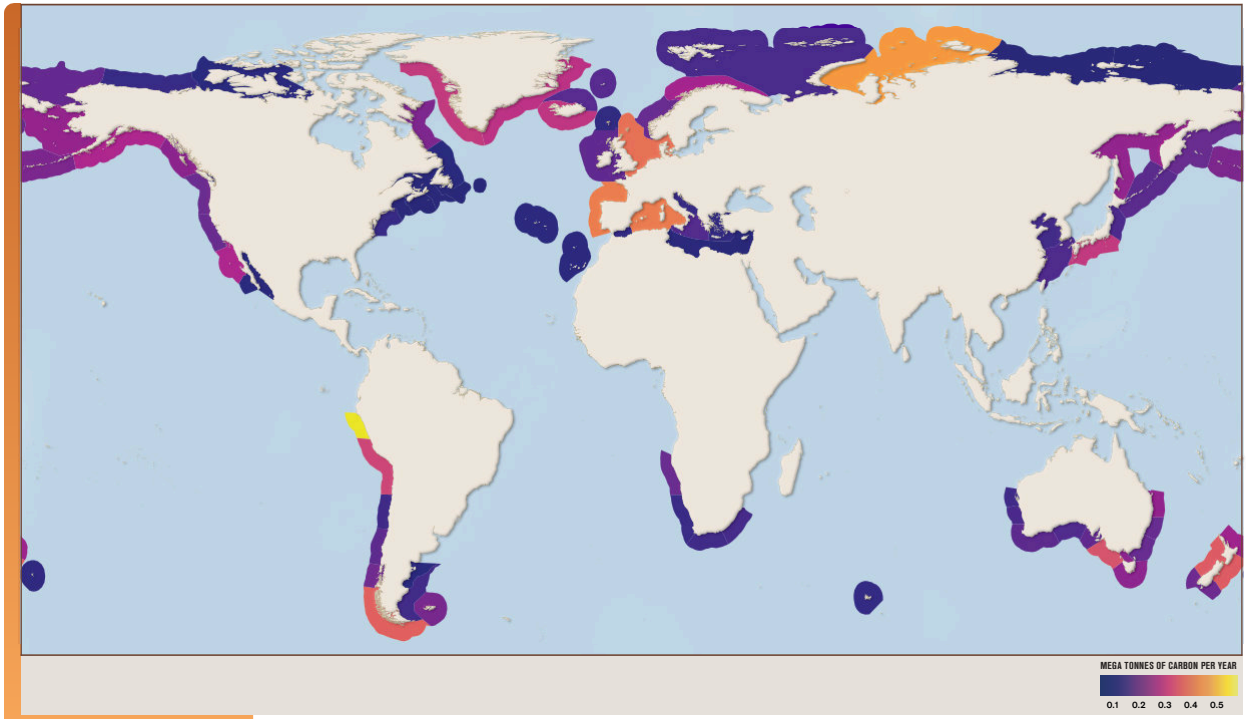

Figure 2.3
Map of Carbon Sequestration

Endnotes

1 https://www.sciencedirect.com/topics/earth-and-planetary-sciences/economic-valuation-of-ecosystem-services
2 https://www.fao.org/fishery/en/collection/capture
3 https://www.nature.com/articles/s41467-023-37385-0
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7 https://onlinelibrary.wiley.com/doi/full/10.1002/ece2.1774
8 https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2022.973251/full
9 https://www.nature.com/articles/s41561-024-01449-7
10 https://onlinelibrary.wiley.com/doi/full/10.1111/brv.12990
11 https://www.fao.org/fishery/en/collection/capture
12 https://www.nature.com/articles/s41467-023-37385-0

3. Kelp Area Restored

Authors:
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3.1 Key Takeaways

1. Kelp restoration is a relatively new field compared to other ecosystem restoration projects.
2. The amount of kelp forest area restored around the world is accelerating.
3. Government-level support has led to successful restoration projects in Japan and Korea.
4. The world has restored approximately 2% (~19,000 ha) of the Kelp Forest Challenge target of one million hectares.
5. The best predictor of successful restoration is proximity to an existing forest, and the priority should always be to restore a kelp forest before it disappears.

3.2 Database

The Kelp Forest Alliance maintains a global database of kelp forest **restoration projects** worldwide. It allows registered users to upload the outcomes of their restoration projects and contribute to the global tally. As of publication, there were 239 projects uploaded from 15 countries, and these entries were used to generate the report figures. While the database is inclusive of project types and countries of origin, it is currently only available in English, and results are biased as a result. The people and organisations related to this database are described in Chapter 5.

South Korea
RESTORED : 14,686 ha

United States of America
RESTORED : 2,813 ha

Japan
RESTORED : 1,151 ha

Norway
RESTORED : 110 ha

Australia
RESTORED : 44 ha

Canada
RESTORED : 20 ha

New Zealand
RESTORED : 7 ha

Italy
RESTORED : <1 ha

Denmark
RESTORED : <1 ha

Spain
RESTORED : <1 ha

Chile
RESTORED : <1 ha

China
RESTORED : <1 ha

Portugal
RESTORED : <1 ha

Global Kelp Restored : 18,849 ha

Global Target : 1,000,000 ha

Figure 3.1
AREA RESTORED BY COUNTRY

3.3 State of Kelp Restoration

Modern kelp restoration started in 1958 and has since seen ~19,000 ha (2% of the Kelp Forest Challenge) of kelp forest area restored (Figure 3.1). Most projects to date have been quite small in area, with ~75% of projects undertaken in the last 70 years under 3 ha in size (Figure 3.2).

Japan and South Korea have restored the most area and have often led the field in past decades. This success has been achieved through a combination of political will, advanced systems for growing kelp, and reliable, long-term project funding and support by the federal government. Elsewhere, kelp restoration work has been largely experimental, supported by limited funding and policy interest[1] and with new methods still under development. These factors have resulted in only small areas being restored in many regions. For example, the United States and Australia have recorded many individual projects (Figure 3.3) over the years but have restored little total area since the 1990s.

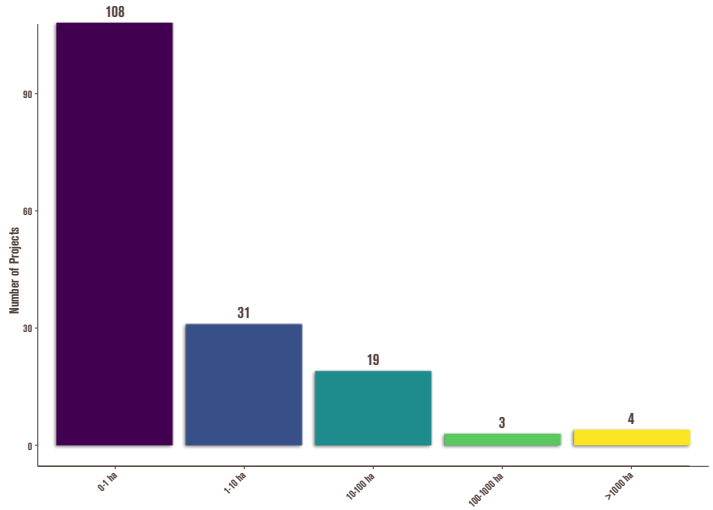

Figure 3.2
Projects by Size

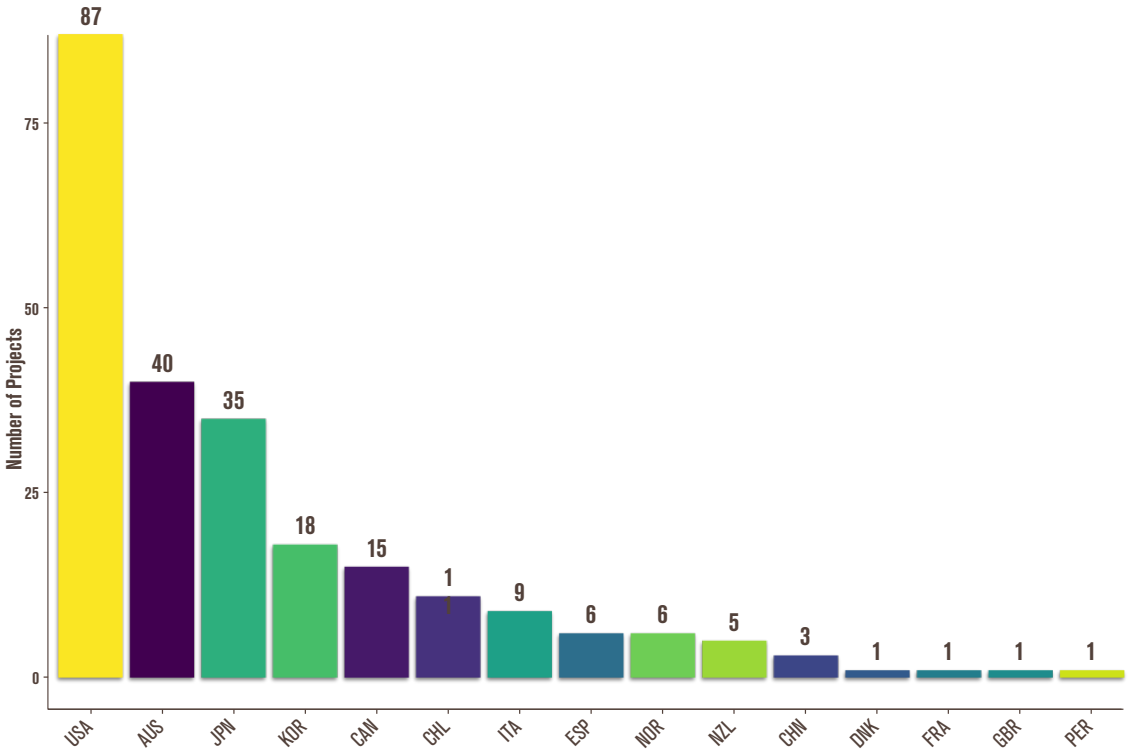

Figure 3.3
Projects by Country

3.4 Successful Restoration

Restoration is most successful when it is done at ecologically meaningful scales (> 1-10 ha), when in close proximity to an existing kelp forest, when the original reason the kelp disappeared is addressed and removed, and when it provides ecological, social, and economic benefits to communities. Success in kelp restoration is best shown by the projects in Japan and Korea. These projects have been well funded by government-backed programs, and this involvement ensured the resources and stability needed to achieve such success. As a result, the projects have restored kelp forests at large scales and seen meaningful ecological and social benefits such as the revival of fisheries[2].

To provide the best chance of large-scale restoration success, future projects should learn from past lessons, while governments should model the stable and committed funding models found in Japan and Korea.

South Korea is home to the world's largest kelp restoration project. Starting in 2009, the federally run Korean Fisheries Resource Agency pledged to restore 54,000 ha of kelp forests by 2030 and has now placed 29,000 ha of area under restoration across the country, with an approximate success rate of 50%. The project initially relied on artificial reefs and transplants, but after facing public opposition to eco engineering, it shifted towards restoring rocky reefs instead of creating new habitat. Restorative techniques leverage the country's aquaculture expertise, including rearing kelp for planting and dispersing zoospores. South Korea has also seen a growing interest in the management of sea urchin populations. The role of these populations in the failure of earlier restoration efforts is being addressed, and this is vital given that urchin barren formation continues to be a prevalent inhibitor of kelp persistence here and globally[3].

Japan has trialled many different restoration methods over the years, with hundreds of projects in the last century. While records for many historic projects are difficult to access in English, there is evidence from the Shizuoka prefecture of the world's largest single restoration project using transplants (870 ha). Japan has now launched J-Blue Credit, the world's only blue carbon kelp forest credit, so new projects are being accelerated. Since 2022, ~600 ha of kelp forest has been restored under this initiative[4].

Resources for Guiding Successful Implementation

The **Kelp Restoration Guidebook** provides the most comprehensive information for effective and ethical kelp forest restoration, starting with project management and continuing all the way through the process to reporting.

An overview of The Korean Fisheries Resources Agency guidelines (translated) is provided **here**, and an overview of the Japanese kelp restoration lessons is **provided here** (Japanese).

The Kelp Ecosystem Monitoring Guidelines also provide support for standardised data collection and reporting in kelp forest ecosystems, restored or otherwise. These guidelines will be useful in better quantifying the benefits resulting from kelp restoration.

3.5 Future Restoration

As kelp restoration grows into an established field across the world and our oceans continue to face existential threats, there is a pressing, yet achievable, need to scale up the number and size of restoration projects. Countries such as Australia, the United States, Canada, and Chile have documented significant kelp decline and may now take the opportunity to scale up their existing restoration projects. There are already emerging large-scale restoration projects in Sydney, Tasmania, Northern California, and Southern Chile. Importantly we also need to act by stewarding and restoring before another headline about a 95% kelp forest decline grabs our attention.

A global roadmap for upscaling kelp forest restoration can be found **here**. However, each country needs to make its own assessment of the amount of area that should be restored, can be restored, and how and where that restoration will take place.

New restoration projects can connect with emerging initiatives such as Nature Based Solutions, the Nature Positive Movement, Natural Capital Account, and, where appropriate, Blue Carbon, such as Japan's J-Blue Credit.

Endnotes

1 https://onlinelibrary.wiley.com/doi/full/10.1111/brv.12850
2 https://www.frontiersin.org/journals/marine-science/articles/10.3389/fmars.2020.535277/full
3 https://kelpforestalliance.com/korea-kelp-restoration-manual
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4

4. Kelp Area Protected

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Nur Arafeh-Dalmau, Annalisa Falace, Jennifer Caselle

4.1 Key Takeaways

1. Most countries need to significantly increase the amount of protected kelp forest habitat over the next six years to meet their 30x30 commitments to the Global Biodiversity Framework.
2. Current data show that 16% of kelp forests are under some form of protection, but only 1.6% of kelp forests are in highly protected areas.
3. Increasing the area of kelp protected should be achieved through a combination of highly protected areas, sustainably managed areas, and traditionally managed areas.
4. 6.8% of areas are not classified in IUCN categories, and few MPA areas overall have been assessed to determine whether or not fishing is adequately managed. Addressing these gaps is a priority.
5. Protection must balance the need to limit activities like fishing while sustaining local cultures and livelihoods.

4.2 MPAs and Kelp Forests

Marine Protected Areas (MPAs) are essential spatial management tools for supporting marine biodiversity by restricting human activities that impact marine life. As a result, the amount of the ocean protected has increased in the past decades. The level of protection varies by MPAs, with some fully restricting activities like fishing, while others allow limited and sustainable use. Although restricted and well-managed MPAs may be the greatest benefit for biodiversity[1] and can provide opportunities for local stakeholders and rights holders, they can also create conflicts. Combining multiple forms of protection is crucial to conserve kelp forests effectively while also accommodating the rights and needs of Indigenous Peoples, local communities, and industries.

MPAs benefit kelp ecosystems by directly or indirectly protecting kelp populations, associated fish, invertebrates, birds, and marine mammals. Directly, they can regulate kelp harvesting and limit development, while indirectly, they protect species vital to kelp health. These include creatures such as predators of sea urchins, and the presence of these predators helps control urchin populations and promotes kelp growth[2]. Overall, MPAs have a positive impact on kelp populations, associated biodiversity, and can help maintain a diverse and healthy ecosystem.

4.3 Protection Classifications

The International Union for Conservation of Nature (IUCN) classifies MPAs into seven categories (Ia-VI) based on their protection levels:

1. **Ia (Strict Nature Reserve)**: Areas strictly protected for biodiversity and research, with minimal human interference.
2. **Ib (Wilderness Area)**: Large, unmodified areas where human impact is minimal.
3. **II (National Park)**: Protected areas managed mainly for ecosystem protection and recreation.
4. **III (Natural Monument or Feature)**: Areas protected for specific natural features.
5. **IV (Habitat/Species Management Area)**: Areas actively managed to maintain, conserve, and restore specific species and habitats.
6. **V (Protected Landscape/Seascape)**: Areas where the interaction of people and nature over time has produced a distinct character with significant ecological, cultural, and scenic value.
7. **VI (Protected Area with Sustainable Use of Natural Resources)**: Areas that allow sustainable use of natural resources while ensuring long-term conservation.

Ideally, using a mix of management strategies allows for tailored conservation approaches that balance strict protection with sustainable use and the respect of different socio-cultural needs. For instance, strictly protected areas (Ia and Ib) can preserve critical habitats and biodiversity hotspots, while categories V and VI can support sustainable livelihoods and cultural practices.

Currently, 6.8% of established MPAs globally have not been classified into an IUCN category, and 86% of all MPAs have not been assessed to confirm if the MPA is truly effective in limiting fishing. Together, these gaps make it challenging to assess the effectiveness of MPAs in protecting kelp forest ecosystems. Ongoing efforts aim to improve the mapping and classification of these areas to better inform conservation strategies and policy decisions.

Figure 4.2
Area Protected by Country

4.4 Total Kelp Protected

This report estimates the amount of Laminarian kelp forest protected by overlaying a published kelp forest biome[3] with a map of marine protected areas categorised by the protection level of those MPAs[4] (see section 8 for full methods).

There is an estimated 15.9% of kelp forests in some form of protected area worldwide (Figure 4.1, as of January 2024). Only 1.6% of these areas are currently classified in IUCN protection categories Ia-III, the highest levels of protection. Approximately 4.2% of kelp is in the lowest form of protection (level VI). Further, a significant portion of kelp under protection is in areas not currently categorised (6.35%, not reported, not assigned, not applicable, Table 4.1).

Despite most countries not meeting the 30x30 targets, South Africa and some sub-national regions in the USA recently established a network of MPAs that currently protect more than 10% of their floating kelp forests[5]. These processes followed participatory approaches based on scientific guidelines.

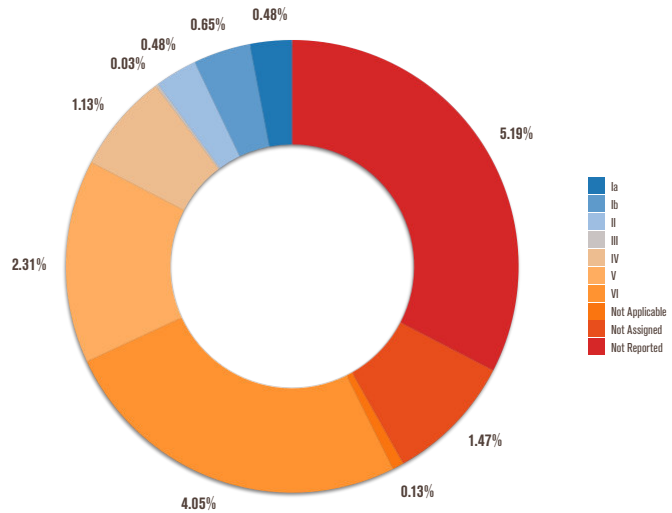

Figure 4.1
Area Catagories

Protection of Fucoids in the Mediterranean

In the Mediterranean Sea, Fucoids (as opposed to Laminarians) from the groups *Cystoseira sensu lato* complex and *Sargassum* spp are the dominant kelp species, as well as the endemic *Fucus virsoides*. The *Cystoseira s.l.* complex is a key group recognised by the European Commission as a habitat of Community interest[6]. The proportion of Mediterranean fucoid forests under protection is currently unknown.

Across the region, as of 2020, 10% of the Mediterranean was classified under some form of protection. However, only 2.5% had a management plan, 1.25% was effectively managed, and 0.03% was in fully protected areas[7].

There is, however, an important opportunity to enhance protection and restoration of fucoids following the adoption of the EU Nature Restoration Law in June 2024, which mandates the restoration of 20% of the EU's land and marine areas by 2030. This law emphasises, in particular, the urgency of marine forest restoration.

Deep Water Kelps

While kelp forests commonly live in shallow waters (< 25 m), there are several known deep-water kelp forests around the world. The conservation status of these populations is particularly difficult to assess, as we have poor maps of their current distribution and an even poorer understanding of their historic distribution. Deep water kelp populations include those in the Galapagos Islands (*Ecklonia galapagensis*), Brazil (*Laminaria brasiliensis* and *Laminaria abyssalis*), Madeira and the Azores (*Laminaria ochroleuca*), and the Mediterranean (*Laminaria rodriguezii* and *Laminaria ochroleuca*). A population of *Ecklonia radiata* in Oman has presumably gone extinct.

As these kelp forests become better mapped, they too will need to be included in conservation targets. Otherwise, they may be lost or threatened as a result of warming oceans or human activities such as trawling; the Mediterranean populations of deepwater *Laminaria rodriguezii* and *L. ochroleuca* have declined by 85% in the last 50 years due to trawling[8].

4.5 Kelp Protected by Country

Only Japan has met their CBD (Convention on Biological Diversity) target of protecting 30% of their kelp forest habitat by 2030. Four additional countries (France, Norway, the United Kingdom, and Spain) have more than 30% of their kelp forests inside MPAs, although most of the kelp area in these countries is unclassified in the IUCN schema. Very few of the classified areas in these five countries are fully protected (Japan - 0%, France - 0%, United Kingdom - <0.1%, Norway - 3.94%, Spain - 0.24%). Given that well-managed MPAs are the most effective type of MPAs, these countries will need to consider increasing existing protection levels to effectively meet the 30x30 targets. Most countries assessed (14/25) have protected 10% or less of their kelp forest habitat. Except for Mexico (see section 8.1), no country has over 5% of its kelp habitat in a highly protected area (IUCN Classification Ia-III).

Endnotes

1 https://academic.oup.com/icesjms/article/75/3/1166/4098821
2 https://pubmed.ncbi.nlm.nih.gov/38546039/
3 http://dx.doi.org/10.1016/j.biocon.2021.109099
4 https://www.protectedplanet.net/en/thematic-areas/wdpa
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6 https://eunis.eea.europa.eu/habitats/10009
7 https://wwfeu.awsassets.panda.org/downloads/wwf_towards_2020_how_mediterranean_countries_are_performing_to_protect_their_sea.pdf
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5. Kelp Community

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5.1 Key Takeaways

1. There is a growing global kelp conservation community, with hundreds of active people working across 25 countries.
2. Academic and NGO groups represent over 50% of the kelp conservation community, which also includes Indigenous Peoples, business, government, media, community and educational groups, impact investors and philanthropists.
3. There are a growing number of alliances, working groups, and resources available to help empower future kelp protection and restoration efforts.

5.2 Kelp forest Community

Kelp covers one-third of the world's coastlines, and as such, the communities of people surrounding these ecosystems are vast and diverse. The Kelp Forest Alliance maintains a database of the people and organisations involved in kelp forest conservation worldwide. Participants register voluntarily to the platform, which includes over 550 people and 316 organisations from 25 countries, and new data are continuously added as people register. These data are accessible to users who create a community account on the Kelp Forest Alliance platform.

The United States and Japan have the largest kelp conservation communities in the KFA database, with nearly 50% of the world's organisations (Figure 5.1) coming from those two countries, followed by Australia, Canada, and the United Kingdom. However, differences in working languages are skewing these results, and English-speaking countries are likely over-represented.

Academia is the largest sector involved in kelp conservation, representing ~32% of all involved, followed by NGOs, who represent ~15%. Other community representatives come from business, government, media, community and educational groups, impact investors, philanthropists, or are Indigenous rights owners (Figure 5.2).

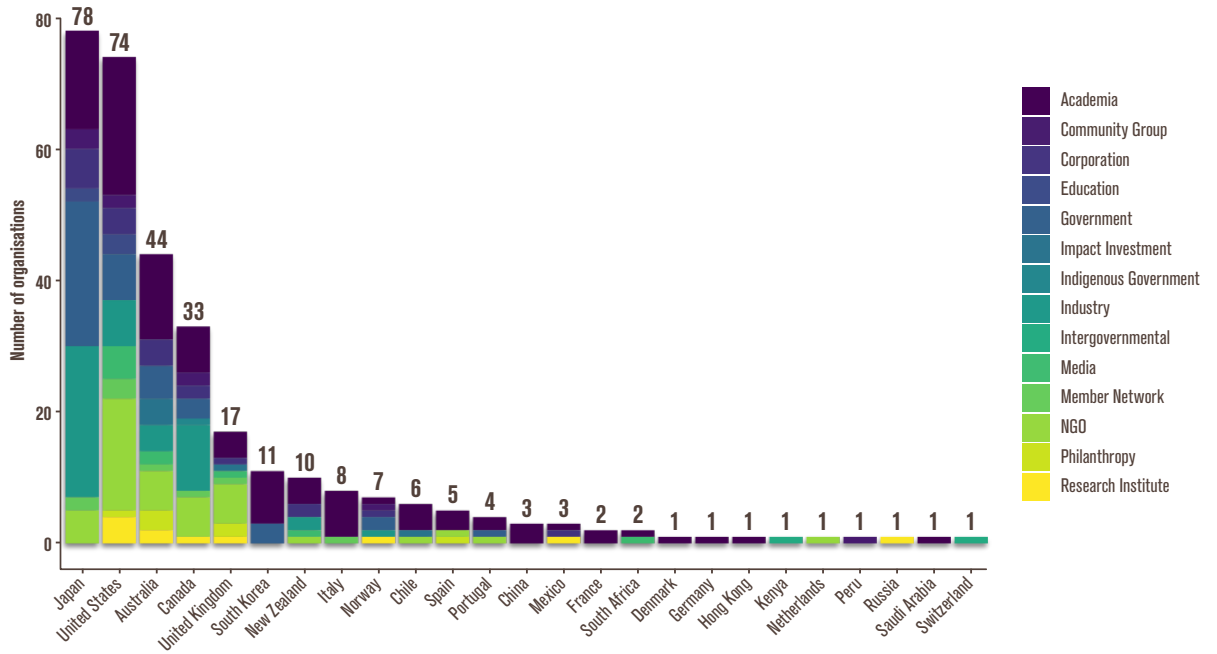

Figure 5.1
Organizations by Country

Within academia, there has been an exponential increase in the number of scientific articles in international journals that focus on kelp forest conservation and restoration, from fewer than 10 per year before 1980 to more than 200 per year since 2020 (Web of Science search). The United States and Australia are responsible for most international scientific publications on kelp conservation, followed by Canada, Chile, New Zealand, England, and Norway, which all have a similar number of published papers. However, it is important to acknowledge this only accounts for outputs published in English, and there are additional outputs in other languages not accounted for here, including Japanese, Korean, Spanish, Norwegian, and Russian.

In addition to the Kelp Forest Alliance, which provides a global home for kelp conservation and outreach, there are many other organisations and regional networks that serve as platforms for scientists, researchers, practitioners, stewards, and resource managers to

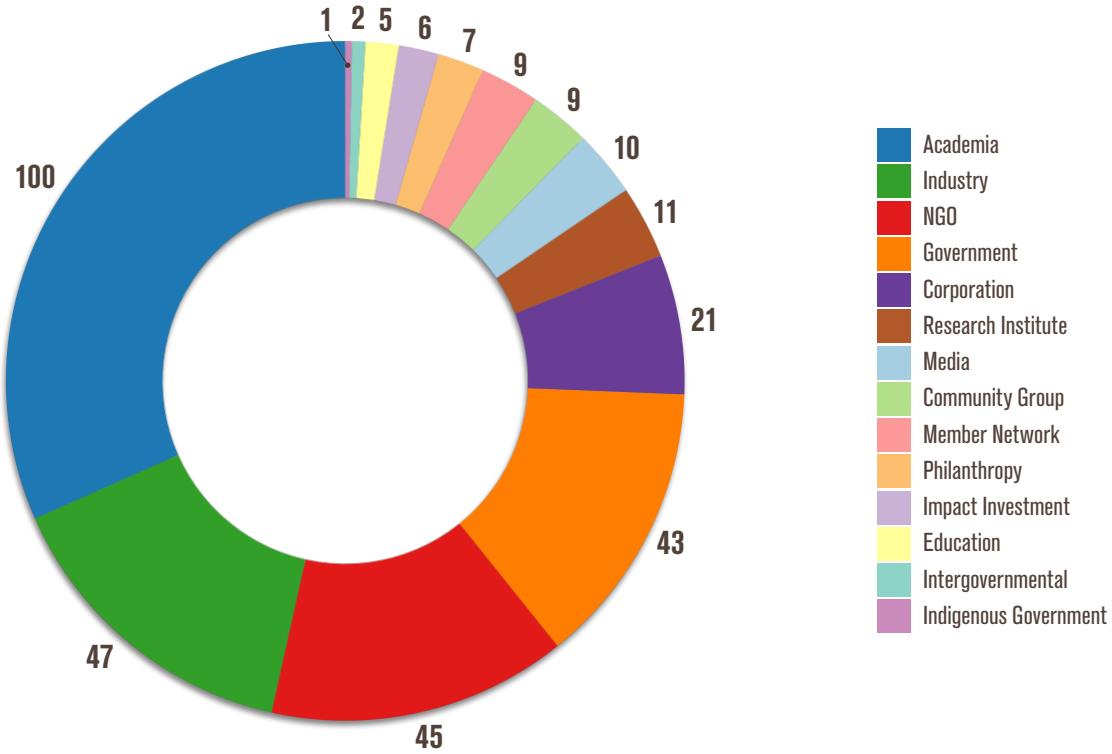

Figure 5.2
Organizations by Sector

exchange ideas, update the community on recent research, and set future goals. Some examples include:

The International Kelp Mappers Community of Practice is a group dedicated to mapping and monitoring of kelp forests through novel remote sensing and other technological methods. It was established in 2019 by The Nature Conservancy (TNC) California, and is now led by the Hakai Institute and University of Victoria Spectral Lab. The group hosts annual meetings showcasing new technology and building collaborations. They also published the **Kelp Mappers Guidebook** and are facilitating working groups in specific regions such as Latin America.

The **Green Gravel Action Group** is a large international network that includes over 65 members from nine countries working on the restoration of kelp forests by seeding (or inoculating) substrates such as small rocks or lines with kelp propagules that are reared in aquaria and then out-planted into restoration areas.

The Kelp Node is a 200-member regional network that ultimately aims to advance local conservation, management, and recovery of kelp forest ecosystems in British Columbia (Canada) and Washington (USA) waters. The network leverages and expands collective regional objectives for kelp conservation and restoration through action-oriented working groups focused on kelp data, science, training/engagement, and policy/governance.

The Eastern Pacific Kelp Forest (EPaK) Recovery Workshop is hosted annually by TNC California to identify synergies, bottlenecks, and knowledge gaps, and to facilitate collaboration such that we may advance our shared conservation goals. Current activities range from methods-review-focused manuscripts, to training workshops, state-of-knowledge documents, knowledge-exchange discussions, and a data-mobilization webinar.

Kelp recovery has also gained attention among local communities and recreational SCUBA divers who are interested in using their underwater time to benefit the ocean. As such, programs exist to train and give access to local communities by including divers in kelp forest monitoring and research, which enhances community engagement and can lead to sustained ecosystem stewardship. For example, **Reef Check** (USA) and **REEF** (USA) focus on training recreational divers to monitor the health of kelp forest ecosystems.

Love Rimu-Rimu (New Zealand) is a community-led NGO which recruits and trains school students in both kelp restoration and monitoring.

The **Sussex Kelp Recovery Project** has brought together over 40 organisations and hundreds of people to understand and protect kelp forests in Sussex (UK) after securing the protection of over 300 km2 of seafloor from trawling.

Operation Crayweed (Australia) and the **Mendocino Bull Kelp Recovery Program** (USA) have recreational diving and non-diving opportunities nested (and funded) within their research program to allow for direct participation by local communities in kelp recovery

efforts and foster sustained community connection. These opportunities also support other ways of knowing, aside from the scientific method, by local communities.

As for community-led efforts, **Caspar Cove** and Tanker Reef in California, USA are investigating whether grazer-suppression efforts by volunteer divers can support kelp regrowth at their local reefs. Results will help managers determine whether in-water purple-urchin culling is a useful kelp restoration tool more broadly as part of the state's developing **Kelp Restoration and Management Plan**. In Japan, **Mobile Sea Otter**s is one of a number of local organisations which encourages local fishers and community members to take part in urchin management and kelp restoration efforts.

In recent years, kelp-themed community gatherings and festivals worldwide have surged, combining conservation, science, and art exhibitions. These events, attracting thousands annually, celebrate kelp-related products and offer participatory activities. Exhibits in Sydney, Hobart, San Francisco, and San Diego bring underwater forests to the public, fostering connections with unseen places. Seaweed's role in food, art, culture, and film is highlighted by events like the **North Coast KelpFest**, the **California Seaweed Festival**, and the **Kelp Forest Photo Awards**.

Since 2013, South Korea has celebrated **Marine Gardening Day** on May 10th. This holiday celebrates people's connection to the ocean and encourages local communities to take part in marine restoration efforts. The day is often focused on school children and encourages education and awareness raising about marine issues, including kelp forest loss.

Kelp forests have also been increasingly capturing people's imagination and attention through impactful visuals (art, books, films and documentaries) in recent years, most famously including the Oscar-winning documentary "My Octopus Teacher" set in a South African kelp forest. In addition, books and web stories such as **The Curious World of Seaweeds**, **The Mysterious World of Bull Kelp**, and **Braiding Sweetgrass** allow for the careful consideration of seaweeds along with the human element of broader ecosystem stewardship.

6

6. Key Kelp Resources

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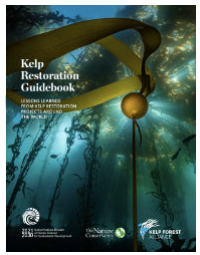
The dissemination and consolidation of knowledge are critical for advancing efforts and ensuring sustainable practices in kelp restoration. Projects are often led by scientists, resulting in lessons buried within academic literature and creating barriers for practitioners, rights holders, policymakers, and the public. To bridge this gap, the global community has coalesced in recent years around products and working groups. Sharing resources through open-access platforms and centralised repositories ensures that valuable insights, from both successes and failures, foster a realistic understanding of restoration processes, and ultimately accelerate the collective learning curve and enhance effectiveness of restoration projects.

Below, we share a non-exhaustive list of some of the main resources available to kelp practitioners today.

Resources

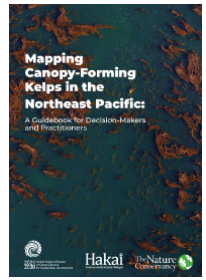
Kelp Forest Alliance - The Kelp Forest Alliance is a collaborative community open to anyone working in or interested in kelp forest conservation. The NGO maintains a web platform that consolidates information on the amount of kelp forest restored, protected, the people and organisations working in kelp, as well as a Knowledge Hub of resources. New users may join via the website.

Kelp Restoration Guidebook - This guidebook leads users through the A-Z of kelp forest restoration and provides summary information and best practices on all aspects of a kelp restoration project. From engaging with the community to transplantation and planning for the future, this document provides easy-to-use and comprehensive information.



KelpWatch - A user-friendly web tool that provides access to multi-decadal Landsat-derived kelp canopy data (*Macrocystis pyrifera* and *Nereocystis luetkeana*) for visualizing changes over time. It simplifies complex datasets with three components: a cloud-based backend with an API, a tiling service for web map display, and a JavaScript-based frontend for intuitive exploration. Users can visualise kelp canopy changes through animations, graphs, and downloadable CSV files, aiding scientists and managers in research, monitoring, and informing strategic kelp restoration efforts.

Kelp Mapping Guidebook - The Kelp Mapping Guidebook outlines tangible steps for practitioners to determine the appropriate tools to map kelp based on the distribution of kelp in a specific area. The methods, tools, and datasets developed from this guidebook are transferable to a variety of other coastal monitoring and mapping projects that may also require unique regional considerations. It has been designed to be accessible to community members and researchers new to the field or outside science and academic institutions.



Kelp monitoring guidelines - This guidebook provides an overview of methodologies for monitoring kelp forest ecosystems, offers instructions for restoration practitioners, and compiles information into an accessible document. It is a valuable resource for tracking kelp forest extent, health, and benefits. The standardised approaches will aid information sharing, synthesis studies, and communication of kelp forest benefits. These guidelines represent the best available information and will be updated with new technologies and research.

https://kelpforestalliance.com/kelp-forest-ecosystem-monitoring

ReefAdapt - Reef Adapt is a management-ready interactive tool designed to assist marine restoration and assisted gene flow planning. Reef Adapt incorporates genetic, biophysical, and environmental prediction data to provide maps that identify areas with populations suited to user-specified restoration or recipient sites under current and future climate scenarios. The web platform also allows users to upload new data to promote expansion to new species and bioregions around the globe.

Into the Blue Report - UNEP's Into the Blue: Securing a Sustainable Future for Kelp Forests global synthesis report is a comprehensive knowledge review on the state of science on the world's kelp forests and provides recommended actions for restoration.

Great Southern Reef Foundation - The Great Southern Reef Foundation is run by an independent team of science, media, and education professionals working to promote the recognition, stewardship, and long-term health of Australia's kelp forests. The Foundation website hosts a variety of free kelp-centric teaching resources, other educational materials and media.

Green Gravel Action Group *(GGAG)* - The GGAG is a global network of macroalgae restoration researchers and practitioners that aims to facilitate the communication of research and protocols for out-planting and for upscaling restoration activities across different macroalgal species, locations, and habitats. The GGAG meets online twice yearly to discuss key questions, activities, challenges, solutions, and project outcomes. The GGAG website hosts contact details for projects and species-optimised protocols for field and lab procedures around the globe. New projects can join the group by getting in contact via the website.

Kelp Niche Mapper - Kelp Niche Mapper is an online web tool designed to summarise parts of the ocean that are ecologically suitable for kelp forest restoration. The tool helps practitioners understand the environmental niche of specific kelp species in a specific bioregion and is currently focused on Laminarian kelp species.

https://georginawood.shinyapps.io/KelpNicheMapper/

IUCN Seaweed Group - The IUCN Seaweed Specialist Group (SWSG) is an international working group for conservation assessment, planning and conservation action, and increasing the public profile of seaweeds worldwide. Initial work includes the assessment of Laminarian species for the IUCN Red List.

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7. Kelp Distribution (Methods Appendix)

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7.1 Key Takeaways

1. Together, there are 25 countries with significant kelp forest populations.
2. By area, five countries: Canada, the United States of America, Russia, United Kingdom contain over 50% of globally estimated kelp habitat.
3. In the Southern hemisphere, Australia, New Zealand, Chile, and Argentina have the most kelp habitat (278,000 km^2 collectively).
4. Estimating the potential kelp area will always create higher numbers than the observed kelp forest.
5. Improving country-level maps of kelp forest habitat is a key priority.

Definitions:

Potential kelp forest habitat: The amount of seafloor that *could be* suitable for kelp to grow.

Observed kelp forest habitat: The amount of seafloor where kelp has been observed and mapped.

7.2 Measuring the Kelp Biome

The area of kelp forest area around the world has been estimated several times. These estimates were obtained either by modelling kelp forest area based on environmental conditions where kelp is known to live (e.g., appropriate temperature, rocky reefs, < 60m depth) or by compiling recorded observations (observations, videos, sonar, photos) of kelp forest habitat from around the globe.

Models with large grid cells (coarse resolution) may overestimate habitat areas because they predict presence within large areas (e.g., 10 km x 10 km) and do not capture variability of coverage of kelp within a cell[1]. Specifically, these models indicate that conditions are suitable for kelp somewhere within each cell, but do not specify that the entire cell is covered by kelp. Consequently, the reported area represents the number of suitable cells, not the actual continuous coverage of the habitat.

Conversely, only using observed data generates an under-estimate, as underwater data collection is technically challenging and prohibitively expensive. As a result, we only have incomplete observations of kelp forest ecosystems (50,000 - 100,000 km^2)[2,3].

This report is focused on which countries have the *most* kelp and the percentage of potential kelp habitat that is *protected (See section 4)*. Because both these numbers are relative, we use the modelled (maximum available habitat) approach to estimate kelp area. We *do not* recommend using these numbers for setting area-based restoration targets because those numbers will not be feasible to achieve.

7.3 Kelp Breakdown

By area, five countries—Canada, the United States of America, Russia, and the United Kingdom—contain over 50% of globally estimated kelp habitat (946,000 km^2). Much of this habitat lies in the high polar regions. In the Southern hemisphere, Australia, New Zealand, Chile, and Argentina have the most kelp habitat (278,000 km^2 collectively). While other countries may have smaller kelp forests (South Africa, Mediterranean countries), many of those forests are unique and host biodiversity endemic to that region. Together, 25 countries are home to kelp forests (Figure 7.1).

7.4 Regional Accuracy

The data used to generate the model influence the results, and data-poor areas may be under-represented. For instance, the modelled kelp biome for Australia missed regions along the East and West coasts[4] where kelp is observed to exist.

7.5 Data Notes

These numbers represent the area in which kelp forest could grow and not necessarily the real distribution of kelp in any given year. They do not reflect local stressors such as pollution, habitat destruction, and other disturbances.

Kelp forests are dynamic ecosystems, and their boundaries may shift naturally from year to year. As a result, any estimate of kelp forest area will, at best, be an approximation. Further, intertidal kelps are not represented in these values because we cropped to the coastline, but they would only slightly increase the total area, as the vast majority of kelp is subtidal.

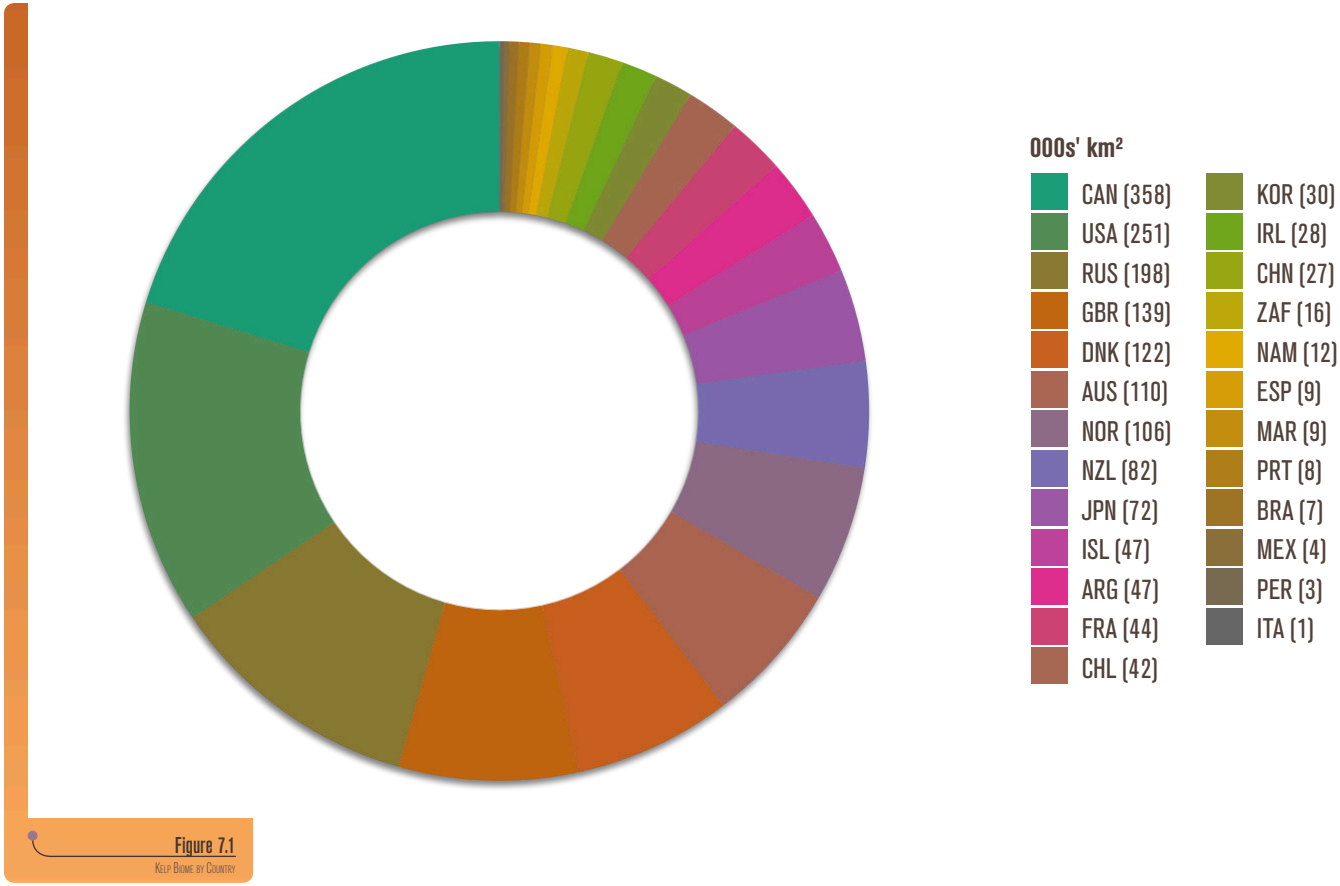

Figure 7.1
Kelp Biome by Country

7.6 Methods

Kelp forests are found in 25 countries across all continents, but the actual area occupied by kelp forest ecosystems is currently unresolved, with observed estimates ranging from 5 M ha to modelled estimates of 150 M ha. Which number is used will necessarily influence any conservation targets that are produced (e.g., 30% of 5 M vs 30% of 150 M ha). Using an underestimate would mean that kelp habitat is left unprotected, and using an overestimate would create an unreachable goal. Additionally, detailed maps of observed or modelled kelp forests will also influence any assessment of the habitat overlap with MPAs. Ideally, this assessment would be based on the observed maps of kelp forest habitat, however, global maps of kelp, or even national-level maps, only exist for those species

that form large surface canopies that can be detected with remote sensing (e.g., giant kelp - *Macrocystis pyrifera*). Even if such maps did exist, kelp forests are dynamic habitats, as mentioned above, and may shift in place from year to year. While the area-based target of the Kelp Forest Challenge was created using an observed estimate of the area of kelp forest (~10 M ha), corresponding maps do not currently exist. Therefore, this report uses the modelled kelp biome to provide its assessment[5]. Given this decision, this report provides an assessment of the amount of *potential* kelp forest habitat protected as opposed to the *realised* amount of kelp forest habitat protected. Future assessments may update this approach as more information becomes available.

The modelled biome comprises 147 species and 59 genera of kelp, the majority of which do not form a floating canopy at the ocean's surface, like the more widely known giant kelp (*M. pyrifera*). We instituted a 60 m depth cutoff, using a global sub-ice bathymetry grid[6] to restrict areas which would be likely too deep for significant kelp forests. We then vectorised the layer and snapped the landward edge to a detailed coastline shapefile[7] to ensure congruency between boundaries. Next, we overlaid the EEZs (exclusive economic zones) of the world and calculated the area of kelp biome that lay within each country's EEZ. Finally, we clipped the kelp forest data layer with the MPA layer to obtain the amount of kelp forest biome that was protected and under different levels of protection. Since the global MPA dataset is continuously updated to include newly designated MPAs, MPAs occasionally overlap with each other. Overlapping MPAs were hierarchically selected so only one MPA would be accounted for, and we prioritised the MPAs that had the highest level of protection.

7.7 Data Gaps

In a global analysis, there are inherent limitations to the country-level assessment. Notably, kelp distribution may be underestimated at the edge its distribution (e.g., the warmest areas of a population[8]) or in some remote areas where little information exists. For example, we observed that giant kelp and palm kelp in Baja California, Mexico and golden kelp in Northern New South Wales, Australia were modelled as absent despite known presence. In addition, kelp forest species from the Indian Ocean islands such as Kerguelen of France and the Prince Edward Islands of South Africa were also absent. This underestimate of kelp forest area may consequently overestimate how much kelp forest is protected in these countries. Future updates of this and other work will therefore need to refine the kelp distribution data. As a result, global and country-level kelp forest estimates may vary if the biome is refined to incorporate these regions, and results should be taken with care and validated with other datasets and regional experts.

Endnotes

1 https://onlinelibrary.wiley.com/doi/full/10.1111/j.1472-4642.2007.00342.x
2 https://link.springer.com/article/10.1007/s10811-023-03103-y
3 https://www.nature.com/articles/s41467-023-37385-0
4 https://www.publish.csiro.au/mf/mf15232
5 https://www.sciencedirect.com/science/article/pii/S0006320721001518?via%3Dihub
6 https://www.gebco.net/data_and_products/gridded_bathymetry_data/#global
7 https://agupubs.onlinelibrary.wiley.com/doi/10.1029/96JB00104
8 https://besjournals.onlinelibrary.wiley.com/doi/full/10.1111/j.2041-210X.2010.00036.x

8. Kelp Area Protected (Methods Appendix)

8.1 Protected Area Database

For this analysis, we used the World Database on Protected Areas (WDPA), which is collaboratively managed by the United Nations Environment Programme (UNEP) and the International Union for Conservation of Nature (IUCN). The WDPA is one of the most comprehensive global datasets on terrestrial and marine protected areas, including data on the geographic location, size, legal status, governance, and conservation objectives of each site. Data was sourced from the Protected Planet website, which provides up-to-date and authoritative information through monthly updates supplied by national governments, non-governmental organizations, and other contributing entities (accurate as of January 2024). The dataset uses the IUCN's protected area categorization to signify which activities are restricted in the area. These areas range from Ia (no extractive or destructive activities allowed) to VI (some extractive or destructive activities allowed). MPAs which were not classified were reported as "Not Reported", "Not Assigned", or "Not Applicable" (Table of classifications and breakdown).

From the full dataset, we made several modifications for our analysis. First, we selected marine or coastal MPAs and split cross-jurisdiction MPAs into components so that areas only occupied a single country's exclusive economic zone (DATABASE). When presented with overlapping management zones (most commonly a "Not Reported" zone overlaid with a ranked zone), we hierarchically selected the area with the highest level of protection to avoid including the same area twice. We further pruned the dataset by removing MPAs that had protections not relevant to kelp forests (e.g., RAMSAR wetland sites, bird sanctuaries) – Data Repository[1].

Limitations of the World Database on Protected Areas: Future work should focus on further refining the estimation of protected kelp with MPA categories that not only report the IUCN classifications but also other regulatory classifications that are becoming available for MPAs, such as those from Protected Seas[2] and the MPA Atlas[3]. Adding these classifications is important because IUCN categories are based on management objectives which, in some instances, may not match on-the-ground regulations. These new classifications will also have to be combined with the improved maps of kelp forest habitat. As an example, work in Mexico estimated that less than 1% of observed canopy-forming kelp forests are inside no-take MPAs compared to the 13% of potential kelp habitat classified as IUCN level Ia presented here[4].

Endnotes

1 Open Science Framework
2 https://protectedseas.net/
3 https://mpatlas.org/mpaguide/
4 https://www.nature.com/articles/s43247-021-00177-9

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