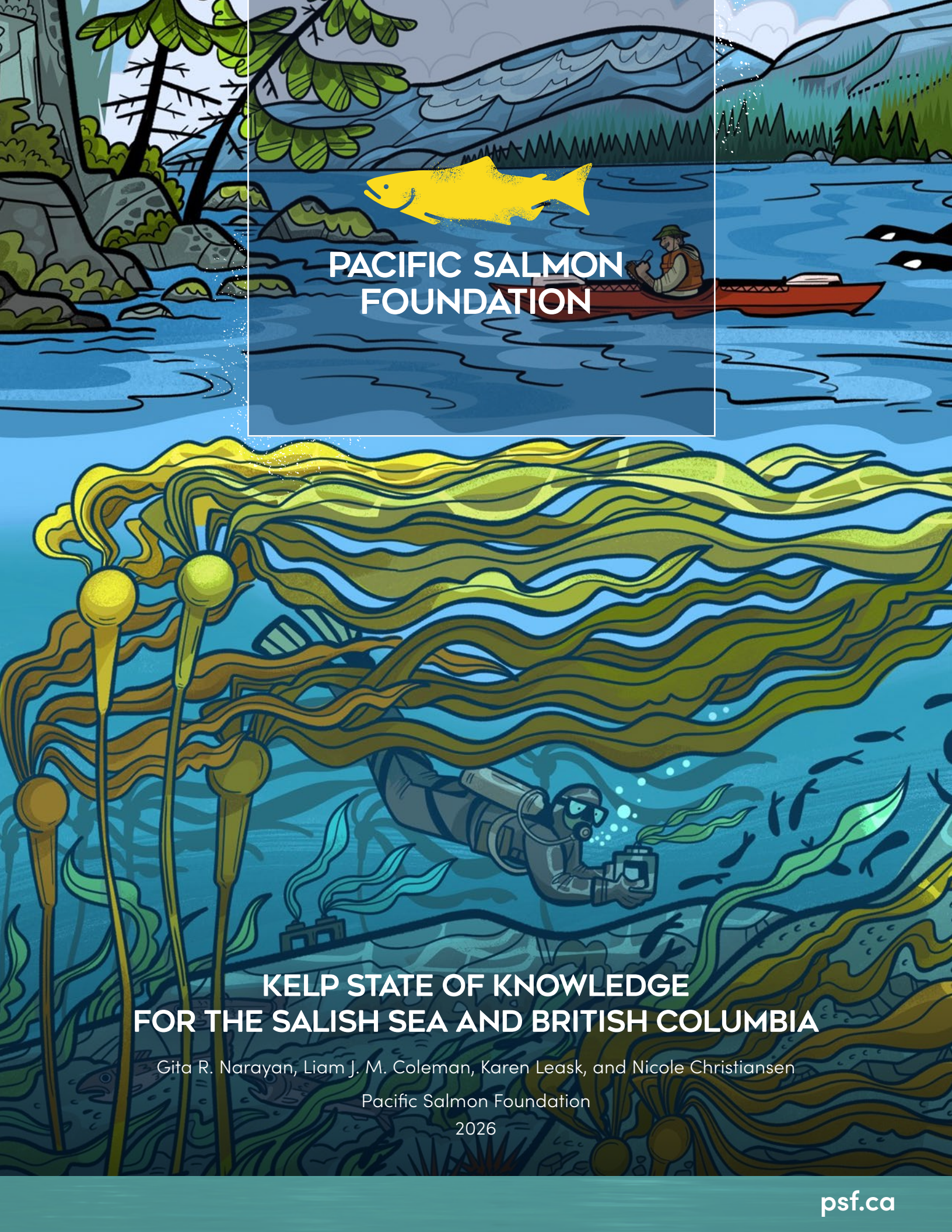


PACIFIC SALMON FOUNDATION

KELP STATE OF KNOWLEDGE FOR THE SALISH SEA AND BRITISH COLUMBIA

Gita R. Narayan, Liam J. M. Coleman, Karen Leask, and Nicole Christiansen

Pacific Salmon Foundation

2026



Illustration:Delaney Cox of Drawing it Out

PREFACE

Estuaries and nearshore ecosystems provide vital support to juvenile and adult Pacific salmon, as well as the larger food web they depend upon. There is increasing interest in protecting and restoring the interconnected nearshore habitats of kelp, tidal marshes, and eelgrass habitats within these critical salmon systems.

However, the success of nearshore recovery projects is hampered by a number of factors: a paucity of open-access information about nearshore habitat restoration and monitoring methodologies, a lack of knowledge about priority areas and suitable site selections for restoration, and a need for knowledge based approaches to conservation strategies under worsening climate change scenarios.

With funding from Fisheries and Oceans Canada's Aquatic Ecosystem Restoration Fund (AERF), the Pacific Salmon Foundation has created a Restoration Resource Hub of open-access informative resources and decision-support tools. The purpose is to guide adaptive nearshore habitat restoration and monitoring approaches for kelp, tidal marsh, and eelgrass habitats.

This report is one of the components of this Hub.
Other documents can be found through this link.



Credit: Liam Coleman

EXECUTIVE SUMMARY

Kelp forests are highly productive and biodiverse marine ecosystems that form along cool-temperate, nutrient-rich coastlines. They provide critical ecosystem services, including cultural and socioeconomic benefits to coastal communities. Due to a variety of compounding factors, including ocean warming and various anthropogenic pressures, kelp forests are declining globally, especially along the North Pacific from Alaska to California. This can lead to a loss of the interconnectedness between nearshore marine habitats and impact the productivity of trophic systems, reducing important nurseries, feeding grounds, and migration corridors for species of high ecological, cultural, and socioeconomic value to coastal communities.

Protection and restoration of kelp forests are urgently needed. This can only be achieved through effective management, which requires a clear understanding of long-term dynamics, including the response to threats and stressors, and ecosystem resilience. To support regional management strategies based on sound ecological understanding of this locally to regionally dynamic ecosystem, this report synthesizes the current state of knowledge of kelp forests thorough a comprehensive review of recent (c.a. 10 years) peer-reviewed scientific literature, non-peer-reviewed sources (e.g., reports produced by governmental agencies and non-governmental organizations (NGOs), interviews with local Indigenous Knowledge Holders, scientists, restoration practitioners, and non-governmental or community groups involved in kelp restoration. The report focuses primarily on bull kelp (*Nereocystis leutkeana*) in the Salish Sea, but also includes highlights from a few adjacent regions, such as the west coast of Vancouver Island, the Central BC Coast, Haida Gwaii, and the Broughton Archipelago. This synthesis also identifies gaps in current knowledge of kelp forests throughout, and provides recommendations.



Credit: Liam Coleman

Recommended citation:

Narayan, G.R., Coleman, L.J.M., Leask, K., & Christiansen, N. (2026).
Kelp state of knowledge for the Salish Sea and British Columbia. *Pacific Salmon Foundation*.
https://doi.org/10.48689/3f3ce431-3bc8-44c1-b082-5b29e155901b

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ACKNOWLEDGEMENTS

The authors of this Kelp State of Knowledge Report would like to express gratitude to all the Coastal First Nations who have stewarded the lands and waters upon which we live and work since time immemorial.

Additionally, we thank the speakers and participants of PSF's Kelp Symposium held in Victoria, BC in February 2025, as well as interviewees who shared their knowledge, experience, and perspectives. This report would not be possible without those insights. We are also grateful to reviewers of the manuscript who provided valuable feedback, and all those who shared information and provided photos and graphics for use in this report. Thanks are also due to the Greening the Salish Sea team at PSF for their knowledge of nearshore ecosystems and support during the writing process, in particular Romina Barbosa, Ann Eriksson, and Sarina Clay-Smith.

We acknowledge Fisheries and Oceans Canada (DFO) for funding this work through the Aquatic Ecosystem Restoration Fund (AERF).



Credit: Eiko Jones

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Gita is a marine ecologist who specialized in algal and protistan taxonomy, bioindicators and long-term research of nearshore coastal ecosystems (reefs and seagrass habitats). She holds a BSc from the University of Alberta, a MSc from the University of Victoria, and a PhD from the University of Queensland (Australia). She carried out two postdoctoral fellowships, at the Leibniz Centre for Tropical Marine Research (Germany), and in the Spectral Remote Sensing Lab at the University of Victoria. The latter was focused on regional drivers of kelp ecosystem change. She is a lecturer at Vancouver Island University, where she teaches courses in aquatic plants and algae and aquatic habitats, among others. In her spare time, she is also a medical herbalist and enjoys bridging her passions for taxonomy, marine ecology, botany, ethnobotany, and health.

Liam J. M. Coleman, PhD

Liam is a marine biologist and an expert in kelp biology. He holds a BSc in biology from the University of Victoria and a PhD in botany from the University of British Columbia. His PhD work examined developmental mechanisms underlying phenotypic plasticity in bull kelp, *Nereocystis luetkeana*. After completing his graduate studies, he worked as a postdoctoral researcher at Simon Fraser University developing a cryopreservation protocol for biobanking of bull kelp. He has since continued to work to help develop kelp biobanking infrastructure in BC. He also teaches undergraduate courses in phycology and nonvascular plant biology at UBC and the Bamfield Marine Sciences Centre.

Karen Leask, MSc

Karen Leask has been learning and teaching about marine biology for many years in Canada and the Philippines, beginning with shellfish, progressing to algae, and with some finfish studies undertaken along the way. She earned a MSc from the University of Victoria for research on larval development of scallops and continues to contribute to studies to improve larval survival in cultured oysters and scallops affected by climate change. Karen recently retired from Vancouver Island University, where she taught classes in technical writing and about kelp and other algae, both macro- and microalgae; their identification, ecology, and culture methods.

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Nicole has a broad background in marine, estuary, and freshwater ecosystems, and has worked in the field of environmental science in the US, Australia, and Canada, including five years at Pacific Salmon Foundation (PSF). As the project manager of the 'Greening the Salish Sea' project, Nicole supported the production of all materials produced by PSF for the 'Restoration Hub'. She resides on Vancouver Island with her family and enjoys all things outdoors.

CHAPTER ONE
KELP IN THE SALISH SEA AND BRITISH COLUMBIA AND ITS VALUE

INTRODUCTION

Kelp forests thrive in cold, nutrient-rich, nearshore waters at temperate latitudes, and are commonly found along the Eastern Pacific Coast, from California to Alaska (Figure 1.1) (Mann, 1973; Steneck & Johnson, 2014). They form structurally complex three-dimensional habitats that support a myriad of marine species, including fish, invertebrates, marine mammals, and birds, and provide ecosystem services valued for their cultural and socioeconomic benefits to coastal communities and Indigenous Peoples (Naar, 2020; Teagle et al., 2017; Turner et al., 2020). However, evidence gathered over the past two decades indicates that kelp forests are declining by two per cent per year in regions throughout the world due to the cumulative effects of multiple stressors (Chapter five), which is likely to have far-reaching consequences for coastal ecosystems and communities (Filbee-Dexter & Wernberg, 2018; Wernberg et al., 2019). Rising sea surface temperatures (SSTs) and increasing intensity and frequency of marine heatwave (MHW) events are major drivers of these losses (Starko et al., 2024a), leading the Intergovernmental Panel on Climate Change (IPCC) to identify kelp forests as the second most at-risk marine ecosystem from climate warming, after coral reefs, in its Sixth Assessment Report (Arafeh-Dalmau et al., 2025; Parmesan et al., 2022).

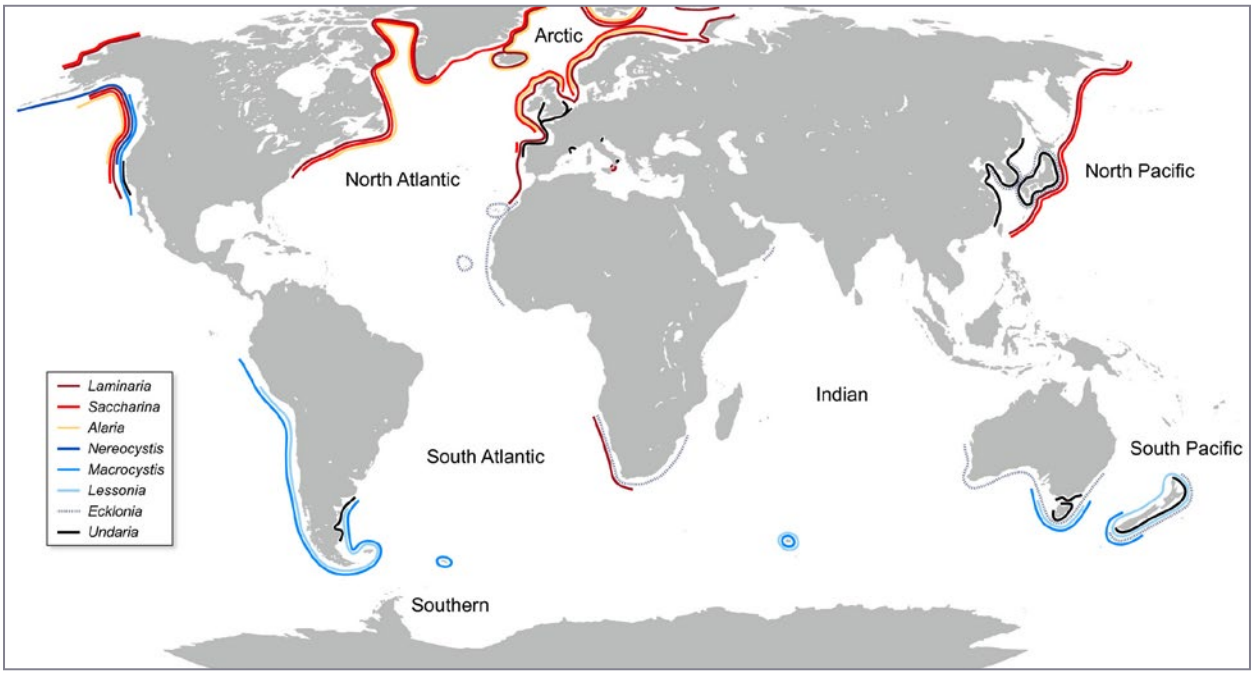


Figure 1.1 Map showing the approximate global distribution of major kelp (Laminariales) genera. Bull kelp (*Nereocystis leutkeana*) forests occur along the Pacific coast of North America (Smale, 2020).

The Salish Sea bioregion

The Salish Sea encompasses the Strait of Georgia, Strait of Juan de Fuca, and Puget Sound, and is a semi-enclosed, glacier-fed fjord estuary spanning the Canada–US border (Figure 1.2) (Sobocinski et al., 2021). Its complex coastline, variable depths, and temperate rainforest setting create a mosaic of oceanic conditions and habitats, with relatively warm, sheltered surface waters compared to the adjacent outer coast and global averages at similar latitudes (Hamilton et al., 2022; Mora-Soto et al., 2024a; Pfister et al., 2018). These conditions support floating, canopy-forming bull kelp forests, whose distribution is closely linked to local temperature, light, and wave exposure gradients. Approximately nine million people live within the watershed, and while coastal economies benefit from kelp-associated ecosystem services, ongoing population growth and development continue to place pressure on nearshore ecosystems (Nijland et al., 2019; Sobocinski et al., 2021).



Figure 1.2 Map of the Salish Sea Bioregion with the Strait of Georgia, Juan de Fuca Strait, and Puget Sound sub-basins.

In the Salish Sea, kelp forests are part of an interconnected seascape of nearshore habitats that includes eelgrass meadows, tidal marshes, terrestrial riparian zones, and temperate forests (Figure 1.3) (Olson et al., 2019). These connected habitats are hotspots of incredible productivity and biodiversity. However, this bioregion is one of the most threatened by projected MHWs (Arafeh-Dalmau et al., 2025), and yet, there is low (approximately two per cent or less) to no legal protection of kelp forests in the Salish Sea or along the stretch of coastline from BC to Oregon (Arafeh-Dalmau et al., 2025).



Figure 1.3 The nearshore bull kelp forests, eelgrass meadows, tidal marshes form a rich mosaic of habitats that support a diversity of life in the Salish Sea (Illustration by Delaney Cox of Drawing it Out).

Kelp forests in BC and WA are characterized by two canopy-forming species, that is, species that form buoyant canopies at the surface of the water and span the full breadth of the water column (Figure 1.4): bull kelp (*Nereocystis luetkeana*) and giant kelp (*Macrocystis pyrifera*) (Druehl, 1978; Foreman, 1984). Bull kelp is among the most widely distributed kelp species in the northeastern Pacific and is the dominant canopy-forming species within the Salish Sea (Foreman, 1984). Giant kelp is common on the west coast of Vancouver Island and along BC's central coast, but is largely absent from the Salish Sea, except along the westernmost coastline of the Strait of Juan de Fuca in Washington State. BC is home to approximately 30 kelp species, and the majority of these species are "understory" kelp species that do not form buoyant canopies. Such species include winged kelp (*Alaria marginata*), walking kelp (*Pterygophora californica*), and sugar kelp (*Saccharina latissima*) (Figure 1.4) (Berry et al., 2021a; Druehl, 1970; Druehl & Clarkston, 2016; Gabrielson & Lindstrom, 2018). Almost all mapping and monitoring of kelp in BC to date has focused on canopy-forming kelp species, and very little is known about the current state of the understory kelp species found in the region (Berry et al., 2019, 2021; Mora-Soto et al., 2024a).

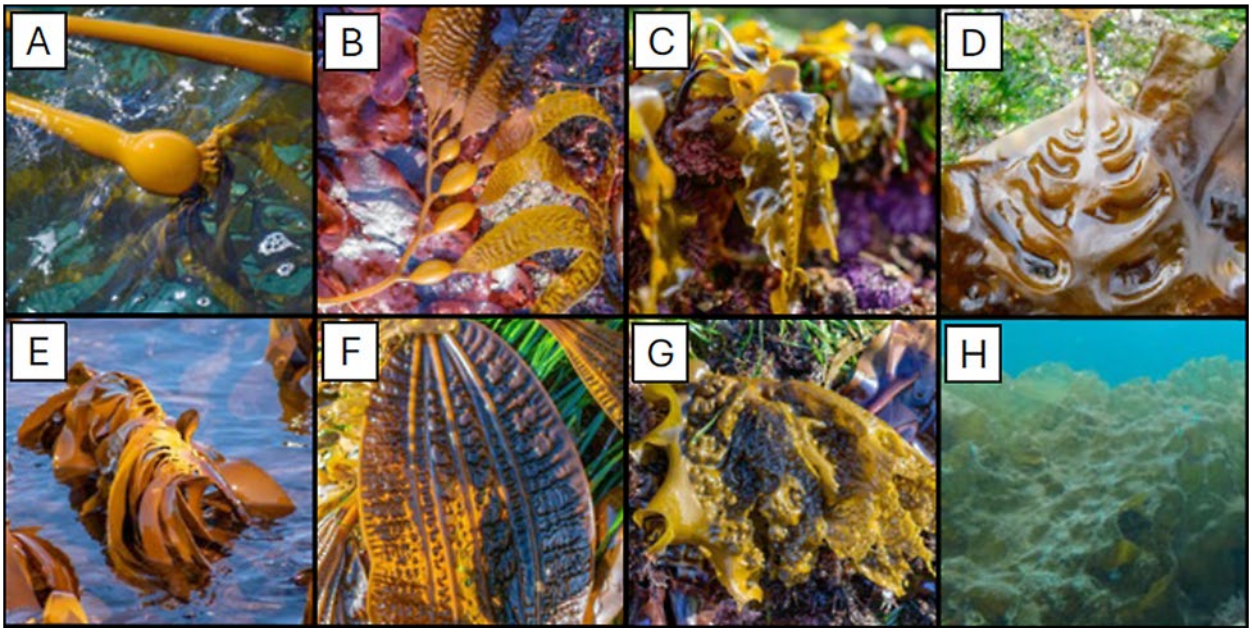


Figure 1.4 Common kelp species found in British Columbia. **A)** Bull kelp (*Nereocystis luetkeana*), **B)** Giant kelp (*Macrocystis pyrifera*), **C)** Winged kelp (*Alaria marginata*), **D)** Sugar kelp (*Saccharina latissima*), **E)** Walking kelp (*Pterygophora californica*), **F)** Seersucker kelp (*Costaria costata*), **G)** Sea cabbage (*Hedophyllum sessile*), **H)** Sea colander (*Neoagarum fimbriatum*).
(Photo: Liam J.M. Coleman, from Handbook for biobanking of kelp in British Columbia; Coleman, 2026).

KELP BIOLOGY

Kelp is a taxonomic term for marine brown algae (Phylum Ochrophyta, Class Phaeophyceae, Order Laminariales) that superficially resemble land plants. These organisms have a complex life cycle known as a sporic or "alternation of generations" life cycle (Figure 1.5) (Graham et al., 2017, and references within). There are two free-living multicellular stages in this life history: a macroscopic diploid (2n) phase called a sporophyte, which is the phase that people generally see and interact with in nature, and a microscopic haploid (1n) phase called a gametophyte, which grows inconspicuously on the ocean bottom. The sporophyte has a complex morphology generally consisting of a root-like holdfast, a stem-like stipe, and leaf-like blades (Figure 1.5). Sporophytes of some species, including giant kelp and bull kelp, also have gas-filled bladders called pneumatocysts that provide buoyancy. Gametophytes, conversely, are morphologically simple and composed only of branched filaments made up of single-file rows of cells. The whole body of either a sporophyte or the gametophyte can be referred to as a thallus.


Credit: Eiko Jones

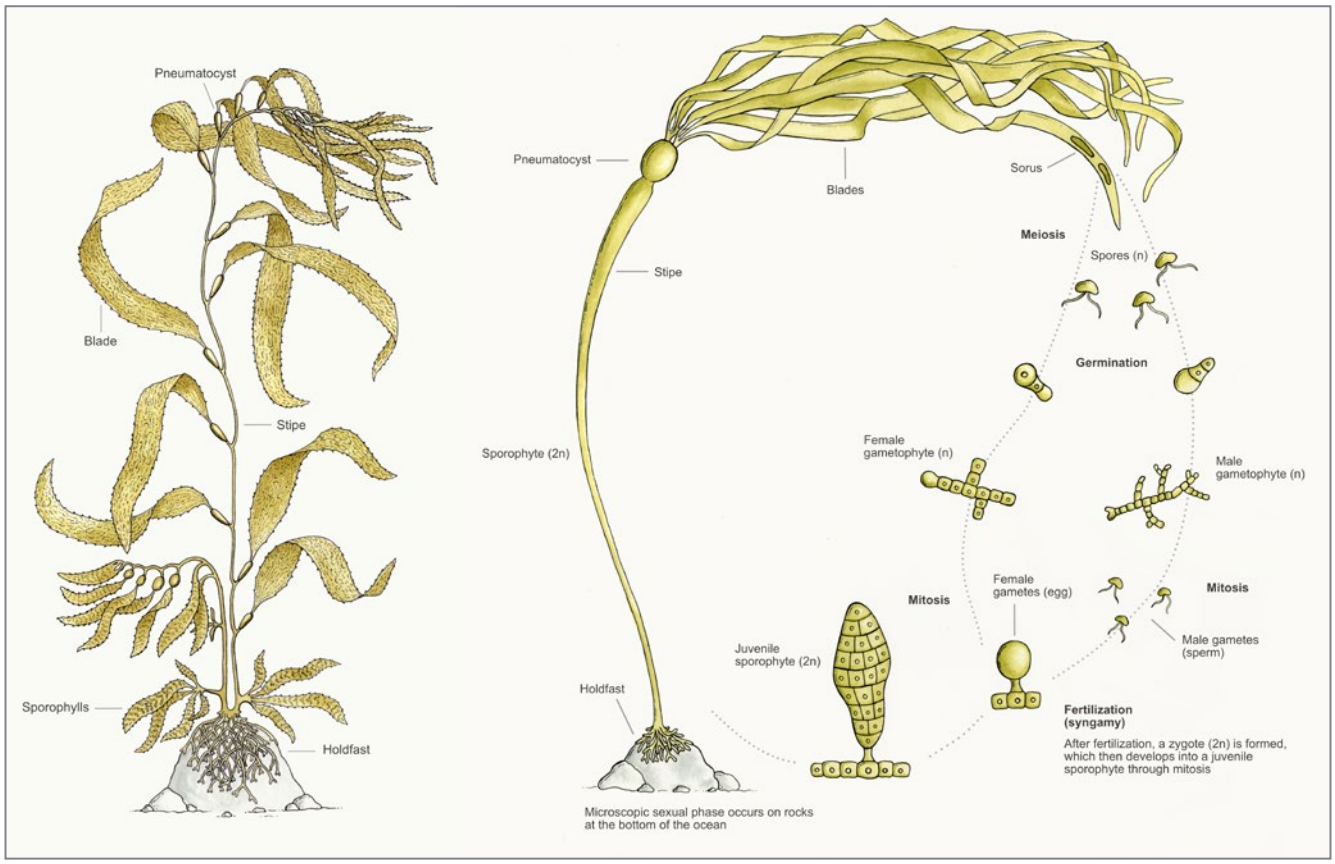


Figure 1.5 Giant kelp morphology (left) and bull kelp morphology and life cycle (right).

Mature, reproductive sporophytes produce spores through meiosis in specialized regions of the blade tissue called sori (singular "sorus"). These spores are released into the water, where they eventually settle onto a surface and germinate into gametophytes. Unlike sporophytes, which have no sex, gametophytes can be male or female. After growing vegetatively on the ocean bottom for a period, gametophytes become reproductive and produce gametes. Male gametophytes release motile sperm cells that seek out female gametes, which remain attached to female gametophytes. When male and female gametes meet and undergo syngamy, they form a diploid zygote that then develops into a new sporophyte.

Some kelp species, such as bull kelp, are annuals, with sporophytes only persisting for roughly one growing season. In contrast, others, such as giant kelp, are perennial, with individual sporophytes lasting potentially many growing seasons. Giant kelp sporophytes can survive five to nine years under optimal conditions (Schiel & Foster, 2006).

BULL KELP

As the most dominant canopy-forming kelp in the Salish Sea, bull kelp will often be a focal species throughout this document and, as such, it is worth highlighting some of its unique traits. The sporophyte of this species is immediately recognizable for its single large pneumatocyst and many blades (Figure 1.5). Bull kelp is one of the fastest growing kelp species and has been shown to be able to grow at rates of up to 14 cm per day under optimal conditions (Kain, 1987). This is how this kelp can grow from microscopic sizes to over 30 m in length in a single growing season (Foreman, 1984; Kain, 1987). Bull kelp tends to establish along cool, exposed to semi-exposed coastlines with high wave or current energies, but can also be found in more sheltered areas with low to moderate currents (Druehl & Clarkston, 2016). It attaches to hard substrates, such as boulders or large cobbles to small pebbles, and can occupy water depths from low intertidal to subtidal but is typically found at depths shallower than 20-40 m, depending on water clarity (Mora-Soto et al., 2024a; Mumford, 2007).

The annual life cycle of bull kelp in the Salish Sea usually runs from October of one year to November of the next, if elevated late summer temperatures don't cause deterioration of tissues to begin earlier (Schiel & Foster, 2006; Springer et al., 2006). Sporophytes begin to grow in the fall and early winter, eventually developing into large stands that reach the surface throughout the spring and summer growing season. Sporophytes become reproductive and begin producing sori on their blades as early as May in the northern Salish Sea. Spores are released from sori from two heights (surface and bottom) in the water column when sorus patches fall off the blades. Spores then develop into gametophytes. While it is largely unknown how long individual bull kelp gametophytes survive *in situ* and exactly when key life history events occur, research on other kelp species suggests they may persist for many months and may be able to delay development to optimally time reproduction. (Carney, 2011; Carney et al., 2013). Bull kelp sporophytes typically begin senescing in the fall to winter, eventually detaching and floating to shores near and far to become beach wrack, or drifting into deeper waters, taking with them nutrients, carbon, and energy.



Credit: Liam Coleman

ECOSYSTEM SERVICES AND THE VALUE OF KELP

Kelps are considered ecosystem engineers, meaning their presence modulates the environment and availability of resources for other species (Jones et al., 1994). Kelps' structural complexity, including height and density, influences environmental conditions such as light availability and water flow, creating habitats that help maintain stable and productive communities (Eckman et al., 1989; Jackson & Winant, 1983; Lamy et al., 2020). Through these properties, the presence of kelp and kelp forests in a marine ecosystem benefits not only the organisms living in that system, but also humans through the provision of numerous ecosystem services (Figure 1.6).

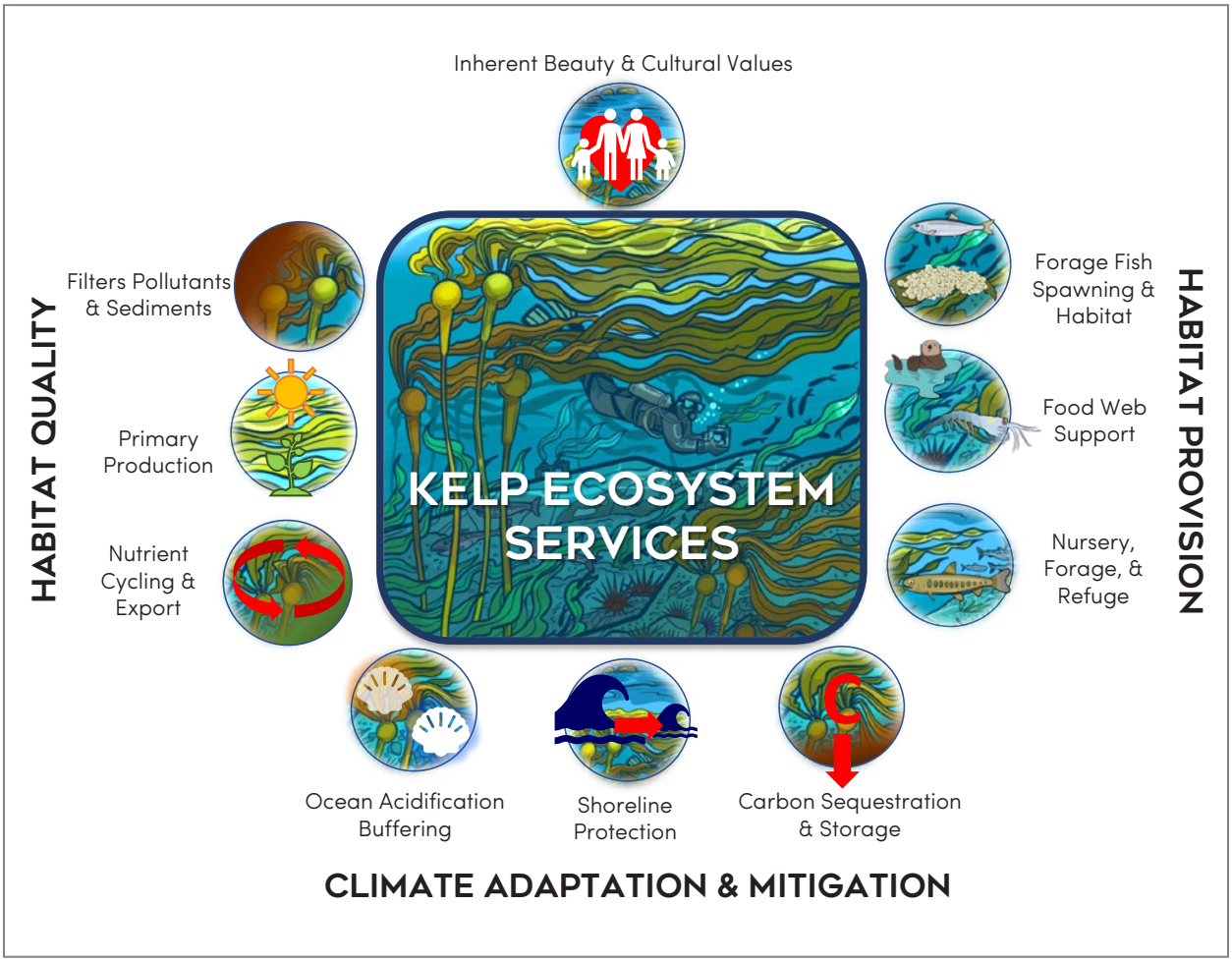


Figure 1.6 Ecosystem services provided by kelp forests. Credit: Delaney Cox and Nicole Christiansen

KELPS PROVIDE HABITAT AND SUPPORT A COMPLEX FOOD WEB

Kelps, through their ability to photosynthesize, are a key primary producer in temperate nearshore areas, which in turn promote secondary production and sustain a rich assemblage of marine life in the coastal trophic food web (Teagle et al., 2017). Kelp forests provide food sources, habitat, and refuge from predators for a myriad of ecologically and commercially valuable marine invertebrates (e.g., abalone, crab, shrimp, sea cucumbers, sea star, squid, octopus, and sea urchins) and fish (e.g., salmonids, Pacific herring, rockfish, lingcod, kelp greenling, sand lance, and surf smelt) (Araujo et al., 2013; Hamilton et al., 2022; Shaffer et al., 2019). Marine mammals (e.g., orcas, seals, and sea otters) and seabirds also frequent kelp forests and feed on species that utilize the habitat (Araujo et al., 2013; Markel & Shurin, 2015). Even in death, kelp has an important role in the broader ecosystem. As kelp senesces, energy and nutrients are exported to nearby beaches and deep, offshore environments. It is well documented in the literature that changes in kelp abundance have cascading effects on marine food webs and ecosystem states (Burt et al., 2018; Filbee-Dexter & Scheibling, 2014; Steneck et al., 2002; Watson & Estes, 2011), and healthy kelp forests contribute to healthy, often resilient, nearshore marine systems.

KELPS MAINTAIN AND IMPROVE WATER QUALITY

Near populated coastal areas, nutrient levels and sediment loads may be high due to human activities and run-off. These effects can produce toxins and alter key water quality properties, such as temperature, light, pH, and oxygen availability, subsequently causing cascading impacts on nearshore ecosystems, which can include fish kills. The effects of climate change can also impact water properties and sediment loads, leading to the increased frequency of algal blooms. Elevated levels of nutrients, such as nitrogen (N) and phosphorus (P) can lead to eutrophication and harmful algal blooms. Fast-growing kelp forests can naturally reduce the negative impacts of eutrophication. Kelps act as a natural water filtration system by absorbing excess nutrients and metals (Umanzor & Stephens, 2023; Xu et al., 2023). Studies of farmed kelp suggest that kelps' water-filtering abilities help reduce pollution by mitigating the amount of nitrogen (Umanzor & Stephens, 2023). Kelp and seagrass blades provide surfaces for fine, suspended particles to settle, thereby removing them from the water column, and improving water clarity and light penetration.



Credit: Liam Coleman

KELPS BUFFER PH

Buffering against the negative effects of coastal ocean acidification, which are projected to worsen with climate change, is another ecosystem benefit that kelp can provide (Hirsh et al., 2020; Hollarsmith et al., 2020; Ling et al., 2020; Young et al., 2022). Under acidic conditions, calcium carbonate producing organisms, such as shellfish, will struggle to form hard shells, impacting the food web and fisheries. Kelps have the potential to mitigate these effects through their demonstrated ability to increase local seawater pH and by taking up dissolved inorganic carbon (DIC) for photosynthesis (Pfister et al., 2019). As such, kelps are a recommended mitigation strategy for ocean acidification for cultured shellfish (Clements & Chopin, 2017).

KELPS DAMPEN WAVE ENERGY AND PROTECTS SHORELINES

Dense, healthy kelp forests provide a natural buffer for shorelines and contribute to the mitigation of coastal flooding and erosion (Elsmore et al., 2023; Gaylord et al., 2007; Teagle et al., 2017). Kelp blades and structure slow current and wave energy, and the 'smooth water' often found shoreward of kelp beds is explained by the attenuation of small, centimetre-scale ripples (Elsmore et al., 2023). Kelps can also modify flow within their beds, redirecting waterborne nutrient particles to suspension feeders (Gaylord et al., 2007). Due to climate change, the frequency and severity of storm events have been increasing along coastal areas, which is a growing concern for coastal ecosystems and communities, kelp can provide resilience, however, extreme wave energy may dislodge kelp.



Credit: Liam Coleman

KELPS CONTRIBUTE TO CLIMATE MITIGATION THROUGH BLUE CARBON

As climate change intensifies, greater focus is being placed on natural climate solutions as a climate mitigation strategy (McHenry et al., 2025). Until recently, natural climate solution (NCS) assessments were largely focused on terrestrial-dominated and freshwater wetland ecosystems (McHenry et al., 2025). However, vegetated coastal ecosystems, including tidal marshes, seagrass meadows, mangrove forests, macroalgal beds, and kelp forests, are some of the most productive ecosystems on Earth (Duarte et al., 2022; Pessarrodona et al., 2022, 2023). Known as 'blue carbon ecosystems' (BCEs), these aquatic habitats have the capacity to sequester atmospheric carbon dioxide and store organic carbon in the marine environment over the long term, thereby acting as carbon sinks (Filbee Dexter et al., 2022; Krause-Jensen et al., 2018; McHenry et al., 2025; Pessarrodona et al., 2023). BCEs are thought to rival terrestrial carbon stores by total extent and per-area basis (Krause-Jensen et al., 2018). However, their actual contribution to carbon sequestration and storage remains uncertain, and often controversial, due to an incomplete understanding of the carbon pathways in these systems (Krause-Jensen et al., 2018; Pessarrodona et al., 2023). Regardless, their conservation, management, and restoration are gaining traction as a practical, cost-effective NCS (McHenry et al., 2025; Pessarrodona et al., 2023). Researchers and kelp coalitions are using kelp's climate mitigation value to advocate for protection status, funding, and inclusion in national carbon inventories, despite knowledge gaps regarding their long-term carbon sequestration (Pessarrodona et al., 2023).

A recent Canada-wide study across 14 institutions and Blue Carbon Canada found that northeastern Pacific kelp forests showed the largest estimated carbon stocks per-area, 1.2 megatons of carbon per hectare (Mg C ha^{-1}), the largest number of kelp species ($N = 17$), the highest estimated annual carbon sequestration (primary production) rates (6.7 Mg C $ha^{-1} yr^{-1}$), and the highest estimated carbon export to neighboring ecosystems, including the deep ocean (0.5 Tg C yr^{1} ; 0.01–0.2 Tg C yr^{1}), where it may be sequestered on time-scales relevant to climate mitigation efforts (<100 years) (McHenry et al., 2025). Giant kelp and bull kelp showed the highest annual carbon sequestration rates per area (7.26 Mg C $ha^{-1} yr^{-1}$ and 6.35 Mg C $ha^{-1} yr^{-1}$, respectively) compared with other non-canopy forming kelp and seaweed species (McHenry et al., 2025). However, the study acknowledged data gaps in kelp distribution and ecological drivers. Further assessments of kelp forests as BCEs are urgently needed to fill these gaps in knowledge. In all, BC's kelp beds have the potential to sequester an equivalent amount of carbon as heating approximately 4000 homes using natural gas (Lang-Wong et al., 2022).



Credit: Nicole Christiansen

SOCIOECONOMIC VALUE OF KELPS

In addition to the above ecosystem services, kelp forests are important for supporting commercial, recreational, and subsistence fisheries, as well as ocean ecotourism (Eger et al., 2023; Teh et al., 2022). Kelp forests globally are estimated to generate approximately US$500 billion annually in goods and services (Eger et al., 2023), with northeastern Pacific bull kelp contributing around US$142,000 ha^{-1} yr^{-1} (totalling approximately US$4.5 billion annually) and giant kelp contributing approximately US$102,000 ha^{-1} yr^{-1} (totalling approximately US$35 billion annually), highlighting their substantial regional and global economic value (Eger et al., 2023). Kelp forests are draws for the recreation and tourism industries, including diving, kayaking, and recreational fishing (Teh et al., 2022; Bennett et al., 2016; Schulte & Lucrezi, 2025). While the direct contribution of kelp forest ecosystems specifically to BC's ocean-based economy is difficult to tease apart, this sector as a whole is believed to be worth over CA$21 billion, which is eight per cent of BC's GDP (Province of British Columbia, 2022). There has also been a burgeoning interest in developing a kelp mariculture industry in the northeastern Pacific region, which would add further value (Buckner et al., 2024; Martone et al., 2025). The rising demand for seaweed products for the purpose of food, medicine (nutraceuticals), textiles, bio-degradable plastics, biofuel, agricultural bio-stimulants, biochar, and/or methane-reducing agri-feed presents diverse opportunities to scale up and sustainably commercialize kelp and seaweed harvesting and farming (Krumhansl et al., 2017). Currently, this industry is still in its early stages in the Salish Sea and across BC, and there is a lack of legislation and regulatory framework to date (Chapter Seven).



Credit: Nicole Christiansen

KELP, SALMON, AND THE FOOD WEB

Pacific salmon (*Oncorhynchus* spp.) are renowned for their migrations from their natal rivers and streams, traversing different habitats to the open ocean and back again to spawn (Potapova et al., 2026). During their juvenile outmigration, salmon face a highly vulnerable life phase where they must grow, avoid predation, and physiologically adjust to seawater (Potapova et al., 2026). Nearshore habitats, including estuarine channels, marshes, eelgrass meadows, and kelp forests, provide a mosaic of niches and complexity in which salmon can find refuge and forage. While there is limited literature directly connecting the significance of kelp forests to salmon, largely owing to the challenges of undertaking surveys in kelp forests (Avila et al., 2026), studies to date combined with field observations, and anecdotal information, show that bull kelp forests function as critical habitat for juvenile salmon and other species that salmon rely on (Shaffer, 2004; Shaffer et al., 2019, 2020, 2023; Kali Braukmann, personal communication, 2025).

Shaffer and colleagues have led several studies investigating the dynamics of salmon, forage fish, and zooplankton in Salish Sea kelp forests, suggesting that kelp forests serve as important seasonal feeding grounds for juvenile salmon. Kelp forest habitats support diverse communities of zooplankton and other small invertebrates, which form an important link in the transfer of energy to higher trophic levels. When compared with adjacent open water, kelp forest zooplankton assemblages contain preferred taxa (harpacticoid copepods and decapods) of forage fish and juvenile salmon (Shaffer et al., 2020). Pacific herring, surf smelt, and juvenile salmon were also shown to preferentially aggregate in kelp forests over the adjacent areas, presumably for feeding and protection from larger predators. As they grow during their first summer at sea, salmon will also develop their hunting skills and practice piscivory. Shaffer et al. (2023) analyzed seven years of video observations and found that the majority of all recorded fish interactions (i.e., where fish intermingle, form schools, and feed) occurred within kelp forests versus in the adjacent open-water habitat (Figure 1.7). Kelp habitat usage was highest in June and July, during outmigration and included multiple species of salmon (Chinook, coho, chum, and pink). While most interactions were mixed-species schooling behaviours, salmon were observed predating on forage fish, in particular, herring. It is generally agreed that feeding and thus growth that occurs during the productive summer months is critical to how salmon will fare during their first winter when food supply is much leaner (Pearsall et al., 2021). While there are likely many benefits for these small fish to feed around kelp, Shaffer et al. (2020) proposed that kelp forests may increase feeding efficiency by creating a contrasting environment (e.g., the silver colour of herring against the backdrop of darker kelp), which may make the detection of prey easier.



Figure 1.7 Snorkelling and underwater video surveys showing juvenile Pacific salmon feeding in a bull kelp bed.

Beyond serving as a location where salmon feed during their first marine summer, the role of kelp forests in the larger food web indirectly benefits salmon at other life phases and is worth recognizing. Forage fish, particularly Pacific herring, are known to utilize kelp forests and other marine vegetation structures for spawning (Schweigert et al., 2018). Spawning is fundamental to the herring population, and abundant herring is vital for salmon for several reasons. Firstly, herring are among the most important prey species for adult Chinook and coho in the Salish Sea, making up the largest portions of their overall diet (Greentree et al., 2026). Secondly, plentiful herring is thought to be protective of salmon, as pinnipeds preferentially hunt herring, if present, over salmon (Pearsall et al., 2021). This is all in addition to the large diversity of life that the structure and production of kelp supports in the greater interconnected food web of the nearshore, as discussed earlier in this chapter. Taken together, the presence of dynamic and healthy kelp forests has a positive, additive effect on multiple life phases of Pacific salmon and contributes to their populations and run sizes.



Credit: Eiko Jones

Millions of years together: A prehistory of kelp and salmon

Kelp forests and salmon have a long evolutionary history together in the northeastern Pacific (Figure 1.8) (Kiel et al., 2024; Vermeij et al., 2019; Wilson & Li, 1999). The earliest salmonid fossils (*Eosalmo driftwoodensis*) known from the region are estimated to be 50 million years old (Wilson & Li, 1999), while evidence of kelp dates back approximately 32 million years (Kiel et al., 2024). Ancient, highly complex, multi-storied kelp forests likely created the first three-dimensional structures to support an evolving, rich and diverse marine community of species (Kiel et al., 2024). These ancient kelp forests may have provided a haven and nursery for Eosalmo during its outmigration, increasing its chances for survival, much as it does for modern salmon today. Together, these co-evolving species, kelp and salmon, shaped the temperate, nearshore ecosystems that we recognize today.

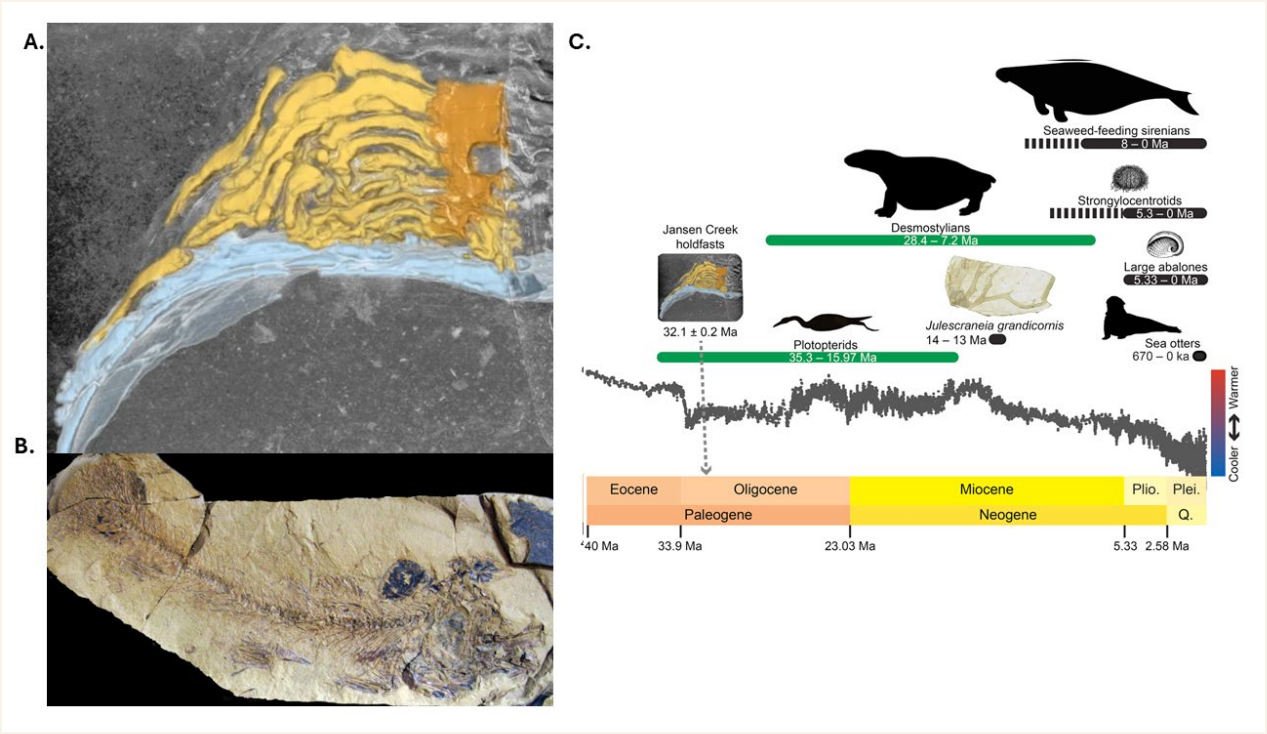


Figure 1.8 Natural history of salmon and kelp. A) X-ray construction of a 32-million-year-old fossilized kelp holdfast (attached to a bivalve shell) discovered in the Olympic Peninsula of Washington State (Kiel et al., 2024; Image credit: Dula Parkinson/Advanced Light Source, Lawrence Berkeley National Laboratory); B) Fossil of Eosalmo driftwoodensis (Wikimedia Commons, CC BY-SA 3.0);
C) The stratigraphic range of fossil kelps and associated organisms. Green bars indicate members of early kelp beds; black bars indicate members of modern, complex kelp assemblages; temperature curve was derived from planktonic foraminiferan oxygen isotope (Kiel et al., 2024; open access under the Creative Commons License 4.0 (CC BY- NC- ND)).

LESSONS LEARNED

- ☑ Kelps are a group of brown algae that form three-dimensional forests in nearshore waters at temperate latitudes, including in the Salish Sea. These forests serve as migration corridors, nurseries and refugia, nutritional resources, and transition gradients for ecologically, culturally, and commercially important species of fish and invertebrate species.
- ☑ Two species, the annual bull kelp (*Nereocystis luetkeana*) and the perennial giant kelp (*Macrocystis pyrifera*), form the buoyant canopies of kelp forests in the northeastern Pacific, with the former predominantly found in the Salish Sea. Most kelp research taking place in and around the Salish Sea has focused on these two species due to their ecological significance.
- ☑ BC is, however, home to many other "understory" kelp species that do not form buoyant canopies and are comparatively understudied.
- ☑ All kelps have a complex life history involving alternation between a macroscopic diploid sporophyte and a microscopic haploid gametophyte.
- ☑ Kelp forests provide important ecosystem services such as recycling of nutrients, buffering shoreline against the impact of wave energy, and drawing down atmospheric carbon, making kelp forests valuable to nearshore ecosystems and communities alike.
- ☑ Studies suggest kelp forests support juvenile salmonids and forage fish (e.g., herring) during vulnerable migration periods.
- ☑ Natural history evidence suggests that kelp and salmon have a long evolutionary history, and likely co-evolved in the northeastern Pacific region over millions of years.



Credit: Ryan Miller

CHAPTER TWO
THE SIGNIFICANCE OF KELP TO FIRST NATIONS

INTRODUCTION

The relationship between kelp forests and coastal First Nations is long and deep, dating back to the first human inhabitants in the northeastern Pacific (Atlas et al., 2020; Turner, 2020; Ulaski et al., 2025). Based on Paleolithic archaeological evidence, the First Peoples who arrived in the region are believed to have travelled a maritime route from Eurasia to the Americas more than 14,000 years ago (Dillehay et al., 2008; Erlandson et al., 2007, 2015). This migration is thought to have been facilitated by species-rich nearshore habitat including kelp forests that spanned the Pacific Rim. The route taken has appropriately been coined the "Kelp Highway". The bounty of these systems likely sustained these early inhabitants through food and medicine (Dillehay et al., 2008).

Precolonial systems of Indigenous management formed from sophisticated social-ecological systems of stewardship, proprietorship, traditional law, culture, linguistics and geography (Atlas et al., 2020; Turner, 2020; Turner & Berkes, 2006). It included customary practices, subsistence technology, and nature-based spiritual practices oriented towards, in most cases, sustainable management of resources over long timescales, which ensured multi-generational sustenance and reciprocity (Atlas et al., 2020; Naar, 2020). Social and ceremonial traditions were structured around seasonal cycles of resource gathering, migration between habitats, sharing and redistribution of resources (Dick et al., 2022). This way of life promoted biodiversity and sustained species abundances, despite environmental disturbances, climate change, and cycles of abundance and scarcity (Atlas et al., 2020; Turner & Berkes, 2006; Ulaski et al., 2025). Over time, these practices and beliefs generated an immense body of traditional ecological knowledge (TEK), which holds many lessons for best practices for the conservation and stewardship of kelp forests. This chapter explores the connection of the First Nations with kelp, how that connection is reviving after the profound disruption of colonization in a time of reconciliation, and how employing 'two-eyed seeing', the incorporation of TEK and Western science, is improving conservation outcomes.



Credit: Nicole Christiansen

Kelp in languages

There are several independent First Nations communities around the Salish Sea, often collectively referred to as 'Coast Salish People' (Figure 2.1, right). Each has its own unique linguistic, cultural, and geographical traditions. Halkomelem (Hul'q'umi'num), a language in the Salishan Language Family, is spoken by several Coast Salish Nations around the Strait of Georgia. In Halkomelem, kelp is called q̓am̓, and salmon is sce:ɬtən (Charlie, 2021). On Vancouver Island, there are two other distinct groups (Figure 2.1, left), and they speak languages from the Wakashan Language Family. Northern Vancouver Island is home to Kwakwaka'wakw Peoples, who speak Kwak'wala and call bull kelp w'awadi, and giant kelp q'áxq'elis (MaPP StoryMap). Western Vancouver Island is home to Nuu-chah-nulth Peoples. In Nuu-chah-nulth, kelp is husmin (kwistuup.net).

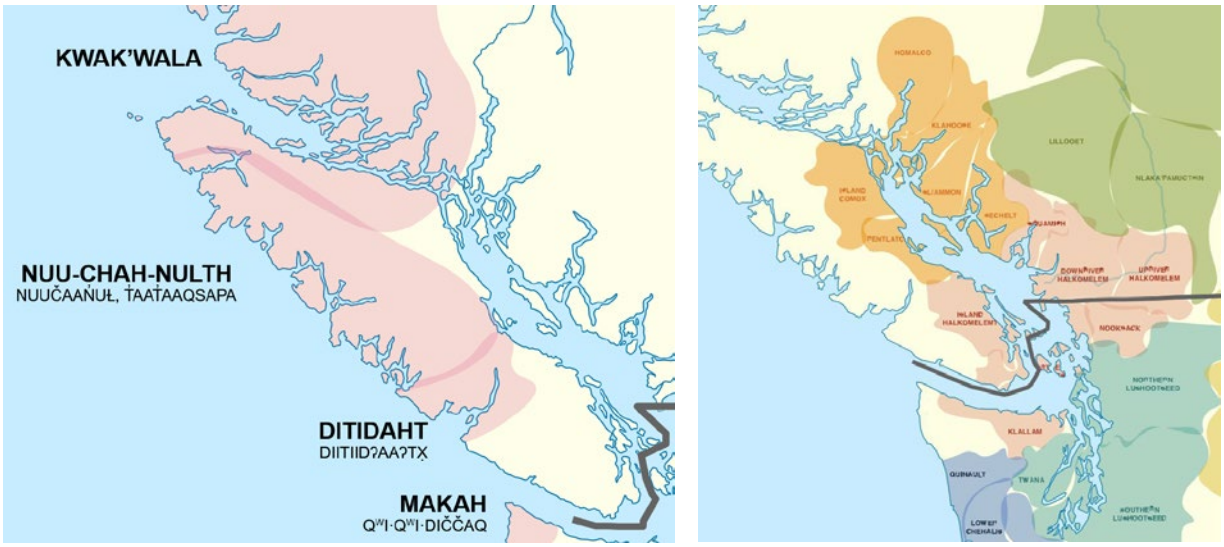


Figure 2.1 The First Nations and tribes around Vancouver Island and the Salish Sea, showing those in the Wakashan Language Family (left) and Salishan Language Family (right) (Wikipedia Creative Commons https://en.wikipedia.org/wiki/Wikipedia:Text_of_the_Creative_Commons_Attribution-ShareAlike_4.0_International_License: https://en.wikipedia.org/wiki/Wakashan_languages#/media/File:Wakashan_map.svg; https://en.wikipedia.org/wiki/Salishan_languages#/media/File:Salishan.svg).



Credit: Liam Coleman

BULL KELP'S ROLE IN INDIGENOUS FISHERIES

The ecological management of kelp by First Nations likely dates to 3000 BCE (before common era), when harvesting and transplanting techniques were used to enhance growth and aid early fisheries practices (Thornton, 2015). Today, TEK emphasizes kelp and its role as a foundational habitat that supports the richness of marine resources for subsistence. Bull kelp is both an important direct food resource and indirect support for key marine food species that inhabit shallow rocky reef habitats, such as salmon, herring, rockfish, crab, and sea urchins (Crocker et al., 2024). Isotopic studies found that kelp-derived carbon and nitrogen in tissues of kelp greenling and black rockfish, directly linked kelp to prized traditional fisheries (Biela et al., 2016).

KELP AND FISHING

Kelp habitats were favoured locations for Indigenous fishing, including the use of fish traps, weirs, reef nets, dip nets, and fish wheels (Atlas et al., 2020). Reef net-fishing used kelp-associated habitats to guide migrating salmon into nets (Naar, 2020). The technique supported sustainable harvesting and was central to precolonial economies and ways of life (Atlas et al., 2020). Coast Salish People historically made fishing lines, ropes, and anchors out of bull kelp to support their fishing activities. Stipes would be treated with dogfish oil to make them long lasting and durable (Turner, 2001).



> **Ah, when the water's quite rough, you can, on some places on the coast, go inside the kelp beds, meaning between the shore and the kelp beds, to get away from some of the rough water.**
>
> - Charlie, 2021

HERRING SPAWN ON KELP FISHERIES

Pacific herring spawn on kelp, other seaweeds, and seagrass, annually in early spring. This event is significant to Coastal First Nations as it represents an important traditional bounty that sustained communities in seasons when other nutrition sources were few and far between. Kelps, mainly giant kelp blades, have are used by several First Nation groups (e.g., Kwakwaka'wakw, Haida, Heiltsuk, and Nuu-chah-nulth nations) for harvesting roe for food and ceremonial purposes (Kobluk, 2012; Schweigert et al., 2018; Thornton, 2015). Kelp coated in herring roe is gathered, cut into pieces, soaked, left to dry in the sun, then eaten with eulachon oil (Naar, 2020; Turner, 2001).

OTHER FUNCTIONAL TRADITIONAL USES OF KELP

First Nations People have used bull kelp's unique stipe and bulb morphology in numerous ways besides food, as noted by Naar (2020) and Turner (2001). The hollow bulb was used as a container for cooking, steaming, and storing foods and medicines. Children played with the stipe and bulb, and when dried, bulbs were made into rattles or used as an instrument to create theatrical effects during ceremonies and rituals (Naar, 2020). Kelps were often used in steam baths, and the hollow, hose-like stipes were used to siphon and move water. Bull kelp was used as a buoy to anchor canoes and boats, and escape rough waters (Charlie, 2021). Medicinally, kelps were used topically to relieve earaches, by placing one end of the hollow stalk on a steaming rock and the other in the ear (similar to ear candling) and internally as a natural remedy for treating iodine deficiency (Naar, 2020; Turner, 2001). Perhaps the most curious use, bull kelp was used to bind an infant's head for the purpose of cranial modification in high-status individuals by the Kwak'wala-speaking Quatsino Tribe from northwestern Vancouver Island (Naar, 2020; Turner, 2001).

> **"A lot of our knowledgeable people who would have used kelp for different things aren't with us anymore. A lot of those traditional practices have been lost. It's just up to my generation and the next few generations to figure out what it's [bull kelp] used for. I've heard from other communities where they say we'd use the kelp to wrap stuff and cook it. We try to utilize neighbouring and other family communities to understand, like, what did your grandfather, your great grandfather or grandmother teach you about this resource?"**
>
> - Jason Leeson, personal communication, October 21, 2025

CULTURAL SIGNIFICANCE THROUGH ORAL TRADITIONS

Fables, myths, songs, and dances about kelp and salmon are common among Coastal First Nations. These traditional oral histories about human and non-human interactions and relationships carried embedded messages that represented traditional knowledge, protocols, laws, and lessons from how to conduct oneself, to how to care for the land, sea and its resources (Atlas et al., 2020). They also contained storied warnings of the consequences of straying from the spiritual and cultural beliefs of the community (Atlas et al., 2020). In some traditional stories, kelp played a role in linking the sea and land, and its critical resources. For example, in the marriage story of the Samish People (Rosario Strait, Deception Pass, Washington), an immortal 'kelp-haired' sea woman named Ko-Kwal-Alwoot, ensured bountiful marine resources for her People, or on the darker side, drowned and snatched children (Naar, 2020; Ryan, 2022). The rich compendium of fables, songs, dances, and artworks signifies the importance of place-based knowledge in guiding the co-existence of Indigenous People with the resources and ecosystems within their territories (Dick et al., 2022).

RE-EMERGENCE OF TRADITIONAL ECOLOGICAL KNOWLEDGE (TEK)

> **I find myself constantly going back to the words of my great grandpa, Chief Dan George. He was a great poet, a great activist for Indigenous rights... One of the quotes and teachings that I think of often, which is one of the most important is: 'Nothing belongs to you. Of what there is, of what you take, you must share'.**
>
> - Hilary Hyland personal communication, October 21, 2025

REVIVING INDIGENOUS-LED MARINE ECOSYSTEM MANAGEMENT

Colonial systems failed to recognize complex, nuanced Indigenous traditional systems of land ownership that are important for intergenerational sustainability, including *in situ* farming practices (Turner, 2020). Treaties largely excluded recognition of traditional plant use for food, medicine, materials or spiritual practices, including harvesting sites and methods of food production and resource management (Turner et al., 2020). As a result, historic place-based knowledge was lost and replaced with colonized introductions of non-native plant species. The loss or reduction of traditional foods and medicines, driven by colonialism, deeply impacted the health of First Nations communities (Dick et al., 2022). In addition, Indigenous traditional fishing practices and technologies, such as the use of traditional weirs and traps and reef nets were actively suppressed, outlawed, or even banned in Canada in favour of extractive, for-profit practices following the arrival of European settlers (~1770), and subsequent colonization (1858) in BC (Atlas et al., 2020; Dick et al., 2022; Turner et al., 2020; Ulaski et al., 2025). In recent years, First Nations have revitalized traditional fishing practices and fisheries management systems to address impacts on salmon and improve prospects for a more sustainable fishery.

Indigenous coastal stewardship was not recognized as a "real" form of conservation, as it was believed that there was no intentional resource management (Turner, 2020; Turner & Berkes, 2006). However, accelerated biodiversity decline and loss have underscored the need to shift how nearshore resources are managed and conserved, given the implications for climate change resiliency, coastal livelihoods, and food security (Ban & Frid, 2018; Ulaski et al., 2025). Indigenous-empowered stewardship represents a "take what you need" counter-narrative to the current system of management, which often keeps livelihoods and biodiversity separate and focuses on maximum sustainable yields-based fisheries management (Atlas et al., 2020; Dawson et al., 2021). First Nations are increasingly recognized as central to biodiversity conservation in BC. Studies show that Indigenous engagement is associated with improved social-ecological outcomes (Dawson et al., 2021), while many post-colonial conservation approaches have been ineffective and harmful and should be abandoned (Ban & Frid, 2018). Across BC and Canada, there is movement towards Indigenous Peoples' rights to govern their lands and resources and engage in meaningful consultation and co-management opportunities (Dick et al., 2022), as discussed in Chapter Seven.

> **We're raised in our communities to never take more than you need. Enough is enough.**
>
> - Jason Leeson, personal communication, October 21, 2025

WEAVING WESTERN SCIENCE WITH TRADITIONAL ECOLOGICAL KNOWLEDGE (TEK)

First Nations, alongside government, non-governmental organizations, and researchers, around the Salish Sea and elsewhere in BC, are working to revitalize TEK management systems that were decimated by colonization (Atlas et al., 2020). TEK, often defined by non-Indigenous people as the knowledge that Indigenous People hold about their environments, is increasingly used as a framework for working partnerships in ecology and conservation, though it is primarily transmitted orally across generations.

> **This information, we're just the messengers for it. It's something we've learned from the environment; it's not ours to keep to ourselves. We have that obligation to not only share our resources but to also share the knowledge of how we care for it.**
>
> - Hilary Hyland personal communication, October 21, 2025

The concept of 'two-eyed seeing' (*Etuaptmumk*), introduced by Mi'kmaw Elder Albert Marshall, emphasizes collaborative cross-cultural work, which avoids one worldview dominating (Bartlett et al., 2012). This cross-cultural approach is being advocated for use in working collaboratively with Indigenous Peoples to create space for weaving Western and Indigenous worldviews and ways of knowing to address ecosystem challenges. This collaborative approach is increasingly guiding mapping, monitoring, research, and restoration of kelps, especially in site selection and the use of traditional cultivation and harvesting.

KELP STEWARDSHIP BY THE INDIGENOUS GUARDIAN WATCHMEN

The Coastal Guardian Watchmen programs and Coastal Stewardship Network provide training, technical tools, collaboration, and networking opportunities across BC and Canada. The initiatives vary between Nations but often include ecosystem-based management, advancing traditional knowledge, community and youth engagement, and collaborations with other Nations. There are many examples of Guardians undertaking work to better understand and restore kelp. Some Nations have Guardians with diving accreditation monitoring by SCUBA, Tla'amin Nation Guardians in collaboration with Kelp Rescue Initiative are surveying with ROV, and K'omoks Guardinas are using drones. There are many examples, here we highlight the efforts of two Nations' programs.

EXAMPLES OF FIRST NATION LED KELP INITIATIVES

Snuneymuxw's restoration of bull kelp forests

The Snuneymuxw First Nation's (SFN) Salish Sea Kelp Restoration Project, is leading efforts to improve conditions for salmon returning to coastal areas around the Nanaimo River Estuary and Gabriola Island by addressing factors limiting their return, including the decline in local bull kelp forests due to sea urchin herbivory. In partnership with Cascadia Seaweed, SFN deployed an automated underwater video camera system ("FishCams") designed to track the biodiversity and abundance of fish species. Preliminary video observations show salmon of different sizes swimming through the bull kelp sites, suggesting that salmon are using these areas at different life stages. In partnership with Simon Fraser University, they are monitoring the lacy crust bryozoan (*Membranipora membranacea*), which grows and encrusts bull kelp blades, weighing kelp down and increasing its susceptibility to breakage. In their restoration trials, they experimented with outplanting kelp grown on tiles and cobbles (green gravel method) in a kelp nursery located near Gabriola Island. Despite these efforts, kelp has yet to establish, likely due to herbivory by green (*Strongylocentrotus droebachiensis*) and red (*Mesocentrotus franciscanus*) sea urchins, the northern kelp crab (*Pugettia productus*), and a gastropod snail (*Lacuna vincta*). These marine invertebrates have decimated kelp and prevented restoration success widely across the Salish Sea. SFN is considering adaptive strategies to address this, including herbivore management by harvesting urchins for 'uni' (gonads), which is a traditional food. However, the quality of the 'uni' being harvested from starved urchin barrens is often poor and unpalatable. They are also following emerging predator restoration research in the San Juan Islands, where the sunflower star (*Pycnopodia heliathoides*), a natural urchin predator, is being grown and reintroduced to urchin barren areas of previous bull kelp forests, with the hope that a similar strategy may be applied locally.

The information above is from an interview with Kali Braukmann (Special Projects Lead) from the Marine Division (under Director John White) of Snuneymuxw First Nation, on September 24, 2025.



Credit: Nicole Christiansen

Tsleil-Waututh (səlilwətaɬ) strategically supporting kelp in Burrard Inlet

Burrard Inlet, now the centre of the city of Vancouver and Canada's largest port, once supported a highly productive ecosystem with stretches that were "so thick with kelp that it was difficult to paddle through" (Tsleil-Waututh Nation & Kelp Rescue Initiative, 2025). For the Tsleil-Waututh (TWN) "People of the Inlet", Burrard Inlet remains the heart of their territory despite extensive change since European contact and subsequent urbanization (Taft et al., 2022). While bull kelp forests still occur in parts of Burrard Inlet (Figure 2.2), substantial alteration of the nearshore environment has constrained both its distribution and restoration potential. This loss of habitat has led to the inaccessibility and dislocation of harvesting areas; disrupted the intergenerational transmission of TEK by elders; reduced the availability of food resources that were once harvested in abundance; and diminished the ability of TWN to practice their culture and way of life. Over time, these cumulative impacts have negatively affected the physical, spiritual, cultural, health and wellbeing of the community (Taft et al., 2022).

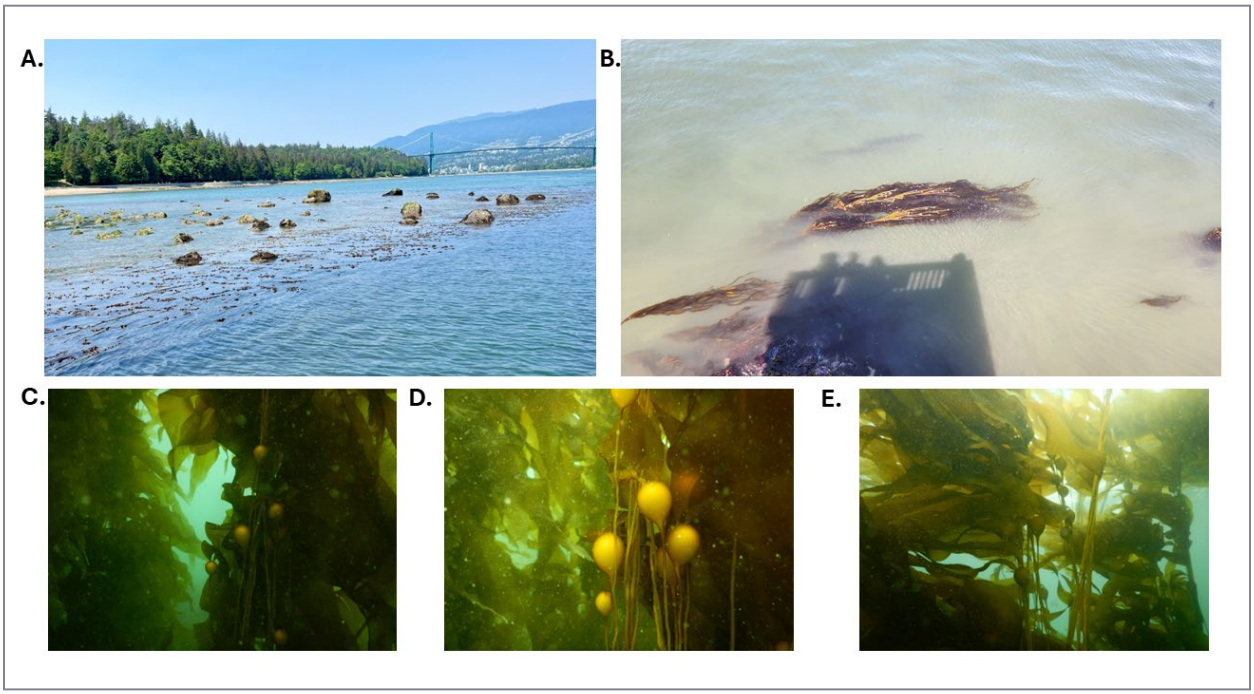


Figure 2.2 Bull kelp forests in Burrard Inlet, BC. Above water near Stanley Park (A-B), and subtidal bull kelp (C-E) (photos courtesy of C. Good, Tsleil-Waututh Nation, and SeaChange Marine Conservation Society)

> **"It's hard to boil down specifically how we're marrying the two sciences. But I think it's in the approach of making sure that nothing's off the table. Really, everything has an importance, everything is interconnected, that is the way that a lot of us in TW have been raised, with respect and interconnectedness to the environment."**
>
> - Hilary Hyland personal communication, October 21, 2025

The TWN have been the "eyes and boots on the ground," filling a gap in conservation and stewardship in Burrard Inlet, with promising results. Guided by the Burrard Inlet Action Plan, the TWN have prioritized ecological reconstruction and habitat enhancement, including bull kelp monitoring and restoration in partnership with organizations such as the Kelp Rescue Initiative, Ocean Wise, and DFO. Since 2023, bull kelp restoration projects near Whey-ah-Wichen (Cates Park) and New Brighton Park have tested methods including kelp-seeded ceramic tiles and green gravel (Figure 2.3; Good, 2024; Tsleil-Waututh Nation & Kelp Rescue Initiative, 2025). Early results suggest both sites can support healthy kelp growth. A lower abundance of urchin grazers in Burrard Inlet is advantageous; however, thermal stress from climate change and marine heatwave events are concerning and will create future restoration challenges. TWN, along with the Kelp Rescue Initiative, have produced guidelines and recommendations for bull kelp restoration, such as resilient strains may need to be considered for future restoration (Tsleil-Waututh Nation & Kelp Rescue Initiative, 2025).

The lack of effective protection measures for bull kelp in Burrard Inlet (Chapter seven), alongside ongoing pressures from shoreline hardening and ocean warming, are key concerns for TWN. Industrial projects requiring offsetting measures, for instance, are often approved without adequately accounting for impacts to bull kelp, resulting in continued degradation or destruction of these habitats. TWN suggests that a more holistic approach is urgently needed for effective protection. This may potentially be achieved by linking bull kelp conservation with water quality and fisheries management policies.

The information above is from an interview with Tsleil-Waututh Nation members and biologists Hilary Hyland (Field Programs Manager), Jason Leeson (Environmental Generalist), and Camryn Good (Marine Biologist Researcher) on September 24, 2025.

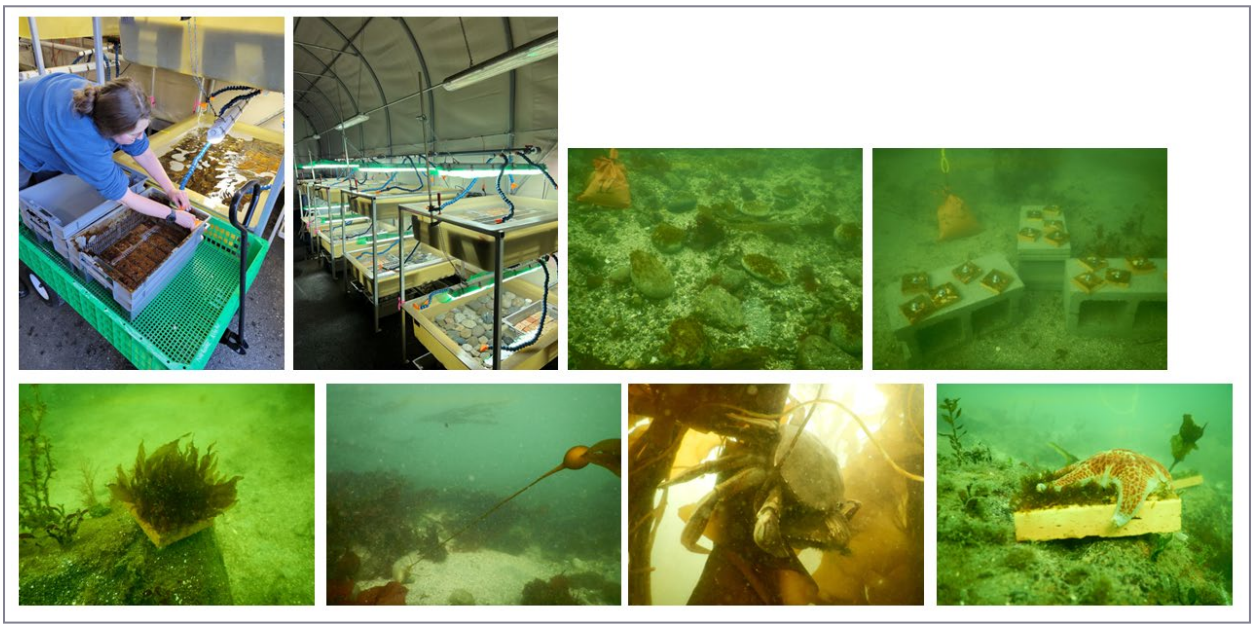


Figure 2.3 Kelp restoration efforts by the Tsleil-Waututh Nation. Images show kelp being cultured in the laboratory before being outplanted in Burrard Inlet. Different restoration techniques are shown seeded onto cobble and gravel, and ceramic tiles (photos courtesy of C. Good and Tsleil-Waututh Nation).

LESSONS LEARNED

- ☑ For millennia, Coastal First Nations through complex systems of stewardship, proprietorship, traditional law, culture, linguistics and geography, managed coastal marine resources and habitats ensuring multi-generational sustenance and reciprocity.
- ☑ Healthy shorelines and kelp forests are intricately linked to healthy fisheries that ensure future food security and sovereignty for First Nations, both in the past and today.
- ☑ Traditional ecological knowledge (TEK) is knowledge that Indigenous People hold about their environments and is increasingly used as a framework for ecosystem and conservation management.
- ☑ Much of the TEK around bull kelp has been lost among younger generations, however, knowledge sharing among communities and re-visitation of oral histories, is revitalizing lost ancestral knowledge.
- ☑ Coastal First Nations are weaving TEK with Western science, to improve current outcomes for salmon and bull kelp forests. A key concern is the lack of protection of bull kelp in the Salish Sea.



Credit: Liam Coleman

CHAPTER THREE
METHODS FOR MAPPING AND MONITORING OF KELP FORESTS

INTRODUCTION

Effective management of kelp forest ecosystems depends on accurate and efficient data collection using methods that capture their spatiotemporal dynamics (Eger et al., 2023; Giraldo-Ospina et al., 2025). Mapping and monitoring kelp forest extent and productivity can identify trends, current status, and the key drivers impacting kelp persistence and resilience (Connell & Sousa, 1983; Holling, 1973). However, this is a challenging and complex task (Mora-Soto, 2025) as the 25,000 km of BC's coastline is rugged, remote, and geomorphologically complex (Teh et al., 2022), and the extent of kelp forests, especially bull kelp, can vary year to year (Hamilton et al., 2022).

Despite these challenges, mapping and monitoring efforts in BC have increased significantly in recent years, driven in part, by advances in high-resolution remote sensing technology that have dramatically improved the ability to monitor floating canopy kelp across vast areas and varying timescales. Researchers are now combining methods to better resolve spatial and temporal patterns of canopy kelp extent and change, identify areas of persistence that may act as climate refugia, and inform areas for protection and restoration prioritization (Gendall et al., 2025; Hollarsmith et al., 2022; Mora-Soto et al., 2024a, 2024b; Schroeder et al., 2020; Starko et al., 2024, 2025; Timmer et al., 2026; Wachmann et al., 2026). In this chapter, we review the suite of methods and tools, and their advantages and applications for mapping and monitoring kelp forests in BC (Table 3.1, Figure 3.1).

Table 3.1 Comparison of direct and indirect methods for mapping and monitoring floating, surface canopy-forming kelp habitats in the Salish Sea and greater British Columbia.

Method	**Objectives** (as described in Reshitnyk et al. 2023)	**Spatial scale & resolution**	**Advantages**	**Disadvantages**	**References/ resources** (protocol, guidebooks, and framework literature)
Field-based *in situ* surveys: Surface boat or kayak-based surveys; and underwater snorkel and SCUBA surveys (with or without video)	▸ Presence/ absence ▸ Species ▸ Density/ biomass ▸ Health status	▸ Local scale ▸ High resolution	*In situ*; location and species specific; pin-point accurate location for ground-truth; accessible; documents biodiversity, including understory beds; uses established local protocols; includes historical time series	Labour and time intensive; costly, may require transport and expensive equipment; timing needs to be in alignment with season, weather, oceanographic conditions; point-data (may not account for inter-annual variability); incompatible data collection methods across studies	Berry and Cowdrey (2021); Berry et al. (2021); Checko (2024); Fretwell and Boyer (2010); Reshitnyk et al. (2023); Thompson (2021); Underhill (2025); Timmer et al. (2026)

Method	**Objectives** (as described in Reshitnyk et al. 2023)	**Spatial scale & resolution**	**Advantages**	**Disadvantages**	**References/ resources** (protocol, guidebooks, and framework literature)
Underwater photography using drop-tow cameras, remotely operated vehicles (ROVs) or autonomous underwater vehicles (AUVs)	▸ Presence/ absence ▸ Species ▸ Density/ biomass ▸ Health status	▸ Local scale ▸ Low to high resolution	*In situ*; mobile, relatively inexpensive; can do deeper depths, longer survey times than SCUBA; reduced personnel; operates in complex areas, maneuverable; non-destructive; can facilitate resampling; allows for uninterrupted continuous recordings; used in highly polluted waters	Low resolution images due to camera motion, high turbidity, high flow/ currents, and/ or changes in depth; equipment corrosion	Buscher et al. (2020); de Mendoca and Metaxas (2021)
Aerial photography by occupied fixed-wing aircraft	▸ Presence/ absence ▸ Species ▸ Density/ biomass ▸ Health status	▸ Regional scale ▸ High resolution (digital (RGB) film; colour infrared (CIR), multi/ hyperspectral sensors)	Short time window for operation; relies on suitable weather and oceanographic conditions; location and species-specific	Can be expensive; requires geospatial surveyors; requires technical expertise in post-processing, and imagery storage	Berry and Cowdrey (2021); Berry et al. (2021); Nearshore Habitat Program of the Washington Department of Natural Resources; Pfister et al. (2018); Province of BC kelp surveys (BCMA); Reshitnyk et al. (2023); ShoreZone Coastal Imaging & Habitat Mapping Protocol (2017); Sutherland (2008); Starko et al., (2024); Timmer et al. (2026)

Method	**Objectives** (as described in Reshitnyk et al. 2023)	**Spatial scale & resolution**	**Advantages**	**Disadvantages**	**References/ resources** (protocol, guidebooks, and framework literature)
Drones / unmanned aerial vehicles (UAVs), unmanned aerial systems (UASs), remotely piloted aerial systems (RPASs)	▸ Presence/ absence ▸ Species ▸ Density/ biomass ▸ Health status	▸ Local scale ▸ High resolution	Relatively low cost; high spatial and spectral resolution; size/ lightweight and mobile; accommodation of a variety of sensors; control and flexibility in data collection	Not suitable for regional scale; requires visual line of sight; influenced by weather and oceanographic conditions; maximum flight altitudes; reliance on batteries; the need to obtain an operator's license; loss or destruction; may limit the participation of citizen science-based volunteers	Berry and Cowdrey (2021); Reshitnyk et al. (2023); Thompson (2021); Timmer et al. (2022, 2024)
Satellite remote sensing using a variety of spatial-temporal scales and multi-spectral sensor resolutions	▸ Presence/ absence ▸ Species ▸ Density/ biomass (at very high resolution)	▸ Regional scale ▸ Variable resolution: Coarse (~10-20 m); medium (<10 m); high (<5 m); very high (<0.5 m)	Relatively low cost (if free); downloadable web archives; large coastal coverage	Costs of images (if not free); timing of environmental conditions; requires *in situ* ground truth surveys; trade-offs—necessity to combine multiple satellite sensors to extend a timeseries; requires technical expertise in post-processing, and imagery storage	Gendall et al. (2023, 2025); Mann et al. (2025); Mora-Soto et al. (2024a, 2024b); Nijland et al. (2019); Reshitnyk et al. (2023); Schroeder et al. (2019, 2020); Starko et al. (2024a); Timmer et al. (2026); Wachmann et al. (2026)

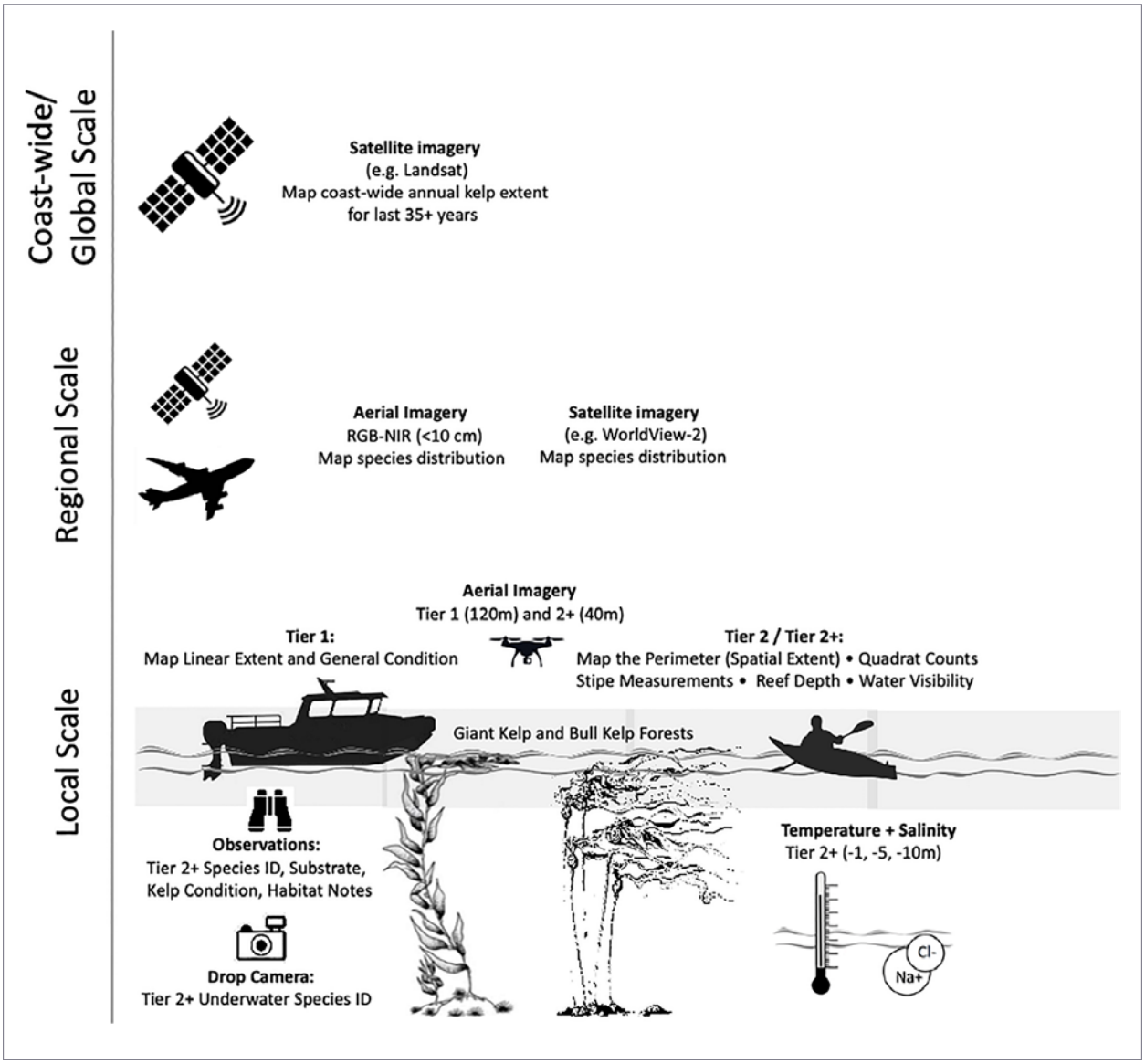


Figure 3.1 Local, regional, and coast-wide scale canopy kelp mapping and monitoring methods including: a) field surveys; b) remotely operated vehicles (ROVs) or autonomous underwater vehicles (AUVs); aerial photography using occupied aircraft vehicles (OAVs); aerial vehicles (UAV's) or drones; and spaceborne earth observation satellite imagery (Cavanaugh et al., 2021b; Thompson 2021; open-access under the Creative Commons Attribution License (CC BY)). Other less common methods include single- and multibeam acoustic (echo-sounding) surveys (Kartveit et al., 2022) and LiDAR (laser imaging, detection and ranging), which has been combined with acoustic surveys to estimate kelp biomass and quantify understory kelp beds elsewhere (Bennion et al., 2019; Young et al., 2015).

DIRECT METHODS: FIELD-BASED SURVEYS

Prior to the development of remote sensing tools, kelp mapping and monitoring relied primarily on traditional field-based surveys in which visual observations were made above-water by boat or kayak. The use of underwater surveys using snorkel, SCUBA, or drop/tow cameras followed and provided additional data on health, biodiversity, and understory species composition. These methods are suitable for mapping individual beds and smaller geographic areas. They generally provide high-resolution, accurate data but can be costly and subject to logistical constraints, including access to remote locations, timing of tides, weather conditions, and seasons. Although ecological sampling methods are generally used, the employment of different protocols may limit comparability across regions; however, this can be overcome as knowledge, standardized protocols, and guidance are shared (e.g., Kelp Node in BC; Fretwell & Boyer, 2010; Reshitnyk et al., 2023; Thompson, 2021). Despite being labour-intensive and spatially limited (Cavanaugh et al., 2021b), field-based surveys are essential for local-scale assessments of conditions, and for collecting accurate, ground-truth data to improve data quality and reduce errors associated with using remote sensing tools (Schroeder et al., 2019; Timmer et al., 2024).



Credit: Liam Coleman

HISTORICAL SURVEYS

Historical datasets are valuable for reducing the problem of "shifting baseline syndrome", a phenomenon prevalent in coastal marine management, where there is a tendency for successive generations to perceive increasingly degraded ecosystem states as normal, due to short temporal perspectives (Soga & Gaston, 2018; Wachmann et al., 2026). In Washington State and BC, there are century-old records documenting kelp presence. Although these early surveys had motivations other than conservation, they offer rare sources of valuable baseline information for assessing long-term ecological change in relation to modern kelp distribution.

Starting in the mid-1800s, the locations of kelp were hand-drawn onto nautical charts as navigational hazards by the British Admiralty (BA) when mapping the BC coast (Figure 3.2). Using this information, Costa et al. (2020) compiled 137 historical (1858–1956) BA charts into a georeferenced mosaic map of kelp presence. Overall, 99 per cent of the kelp features occurred where they should, at a threshold of 40 m water depth, which reflects the natural depth occurrence of kelp in the region today (Costa et al., 2020; Graham et al., 2007).

Surveys for commercial purposes in the early 1900s to identify kelp-based potash and iodine supplies documented kelp extent and biomass in the northeastern Pacific (Cameron, 1916; Cameron, 1915; Foreman, 1984; Pfister et al., 2018; Rigg, 1915; Wood, 2017). The records from these surveys were digitized and georeferenced by the Washington State Department of Natural Resources (DNR) (Larsen, 2025; Pfister et al., 2018).

These datasets can then be compared with aerial photographs (Sutherland et al., 2008) and satellite imagery data to produce a long-term time series of kelp change in the Salish Sea (Table 3.2; Gendall et al., 2025; Mora-Soto et al., 2024a, 2024b; Pfister et al., 2018). The BA dataset has since been used to analyze changes in kelp distribution over centennial time scales around Haida Gwaii (Gendall et al., 2025), the Salish Sea (Mora-Soto et al., 2024a, 2024b), and the West Coast of Vancouver Island (Wachmann et al., 2026).

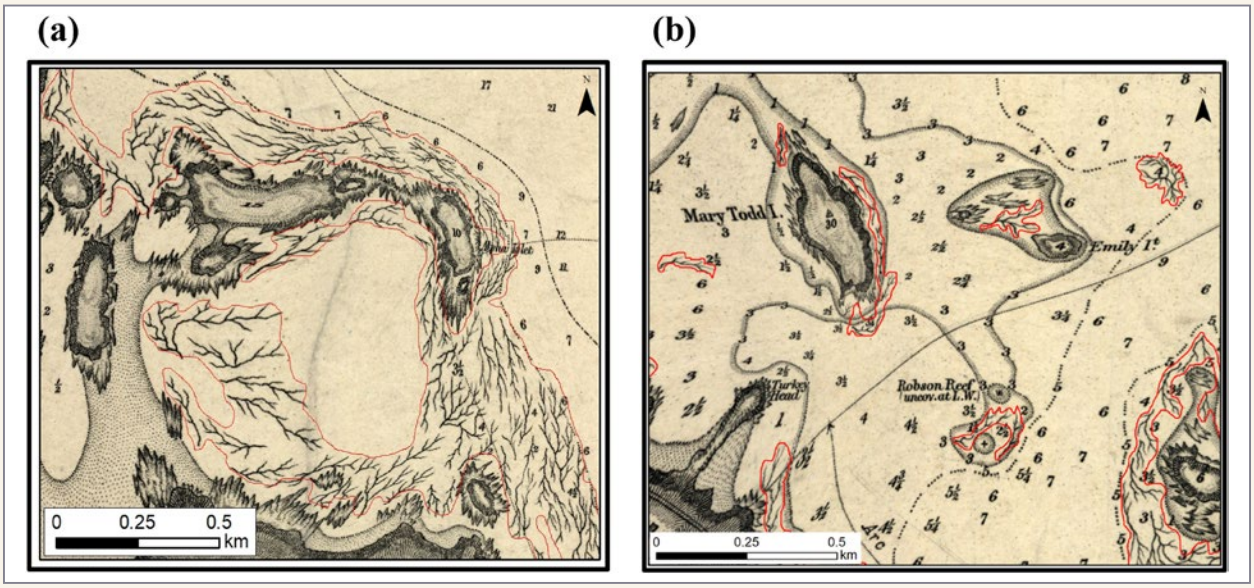


Figure 3.2 An example of the historical (1858–1956) British Admiralty navigational maps (a and b) that were hand-digitized and georeferenced for kelp presence. Kelps were possibly marked as potential navigational hazards, and dendritic symbols were depicted as surface floating "kelps" (blade and stipe structures; Costa et al., 2020).

Nautical charts have been used elsewhere to understand earlier canopy kelp extent, including those taken from Darwin's HMS Beagle expedition in sub-Antarctic regions (Mora-Soto et al., 2021).

SURFACE KAYAK-BASED SURVEYS

Kayak surveys are perhaps the most practical and valued method for mapping floating canopy kelps, especially by community-based citizen science groups in the Salish Sea. To carry out kayak surveys, volunteers receive in-person training using survey-specific tools such as data sheets, a GPS, kayak, and a standardized mapping protocol (Fretwell & Boyer, 2010; Underhill et al., 2025). Surveys are carried out along the shoreline at low tide, during the peak of annual growth, usually from June through September. The surveyor collects waypoint data around the perimeter of a bull kelp bed, which are digitized and mapped geospatially to describe the bull kelp extent and area (Underhill et al., 2025). Fine-scale, field data acquisition by kayak can be timed to satellite image acquisition, where possible, to validate kelp classification techniques and ground-truthing (Schroeder et al., 2020).

Kayak-based methods are being carried out annually in the Southern Gulf Islands by Mayne Island Conservancy Society and their partners, including the Pender Islands Conservancy Association, Galiano Conservancy Association, Saturna Island Marine Research and Education Society (SIMRES), and Valdes Island Conservancy (Underhill et al., 2025). Mayne Island Conservancy's citizen science efforts have been ongoing since 2010, and since 2019 with partners. Data can be accessed from the PSF Marine Data Centre. Similarly in Puget Sound, kayak-based bull kelp surveys are carried out annually by community scientists led by the Marine Resources Committee of the Northwest Straits Commission (Whitty, 2025), using a protocol initially developed in 2014 (Bishop, 2023). Data from 2015 onwards is available at SoundIQ.


Credit: Mitch Miller

UNDERWATER SNORKEL AND SCUBA SURVEYS, WITH OR WITHOUT VIDEO

Snorkel and SCUBA surveys, although costly and logistically complex, have a niche role in understanding the subsurface dynamics and drivers of kelp forest ecosystems (Shaffer, 2020; Shaffer, 2025). Underwater surveys can include stipe density, understory macroalgae, plankton, fish, and invertebrates to characterize habitat structure and species biodiversity (Rhoades & Good, 2025). They provide a better understanding of the value of kelp ecosystems as critical nurseries, foraging grounds, and migration corridors, as well as the health and condition of the system. Surveys are carried out using standardized methods such as weighted linear transect lines (~100 m length) and/or quadrats, at consistent depths, tides and conditions, generally parallel to the shoreline, and during the peak of annual bull kelp growth from June through September. A protocol to survey fish and zooplankton in kelp forests, using standard snorkelling and video methods, is available from PSF and Coastal Watershed Institute (Avila et al., 2026).

Several groups employ underwater surveys to support their conservation goals. In BC, the Tsleil-Waututh Nation, along with their partners, carried out trial restoration and monitoring of bull kelp using SCUBA in Burrard Inlet between 2023 and 2024 (Chapter Two; Good, 2024). Their ongoing aim is to scale up efforts and improve methodology, and monitoring supports adaptive management. To encourage broader adoption of standardized methods, the Kelp Rescue Initiative, along with several partners, recently developed protocols for monitoring kelp forest habitats and trained Indigenous Guardian divers to carry out underwater surveys in their territories. The Puget Sound Kelp Conservation and Recovery Plan of the Northwest Straits Commission is expanding its survey methods to include SCUBA-based monitoring to better assess the value of kelp ecosystems as critical species habitats, as bull kelp has been in decline (Berry et al., 2021; Whitty, 2025).

SCUBA surveys are often combined with underwater cameras to monitor habitat dynamics and identify fish species that utilize kelp forests (Bates, 2025; Bates et al., 2024; Shaffer et al., 2019; Shaffer, 2025). A low-cost, high-resolution, and time-efficient tool was developed to monitor fish biodiversity and population dynamics in sugar kelp and canopy kelp farms in BC. This technology uses a modified underwater (LookSeas) camera or a "FishCam" with an online platform for visualization (Bates, 2025; Bates et al., 2024). The camera can capture 5-min underwater videos at hourly intervals, generating thousands of hours of footage. Post-processing involves training an open-source AI algorithm to identify and count millions of common fish taxa, with hourly estimates of per-taxon abundance, which reduces the need for hours of human labour (Bates et al., 2024). Underwater cameras, combined with machine learning technology, can provide an effective monitoring tool to understand the biodiversity of kelp forests, how they are being used by key species, and their role as refuge.



Credit: Nicole Christiansen

REMOTELY OPERATED VEHICLES (ROVS) AND AUTONOMOUS UNDERWATER VEHICLES (AUVS)

Field surveys can be complemented using remotely operated vehicles (ROVs) or autonomous underwater vehicles (AUVs). Their use is not yet common in the Salish Sea but has potential. Technological advancements have made the use of these tools relatively inexpensive, with advantages over the limitations that SCUBA diving presents, including fewer personnel requirements and constraints on depth and survey duration (Buscher et al., 2020). ROV's are relatively easy to operate, suitable for complex habitats, and enable non-destructive, repeatable, continuous surveys including in hazardous conditions (Buscher et al., 2020; de Mendonça & Metaxas, 2021). Disadvantages may include low resolution or reduced image quality due to camera motion, high turbidity, high flow/currents, rapid changes in depth, and equipment corrosion from saltwater; ROV use may also require technical expertise for imagery post-processing, which can also be time-consuming (de Mendonça & Metaxas, 2021).

The Songhees First Nation has applied a low-cost, mini–Trident ROV for monitoring (Buscher et al., 2020). This tool was used for marine conservation planning around the Tl'ches Archipelago near Victoria, which represented the first Indigenous-led survey to establish ecological baselines and assess the use of ROVs for marine planning (Buscher et al., 2020, 2021). Initial baseline data documented many culturally important species and up to 27 species of macroalgae, including bull kelp (Buscher et al., 2020). Limitations of ROV use included reduced performance in high-flow conditions and in dense kelp beds, underscoring the importance of tool selection.



Credit: Eiko Jones

INDIRECT METHODS: REMOTE SENSING

Since canopy-forming kelps are visible at the ocean surface, they can be detected using remote sensing tools such as aerial photography by fixed-wing occupied aircraft vehicles (OAVs), unmanned aerial vehicles (UAVs) more commonly called drones, and spaceborne Earth observation satellites (Cavanaugh et al., 2021b; Reshitnyk et al., 2023). These tools have made it possible to map vast geographical areas.

The history of remote sensing has been shaped by a series of evolving technological advancements that have revolutionized the collection of increasingly accurate, high-resolution data. Aerial photography by OAVs is a well-established tool used to map large areas of the coast, with imagery available as far back as the 1930s for BC (Burt et al., 2018; Coastal and Ocean Resources, 2022; Foreman, 1984; Starko et al., 2024a; Timmer et al., 2024). Earth observation satellite technology arrived with the launch of Landsat-1 in 1972, which resulted in the rapid evolution of a variety of commercial satellites with operating bands that cover the electromagnetic spectrum. A range of coarse to very high-resolution multispectral imagery is now available, which can be visually enhanced using deep-learning algorithms to detect changes at the land-ocean interface, where anthropogenic climate and environmental stressors tend to be intensified (Reshitnyk et al., 2023; Schroeder et al., 2019). The earliest mapping efforts used Landsat satellite data to map canopy kelp in the Pacific Northwest (Jensen et al., 1980). Refinement of methods followed and showed the efficiency of satellite remote sensing to generate consistent, long-term datasets over large spatial areas (Deysher, 1993; Stekoll et al., 2007). Satellite technology is now increasingly being used to map and monitor the extent of floating kelp canopies over large swaths (>100-1000s of kilometres) of the Pacific coast (Bell et al., 2020a; Cavanaugh et al., 2010; Jensen et al., 1980). For example, decadal-scale, satellite-based time series are available for giant kelp for much of California, where relatively straight coastlines and consistent or 'good' environmental conditions (low cloud cover, predictable tidal heights and currents) have allowed for the use of low spatial resolution imagery (e.g., Landsat 30 m) by several studies (Bell et al., 2020a; Cavanaugh et al., 2011; Finger et al., 2021; Hamilton et al., 2020). However, there was no equivalent for bull kelp to document their (>90 %) loss and shift to sea urchin barren states near the southern edge of their distribution in northern California, prompting the need for their long-term monitoring more recently (Finger et al., 2021; McPherson et al., 2021; Ricart et al., 2025; Rogers-Bennett & Catton, 2019). This is also true for the inner waters of the Salish Sea, where bull kelp declines have been linked to marine heatwave events, with recent investigations into their trends occurring over the past few years (Berry et al., 2021; Mora-Soto et al., 2024a, 2024b; Pfister et al., 2018; Starko et al., 2024). Today, UAVs or "drones" are also transforming mapping for conservation management, restoration, and protection (Castellanos-Galindo et al., 2019; Jiménez López & Mulero-Pázmány, 2019). Drones are increasingly being used to study changes in a variety of nearshore ecosystems (Castellanos-Galindo et al., 2019; Jiménez López & Mulero-Pázmány, 2019) including tidal marshes (Doughty & Cavanaugh, 2019; Haskins et al., 2021), eelgrass meadows (Nahirnick, Costa, et al., 2019; Nahirnick, Reshitnyk, et al., 2019), intertidal macroalgae (Rossiter et al., 2020), and algal blooms (Kislik et al., 2018).

Remote sensing tools are effective for detecting floating kelp canopies at the ocean surface, much like terrestrial vegetation. Floating kelps strongly scatter and reflect visible, near-infrared (NIR) light, while the surrounding seawater absorbs it (Figure 3.3) (Bell et al., 2018; Cavanaugh et al., 2021b; Schroeder et al., 2019). Therefore, passive optical sensors (e.g., multispectral satellite sensors) help visualize kelp by leveraging the distinct spectral contrast between kelp and seawater, where kelp appears as a bright pinkish-red-coloured object against a dark, opaque background (Jensen et al., 1980; Schroeder et al., 2019). However, limitations include reduced sensitivity to subtle pigment changes and temporary submergence due to tides, currents, and waves (Britton-Simmons et al., 2008; Schroeder et al., 2019; Timmer et al., 2024). These can create challenges in distinguishing canopy kelp from the surrounding seawater in imagery, as results may be influenced by sun glint, breaking waves, currents, dissolved organic matter, and/or algal blooms (Cavanaugh et al., 2011; Mora-Soto et al., 2020).

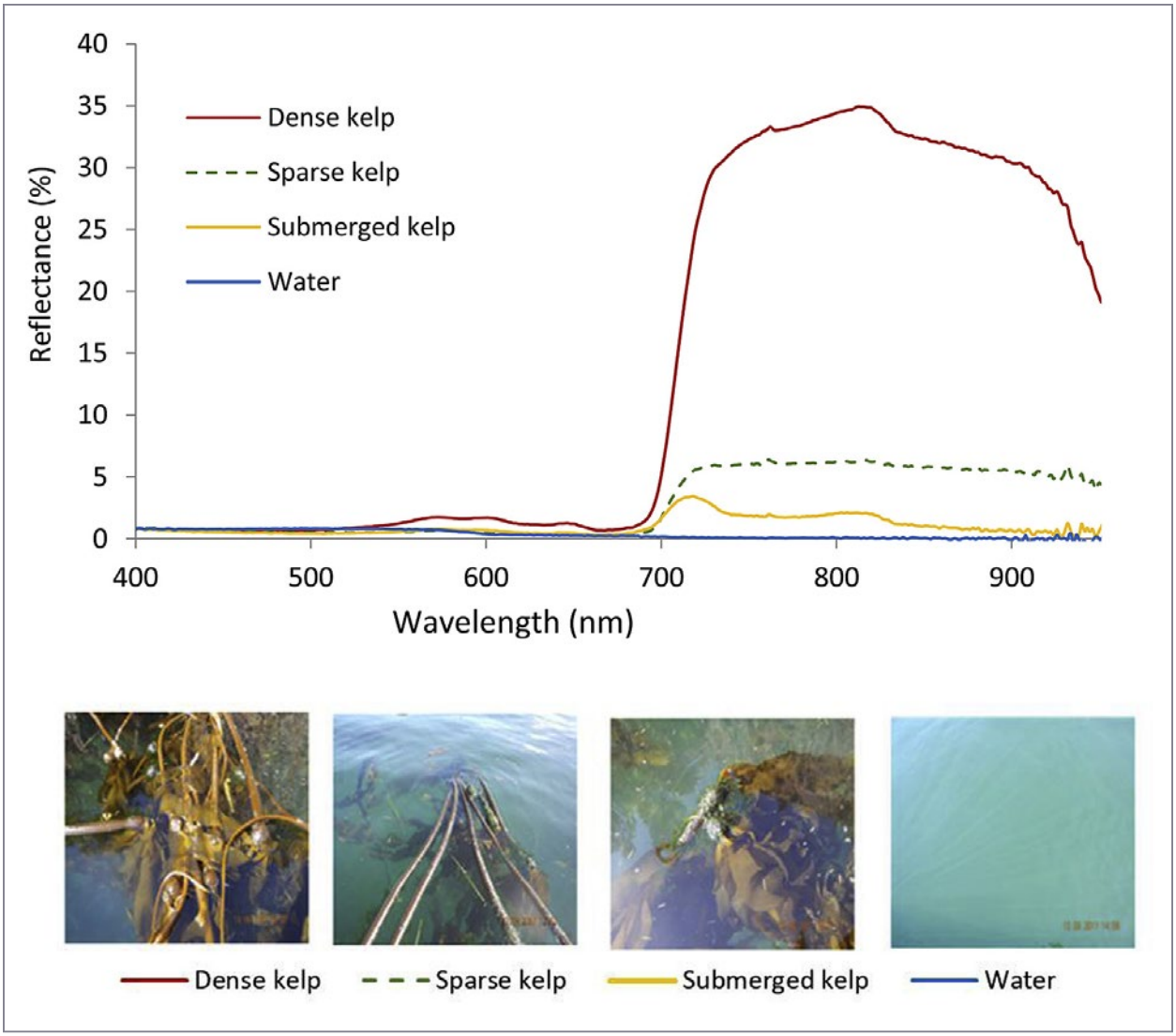


Figure 3.3 Kelp's high photosynthetic reflectance in the near-infrared (NIR) wavelength (700-1000 nm) in contrast to the surrounding seawater. Here we see a comparison of reflectance of dense (>50% of 1m^2 covered), sparse (<50% of 1m^2 covered), submerged kelp (all plants slightly below water surface) and ocean water measured with a Fieldspec Pro® spectroradiometer in the coastal waters of British Columbia, Canada (Schroeder et al. 2019; open access under the CC BY-NC-ND license).

When mapping with remote sensing imagery, the morphological characteristics of giant kelp and bull kelp should be considered, because they influence how well the kelp forest canopy can be detected at the ocean surface. Giant kelp typically forms dense raft-like bands due to its buoyant surface blades, making it readily detectable (Cavanaugh et al., 2010, 2021b). Bull kelp, on the other hand, has buoyant pneumatocysts with submerged blades that appear at the surface as narrow, fringing bands (Schroeder et al., 2020). Sparse or submerged bull kelp beds can be difficult to differentiate due to low NIR reflectance and mixed pixels (land, water, and kelp) (Cavanaugh et al., 2021b; Schroeder et al., 2019; Timmer et al., 2024). Higher resolution technology is often needed to detect fringing bull kelp beds close to shorelines (Britton-Simmons et al., 2008; Schroeder et al., 2019).

REMOTE SENSING BY AERIAL PHOTOGRAPHY USING OCCUPIED AIRCRAFT VEHICLES (OAVS)

Remote sensing by aerial photography from occupied aircraft vehicles (OAVs) has been used to map the entire coastline of BC (e.g., ShoreZone), including kelp beds, over the last 50 years (Foreman, 1984; Jensen et al., 1980). This method captures very high-resolution images (~0.1–2 m) using sensors such as red–green–blue (RGB) and near-infrared (NIR) systems mounted on low-flying planes or helicopters (Reshitnyk et al., 2023; Schroeder et al., 2019). Flights are carefully timed to optimize visibility, typically during low tide, calm sea conditions, and favourable sun angles, with surveys conducted in mid-summer when kelp is most visible. Images are collected with high overlap to ensure coverage and clarity (Reshitnyk et al., 2023). After collection, images are stitched together, hand-digitized, and georeferenced to create seamless maps (orthomosaics) of survey areas (Reshitnyk et al., 2023; Schroeder et al., 2019). OAVs offer advantages, including nimble deployment when environmental conditions are suitable; high-resolution imagery that can discern between giant kelp and bull kelp canopies; and access to extensive, and remote areas (Reshitnyk et al., 2023; Schroeder et al., 2019). However, it is costly, requires contracting geospatial surveyors, relies on expertise for post-processing, and necessitates storage of the large imagery files (Reshitnyk et al., 2023; Schroeder et al., 2019).

Bull kelp populations in BC were initially surveyed by OAV in the 1970s by Ron Foreman, who developed the Kelp Inventory Method (KIM-1) to address the problem of "poor repeatability, inaccuracy in estimating aerial extent and mean biomass, non-representative sampling, and lack of consideration of tidal influences" (Foreman, 1984; Wheeler & Black, 1990). Modified KIM-1 was successfully used by several studies over a 20-year period within the Pacific North Coast Integrated Management Area (Blakley & Chalmers, 1973; Coon et al., 1979; Coon et al., 1978; Field et al., 1977; Field & Clark, 1978; Foreman, 1984; Sutherland, 1989, 1998, 1999; Sutherland et al., 2008). KIM-1 ended after 2007 surveys, but data from these surveys has been used to inform management decisions (Sutherland et al., 2008).

Today, ShoreZone provides a georeferenced aerial imagery and video archive for classifying habitats that span shoreline areas across the northeast Pacific, from Alaska to Oregon (Coastal and Ocean Resources, 2022; Cook et al., 2017). Collected data has supported conservation, planning, and change detection (Coastal and Ocean Resources, 2022). In August of 2021, the BC ShoreZone project mapped bull kelp beds along 1,360 km (385 ha) of subtidal shoreline in the Salish Sea (Coastal and Ocean Resources, 2022).

More recently, archived, undigitized, black and white, coastal aerial images dating back to 1972 were used to construct a baseline from which 50-year changes in bull kelp beds were mapped around (~57 km of coastline) Denman Island, in the northern Salish Sea (Table 3.2, Figure 3.4) (Timmer et al., 2026). Historical aerial imagery was complimented by modern data (2023), which was collected by resurveying sites during low tide, using snorkel and SCUBA, to assess changes in community composition. In addition, a time-series of kelp canopy was developed using 30-m resolution Landsat imagery (1984–2024).

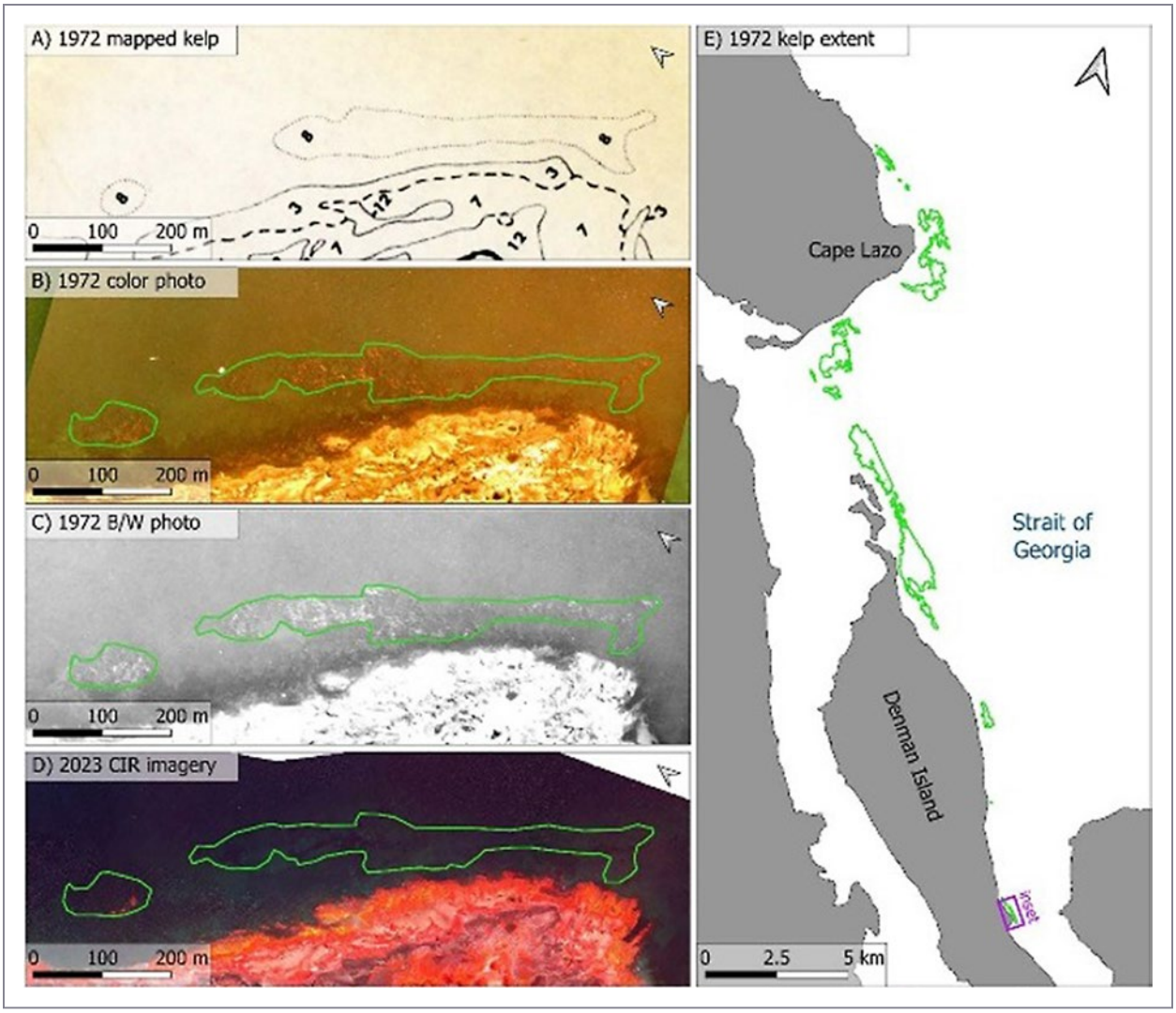


Figure 3.4 Maps depicting the modern (2023) loss of surface canopy-forming bull kelp compared to the 1972-historic extent in the northern Salish Sea near Denman Island off Comox. (A) shows a vegetation map created from 1972 aerial and ground truth surveys. Aerial photographs in colour (B) and black and white (C) were overlaid with manual delineations (green polygons) of bull kelp extent in 1972. In the same location, (D) a colour-infrared image of bull kelp shows the area re-surveyed by Timmer et al. (2026) in 2023, with bull kelp no longer present. In the map to the right (E), the entire extent of bull kelp within the survey region can be seen along Cape Lazo and Denman Island. Note the location of inset panels A–D in the purple rectangle. (Timmer et al., 2026; open access under the CC BY 4.0 license).

In Washington State, several programs have monitored, mapped, and quantified floating kelp using a combination of indirect and direct methods (Table 3.2). These include decadal-scale aerial survey datasets, along with historical baseline surveys (Cameron, 1915; Rigg, 1915) spanning over 100 years (Berry 2020; Berry et al., 2021; Britton-Simmons et al., 2008; Pfister et al., 2018). Aerial imagery collection is ongoing (resumed in 2022) and occurs across a large portion of the state's coastlines in order to track kelp trends to inform the WA State Floating Kelp Vital Sign Indicator.

REMOTE SENSING BY AERIAL PHOTOGRAPHY USING UNMANNED AERIAL VEHICLES (UAVS)

The use of consumer-grade drones is proving to be a promising tool for local-scale mapping. They are a viable alternative to other established remote sensing platforms due to their relatively low cost (approximately US$500-10,000), fine-scale (< 5 cm) spatial resolution, and small, lightweight sizes that support RGB sensors, multi- and hyperspectral sensors (Bell et al., 2020b; Bennion et al., 2019; Cavanaugh et al., 2021a; Reshitnyk et al., 2023; Saccomanno et al., 2023). They offer greater control and flexibility for the timing of data collection, with the potential to mitigate the limitations imposed by suboptimal flight conditions on data quality (Table 3.1; Cavanaugh et al., 2021a; Saccomanno et al., 2023). Imagery is stitched together to create georeferenced orthomosaics using tools, such as the KelpOMatic (Berry & Cowdrey, 2021; Reshitnyk et al., 2023). Limitations include regulatory requirements (e.g., Transport Canada), obtaining a pilot and operator certification, line-of-sight constraints, battery limits, potential loss of the drone, and sensitivity to weather and tides, making drones ineffective for coast-wide scale mapping (Reshitnyk et al., 2023; Saccomanno et al., 2023).

The success of using drones for mapping floating and submerged canopy kelps depends on the timing of data collection (Pfister et al., 2018; Reshitnyk et al., 2023; Timmer et al., 2024). A decadal-scale study from southern California showed that the environmental limitations (e.g., cloud cover) of using satellite technology can be mitigated by high-frequency, local monitoring using drones (Bell et al., 2020b). This is especially crucial in BC, where there are large tidal ranges (>4 m), higher current velocities (>3 m/s or 6 knots), frequent cloud cover, and high precipitation. These conditions limit the availability of suitable remote sensing imagery (Cavanaugh et al., 2021b), and significantly impact canopy kelp visibility, affecting abundance and biomass estimates (Cavanaugh et al., 2021a; McPherson & Kudela, 2022). A study by Timmer et al. (2024) combined drone-based imagery with field observations of buoyancy-related characteristics of bull kelp and giant kelp to show how they were affected by tidal heights and current speeds. Their results emphasize the importance of *in situ*, local, environmental conditions at the time of data collection for accurate estimates of kelp extent in BC's kelp forests.

To date, few published studies have used drones to document the spatiotemporal dynamics of kelp forests in coastal BC, however their use is increasing. Burt et al. (2018) used high-resolution drones to quantify annual changes in the spatial extent and density of kelp canopy cover in association with kelp ecosystem predators, including sea otters and sunflower stars, along a 40 km stretch of central BC coastline. Exploratory work in Puget Sound suggests strong potential for drones to monitor bull kelp canopies and complement kayak surveys (Berry & Cowdrey, 2021; Cowdrey & Claar, 2024). Drones are increasingly being used by kelp monitoring programs, including Hakai Institute, the Marine Plan Partnership (MaPP) for the North Pacific Coast, Parks Canada, North Island College, the Washington State Department of Natural Resources, and several First Nations groups, including the Snuneymuxw First Nation (Nanaimo), and the Mamalilikulla First Nation (Broughton Archipelago). Established guidelines for drone use in BC provide a foundation for continuing these efforts (Reshitnyk et al., 2023; Saccomanno et al., 2023; Thompson, 2021).

REMOTE SENSING USING SPACEBORNE EARTH OBSERVATION SATELLITES

BC's complex, fjord-filled coastlines and frequently changeable environmental conditions present several challenges for satellite-based mapping. Mapping effectiveness regionally is influenced by seasonal and environmental variability, and spatial resolution constraints that often result in data gaps (Mora-Soto, 2025). These geographic limitations emphasize the trade-off between acquiring high-resolution imagery that improves detection of small, nearshore floating canopies, and lower-resolution imagery that enables a longer time perspective of BC's kelp forests (Gendall et al., 2025; Man et al., 2025; Mora-Soto et al., 2024a, 2024b; Wachmann et al., 2026).

Considering BC's vast coastal areas, satellite imagery is considered more cost and time-efficient than diver and boat-based surveys (Cavanaugh et al., 2010; Schroeder et al., 2019). The kelp mapping framework workflow involves: 1) imagery acquisition and quality assessment; 2) preprocessing and enhancements; 3) object-based image classification using analysis software; and 4) accuracy assessment (Gendall et al., 2023; Mora-Soto et al., 2024a, 2024b). Data acquisition is the first step, and low resolution satellite imagery covering a broad time series (e.g., Landsat series and Sentinel) can be freely downloaded, whereas higher resolution imagery (e.g., WorldView Series and QuickBird) is proprietary, and can be bought from archived databases, and/or satellites can be tasked to collect imagery for a specific time and location (Table 3.3) (Schroeder et al., 2019). However, costs for tasked missions are high (US$27-45 per km^2), and require a minimum order size (Schroeder et al., 2019). Limitations of using satellite imagery can include the high cost of acquiring private/commercial high-resolution imagery, imagery obtained during non-optimal conditions, the need for labour-intensive and complimentary field data collection, technical expertise, and the requirement to integrate multiple multispectral sensors to obtain a longer time series dataset (Bell et al., 2020a; Cavanaugh et al., 2010; Gendall et al., 2023, 2025; Mora-Soto et al., 2024a, 2024b; Schroeder et al., 2019). Errors in image detection can often be associated with sparse, fringing, or partially submerged kelp canopies, and as a result, ground-truthing is necessary to confirm kelp presence (Gendall et al., 2025). To minimize errors, imagery acquisition should:

- prioritize the highest resolution imagery (<3 m) for small, nearshore kelp beds;
- be timed around peak summer growth (July-September);
- be collected during low tidal heights (<3 m above lower low-water datum);
- be in areas with rocky substrates, <30-40 m bathymetry, and at low slope angles (<30˚), to minimize the adjacency effects with land that can result in false positive kelp (or other vegetation) detection; and
- consider environmental conditions (clouds, tidal height, haze, glint, turbidity, algal blooms) that can reduce kelp detection (Gendall et al., 2023; Mora-Soto et al., 2024a; Wachmann et al., 2026).

A few recent studies have begun to integrate medium to high resolution satellite imagery time series data (Table 3.3), combined with archived aerial photographs (e.g., ShoreZone), historical charts, and environmental climatology data (Table 3.2) to assess kelp distribution, resilience, and change over time in the Salish Sea (Chapter four; Berry et al., 2021; Mora-Soto et al., 2024a, 2024b; Schroeder et al., 2020) and BC (Costa, 2025; Gendall et al., 2025; Man et al., 2025; Starko et al., 2024a; Wachmann et al., 2026). Much of this work has been spearheaded by researchers in the Spectral Remote Sensing Laboratory at the University of Victoria and their partners (Costa, 2025), and the Washington State Department of Natural Resources in the US (Berry et al., 2021).

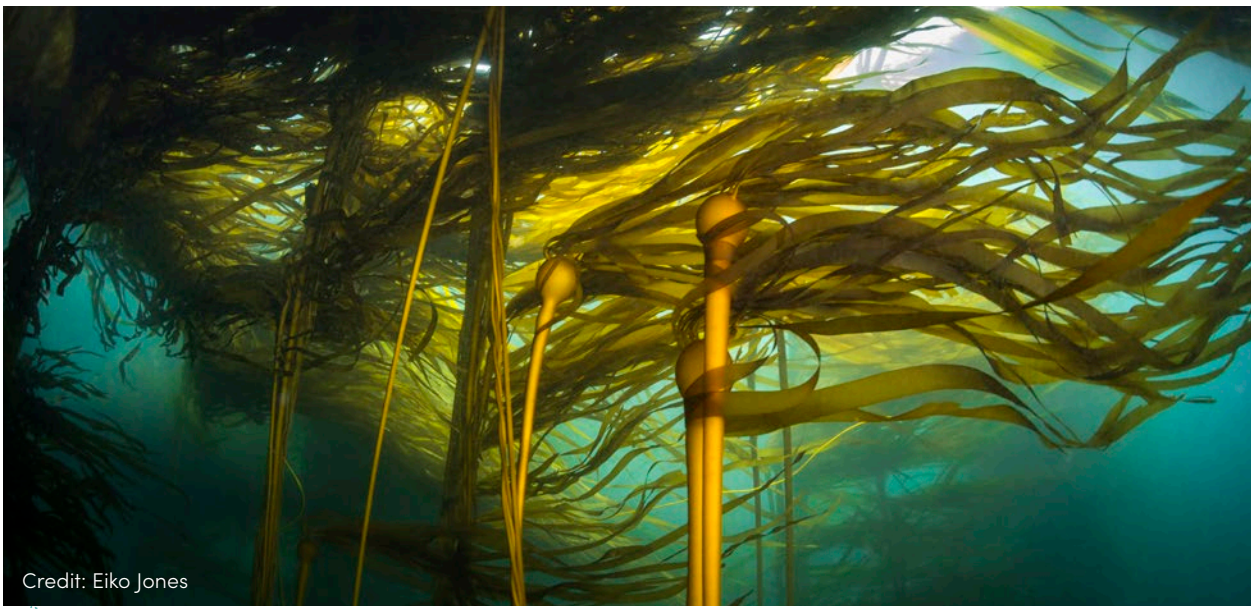
Satellite-based studies of bull kelp in the Salish Sea

The first satellite-based bull kelp study was carried out in Cowichan Bay (Schroeder et al., 2020). It utilized high-resolution satellite imagery combined with kayak-based kelp and *in situ* environmental datasets associated with local climate variables, for the period between 2015 and 2017, which overlapped with the Blob marine heatwave event.

Mora-Soto et al. (2024a, 2024b) created maps of bull kelp distribution for the Salish Sea, by employing satellite imagery from multiple sources, aerial photography (BC ShoreZone), ground-truthed data, several environmental datasets including Landsat-based sea surface temperature data (Wachmann et al., 2024), historical data (Costa et al., 2020), and existing mapping frameworks (Gendall et al., 2023; Pfister et al., 2018; Schroeder et al., 2020). They associated kelp trends with climatology data to produce a 50-year time series (1972 to 2022) for the southern Salish Sea (Mora-Soto et al., 2024a). Medium- to high-resolution (<1 m to 20 m) imagery (2005-2022) was prioritized to map mostly small (<10 m) nearshore, fringing bull kelp beds (Table 3.3). Next, to better understand long-term trends in bull kelp, they mapped changes in areal extent across the entirety of the Salish Sea, an area of 2,086 hectares, using archived high-resolution (<6 m) satellite imagery, for two time periods that were characterized by anomalous SSTs as the: preBlob (preBlob: 2002-2013); and Blob+Post (2014-2022; Mora-Soto et al., 2024b). Data validations were made using field surveys, with an accuracy of 70 per cent. They then compared these modern distribution patterns with historical data (1858-1956) of kelp presence to extend their time series to a centennial scale, which will be reviewed in Chapter Four.

Most recently, Timmer et al., (2026) created a 50-year time-series of bull kelp canopy for a localized area, near Denman Island in the northern Salish Sea using data from snorkel and SCUBA surveys (2023), archived aerial photographs (1972-1984), and 30-m resolution Landsat imagery (1984–2024).

Recent studies highlight the effectiveness of using remote sensing data for not only mapping surface kelp canopy extent and area, but also for better understanding the drivers influencing kelp distribution trends over time. Moreover, the approach of using indirect and direct mixed methods to fill in spatial and temporal gaps is gaining momentum regionally (Table 3.2). Challenges are being met through enhancements in technology, ongoing research, and the use of multiple different platforms that allow for broader coverage across the vast geographic regions, and over time for the Salish Sea and BC-wide regions.



Credit: Eiko Jones

Table 3.2 Summary of recent mapping and monitoring (research and citizen science) studies that have used a mixed-method approach to quantify spatiotemporal distribution patterns of canopy kelps, including giant and bull kelp in the Salish Sea, greater British Columbia (BC) and Washington (WA).

Location	Objective	Methods	Resolution	Time series or year(s) of study	Reference(s) / Sources of data
Salish Sea, WA (~200 km)	Presence/ extent	Historic field surveys (digitized) and archived (colour infrared) aerial photos	High	1989 to 2015 compared with historical 1911-1912	Pfister et al. (2018)
Cowichan Bay and Sansum Narrows, Salish Sea, BC (~50 km)	Presence/ extent	Kayak surveys (2016) following Fretwell and Boyer (2012); and archived satellite imagery	High (1.2 -2.6 m)	2004 to 2017	Schroeder et al. (2020)
Southern Gulf Islands (Mayne, Galiano, the Penders, and Saturna Island) (~31 ha)	Presence/ extent	Kayak surveys (2016) following Fretwell and Boyer (2012); annual citizen science surveys of bull kelp	High	2010 to 2025	Underhill et al. (2025)
Coastwide BC, including Salish Sea	Presence (historical)	Historic field surveys: 137 historical British Admiralty nautical charts digitized and georeferenced	--	Historical 1858 to 1956	Costa et al. (2020); data acquired from: Canadian Hydrography Services (CHS)
South Puget Sound, Salish Sea, WA (425 km^2)	Presence/ extent	Field surveys and aerial photos; synthesized 48 individual, diverse, archived datasets of (3,352 instances of) bull kelp	Mixed	1873 to 2018	Berry et al., (2021); Washington Department of Natural Resources; US Geological Survey
Saturna Island, Interim Sanctuary Zone (ISZ), Salish Sea, BC (~2.5 km)	Presence/ extent (abundance)	Kayak surveys following Fretwell and Boyer (2012)	High	2023	Checko (2024)
Southern Salish Sea; and greater Salish Sea, BC (a. 1655 ha; and b. 2607 ha)	Presence/ extent	Multi-satellite imagery, aerial photos, historic British Admiralty nautical charts	Medium to high resolution	-1972 to 2022; -1984 to 2022 compared with 1858 to 1956	Mora-Soto et al. (2024a, 2024b)
Northeast coast of Moresby Island, Haida Gwaii, BC (800 km^2)	Presence/ extent	Multi-satellite imagery, aerial photos, historic British Admiralty nautical charts	Medium to high resolution (0.5-60 m)	1973 to 2021; compared with historical 1858 to 1956	Gendall et al. (2023, 2025)

Location	Objective	Methods	Resolution	Time series or year(s) of study	Reference(s) / Sources of data
Broughton Archipelago (<23 km)	Presence/ extent (area)	Field visit; archived satellite imagery	Medium to high resolution (0.46-0.3m)	1984 to 2023	Mann et al. (2025)
Western Strait of Georgia, near Denman Island (~57 km)	Presence/ extent	Archived aerial photos (1972-); and field surveys by snorkel and SCUBA; time-series using 30-m resolution Landsat imagery (1984–2024).	High	1972 to 2024	Timmer et al. (2026)
West Coast of Vancouver Island (~5,600-km)	Presence/ extent	Satellite imagery (Sentinal-2), historic British Admiralty nautical charts; historic Canadian Hydrographic Services data	Medium (10 m)	2020-2023; compared with 1858 to 1956	Wachmann et al. (2026)

Table 3.3 Information on the Earth observation satellite data used to map floating kelp canopies in BC by recent studies in the Cowichan Bay (CB), Salish Sea (SS), Broughton Archipelago (BA), Haida Gwaii (HG), and the west coast of Vancouver Island (WCVI).

Satellite (sensor)	Spatial resolution (multi-spectral)	Cost/Source	Years covered (general)	Years covered in BC studies (summer)	Location	Reference
Landsat (1-3) series	60 m	Free from USGS	1972-1983	1973-1974; 1976-1977	HG	Gendall et al. (2025)
Landsat (4-8)	30 m	Free from USGS	1984-Present	1982, 1984-1986; 1988-1992; 2001-2002	HG	Gendall et al. (2025); Man et al. (2025); Timmer et al. (2026)
QuickBird/-2	2.5 m	Private; $10.50+ per km^2	2002-2014	2004, 2006-2013	CB, SS, HG	Schroeder et al. (2020); Mora-Soto et al. (2024a); Starko et al. 2024a; Gendall et al. (2025)
Worldview-2	1.8, 2.5, 2.6 m	Private; $15.00+ per km^2	2009-Present	2011-2012, 2015-2023	CB, SS, WCVI	Schroeder et al (2020); Mora-Soto et al. (2024a); Gendall et al. (2025); Wachmann et al. (2026)

Satellite (sensor)	Spatial resolution (multi-spectral)	Cost/Source	Years covered (general)	Years covered in BC studies (summer)	Location	Reference
Worldview-3	1.2 m	Private; $15.00+ per km^2	2014-Present	2016-2017, 2021	CB, WCVI	Schroeder et al (2020); Starko et al. (2024a); Wachmann et al. (2026)
Ikonos	3.2 m	Private; $10.00+ per km^2	1999-2015	2005	SS	Mora-Soto et al. (2024a)
PlanetScope	4.0 m	Available to researchers from Planet Labs Inc.	2018-Present	2018-2023	SS, BA	Mora-Soto et al. (2024a); Gendall et al. (2025); Man et al. (2025)
Kompsat	4.4 m	Private; $4.00+ per km^2	--	2007, 2017	SS	Mora-Soto et al. (2024a)
Rapideye	5.0 m	Available to researchers from Planet Labs Inc.	2009-Present	2009-2012, 2014-2015, 2017	SS	Mora-Soto et al. (2024a); Gendall et al. (2025)
Spot-2-4	10-20.0 m	Available to researchers from Centre National D'etudes Spatiales (CNES)	1989-2013	2006, 2008, 2011	SS, HG	Mora-Soto et al. (2024a); Gendall et al. (2025)
Spot-5-7	6.0-20.0 m	Private; $2.50+ per km^2	2002-Present	2006, 2019	SS, HG	Mora-Soto et al. (2024a); Gendall et al. (2025)
Sentinel-2	10 m	Free from ESA	2018-Present	2020-2023	WCVI	Wachmann et al. (2026)
Geo-Eye-1	1.84 m	Private; $12.50+ per km^2	2018-Present	2017	HG	Gendall et al. (2025)

LESSONS LEARNED

- ☑ BC's 25,000 km of coastline pose challenges for mapping and monitoring kelp forests.
- ☑ Five main methods are being used, including direct methods (kayak-based, snorkel and SCUBA, remotely operated vehicles (ROVs), or autonomous underwater vehicles (AUVs)), and indirect methods (aerial photography by low-flying planes, drones, and Earth observation satellites).
- ☑ Community-based citizen science groups have successfully carried out annual kayak-based monitoring in the southern Gulf Islands of the Salish Sea since 2010.
- ☑ Underwater kelp surveys by snorkel and SCUBA (with or without video footage) are increasing our knowledge of kelp forest community dynamics and helping us better understand the role of kelp forests as critical nurseries and migration corridors.
- ☑ Advancements and improvements in remote sensing technology over the last fifty years have allowed great strides in accurately detecting kelp from above.
- ☑ A variety of environmental factors can dampen the effectiveness of mapping efforts, resulting in data gaps. Knowledge of the environmental criteria for kelp detection, especially in areas where kelp is deemed 'not present', is increasing.
- ☑ Challenges for acquiring and using satellite-based imagery and data are being met through advancements and enhancements in satellite technology, ongoing research, and the use of multiple platforms that allow for broader coverage across the vast geographic regions, and over time.
- ☑ Kelp researchers in BC are employing a mixed-methods approach and incorporating historical datasets to understand bull kelp trends associated with environmental and climate drivers in the Salish Sea and around BC.



Credit: Eiko Jones

CHAPTER FOUR
DISTRIBUTION TRENDS OF BULL KELP IN THE SALISH SEA

INTRODUCTION

The nearshore waters of the Northeast Pacific Ocean, including the Salish Sea, are ideal kelp habitat. The combination of environmental conditions found here, especially cool temperatures and high nutrient availability, has allowed this region to become a hotspot for kelp biodiversity. As discussed in Chapter one, at least 30 kelp species can be found in BC alone, including the canopy-forming bull kelp and giant kelp (Druehl & Clarkston, 2016). However, even though conditions in the Northeast Pacific are largely favourable for kelp growth, these conditions do vary on local scales and different kelp species and life history stages can have distinct environmental tolerances. A given species will only establish where local conditions, including temperature, light levels, nutrient availability, salinity, water motion, and substrate conditions, do not consistently exceed these tolerances. Environmental factors thereby shape the distribution of a species. For example, while BC's exposed outer coastlines provide suitable conditions to support both bull kelp and giant kelp, the estuarine Salish Sea mostly supports only bull kelp, which is more able to tolerate the naturally higher temperatures and lower salinity found in this region than giant kelp is (Druehl, 1978). In this chapter, we examine the abiotic and biotic environmental conditions that drive kelp distributions, with a focus on bull kelp in the Salish Sea. We then discuss what the current distribution of bull kelp in the Salish Sea is, how it has changed over time, and what environmental parameters might be driving observed changes.



Credit: Nicole Christiansen

FACTORS CONTROLLING KELP DISTRIBUTION

SEA SURFACE TEMPERATURE (SST)

Temperature is currently the most researched environmental parameter driving kelp distribution, as it is perhaps the factor most likely to be affected by climate change (Hollarsmith et al., 2022). While the exact thermotolerances of individual kelp species can vary, most species can survive at a range of temperatures between about 4 and 23 °C (Lüning & Freshwater, 1988; Supratya et al., 2020) and generally perform best at temperatures <17-18 °C (e.g. Fernández et al., 2020; Lüning & Freshwater, 1988; Supratya et al., 2020). Bull kelp specifically can tolerate a temperature range of approximately 4-20 °C but performs best at temperatures of approximately 12 °C (Table 4.1) (Supratya et al., 2020). Giant kelp is slightly more thermotolerant and can grow at temperatures of approximately 6-24 °C; it performs best at about 14 °C (Fernández et al., 2020). In the Salish Sea, summer SSTs can range from approximately 12 °C in the coolest areas to 19 °C in the warmest areas (Barbosa et al., 2026). The upper end of this range is high enough to stress bull kelp (Suprataya et al., 2020). As SSTs continue to increase due to the effects of climate change, kelp populations at the upper limit of their thermal distribution, such as those that occur within warm sheltered inlets, may experience physiological distress and reduced fitness, and decline as a result (Suprataya et al., 2020).

Table 4.1 Estimates of tolerances of bull kelp and giant kelp sporophytes to key abiotic environmental factors, as characterized by growth.

Environmental factor	Bull kelp sporophyte		Giant kelp sporophyte	
	Tolerable range	Optimum	Tolerable range	Optimum
Temperature (°C)	5-20[a]	12[a]	6-24[b]	14[b]
Light (mol m^{-2} day^{-1})	>4-17[c]	>29-36[c]	>1[d]	>1.5[e]
Nutrients (µM NO^3)	>0.1[c]	>1[c]	0.1-0.5[f]	>1-2[f]
Salinity (ppt)	≥20[g]	32[g]	>22[h]	32[h]

[a]Supratya et al. (2020); [b]Fernández et al. (2020); [c]Pointier et al. (2024); [d]Tait (2019); [e]Dean and Jacobsen (1984); [f]Zimmerman and Kremer (1986); [g]Farrugia-Drakard et al. (2025); [h]Fernández et al. (2026)



Credit: Mitch Miller

It's getting hotter — will it get too hot?

Mean summer SST, shaped by large-scale climate drivers such as El Niño and Pacific Decadal Oscillation and punctuated by MHWs, is likely the dominant factor driving interannual variation of kelp forests in the Salish Sea (Mora-Soto et al., 2024b, 2024a; Pfister et al., 2018). The region is warming more rapidly than much of the northeastern Pacific, with projected increases of +1.5 °C (Khangaonkar et al., 2019) to as much as 3 °C (Riche et al., 2014) by 2100; during the 2015-2016 marine heatwave, temperatures increased by +2.3 °C (Khangaonkar et al., 2021). Persistence under these changing conditions will require adaptation or acclimation and may result in range shifts or local extinctions (Fales et al., 2023; Hollarsmith et al., 2020).

LIGHT AND TURBIDITY

As a primary producer, kelp requires light for photosynthesis, which must occur for kelp to survive and grow. As such, light availability is a major regulator of kelp productivity. Photosynthesis is generally constrained by the "one per cent rule," whereby primary production is limited to depths receiving at least one per cent of the surface irradiance (Lüning, 1980). The depth at which this occurs is strongly influenced by water clarity. High turbidity in the water column, which can be caused by high nutrient or sediment loads, reduces light penetration and thus negatively affects kelp productivity and growth at a given depth (Deysher & Dean, 1986; Rubin et al., 2017). Currently, in the Salish Sea, steep bathymetry confines bull kelp to narrow nearshore bands to depths of 30–40 m (Mora-Soto et al., 2024a; Schroeder et al., 2020). However, if turbidity were to increase in the future, which could happen due to increasing freshwater discharge from the Fraser River resulting from climate change-induced increases in glacial melting and precipitation (IPCC, 2023), that depth may decrease.

NUTRIENT AVAILABILITY

Like other primary producers, kelps require nutrients, which they absorb from the seawater. Nitrogen is required for synthesizing the chlorophyll that kelps use to perform photosynthesis, and as such, nitrogen deprivation can limit kelp growth. It has been found that an ambient nitrate concentration of <1 μM can significantly decrease growth of bull kelp (Pontier et al., 2024) and giant kelp (Zimmerman & Kremer, 1986). Furthermore, some studies report that high nutrient availability might be able to mitigate the damaging effects of high temperature on kelp physiology and further compounding effects from thermal stress (Fernández et al., 2020). In the Salish Sea, nutrients are naturally most available in the spring but can become limiting by the fall. It is predicted that climate-driven changes in ocean current dynamics and increased water column stratification will lead to declines in upper-ocean nutrient availability, which would be detrimental to kelp in affected areas (IPCC, 2023).

SALINITY

As marine species, all kelps require ambient salinity to remain within specific ranges to avoid damaging effects of osmotic stress, which can negatively impact growth and reduce or prevent recruitment (Hollarsmith et al., 2022, and references within). The exact salinity range that can be tolerated varies between species. Bull kelp can grow and recruit at salinities as low as 20 ppt, but growth rates are highest at 32 ppt; growth and recruitment fail at a salinity of 13 ppt (Farrugia Drakard et al., 2025). Giant kelp is less tolerant of low salinity conditions than bull kelp, showing reduced growth and recruitment after even brief exposure to salinities of 22 ppt or lower (Farmer et al., 2026). In the Salish Sea, the mean summer salinity is 21.2 ± 8.3 ppt (Barbosa et al., 2026), though local variability is high. As such, bull kelp is widely distributed throughout the Salish Sea, even near the Fraser River plume, where salinity ranges from 9-25 ppt (Good, 2024). Conversely, giant kelp is largely restricted to the more oceanic western Strait of Juan de Fuca, where salinity approaches open-ocean levels (Hollarsmith et al., 2022).



Credit: Liam Coleman

WATER MOVEMENT

Bull kelp and giant kelp both benefit from exposure to moderate wave action or currents. Water moving over a kelp thallus at speeds as low as 4-6 cm s^{-1} can significantly increase nutrient uptake by disrupting diffusion boundary layers over the surface of the kelp (Gerard, 1982; Hurd et al., 1996). This is thought to explain reduced growth rates in kelps growing in low flow conditions (e.g. Gerard, 1982; Hurd et al., 1996; Wheeler, 1980). Additionally, high wave exposure is also often correlated with decreased local SST, higher salinity, and higher nutrient availability due to increased vertical mixing, making wave exposed shores potential refugia from stressfully high temperatures (Starko et al., 2022, 2024a). These reasons likely explain why kelp canopy density in wave-exposed areas has been found to be positively correlated with large-scale wave fetch and fine-scale water motion (Smale et al., 2016; Starko et al., 2019). However, it should be noted that there is an upper limit to the benefits of water motion to kelp, and extremely high levels of wave action can damage or dislodge kelp thalli (Denny & Gaylord, 2002, and references within). Exactly how much water motion is too much varies with each individual kelp and depends on a myriad of factors, including the individual's size, shape, material properties, and attachment strength (Denny & Gaylord, 2002, and references within).

SUBSTRATE QUALITY, WATER DEPTH, AND SLOPE

Kelps generally require hard, rocky substrates at relatively shallow depths (30-40 m) for recruitment (Mora-Soto et al., 2024a; Schroeder et al., 2020). Field experiments indicate spores can settle directly on natural rocks, as well as artificial substrates like rope and tiles, which are used for restoration (Martone, 2025). Seafloor slope also influences kelp distribution, low-slope coastal platforms support larger kelp beds, whereas steep slopes are limited in suitable habitat (Mora-Soto et al. 2024a; Barbosa et al., 2026).

BIOTIC DRIVERS SHAPING KELP ECOSYSTEMS

In addition to the abiotic environmental factors described above, trophic interactions between herbivorous grazers and their predators can determine whether an otherwise suitable habitat supports a healthy kelp forest or an urchin-dominated barren. Two keystone species, the sea otter and the sunflower star, which have had abrupt large-scale die-offs historically and more recently, respectively (Burt et al., 2018), play leading roles in moderating the system through predation, limiting the abundance and size of grazing sea urchins and thereby indirectly influencing kelp extent, abundance, and size (Burt et al., 2018; Estes & Duggins, 1995). In the absence of otters and sunflower stars, kelp growth is largely restricted to areas where urchins have been excluded by strong wave action or are at low densities or absent due to other factors (Estes et al., 1978; Estes & Duggins, 1995).



Credit: Eiko Jones

TRENDS IN BULL KELP DISTRIBUTION IN THE SALISH SEA

Recent mapping and monitoring studies generally indicate spatial and temporal persistence of bull kelp across the Salish Sea, with notable regional exceptions. Similar findings of bull kelp persistence from the north Pacific coast have been observed, including parts of Haida Gwaii (Gendall et al., 2025), the western coast of Vancouver Island (Starko et al., 2022), Washington (Pfister et al., 2018), and Oregon (Hamilton et al., 2020). However, trends are geographically variable, reflecting localized environmental conditions and biotic stressors. The addition of data from century-old historical maps (1858-1956) has provided a longer-term perspective of change, revealing substantial declines, from 21 per cent to as much as 79 per cent, of bull kelp in the northern subregions of the Salish Sea (Costa, 2025; Mora-Soto et al., 2024b; Timmer et al., 2026). In contrast, largely stable bull kelp forests (approximately 70 per cent) were maintained in southern subregions (southern Gulf islands, Burrard Inlet, Strait of Juan de Fuca), despite thermal anomalies such as the Blob, which elevated SSTs beyond bull kelp's thermal tolerance limit (Mora-Soto et al., 2024b; Schroeder et al., 2020; Underhill et al., 2025). Significant declines have also been recorded in the warm, southernmost South Puget Sound sub-basins in Washington State (Berry et al., 2021). In the remainder of the chapter, we summarize recent spatiotemporal studies of bull kelp persistence, resilience, and decline across the different geographic subregions of the Salish Sea with particular emphasis on Mora-Soto and colleagues' (2024a, 2024b) comprehensive spatial and temporal (decadal to centennial-scale) trend analyses.



Credit: Liam Coleman

WHAT MODERN STUDIES SHOW OF BULL KELP PERSISTENCE, RESILIENCE, AND DECLINE

Persistence versus resilience

In an ecological context, persistence refers to the continued existence of kelp forests through time (Connell & Sousa, 1983), while resilience is a return to a reference state following a disturbance (Holling, 1973). Marine heatwaves, particularly the Blob, serve as key disturbance events for evaluating kelp resilience in the Salish Sea (Mora-Soto et al., 2024a, 2024b; Pfister et al., 2018; Schroeder et al., 2020).

Cowichan Bay and southern Gulf Islands

An initial local time series (2004 to 2017), combining satellite imagery and kayak-based ground-truthing, found high bull kelp persistence in Cowichan Bay, particularly along the north shoreline and in Sansum Narrows (Schroeder et al., 2020). These areas are characterized by rocky substrates and strong currents. Lower persistence was found along the south side of Cowichan Bay, where sandy substrates and sheltered, low-energy current conditions favour eelgrass (Schroeder et al., 2020). Kelp was also absent north of Sansum Narrows despite available hard substrates, likely due to higher SSTs and turbidity. Findings of decline in kelp cover between 2015 (high cover) and 2017 (low cover) were thought to reflect either natural variation or influence of the Blob (Schroeder et al., 2020).

A long-term (2010–2025) citizen science program led by the Mayne Island Conservancy documented generally stable and persistent bull kelp across the southern Gulf Islands (Underhill et al., 2025). Findings from these surveys support the presence of stable and persistent bull kelp, except declines were noted along more exposed coastlines, facing the Strait of Georgia, where SSTs are relatively warmer (Underhill et al., 2025), consistent with findings that identify this area as less stable for long-term kelp growth (e.g., Mora-Soto et al., 2024a).

At finer spatial scales, a 2023 study in a Vessel Restricted Zone (VRZ) located off Saturna Island in the Southern Gulf Islands found localized declines in bull kelp (Checko, 2024). Checko (2024) estimated that at least 41 per cent of the VRZ coastline had no bull kelp, and only six per cent supported dense bull kelp beds in 2023; anecdotal evidence suggests these figures represent a decline from historic levels. The author attributed red and green sea urchins, which were present on 75 per cent of the coastline, as the main cause of declining bull kelp populations. This was affirmed through successful kelp growth where urchins were experimentally excluded.

Strait of Juan de Fuca, Puget Sound

In Washington, a study by Pfister et al. (2018) found that bull kelp persisted for over a century in colder, wave-exposed western parts of the Strait of Juan de Fuca. Many kelp beds documented in the early 1910's remain, although declines were seen in eastern urban areas (e.g., Port Angeles and Port Townsend) (Pfister et al., 2018). Similarly, Berry et al. (2021) found overall persistence across South Puget Sound over about 145 years; however, warmer sheltered areas experienced substantial decline (63-96 per cent) (Berry et al., 2021). These findings have raised concerns and prompted coordinated action towards better understanding the natural versus climate-driven variability of bull kelp (Berry et al., 2021; Calloway et al., 2020).

Southern Strait of Georgia

In an initial study of the southern Salish Sea, Mora-Soto et al. (2024a) found overall spatiotemporal persistence and resilience, with the strongest signals (approximately 20 per cent cover and 80 per cent presence across periods) in the cold, exposed south coast of the Strait of Juan de Fuca. Here, mixing and cooler SSTs (approximately 12.0–15.0 °C) supported stability despite suboptimal periods (2014–2019) during and after the Blob. The moderately exposed southern Gulf Islands also showed persistence, consistent with other studies (Schroeder et al., 2020; Underhill et al., 2025). Notably, some warm, sheltered areas (i.e., Saanich Inlet and the northwestern Gulf Islands) exhibited increased kelp cover despite thermal anomalies. In contrast, exposed coastlines of the southeastern Gulf Islands facing the Strait of Georgia showed lower persistence and higher variability, suggesting reduced resilience under continued warming. The authors emphasize the need for further validation using *in situ* experimental data (Mora-Soto et al., 2024a).

Northern and southern Strait of Georgia

In their second study, Mora-Soto et al. (2024b) compared decadal-scale changes in bull kelp presence throughout the Salish Sea, highlighting how kelp cover changed after the Blob. In total, 2,068 ha of bull kelp were mapped. Prior to the Blob, bull kelp was distributed throughout the Salish Sea, with larger, more continuous forests being found in southern regions (i.e., the Strait of Juan de Fuca, southern Gulf Islands, and Burrard Inlet) and smaller, narrower forests being found in the northern regions (i.e., the central Strait of Georgia, Quadra Island, and Discovery Passage). During and after the Blob, declines became pronounced in the northern regions, suggesting lower resilience relative to the southern regions (Figure 4.1). Differences in local environmental conditions, such as nutrient availability and current dynamics, likely contribute to these factors.

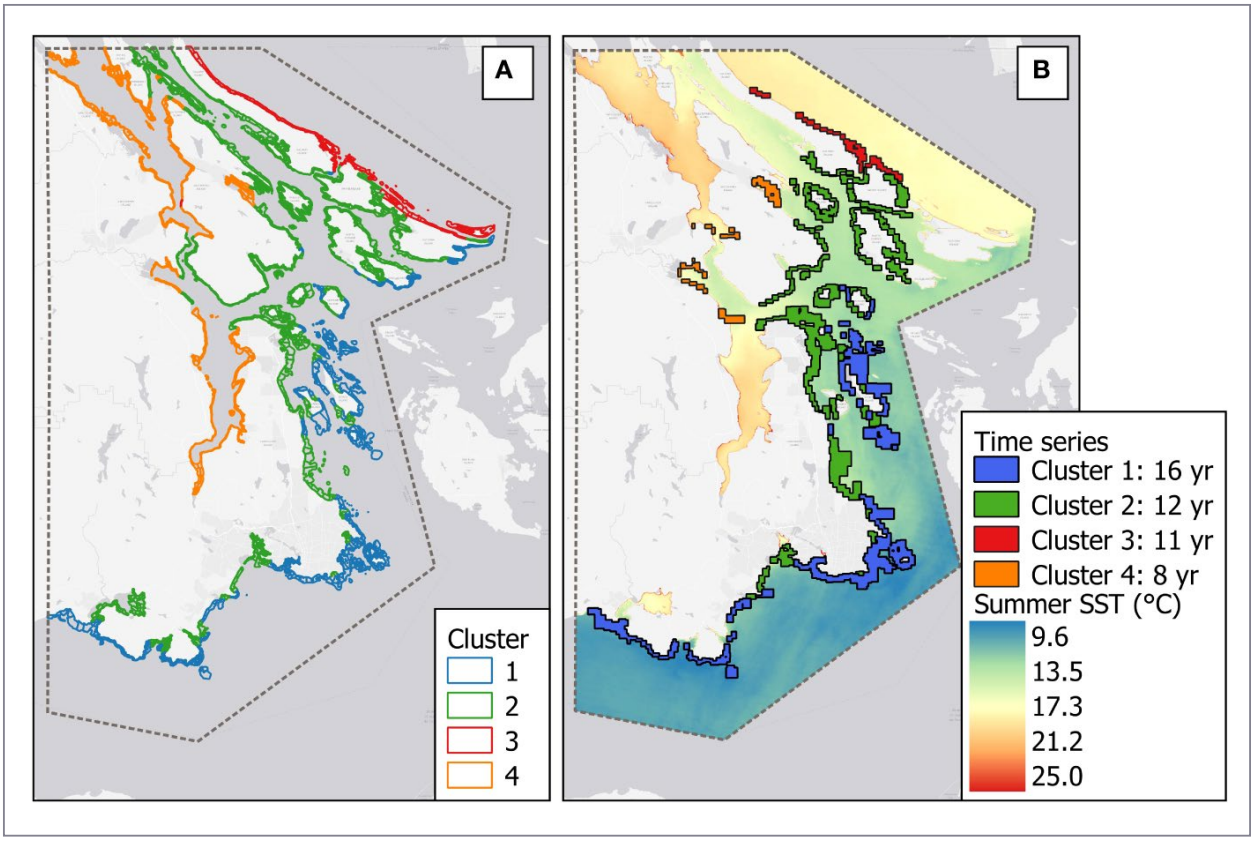


Figure 4.1 Changes in bull kelp area in the Salish Sea (A) before the Blob (2002–2013) and (B) during and after the Blob (2014–2022). The size of the circles represents area per segment (Mora-Soto et al., 2024b; Creative Commons Attribution License (CC BY)).

Mora-Soto et al. (2024b) extended their analyses by comparing modern distribution patterns (both before and after the Blob) with historical baselines (1858–1956) derived from British Admiralty charts (Costa et al., 2020), identifying areas of non-persistence (Figure 4.2). Overall, bull kelp has declined substantially in the northern regions of the Salish Sea, showing as much as 79 per cent loss compared to historic levels. Southern regions showed greater long-term persistence and resilience, with only 29 per cent loss compared to historic levels. A recent study from Timmer et al. (2026) shows that historic bull kelp forests near Denman Island are no longer present (Figure 3.4), and declined decades before the Blob, reinforcing the observation of Mora-Soto et al. (2024b) that kelp forests in the northern Salish Sea are showing dramatic losses.

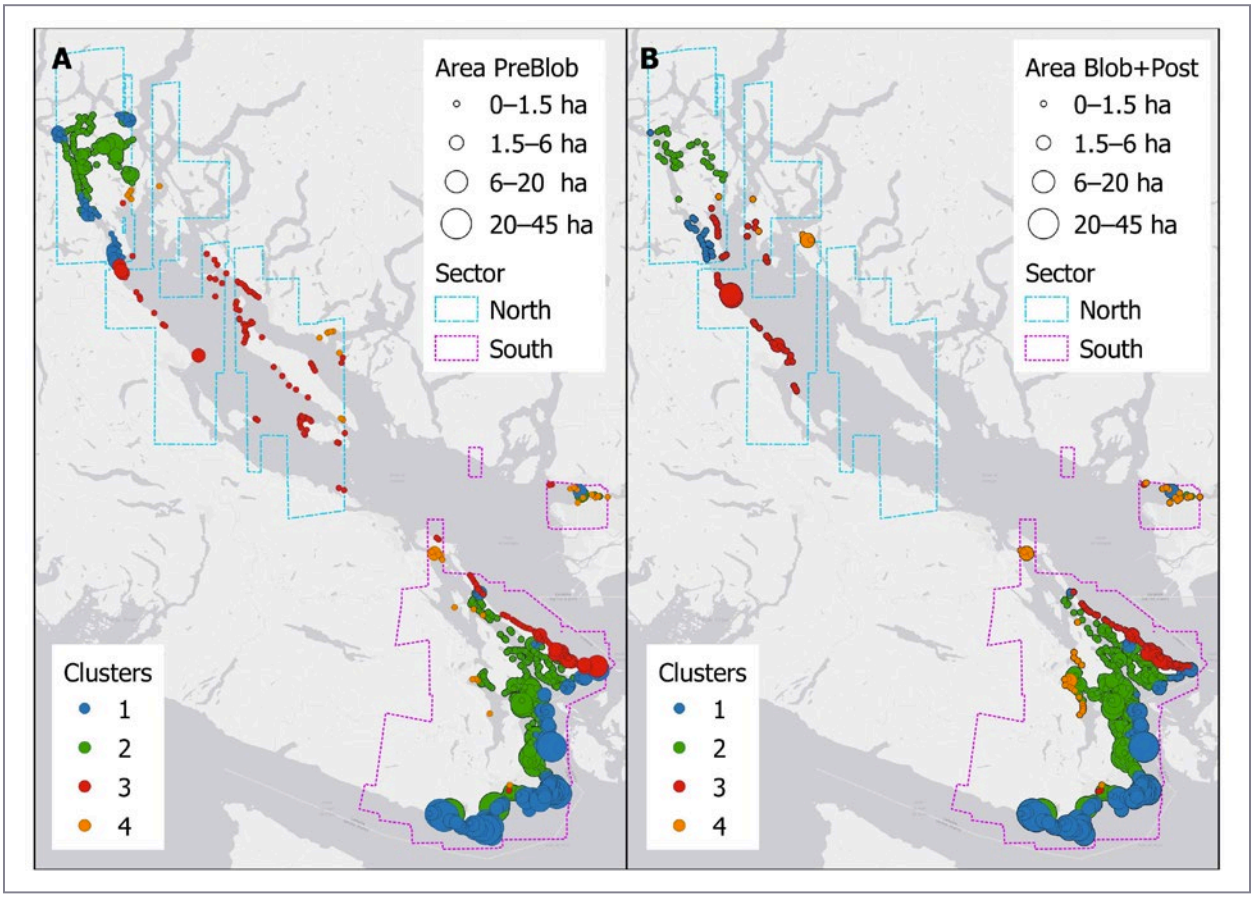


Figure 4.2 A comparison of long-term persistence in kelp area during (A) before the Blob (2002–2013) and (B) during and after the Blob (2014–2022), with respect to historical (1858–1956) data from British Admiralty nautical charts (Costa et al. 2020; Mora-Soto et al., 2024b; Creative Commons Attribution License (CC BY)).

SUMMARY OF RECENT TRENDS IN BULL KELP DISTRIBUTION IN THE SALISH SEA

Bull kelp forests have shown persistence and resilience to local to regional anomalous warming in the Salish Sea. The highest persistence and resilience of relatively large bull kelp forests occur in the cold, exposed, wind and current-driven, high-salinity, nutrient-rich, and ocean-influenced Strait of Juan de Fuca (Mora-Soto et al., 2024a, 2024b; Pfister et al., 2018). Other persistent areas included the slightly warmer, moderately exposed and highly urbanized Burrard Inlet near Vancouver and parts of the southern Gulf Islands (Mora-Soto et al., 2024a, 2024b). Persistence also occurred in some warm, sheltered areas of the southern Gulf Islands, where variable but favourable environmental conditions such as wind-driven mixing, nutrient inputs from the Fraser River, and lower sea urchin densities may support kelp growth (Checko, 2024; Mora-Soto et al., 2024a; Pfister et al., 2018; Schroeder et al., 2020; Underhill et al., 2025). Although these areas approach or exceed the physiological thresholds, they may host populations with heat tolerance or local adaptation.

In contrast, non-persistent kelp is more common in the northern subregions (Mora-Soto et al., 2024b; Timmer et al., 2024) with dramatic declines also documented in the southernmost Salish Sea (Puget Sound), which has prompted increased and coordinated mapping and monitoring initiatives (Berry et al., 2021; Calloway et al., 2020). Further work is needed to distinguish natural variability from drivers of localized decline, particularly where losses may not be readily detected by satellite imagery alone.

These studies help identify areas that may support stable kelp forests suitable restoration (e.g., Barbosa et al., 2026) or function as climate refugia (Costa, 2025). These areas may require further research into the environmental drivers shaping kelp forest productivity and distribution. Persistent and resilient bull kelp forests are critical for supporting stable and biodiverse nearshore ecosystems that ensure the continued provision of ecosystems services, especially culturally, ecologically and commercially important salmon, rockfish, herring, and invertebrate species. These areas may therefore be prioritized for protection and conservation management (Hollarsmith et al., 2022).



Credit: Liam Coleman

LESSONS LEARNED

- ☑ Kelp distribution and productivity are governed by interacting abiotic (temperature, light, nutrients, salinity, surface conditions, substrate, slope) and biotic drivers. Shifts in trophic structure (e.g., grazer–predator balance) can strongly influence kelp extent, abundance, and size.
- ☑ Bull kelp in the Salish Sea exhibits a mosaic of persistence, resilience, and decline across spatial and temporal scales, consistent with patterns observed elsewhere along the northeast Pacific coast.
- ☑ The highest persistence and resilience—and the largest, most stable kelp forests—occur in cold, exposed, oceanic-influenced environments, particularly the Strait of Juan de Fuca in the southern Salish Sea.
- ☑ Moderate to low persistence occurs in slightly warmer, moderately exposed to semi-protected areas, such as the southern Gulf Islands. In some warm, sheltered locations, persistence may be supported by favourable local conditions (e.g., wind-driven mixing, nutrient inputs, reduced urchin grazing).
- ☑ In contrast, non-persistence and decline are more pronounced in northern subregions and in warm, sheltered southern areas (e.g., South Puget Sound), where losses of 63–96 per cent relative to historical baselines have been documented.
- ☑ Marine heatwave events, particularly the Blob, have served as key disturbance markers for assessing resilience, with the strongest impacts observed in northern regions (up to 79 per cent decline in kelp area and distribution).
- ☑ Apparent declines in mapping studies may reflect true absence, detection limitations (e.g., satellite imagery constraints), fine-scale spatial variability, natural interannual variability, or interacting stressors such as urchin grazing.
- ☑ Further long-term, high-resolution datasets are needed to disentangle drivers of decline and distinguish natural variability from climate- and stressor-driven change. Reports of large or rapid losses warrant targeted investigation.
- ☑ Identifying where bull kelp shows persistence, resilience, or decline is critical for prioritizing areas for restoration, protection, and management, and for locating potential climate refugia within the Salish Sea.



Credit: Eiko Jones

CHAPTER FIVE
STRESSORS IMPACTING KELP DISTRIBUTIONS IN BC

INTRODUCTION

Kelp forests in British Columbia are facing multiple stressors that are driving changes in their distribution. Stressors can be broadly categorized as direct (e.g., temperature, light, nutrients) or indirect (e.g., climate change, coastal development, trophic shifts). Indirect stressors are generally anthropogenic and act by altering environmental conditions, which in turn influence direct stressors affecting kelp health and survival (Hollarsmith et al., 2022). While some stressors, in particular climate-driven ocean warming, have become subjects of intense study in recent years and are strongly suspected to be major drivers of kelp forest decline (Starko et al., 2022; Wernberg et al., 2013), many other possible stressors remain understudied. A definitive list of which stressors are currently contributing to kelp losses in BC is not yet possible to assemble. To address this gap, Hollarsmith et al. (2022) synthesized expert knowledge and literature to identify potential stressor pathways that could affect kelp in BC and evaluated supporting evidence. This chapter summarizes those findings, while integrating additional literature to clarify direct stressors and their underlying drivers.



Credit: Nicole Christiansen

CLIMATE CHANGE

Climate change is the dominant global stressor facing kelp today and can impact regional kelp distribution through multiple pathways, including changes in temperature, salinity, nutrient availability, water clarity, benthic sedimentation, and contaminant levels (Figure 5.1). Ocean temperatures are rising globally due to increased absorption of heat trapped by the greenhouse effect into the ocean; there is very high scientific confidence in this relationship (IPCC, 2023). Climate change-driven changes in salinity, nutrients, water clarity, sedimentation, and contaminant concentrations are caused by a combination of increasing levels of freshwater runoff into the ocean (itself resulting from increased precipitation and glacial melting), reduced upwelling, increased oceanic stratification, and increased frequency of storms (reviewed in Hollarsmith et al., 2022). While the effects are somewhat variable and dependent on local factors, a change in any of these factors has the potential to affect kelp health and distribution, and changes in multiple factors may interact to yield even more significant impacts (Rogers-Bennett & Catton, 2019; Wear et al., 2023; Wernberg & Straub, 2024).

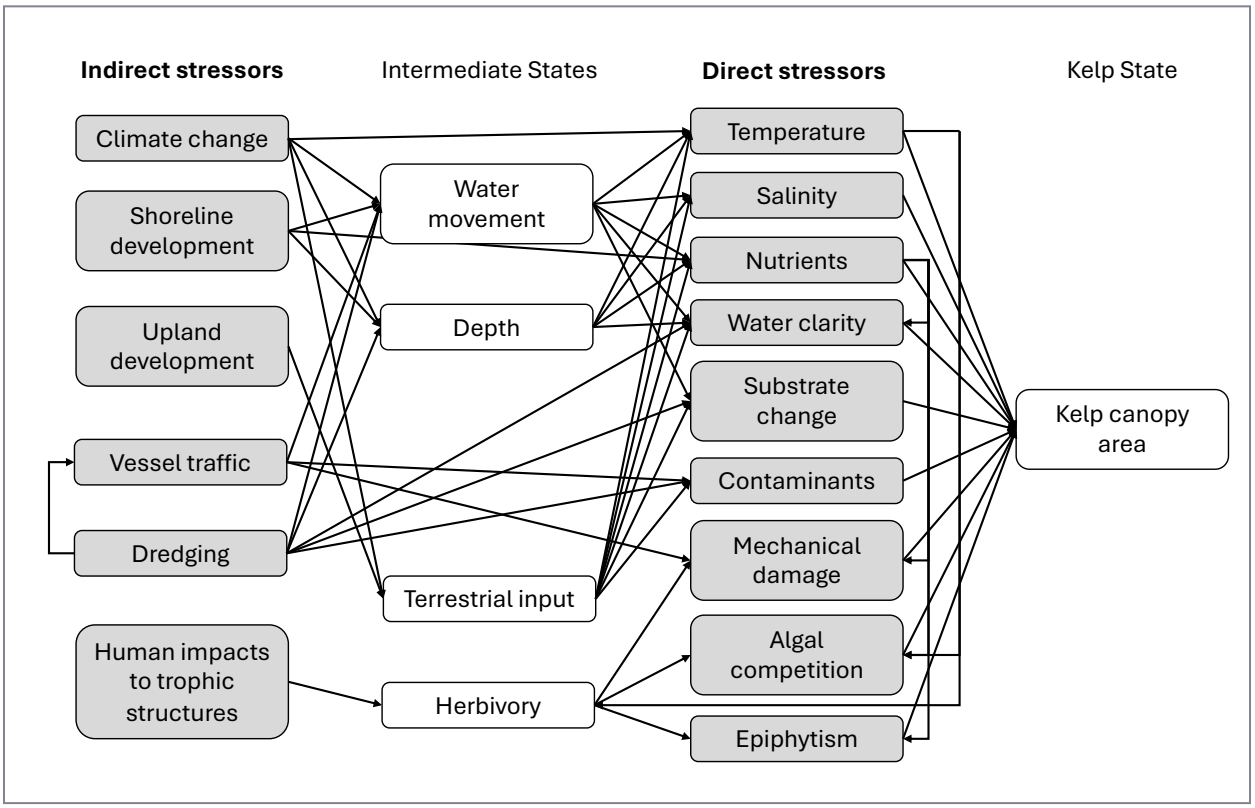


Figure 5.1 A conceptual framework of the key kelp drivers and stressors, showing the relationship between indirect and direct stressors, and the intermediary influences between them, which affect canopy kelp cover. Temperature, due to ocean warming, is the most widely studied driver linked to observed kelp forest losses, both globally (Arafeh-Dalmau et al., 2019; McPherson et al., 2021; Wernberg et al., 2013, 2016) and locally (Berry, 2020; Mora-Soto et al., 2024a, 2024b; Pfister et al., 2018; Starko et al., 2022, 2024a). This diagram was recreated and modified from Hollarsmith et al. (2022).

As discussed in Chapter four, kelp requires cool temperatures to survive. While there is variability in thermal performance and thresholds between species (Lüning & Freshwater, 1988) and even populations (Harden et al., 2024), most kelp species show decreases in performance at temperatures between approximately 17 and 20 °C; exceeding 20–23 °C for more than brief periods is usually lethal for all life history stages in most species (Fales et al., 2023; Le et al., 2022; Lüning & Freshwater, 1988; Supratya et al., 2020; Umanzor et al., 2021; Weigel et al., 2023). Some studies report that high nutrient availability can mitigate the damaging effects of thermal stress (Fernández et al., 2020; Gao et al., 2013; Umanzor et al., 2021), but other studies do not find this (Fales et al., 2023; Weigel et al., 2023). Additionally, perhaps in support of the latter observation, one study found that elevated temperatures (e.g., 21 °C) strongly altered kelp blade-associated microbiome composition, whereas nutrient availability had a lesser effect (Molnar et al., 2025). This suggests the potential for microbiome dysbiosis under thermal stress.

Multiple field-based studies report that losses of wild kelp forests are often associated with high local temperatures, as well as low nutrient availability and low salinity; areas where such losses are taking place are often sheltered from waves and currents and may be located in bays or inlets where the marine environment is more subject to terrestrial influences (Berry et al., 2021; Mora-Soto et al., 2024b; Starko et al., 2022). Conversely, localized areas of kelp persistence are often observed to be associated with high current or wave exposure, low temperature, high salinity and nutrient availability (Berry et al., 2021; Starko et al., 2022, 2024a). Greater exposure to the open ocean reduces stratification through increased mixing, which keeps sea surface temperatures low and available nutrients and salinity high (Berry et al., 2021). These observations suggest that areas of high wave or current exposure may represent climate refugia where kelp forests could naturally remain more persistent under future conditions (Starko et al., 2022).



Credit: Nicole Christiansen

Future-proofing kelp forests

Rising ocean temperatures are prompting an interest in "future-proofing" kelp by enhancing its tolerance to future climatic conditions (Dykman et al., 2025; Wood et al., 2019). Without intervention, it's feared that conditions are changing so rapidly that natural adaptation can not keep pace, and kelp may reach a tipping point beyond which restoration and recovery will not be possible. Places of low genetic diversity, which is the case in areas of the Salish Sea (Bemmels et al., 2025; Gierke et al., 2023), are especially vulnerable. Possible solutions for future-proofing kelp are:

1. **Selective breeding for thermotolerance:** Identify and propagate thermotolerant strains of kelp (e.g., Liu et al., 2014) for restoration in areas that have become too warm for existing population genotypes.
2. **Thermal priming:** Sublethal heat exposure, 'thermal priming,' may induce increased, potentially heritable stress tolerance (Gauci et al., 2024). Demonstrated in sugar kelp (*Saccharina latissimi*) (Gauci et al., 2024), this technique warrants more research in other local species. Bull kelp has shown that priming can upregulate heat shock protein 70, suggesting the technique may have promise for restoration and aquaculture applications (Hotz et al., 2025).



Figure 5.2 Research is underway to test thermotolerance of kelps at a lab in SFU.
Credit: Liam Coleman

3. **Biobanking:** Biobanking, the storage of biological material (Day & Stacey, 2008), acts as 'insurance' for preserving genetic diversity and has the potential to help future conservation efforts (Barrento et al., 2016), should regional populations be lost. Biobanks can support genetic research and breeding programs, including the development of strains with desirable traits, such as increased tolerance to environmental stressors (Harden et al., 2024; Liu et al., 2014; Vissers et al., 2024). For more on biobanking, see: Handbook for biobanking of kelp in British Columbia (Colman, 2026).

Further research is needed to clarify the mechanisms underlying kelp thermotolerance (Figure 5.2). Multiple studies indicate that heat shock proteins play a role in kelps' response to thermal stress (Hara et al., 2022; Hotz et al., 2025; Mao et al., 2026), as they do in many other organisms. With improved understanding, it may be possible to leverage these genetic mechanisms of thermotolerance for breeding or even genetic engineering to help propagate thermotolerant kelp strains.

Ocean warming can harm kelp directly by exceeding physiological limits (e.g., Supratya et al., 2020; Weigel et al., 2023) or indirectly through cascading ecological effects (Starko et al., 2022, 2024a). An example of this is the emergence of sea star wasting disease, which has been linked to the Blob marine heatwave (Hamilton et al., 2021; Harvell et al., 2019). In Barkley Sound, kelp loss was likely exacerbated by overgrazing from sea urchins that had been released from predation pressure following the mass die-off of the sunflower star due to the disease (Starko et al., 2022) (Figure 5.3). Similar dynamics have been proposed for localized kelp loss on BC's central coast, where declines occurred in relatively cool areas, and therefore losses were more likely driven by urchin herbivory following the sunflower star die-off (Starko et al., 2024a). Despite localized increases in urchins in various parts of BC, persistent populations of giant kelp have been observed in Barkley Sound on sandy substrates at unusually great depths below the thermocline (Starko et al., 2022). Sandy substrates appear to deter urchins by acting as a barrier to movement, and thus creating a refuge from herbivory for kelp capable of colonizing these areas (MacGregor & Johnson, 2022), although this effect is not universal (Laur et al., 1986). Urchin herbivory is also reduced in areas of high wave exposure (reviewed in Kawamata, 2010; Lauzon-Guay & Scheibling, 2007), further highlighting high-energy environments as potential refugia from kelp stressors.



Figure 5.3 The sunflower star, *Pycnopodia helianthoides*, is an important predator of sea urchins. The mass die-off of sunflower stars due to sea star wasting disease is thought to have increased urchin herbivory on kelp in local areas throughout BC. Credit: Eiko Jones

Urchin herbivory is not the only indirect ecological effect of ocean warming impacting kelp in BC. Following the Blob marine heatwave, increased fouling of kelp by the encrusting bryozoan *Membranipora* sp was observed (Figure 5.4) (Denley et al., 2025). These epiphytic invertebrates are common in BC and typically benign, but when present in high abundance, can damage blade tissue and increase susceptibility to breakage, potentially leading to substantial kelp loss, as previously observed in Atlantic Canada (Krumhansl et al., 2011; Saunders & Metaxas, 2008). In the wake of the Blob, First Nations observers on the Central Coast of BC reported local giant kelp blades so heavily fouled by *Membranipora* that they sank to the seafloor and quickly disintegrated (Denley et al., 2025). Subsequent work suggests outbreaks were more likely to occur in warmer areas and less likely in areas of high wave exposure (Denley et al., 2025). A bryozoan monitoring project led by the University of Victoria is currently underway to assess the extent of *Membranipora* impacts in BC and improve predictions of outbreak timing and location.

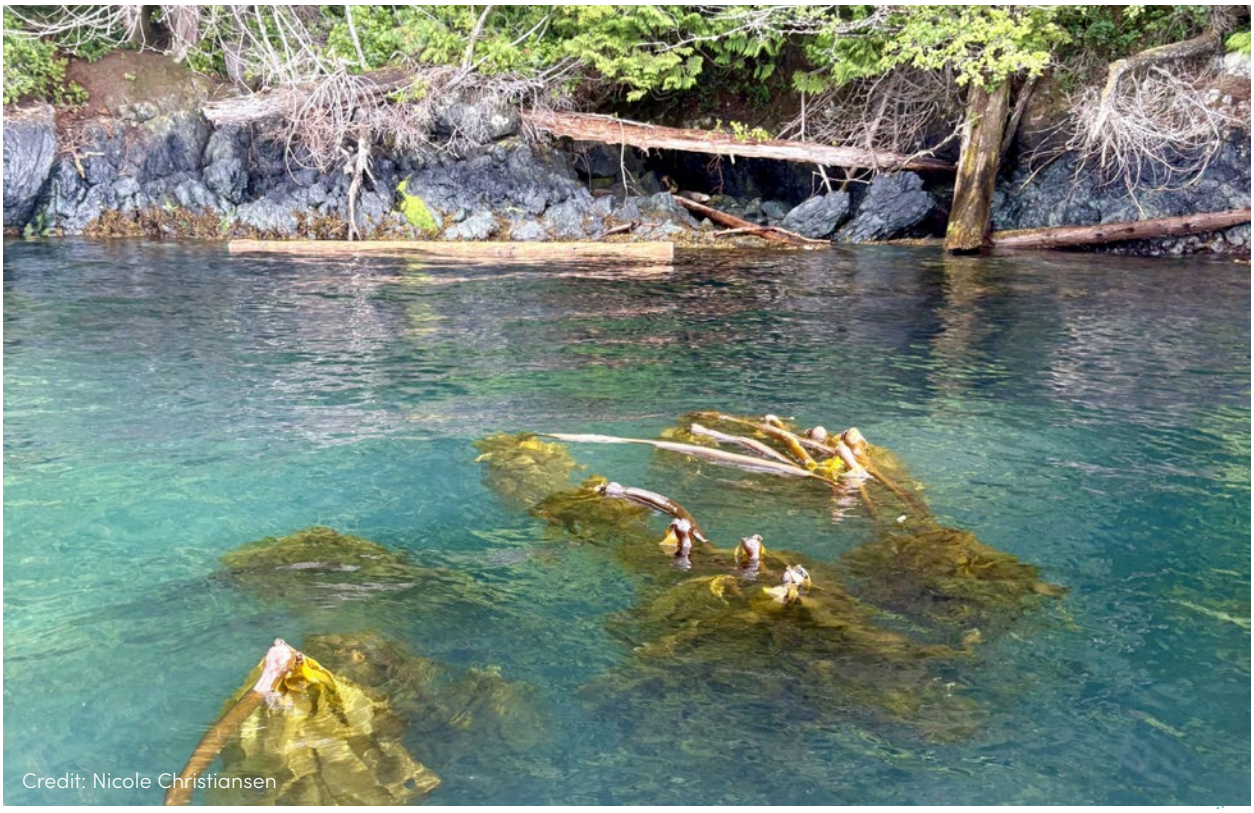


Figure 5.4 Kelp fouled with encrusting bryozoan, *Membranipora* sp. Credit Amnit Sokhey

SHORELINE AND UPLAND DEVELOPMENT

Hollarsmith et al. (2022) define shoreline development as shoreline hardening and the installation of over- or near-water structures (Figure 5.5). These activities may impact kelp by altering salinity, nutrient availability, temperature, water clarity, and sedimentation, which can also drive changes to fish ecology by reducing fish habitat quality (e.g., spawning and feeding grounds) (Munsch et al., 2017). Globally, shoreline development is associated with higher air and substrate temperatures, which can elevate nearshore temperatures, as well as lead to increased nutrient inputs into the ocean from terrestrial sources (Jordan et al., 2009). Effects on water clarity and sedimentation were more variable and dependent on specific locations and development. One study, curiously, attributed increased macroalgal cover in a busy port to reduced herbivory caused by high levels of pollutants (Fowles et al., 2018). In BC, shoreline development has been associated with a decrease in benthic sedimentation through increased deposition of cobbles (Dethier et al., 2016), though no studies have directly examined the impacts of shoreline development on salinity, nutrients, or water clarity in the Salish Sea.

Upland development includes logging, agriculture, urbanization, damming, and industrial activities (Hollarsmith et al., 2022), all of which cause altered runoff dynamics that can impact kelp (Figure 5.5). Globally, these activities can reduce salinity through increased freshwater input (Corcoran et al., 2010), elevate nutrient loading through input of industrial and agricultural runoff (Canton et al., 2012; Garrido-Pérez et al., 2002; Lalonde & Ernst, 2012), decrease water clarity (Desmond et al., 2015), and increase sedimentation (González et al., 2014; Gorostiaga & Diez, 1996) and contaminants (Harris et al., 2011; Xu et al., 2016). In some cases, these impacts have been directly linked to kelp loss, specifically sediment release from mining (González et al., 2014), and sewage discharge (Stull, 1996). Locally, upland development has been associated with increased marine contamination (Martin & Nesbitt, 2015; Poirier, 2006), and variable nutrient effects (Mackas & Harrison, 1997). The removal of the Elwha Dam in Washington State provides a contrasting example, where increased water clarity and reduced sedimentation were observed over time (Glover et al., 2019; Rubin et al., 2017), although short-term increases in sediment delivery were also linked to kelp loss (Rubin et al., 2017).



Credit: Nicole Christiansen

VESSEL TRAFFIC AND DREDGING

Vessel traffic (small and large vessels, Figure 5.5) may impact nutrients, temperature, water clarity, and contaminants, and cause direct mechanical damage to kelp (Hollarsmith et al., 2022). Global evidence supports increased contamination (Choi et al., 2009) and decreased water clarity (Garel et al., 2008), but there is limited research on other potential effects, particularly in the Salish Sea. Hollarsmith et al. (2022) suggested that dredging affects water clarity, sedimentation, and contaminants. These relationships are well supported in the literature, with dredging shown to decrease water clarity and increase sedimentation and contamination (de Jonge et al., 2014; Hedge et al., 2009; Nielsen et al., 2015). Increased sedimentation may negatively impact sugar kelp (Lyngby & Mortensen, 1996), though research is limited.



Figure 5.5 Anthropogenic activities such as logging, shipping and coastal development are stressors impacting kelp forests.

HUMAN IMPACTS ON TROPHIC STRUCTURES

Hollarsmith et al. (2022) include fishing and hunting, invasive species introductions, and species reintroductions in this category, noting their potential to alter grazing pressure, competition, and epiphytism. The global literature generally supported a positive relationship between human impacts and these negative outcomes. For example, in the northwest Atlantic, the introduced invasive green alga, *Codium fragile*, has reduced kelp cover in Nova Scotia, and Maine, USA by outcompeting native kelps for space (Levin et al., 2002; Scheibling & Gagnon, 2006). Similarly, in the northeastern Pacific, the introduction of the invasive brown algae *Sargassum muticum* has been shown to be able to outcompete local kelps for space (Britton-Simmons, 2004).

The classic textbook example of a human-altered trophic cascade is the relationship between kelp, sea urchins, and sea otters. Sea otters were nearly extirpated from the Northeast Pacific during the 18th-century fur trade, removing predation pressure on sea urchins and leading to widespread over-grazing of kelp (Estes & Palmisano, 1974). In the absence of sea otters, urchins can become abundant, leading to barrens characterized by low biodiversity, primary productivity, and food web complexity (Filbee-Dexter & Scheibling, 2014). Although sea otters have been reintroduced to parts of their historic range and populations have increased, they have still not reached their previous population sizes (Watson & Estes, 2011). In BC, sea otters can now be found along much of the west coast of Vancouver Island, though they remain absent from southwest Vancouver Island and the Salish Sea. Areas of BC with persistent otter presence tend to have low urchin abundances and extensive kelp forests, whereas areas without otters have high urchin abundances and reduced kelp (Watson & Estes, 2011).



Credit: Sergey Guk, Pexels

High sea urchin abundances remain a challenge for kelp forests in areas of the BC coast where sea otters are absent (Figure 5.6), such as the Salish Sea. Urchins can limit the success of kelp restoration projects (e.g., Dykman et al., 2025) and are likely to continue to limit recovery without sustained control. As a result, researchers and practitioners have explored both exclusion and reduction strategies. Experiments suggest that fencing can effectively exclude urchins from restoration sites, although not uniformly and high costs limit scalability (Sharma et al., 2021). One exclusion study that mimicked sea otter reintroductions in the Salish Sea yielded no change in the seaweed community, even after two years, contrary to the hypothesis that preventing urchin herbivory should increase macroalgal abundance, suggesting that other factors such as grazing by other invertebrates and density of macroalgal stands play a role in maintaining community structure (Carter et al., 2007). Another study found that bull kelp was more abundant in areas of the Salish Sea (e.g., Saturna Island) where sea urchins were locally excluded (Checko, 2024). Urchin culling can increase kelp cover (Miller et al., 2022, 2024; Williams et al., 2021), but effectiveness typically relies on repeated interventions, impacting potential long-term feasibility (Miller et al., 2022, 2024). Further work is needed to develop scalable, long-term solutions as urchin pressure remains a persistent obstacle to kelp recovery; see Chapter six for more information on herbivore exclusion in kelp forest restoration.



Figure 5.6 Red sea urchins (*Mesocentrotus franciscanus*) are important kelp grazers that, in the absence of predators, can level entire kelp forests, turning once richly productive and complex ecosystems into what are known as urchin barrens. Credit: Eiko Jones

RELATIVE IMPORTANCE OF STRESSORS

Raymond et al. (2024) ranked stressors affecting both the sporophyte and gametophyte stages of bull kelp, giant kelp, and understory kelps in Washington, incorporating uncertainty into their assessment. With high certainty, they identified temperature and substrate change as the stressors most likely to impact all species and life stages. They highlighted greater uncertainty regarding the impacts on gametophytes and species other than bull and giant kelp. The results of this study further reinforce the conclusion that climate change and its impacts are likely the dominant stressor, while underscoring the need to better consider understory species and full life histories in stressor assessments.

Top threats to kelp forests

At the 2025 PSF Kelp Symposium, 83 kelp experts and practitioners from BC or Washington were asked to rank the most significant stressors to kelp forests in their area. Temperature (and marine heatwaves) was identified decisively as the top threat (Figure 5.7), consistent with Raymond et al. (2024). It should be noted that the symposium attendees (1) were not given the same list of choices as those considered in that study and (2) were not asked to separately consider different life history stages or species. Sea urchins were also identified by the symposium participants as a major threat, aligning with Raymond et al. (2024), but primarily to kelp sporophytes.



Figure 5.7 The results of a survey posed to attendees of the 2025 Pacific Salmon Foundation Kelp Symposium. Attendees were asked to rank what they believed to be the most significant stressors facing kelp forests in their local areas (BC and WA). Temperature and marine heatwaves dominated the response.

LESSONS LEARNED

- ☑ Kelp forests in BC are facing multiple stressors that are causing changes in their distributions.
- ☑ A range of indirect anthropogenic stressors, including climate change, shoreline and upland development, vessel traffic, dredging, and changes to trophic structures, can alter environmental conditions that can directly affect kelp health (direct stressors).
- ☑ Climate change, particularly ocean warming, represents the most significant and well-studied stressor affecting kelp.
- ☑ Multiple studies attribute the loss of kelp cover in BC, at least in part, to high temperatures, although other stressors, such as substrate changes, herbivory, epiphytism, and invasive species may also contribute to these losses.
- ☑ High sea urchin abundances in areas lacking sea otters or sunflower stars can restrict kelp growth and limit the effectiveness of restoration projects.



Credit: Liam Coleman

CHAPTER SIX
KELP FOREST RESTORATION – WHAT WE HAVE LEARNED SO FAR

INTRODUCTION

Recent kelp losses throughout the Salish Sea (e.g., Chapter four, Berry et al., 2021; Mora-Soto et al., 2024b; Starko et al., 2022, 2024) have ignited interest in kelp forest restoration to rebuild resilient, self-sustaining populations. Early restoration efforts began in the mid-2000s, when the Nile Creek Enhancement Society (NCES) outplanted seeded lines (twine with young kelp sporophytes attached) at the mouth of Nile Creek and eventually around greater Baynes Sound (Heath et al., 2015a). These early efforts created a foundation for learning and innovating. Since then, restoration activity has expanded, particularly in the 2020s as kelp continued to decline and funding increased, with multiple organizations undertaking projects to address local kelp declines and to trial different methods (Figure 6.1 and Table 6.1). As of 2024-2025, over 25 sites, spanning from the Sunshine Coast to the Southern Gulf Islands, were restored using various techniques, including seeded lines, green gravel, urchin exclusion, and increased genetic diversity (Heath et al., 2022; Schuster, 2025). Many projects are led by or carried out in collaboration with First Nations, including Snuneymuxw, Tla'amin, Tsleil-Waututh (səlilwətaɬ), Squamish (Sḵwx-wú7mesh Úxwumixw). Restoration efforts are underway beyond the Salish Sea in BC, including Barkley Sound, Haida Gwaii, and the northern and central coast. Despite rapid growth in effort and accumulated knowledge, significant gaps and challenges remain. This chapter synthesizes lessons learned to date by comparing restoration methods used in BC, identifying common challenges, and outlining recommendations for future kelp restoration efforts.



Figure 6.1 Bull kelp growing at experimental restoration sites in the northern Salish Sea. Heavy growth of bull kelp from seeded lines deployed at the Maude Reef site in Lambert Channel, despite epizoans and grazers, is shown on the left (Photo credit: Heath, Zielinsky, & Zielinsky, 2015). Bull kelp sporophytes growing attached to a concrete block (right) (photo courtesy of Kelp Rescue Initiative).

Table 6.1 Timeline of the number of kelp restoration project sites in the Northern Salish Sea, by outplant/grow out year, up to February 2025 (Heath et al., 2015a; Help the Kelp, 2015; Tomlin, 2020; Ennis, 2024; Vital Kelp, and Ennis, 2024; Lee-Ann Ennis, Vital Kelp, personal communication, April 02, 2025; Snuneymuxw First Nation, 2024; Tla'amin Nation, Feb. 2025; Andy Lamb, Thetis Island Marine Explorers, personal communication, February 11, 2025)

Year	Number of Sites	Group (sites outplanted)
2006	1+	Nile Creek Enhancement Society (NCES) (1+ site: Nile Creek)
2007	1	NCES (1 site: Nile Creek)
2008	1	NCES (1 site: Nile Creek)
2009	2	NCES (1 site: Nile Creek); Help the Kelp Gabriola (HtKG) (1 site: Clark Bay)
2010	1	NCES (1 site: Nile Creek)
2011	2	NCES, Hornby Island Diving (HID) (1 site: Maude Reef, Hornby Island); HtKG (1 site: Clark Bay)
2012	1	NCES, HID (Maude Reef)
2013	2	NCES, HID (Maude Reef), HtKG (Clark Bay)
2014	1	NCES, HID (Maude Reef)
2015	3	NCES, HID, Comox Valley Project Watershed Society (PWS) (3 sites: Maude Reef, northern Baynes Sound, Island Scallops)
2016	4	NCES, HID, PWS (4 sites: Maude Reef, northern Baynes Sound, Cape Lazo shoal, Royston)
2017	3	NCES, HID, PWS (3 sites: Maude Reef, Maude Reef deeper, Cape Lazo shoal)
2018	2	MABBRI (2 sites: Winchelsea Islands, Northumberland Channel)
2019	4	PWS, HID (1 site: Maude Reef); MABBRI (2 sites: Winchelsea Islands, Northumberland Channel); Independent, L. Ennis (1 site: Nelson Island)
2020	1	PWS, HID (1 site: Maude Reef)
2021	1	PWS, HID (1 site: Maude Reef)
2022	1	Vital Kelp (1 site: Jeddah Point)
2023	8	Ocean Wise (1 site: Burrard Inlet); Neptune Terminals (1 site: Burrard Inlet); Thetis Island Marine Explorers (3 sites: Thetis Island)
2024	11	Ocean Wise (2 sites: Burrard Inlet, Átl'ka7tsem/Howe Sound); Kelp Rescue Initiative (KRI) (5 sites: Burrard Inletx3, Maude Reef, Denman I.); Neptune Terminals (1 site: Burrard Inlet); Thetis Island Marine Explorers (3 sites: Thetis Island)
2025	14+	Ocean Wise (1 site: Átl'ka7tsem/Howe Sound); KRI (3 sites: Maude Reef, Denman Is., scaling up at northern Baynes Sound; BC Conservation Foundation (BCCF), Tla'Amin Nation (10 sites: Okeover Inlet)

OVERVIEW OF THE STEPS TO PREPARE FOR RESTORATION

CONSULTATION

Early and meaningful consultation with local First Nations communities is essential; engagement should be initiated at the outset of a potential kelp restoration project. Input from community members, fishers, divers, and others with local ecological knowledge is not only respectful but can also help identify priority areas and provide insight into historical conditions and potential drivers of kelp decline.

SITE SELECTION

Selection of sites with the greatest probability of restoration success is critical. Such selection often focuses on areas with known current or historical kelp presence. However, climate-driven shifts can mean that previously suitable areas may no longer support kelp. Habitat suitability and restoration potential maps, (e.g., Barbosa et al. 2026), which incorporate warming trends and marine heatwaves, can help identify areas with a higher likelihood of success.

APPROVAL AND PERMITTING

Kelp restoration activities in BC require approval through the BC Aquatic Plant Program (AquaticPlants.Program@gov.bc.ca). Applications should describe activities, timing, species and methods used, and engagement with First Nations. Collection of whole plant or reproductive material, as well scuba activities require permits (Pawluk & Denley, 2025).

COLLECTION OF KELP 'SEED'

Mature reproductive kelp blades (with sori) should be sourced locally within 50 km of the intended restoration site to reduce risks of pathogen transfer and maintain local population genetics (Pawluk & Denley, 2025). At least 20 individuals should be sampled, ideally at least a month prior to outplanting. In the Salish Sea, reproductive blades of bull kelp reliably are present from mid-to-late summer to early fall. Sori are then returned to a laboratory space to release spores, which are used to form cultures of ('seed').



Credit: Liam Coleman

GROWTH OF KELP 'SEED'

Kelp seed is typically cultured in nurseries on substrates (e.g., twine, rope, rocks, tiles) prior to outplanting (e.g., seeded line or green gravel methods). Nursery rearing allows juvenile sporophytes to form from gametophytes and then grow to a size that improves survival under field conditions where they will face competition, sedimentation, and grazing. After initial settlement of spores on clean substrate material (string, twine, rocks, or tiles), a brown fuzz will appear on the substrate material after about two weeks, indicating growth of gametophytes and, eventually, juvenile sporophytes (Figure 6.2), and it will be ready for outplanting at the restoration site within two to four weeks. See below for a selection of resources for producing kelp seed in a nursery:

- ***Handbook for Biobanking of Kelp in British Columbia*** (Coleman, 2026): Methods for collection, spore release, and storage of bull kelp.
- ***Kelp Farming Manual*** (Flavin et al., 2013): How to design and operate a seaweed nursery.
- ***Kelp Cultivation Handbook*** (Puget Sound Restoration Fund (PSRF)): Guide for nursery production of bull kelp seed.
- ***New England Seaweed Culture Handbook: Nursery Systems*** (Redmond et al., 2014). Methods that are adaptable to production of bull kelp seed.
- ***Scaling a New Cost-Effective Intervention Tool to Restore and Future-Proof Coastal Kelp Forests*** (Lamb et al., 2023): Green gravel method of producing kelp seed.
- ***Kelps on demand: Closed-system protocols for culturing large bull kelp sporophytes for research and restoration*** (Supratya & Martone, 2023): Tumble culture system, with the potential for temperature and flow experiments.

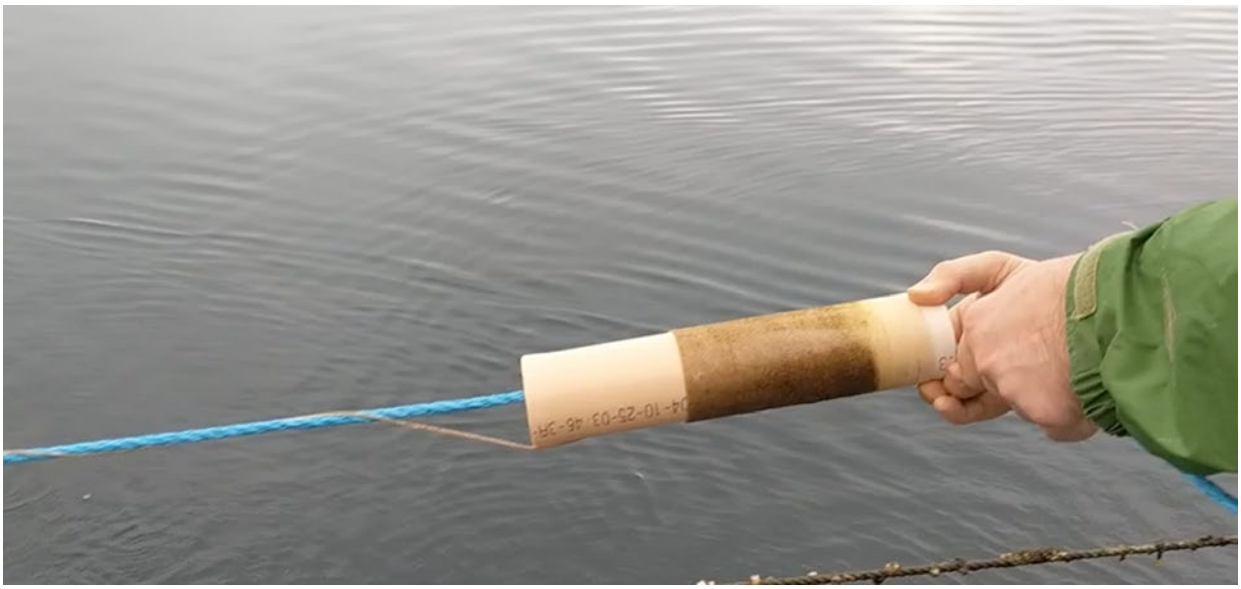


Figure 6.2 A spool of line seeded with kelp is deployed on a rope that will be anchored near the sea bottom (photo credit: K. Leask).

Nursery production provides opportunities for comparing kelp growth, health, and resilience across source populations exposed to different environmental conditions, as well as selective breeding for thermal tolerance. In response to the warming conditions in the Salish Sea, researchers are investigating the thermal tolerance of kelp from different locations by culturing the early life stages (spores, gametophytes, juvenile sporophytes) under various temperature regimens (Martone, 2025; Schuster, 2025). See below for a list of nurseries that have been providing seed and other services for bull kelp restoration in the Salish Sea and other locations in BC:

- Canadian Kelp Research, Bamfield, Barkley Sound, BC;
- Green Seas Kelp Co., Comox, BC;
- West Coast Kelp, Bamfield, Barkley Sound, BC;
- Ocean Wise Canada at Pacific Science Enterprise Centre in West Vancouver, BC;
- Kelp Rescue Initiative (KRI),Bamfield, Barkley Sound, and Deep Bay Marine Field Station, BC;
- Vital Kelp, Pender Harbour, BC;
- Tla'amin Nation, Lund, BC;
- Centre for Applied Research, Technology and Innovation (CARTI), North Island College, Campbell River, BC;
- Cascadia Seaweed at Cedar, BC
- Puget Sound Restoration Fund's (PSRF) NOAA's Manchester Research Station, Port Orchard, WA. and turbidity. Findings of decline in kelp

Cutting out the middleman: seeding without a nursery

Direct seeding methods are being developed to reduce reliance on nursery operations and simplify outplanting. One trial aims to increase accessibility for First Nation communities by enabling on-site seeding. In this trial, kelp sori were placed with clean beach rocks and seawater in coolers with ice packs, allowing spores to settle directly on the rocks before use in restoration (Martone, 2025). Preliminary results found that even short exposure (~2 hours) can produce sufficient settlement and growth of juvenile sporophytes, suggesting treated rocks can be deployed directly into restoration sites. Another method involves suspending gametophytes in an alginate binder, called "Gametoglue", that could be deployed directly onto benthic substrate (Figure 6.3) (Schuster, 2025). These methods aim to lower logistical barriers and expand scalability and accessibility.





Figure 6.3 "Gametoglue," a method being developed for direct seeding of bull kelp gametophytes to a substrate at a restoration site (photo credits: Kelp Rescue Initiative).

MAINTAINING KELP FOR STORAGE

Gametophytes can be maintained in nurseries for extended periods under low light or red light, with low nutrients. This approach suppresses sexual maturity while allowing for continued vegetative growth, providing nurseries with the ability to supply seed "on demand" and to develop seed banks (Le et al., 2022; Redmond et al., 2014; Supratya & Martone, 2023; Coleman, 2026). While gametophyte cultures can be kept for years, they do require regular maintenance and sub-culturing and are vulnerable to infections and genetic mutations. To address this problem, some nurseries are using a seaweed bioreactor, a method of boosting gametophyte growth (Figure 6.4). The use of cryopreservation methods for storing gametophytes can also help mitigate these issues (Coleman et al. 2025; Coleman, 2026).



Figure 6.4 A bank of seaweed bioreactors in the Seaweed Innovation Hub at North Island College's Centre for Applied Research, Technology and Innovation (CARTI), designed and built by Industrial Plankton. Light, nutrients, pH, and air can be controlled for each bioreactor to promote vegetative growth in gametophytes, while minimizing exposure to contaminants. It also continuously mixes and chops the growing clusters of gametophytes (Photo by K. Leask, 2025).

RESTORATION METHODS USED IN THE SALISH SEA AND OTHER LOCATIONS IN BC

There are different strategies for restoring and enhancing bull kelp in the Salish Sea and BC. The following sections summarizes the approaches that have been taken. For more information on individual kelp restoration projects, see the Review of Restoration Methodologies used in the Salish Sea and other British Columbia locations (Leask, 2025) and visit PSF's Kelp restoration mapping portal.

SORUS TRANSFER

Transferring sori is a straightforward procedure that does not require specialized laboratory equipment. Reproductive blades (sori) are collected from local populations, cleaned, treated with iodine, dried, and placed in mesh bags or perforated containers that are anchored and suspended near suitable substrates. Spores are released from the sori into the surrounding environment. Hopefully resulting in passive recruitment. This method has been trialled near Nike Creek Sound, around Gabriola Island, and in Puget Sound, but results have been inconclusive (Leask, 2025). While some observations suggest possible increases in kelp abundance following deployment, distinguishing enhancement-driven recruitment from natural variability has proven difficult. Overall, there is limited evidence of consistent success, and use of the method has not been widely continued.



Credit: Liam Coleman

SEEDED LINES

Seeding lines is the most widely used restoration method in the Salish Sea. Adapted from aquaculture, the method places ropes or twine seeded with juvenile kelp near the seafloor, with the aim of establishing reproductive adults that can in turn seed the surrounding areas (Figures 6.5 and 6.6). See Table 6.2 for a summary of projects that used seeded lines in the Northern Salish Sea up to 2025. Of the 18 trials (site-year) that reported results, 10 (56 %) achieved growth to near the surface and nine (50 %) produced sori. Recruitment was rare, observed in only two trials (11 %). At Maude Reef, recruits were recorded on long-term mooring lines in 2016 and 2017, with one observed in 2019 and six in the following year (Heath et al., 2017; Heath et al., 2022). Reduced growth and reproduction were linked to grazing and high temperatures, while complete failure was associated with late deployment, biofouling, storm damage, and poor site selection. The two examples where recruitment took place were attributed to lower grazing pressure and cooler temperatures (Hayford, 2025; Heath et al., 2022).



Figure 6.5 Bull kelp growing to reach the surface at an experimental restoration site at Maude Reef, Hornby Island, Lambert Channel (Heath et al., 2020).

SPOTLIGHT ON SEEDING METHOD

SOURCE

Kelp sporophytes are produced from reproductive sori collected from kelp near the restoration site or from nursery collections. See sections above on 'Collection of Kelp Seed,' and 'Maintaining Kelp for Storage.'



SETTLE

Settlement spools are prepared by tightly wrapping twine/string around PVC pipe. These spools are then exposed to kelp spores, often using larger PVC "settlement tubes," before being placed in aquaria filled with chilled culture media (usually Guillard's solution or Provasoli enriched seawater). It is imperative that all materials are clean and free of any chemical residues.



GROW

Settled kelp propagules on spools are left in aquaria with lights on both sides at a temperature of 10°C and exposed to around 30 µmol/m^2/s of white light on a 12:12 photoperiod for 2-4 weeks. By the end of this period, the seeded lines will ideally contain small sporophytes at a density of 1-5 per cm, with each sporophyte only a few mm up to 1 cm tall. See 'Growth of Kelp Seed.'



DEPLOY

Lines bearing the seeded twine are outplanted on secure structures able to withstand drag from mature kelp while remaining removable (see illustration based on structures used at Hornby (Heath et al. 2015)). Deployment is typically Dec-Feb; later winter outplanting may improve survival by avoiding grazers, while still preceding spring diatom blooms (Allen, 2018).



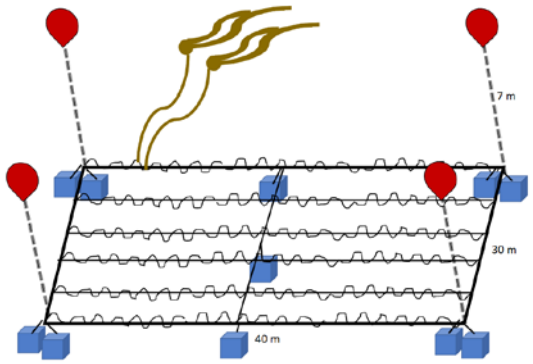


Figure 6.6 Generalized method for seeding lines with kelp for restoration.

Table 6.2 Timeline of the number of kelp restoration project sites in the Northern Salish Sea, by outplant/grow out year, up to February 2025 (Heath et al., 2015a; Help the Kelp, 2015; Tomlin, 2020; Ennis, 2024; Vital Kelp, and Ennis, 2024; Lee-Ann Ennis, Vital Kelp, personal communication, April 02, 2025; Snuneymuxw First Nation, 2024; Tla'amin Nation, Feb. 2025; Andy Lamb, Thetis Island Marine Explorers, personal communication, February 11, 2025).

Group	Site	Year	Method	Results	Sori, recruits
Nile Creek Restoration Society & Comox Valley Project Watershed Society	Maude Reef, Denman Island	2015	6 x 30 m lines deployed in January	Heavy growth in May, reached the surface, began deteriorating due to heat and bryozoans; done by August. Water temp at bottom reached 18 °C in late May, fluctuated between 12 and 20 °C through June, cooled in July but half the days were above 15 °C.	Small amount of sori
	Northern Baynes Sound	2015	1 x 30 m line; deployed in January	Grazed by kelp crabs before reaching surface.	No
	Island Scallops	2015	1 x 30 m line; deployed in January	Some growth, 30 to 50 cm long, patchy distribution noted in July (only site visit).	Not reported
	Maude Reef, Denman Island	2016	6 x 30 m lines; deployed in January	Grew well and remained quite healthy into August.	Significant sori production and release.
	Maude Reef deeper site	2016	1 x 30 m	Grew well and remained quite healthy into August and even October.	Significant sori production and release.
	Maude Reef, Denman Island	2017	6 x 30 m lines	Grew well. Healthy bull kelp plants observed into September.	Significant sori production and release.
	Maude Reef, deeper site	2017	1 x 30 m	Grew well. Healthy bull kelp plants observed into October.	Significant sori production and release.
	Cape Lazo shoal	2017	1 x 30 m	Storm damage to site.	No
	Maude Reef, Denman Island	2018-2019	6 x 30 m; Dec. 27	Sansum Narrows and Oyster River bull kelp seed. Temperatures exceeded the 17 °C threshold for prolonged exposure, leading to tissue degeneration mid-July. Nov. 15 all bull kelp floats gone.	1 x 2' tall recruit; Some sori in July.
	Maude Reef, Denman Island	2020-2021	4 x 30 m, 1 x 30 m in exclosure; Dec. 24	Rapid decline in bull kelp condition with arrival of a heat dome in late June (18°C to 26.7°C, June 23 to 30) and a continuing heat wave in July. Green urchins gone. Aug. 27 some bull kelp still present but in poor condition, deeper kelp in relatively better condition.	Six bull kelp recruits from 2019; some sori in Aug.

Group	Site	Year	Method	Results	Sori, recruits
Help the Kelp	Clark Bay, Gabriola Island	2011	2 x 30 m; deployed in January	Kelp failed to grow, and other kelp species colonized the lines.	No
MABRRI	Northumberland Channel	2018	2 x 30 m; deployed in March	No growth on seeded lines, possibly deployed too late.	No
	Winchelsea Islets	2018	2 x 30 m; deployed in March	No growth on seeded lines, possibly deployed too late.	No
	Northumberland Channel	2019	3 x 30 m; deployed January 13	Good growth through to August then 50 per cent lost to urchin grazing; surviving kelp produced sori. Sea surface temperatures were cooler in 2019 than 2018.	Sori
	Winchelsea Islets	2019	3 x 30 m; deployed January 13	Good growth through to August then all lost to urchin grazing. Sea surface temperatures were cooler in 2019 than 2018.	No
Indepen-dent	Nelson Island	2018-2019	13 x 15 m; deployed December 20, 2018	Rapid growth in March; an epiphyte and fish community developed by July; kelp die off occurred in the summer, possibly a natural process.	Sori
Thetis Island Dive Team	North Cove, Thetis Island	2022-2023	1 x 20 m line; deployed December2022	Kelp grew well on lines at Fraser Point until spring/ summer when it was deci-mated by northern kelp crabs.	No
	Pilkey Point, Thetis Island	2022-2023	1 x 20 m line	Kelp grew poorly and sparsely for a short time. No history of bull kelp here.	No
	North Cove, Thetis Island	2023-2024	1 x 20 m line; deployed December 2023	Fewer than 10 grew to 10 cm with pneumatocysts before being grazed by kelp crabs. Nearby rock jetty provided habitat for crabs.	No
Ausenco Viterra-Cascadia terminal capacity expansion	Second Narrows, Burrard Inlet	2021	18 lines of bull kelp and 18 lines of sugar kelp were anchored around an artificial reef	Not reported	Not reported

SEEDED STONES ("GREEN GRAVEL") OR TILES

"Green gravel," culturing kelp on small rocks in a nursery and deploying them directly, is a newer method that reduces the need for *in situ* infrastructure and diver-assisted installation, increasing flexibility and scalability (Figures 6.7 and 6.8). The green gravel method was first trialled locally in BC in Barkley Sound in 2021 with bull kelp, sugar kelp, and giant kelp (Ocean Wise, 2024d). Since then, nursery and deployment methods have been adapted by species and expanded to sites in the northern Salish Sea (Strait of Georgia), with multiple organizations now testing this approach.

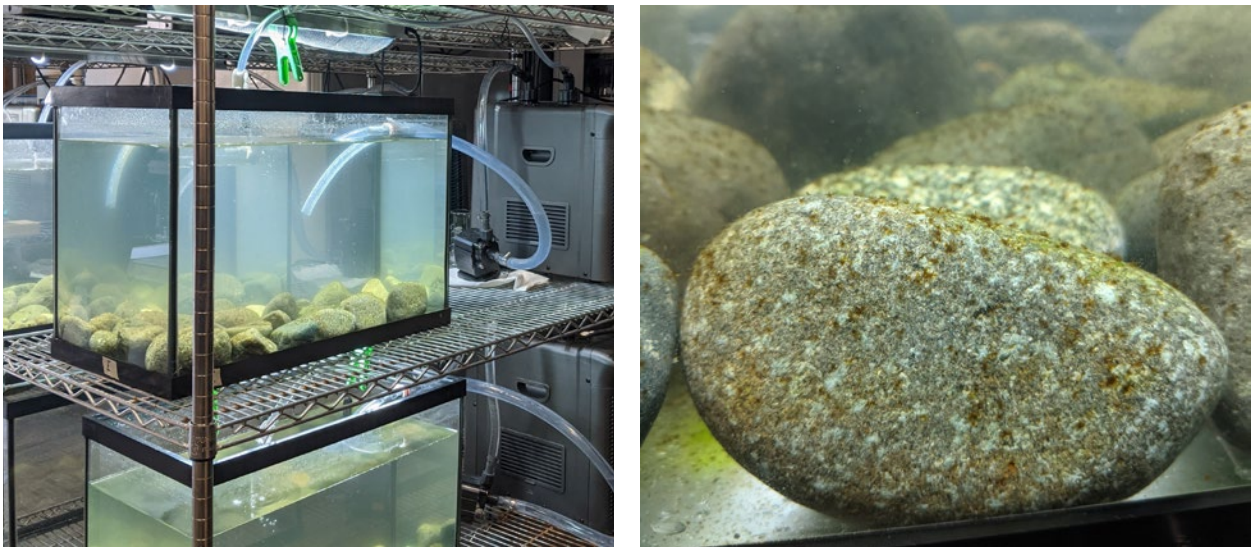


Figure 6.7 Left: cobbles seeded with bull kelp in aquaria with recirculated, chilled water at the Seaweed Innovation Lab, North Island College's Centre for Applied Research, Technology and Innovation (CARTI). Right: close-up of a cobble stone showing juvenile bull kelp sporophytes as brown patches (Photo credit: K. Leask, 2025).



Figure 6.8 Deployment of bull kelp grown on large cobble stones in Kelp Rescue Initiative's nursery in northern Baynes Sound (Photo credit: S. Leduc, VIU, 2024).

To date, there has been variable success with the method, with some attempts (five out of nine) resulting in growth and only one attempt resulting in sorus development at the end of the season (Table 6.3). For the cases that did not result in growth, the suspected causes of failure included insufficient anchoring by small gravel and oyster shells, grazing by sea urchins, kelp crabs, and gastropods, and sedimentation. Practitioners generally found that the rapid growth of the stipe and pneumatocyst of bull kelp, combined with the slower development of haptera (holdfast for attachment), can cause kelp sporophytes to become buoyant and detach before establishing secure attachment to stable substrate. Using larger, cobble-sized substrate (fist to grapefruit size) or attached tiles (Figures 6.9 and 6.10) can improve retention compared to smaller rocks (3–5 cm) (Good, 2024; Schuster, 2025).

Table 6.3 Timeline of the number of kelp restoration project sites in the Northern Salish Sea, by outplant/grow out year, up to February 2025 (Heath et al., 2015a; Help the Kelp, 2015; Tomlin, 2020; Ennis, 2024; Vital Kelp, and Ennis, 2024; Lee-Ann Ennis, Vital Kelp, personal communication, April 02, 2025; Snuneymuxw First Nation, 2024; Tla'amin Nation, Feb. 2025; Andy Lamb, Thetis Island Marine Explorers, personal communication, February 11, 2025)

Group	Location	Date	Method	Results	Sori, recruits
Neptune Terminals, UBC's Patrick Martone Lab, Tsleil-Waututh Nation	Burrard Inlet	2023-2024	Thermal and salinity tolerance trials of bull kelp grown on tiles outplanted at an industrial site.	Good growth observed. Plans to repeat next year.	Not reported
Thetis Island Dive Team, Ocean Wise, Canadian Kelp Resources	Rocket Shoal, Thetis Island	2023	Gravel deployed from boat.	No growth when checked.	No
	Escape Reef, Thetis Island	2023 Dec	Gravel deployed from boat.	No growth when checked in May 2024.	No
Ocean Wise & Tsleil-Waututh First Nation	Burrard Inlet	2023-2024	Sugar kelp (Saccharina latissima) on pebbles/cobble and oyster shells held in False Creek from Feb. to May then outplanted to Burrard Inlet.	Kelp growth met and exceeded expectations. Oyster shell lacked sufficient weight to hold kelp in place as it grew. Good growth despite late outplanting.	Not reported
KRI & VIU DBMFS 2024)	MaudeReef, Hornby Island	2024	Urchin control with cages, fencing, and experimental blocks.	Fencing worked well but extent of growth was not described.	Not reported
	Denman Island south	2024	Compared four restoration methods: three sizes of gravel (pea gravel, medium gravel, cobble) , tiles, seeded line, and direct seeding.	Kelp growth and survival best on cobble.	Not reported
	Denman Island and Comox	2025	Outplanting of 1,700 m^2	Pending	Pending

Group	Location	Date	Method	Results	Sori, recruits
Snuneymuxw First Nation and Cascadia Seaweed	Nanaimo Harbour and	2023/ 2024	Due to diatom overgrowth problems in the nursery, small rocks were outplanted early.	No success with small rocks: they were buried by sediment or tumbled away; some evidence of urchins and kelp crabs, and gastro-pod grazing.	No
	4 sites: Taylor Bay, DeCoursey Passage, Newcastle	2024/ 2025	Sori collected from Gabriola Passage, False Narrows population ~ 30 individuals. Green gravel-cobble >fist size and tiles affixed to concrete blocks. Outplant end of Nov., in Dec, and end of March. 1 m sq transects with cobble about 5 cm apart: 3 quadrats per site.	Of 4 sites, one was lost, one was devoured by small urchins, the Newcastle site reaching 5 cm; one more successful site; 50% success so far.	Pending



Figure 6.9 Bull kelp haptera attached to concrete block (photo credit: C. Good, Kelp Rescue Initiative).

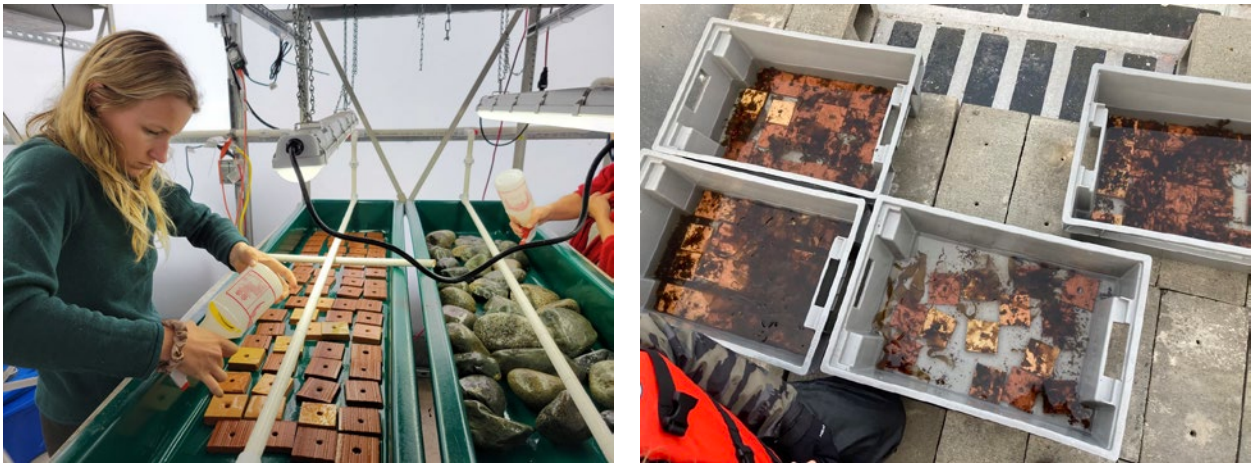


Figure 6.10 Left: tiles and cobble stones inoculated with bull kelp gametophytes (Photo courtesy of Kelp Rescue Initiative). Right: clay tiles with attached juvenile bull kelp in totes with seawater transported for restoration (Photo credit: L. Dykman, Kelp Rescue Initiative).

Detailed methods for green gravel production can be found in Scaling a *New Cost-Effective Intervention Tool to Restore and Future-Proof Coastal Kelp Forests* by Lamb et al. (2023) with additional guidance available in: Kelp Restoration Guidebook: Lessons Learned from Kelp Projects Around the World and at greengravel.org.

Other innovations for outplanting are being developed in collaboration with First Nations to improve accessibility and incorporate Indigenous traditional knowledge (Martone, 2025). Trials with səlilwətaɬ (Tsleil-Waututh Nation) explore the use of oyster shell (Ocean Wise, 2024a) and cedar rope (Martone, 2025) as potential substrates for kelp seed collection.

Resources for restoration outplanting methods

Some resources are available to guide practitioners in planning, designing, implementing, and monitoring kelp restoration.

- Kelp Forest Restoration in Action: Chapter in "Kelp Restoration Guidebook: Lessons Learned from Kelp Projects Around the World" (Eger et al., 2022) describes methods used for restoring kelp practiced around the world, including advice on planning and obtaining permits.
- Puget Sound Restoration Fund, Final Report. Bull Kelp Early Life History Study (Allen, 2018): A systematic study into the timing and life stage of kelp for outplanting in Puget Sound.
- The Process for the Marine Forest Project (Korea Fisheries Resource Agency, 2019) provides information for planning site selection, artificial reefs, methods of outplanting and transplanting, herbivore control, monitoring, and evaluation. Although written for South Korea, many adaptable methods are suggested.

TRANSPLANTING SMALL SPOROPHYTES

Small kelp sporophytes can be collected from a donor site (natural beds, seeded lines, or dislodged individuals) and temporarily attached to a substrate until a permanent holdfast develops. A range of attachment methods have been trialled with varying degrees of success, including combinations of natural rubber bands (Figure 6.11), nylon cord, cable ties, surgical tape, hard plastic clips, anchored ropes, and epoxy resin. Substrate size is a key constraint. As with green gravel, rapid growth can lead to buoyancy before secure attachment is established. Stones or cobbles that are at least fist-sized (Figure 6.11) are recommended (E. Fulton, Redd Fish Restoration Society, personal communication, February 25, 2025; L. Ennis, Vital Kelp, personal communication, April 02, 2025; Shaw et al., 2018). See Table 6.4 for a list of transplantation trials that have been conducted in the Salish Sea.

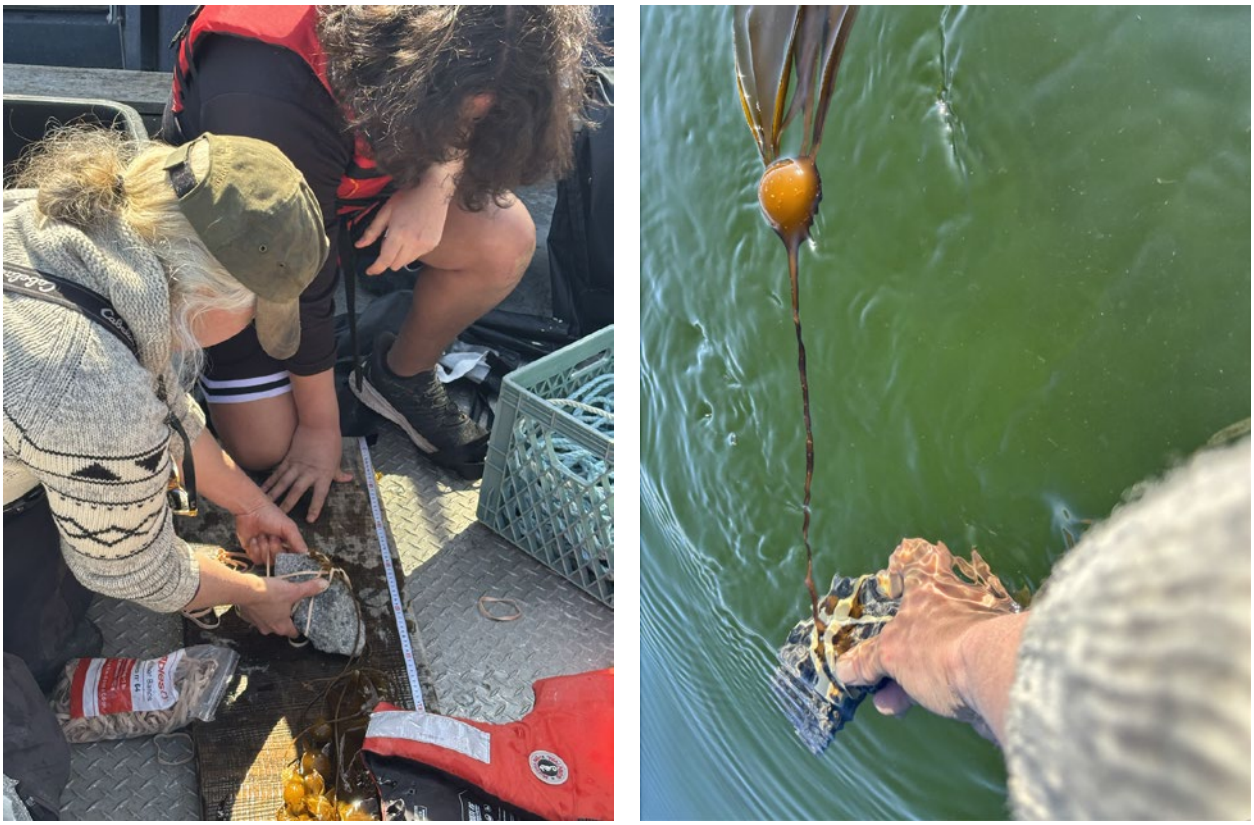


Figure 6.11 Kelp grown on lines, detached, and attached to rocks with natural rubber bands, deployed from a boat (Photos provided by L. Ennis, 2025).

Table 6.4 Growth and maturity of bull kelp (unless otherwise stated) transplanted to sites in the Northern Salish Sea. The date of deployment is shown, along with some suggested drivers of success or failure. The presence of sori or recruits was confirmed at some sites and not reported (NR) at others; lack of sori development is assumed where growth did not reach the surface or sporophytes were prematurely lost. MABRRI = Mount Arrowsmith Biosphere Region Research Institute. PWS = Project Watershed Society.

Group	Location	Date	Method	Results	Sori, recruits
MABRRI	Winchelsea Islands and Northumberland Channel	June 6, 2018	24 stray bull kelp sporophytes from the area were attached to the lines at the two sites using two methods: cable ties or surgical tape on rope.	By August 16, 2018, seven individuals remained between the two sites: four cable ties, three surgical tape. Individuals that did not survive either snapped along the stipe, were grazed, or were absent from the site. Transplants survived 76 days; 30 per cent survived to day 89. Growth was much faster at the Northumberland site.	Five individuals were observed to have sori over the summer.
PWS	Maude Reef, Denman Island	Apr. 5, 2020	Collected 20 wild juvenile bull kelp on cobbles from the Oyster River estuary and transported to exclosure.	Sori patches visible in early May. Of the nine kelp remaining on May 22, larger kelp were producing sori and ends of blades were starting to break down. On June 11, one red urchin was found inside exclosure with just three kelp. By July 24, only holdfasts and stipes present, floats and blades were gone.	Many sori by mid- May.
Vital Kelp	Jeddah Point, Sunshine Coast	2021-2022	Line grown bull kelp was transferred off line onto fist-sized rocks and attached using natural rubber bands.	Natural attachment of juvenile kelp to rocks was observed within 2-4 weeks. Approximately 2/3rds of 100 transferred kelp survived, matured and produced sorus material.	Sori
Ocean Wise Canada with the Tsleil-Waututh First Nation	Burrard Inlet *(səl̓ilw̓ət)*	2023-2024	Bull kelp was grown on a local farm to 35 cm, detached from the farm substrate and reattached to rocks which were lowered into *səl̓ilw̓ət*.	No outcomes achieved, probably due to poor site selection, as site may be too deep and turbid for the bull kelp to survive.	No
Ocean Wise Canada with the Tsleil-Waututh First Nation	Burrard Inlet *(səl̓ilw̓ət)*	2024	Sugar kelp was grown on both pebbles/cobbles and oyster shells. In February 2024, kelp was outplanted into False Creek and transplanted in Burrard Inlet in early May 2024.	Growth and health of outplanted kelp exceeded expectations despite the date of outplanting (February) being later than the recommended December.	Not reported
Tla'amin Nation, shishalh Nation, BCCF, and Vital Kelp	OkeoverInlet, Quathet-Regional District	2024-2025	Locally produced kelp seeded on gravel, tiles, and twine were grown at a shellfish culture site. Young kelp were detached from the substrates and transferred to large cobble stones and attached with natural rubber bands in early April, 2025.	Pending	Not applicable

HERBIVORE MANAGEMENT

Grazing by herbivorous invertebrates impacts kelp extent (Chapter four; Ennis, 2024; Borden, 2018) and is a major constraint on restoration. Often linked to trophic imbalance from the loss of predators (e.g., rockfish, lingcod, sea otters, sunflower stars) (Chapter five; PSRF, 2024), high grazing pressure, has led to repeated restoration failures and in some cases, site abandonment or avoidance like at Denman Island, Thetis Island, and various locations in Puget Sound (Heath et al. 2015b; Heath et al., 2022; A. Eriksson, personal communication, February 11, 2025; A. Lamb, personal communication, February 11, 2025). The most common agent of over-grazing of outplanted and wild bull kelp in the Northern Salish Sea is sea urchins, including green (*Strongylocentrotus droebachiensis*) and red (*Mesocentrotus franciscanus*), with purple sea urchins (*S. purpuratus*) on the outer coasts (Heath et al., 2022; Lamb et al., 2011). Damage has also been reported from northern kelp crabs (*Pugettia productus*), especially in Puget Sound (Hayford, 2025), gastropod snails such as *Lacuna vincta* (Carney et al., 2005; J. Clarke, Cascadia Seaweeds, personal communication, March 18, 2025), and caprellids.

Several mitigation approaches have been trialled to reduce sea urchin grazing. Exclosure devices, including cages and fencing (e.g., Table 6.5; Figure 6.12), have proven effective at excluding urchins while allowing kelp to establish (Heath et al., 2017; Schuster, 2025). For example, a Vexar™ fence deployed at a site near Denman Island successfully prevented urchins from accessing restoration plots (Schuster, 2025). Urchin culling has also been used to reduce grazing pressure. However, both approaches have limitations: culling often requires repeated effort, as populations can recover within a year or more (Parks Canada, n.d.), while the logistics of deploying and maintaining exclosures at larger spatial scales are not considered feasible for most restoration efforts (Schuster, 2025). It has also been suggested that outplanting in late winter may reduce grazing as alternative food sources are available (B. Timmer, KRI, personal communication, February 25, 2025).

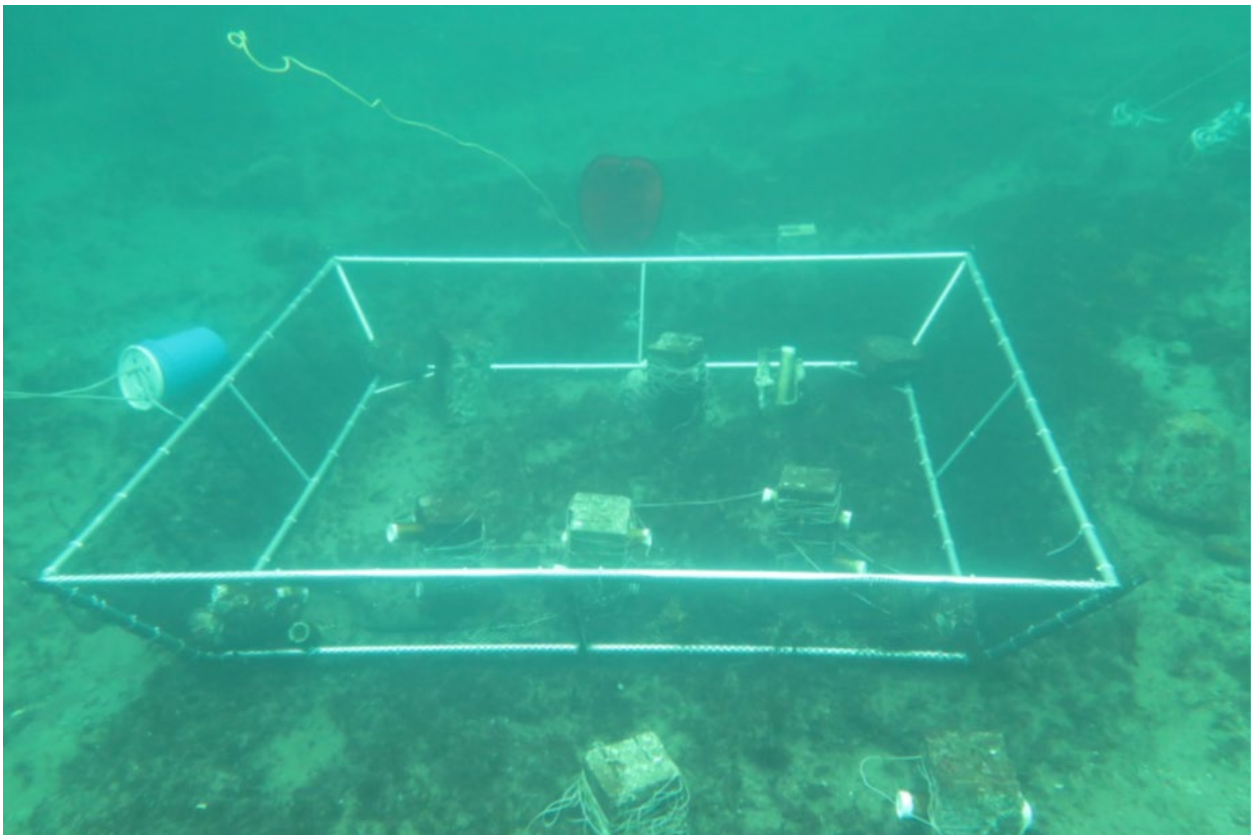


Figure 6.12 Sea urchin "exclosure" device deployed on the sea bottom at Maude Reef, Hornby Island (2017–2021) (Heath et al., 2020).

Table 6.5 List of grazer exclusion trials that have been conducted in BC and WA. CVPWS = Comox Valley Project Watershed Society. SIMRES = Saturna Island Marine Research and Education Society. KRI = Kelp Rescue Initiative. UVic = University of Victoria. BMSC = Bamfield Marine Sciences Centre.

Group	Location	Date	Method	Results
CVPWS	Maude Reef, Hornby Island	2019-2022	Urchin fence	Successfully reduced urchin grazing
The Haida Nation, Federal Government, Pacific Urchin Harvesters Association	Haida Gwaii	2019-2022	Urchin culling	Kelp cover increased following cull
Checko, R.F, and SIMRES	Saturna Island	2023	Urchin fence	Successfully reduced urchin grazing
KRI, UVic, BMSC, and Hornby Island Diving	Denman Island	2024	Urchin fence	Effective at preventing grazing, may be too costly to scale and implement continuously
KRI, UVic, BMSC	Barkley Sound	2024	Urchin cages	Ineffective



Credit: Nicole Christiansen

SITE RECLAMATION/REHABILITATION

Construction of artificial reefs to encourage kelp recruitment, restore habitat, and attract fish and invertebrates has been undertaken in Burrard Inlet, Roberts Bank, Esquimalt Harbour, and Puget Sound (Table 6.6). Across projects, outcomes varied but generally show kelp and associated communities can establish on artificial reef structures, with success strongly influenced by depth, substrate, and location, and full recovery often requiring multi-year monitoring.

Table 6.6 Artificial reef construction and habitat remediation projects that have been conducted for kelp conservation in BC and WA.

Project / Lead	Location & Year	Description
Archipelago Marine Research Ltd. for DND	Esquimalt Harbour (2017)	Sugar kelp transplant and outplanting as part of sediment remediation (Archipelago, 2021a).
Archipelago Marine Research Ltd. & SNC Lavalin for DND	Esquimalt Harbour (2012)	Construction of ~3 artificial rocky reefs (~11,000 m^2 each); colonization within one year by kelp, algae, invertebrates, and fish (Archipelago, 2021b).
Ausenco	Burrard Inlet (2021)	Sugar and bull kelp outplanting during terminal expansion (Ausenco, 2025).
Delta Port Metro Vancouver	Deltaport Third Berth (2008–2009)	Subtidal reef construction leading to moderate–abundant algal colonization and increased faunal diversity, though lower than reference sites (Fehr et al. 2012; Park et al. 2018).
Vancouver Port Authority	Roberts Bank (1983–2000)	Multi-phase subtidal reef construction; early deep reefs had limited macroalgae, while later reefs supported diverse invertebrates, fish, and kelps (Nereocystis, Saccharina) (Williams and Millar, 2006).
Pacific Shellfish Institute	Puget Sound (1990; monitored 1991–1994)	Artificial reef construction supporting kelp (*Nereocystis, Laminaria, Sargassum*) colonization across sites, increasing with suitable substrate and over time (Cheney et al., 1994).

BIODIVERSITY OBSERVED AT BULL KELP RESTORATION SITES

Fish and invertebrate observations indicate that restored bull kelp can rapidly provide functional habitat. Salmon, Pacific herring (Figure 6.13) and other forage fish, resident fish species such as shiner perch, rockfish, and invertebrates such as crabs and caprellid amphipods have been frequently observed in and around restored kelp (Ennis, 2024; Heath et al., 2017; Tomlin et al., 2020). Tube-snout eggs have also been observed on restored bull kelp (Ennis, 2024). Diver surveys from REEF.org at the Maude Reef kelp restoration site in Lambert Channel (2019–2021) recorded 75 species within the kelp forest and 67 species adjacent to it (Heath et al., 2022), reinforcing kelp beds as important refuge and foraging habitat for fish and invertebrate species in the Salish Sea. Underwater video and automated image analysis have been proposed to improve biodiversity monitoring at restoration sites (Bates, 2025).



Figure 6.13 School of herring above culture lines at Maude Reef restoration site in Lambert Channel on July 24, 2020 (Heath et al., 2022).

MEASURING SUCCESS

A key component in any kelp restoration project is to have useful methods for measuring success. These often include documenting restored kelp growing to the water's surface, successful sorus production (Figure 6.14), and the appearance of a second generation of new recruits produced from the restored kelp, perhaps the greatest indication of success possible. These metrics of success can be used to compare the efficacy of different restoration methods. Across restoration trials in BC and the Salish Sea (up to Feb 2025), transplanted kelp have shown the most consistent surface growth and sorus production (Figure 6.13), though densities have been relatively low. Under suitable conditions (site selection, timing, environmental conditions), bull kelp can grow from benthic to surface stage in under three months and reach maturity with sori by May (Heath et al., 2015b). Success is constrained by temperature, as spore viability declines above 17 °C (Korabik et al., 2023; Muth et al., 2019; Schiltroth et al., 2018; Weigel et al., 2023), and sustained periods of greater than 18 °C (30 days or more) can cause blade loss and premature sori senescence (Heath et al., 2022; H. Hayford, PSRF, personal communication, March 25, 2025).

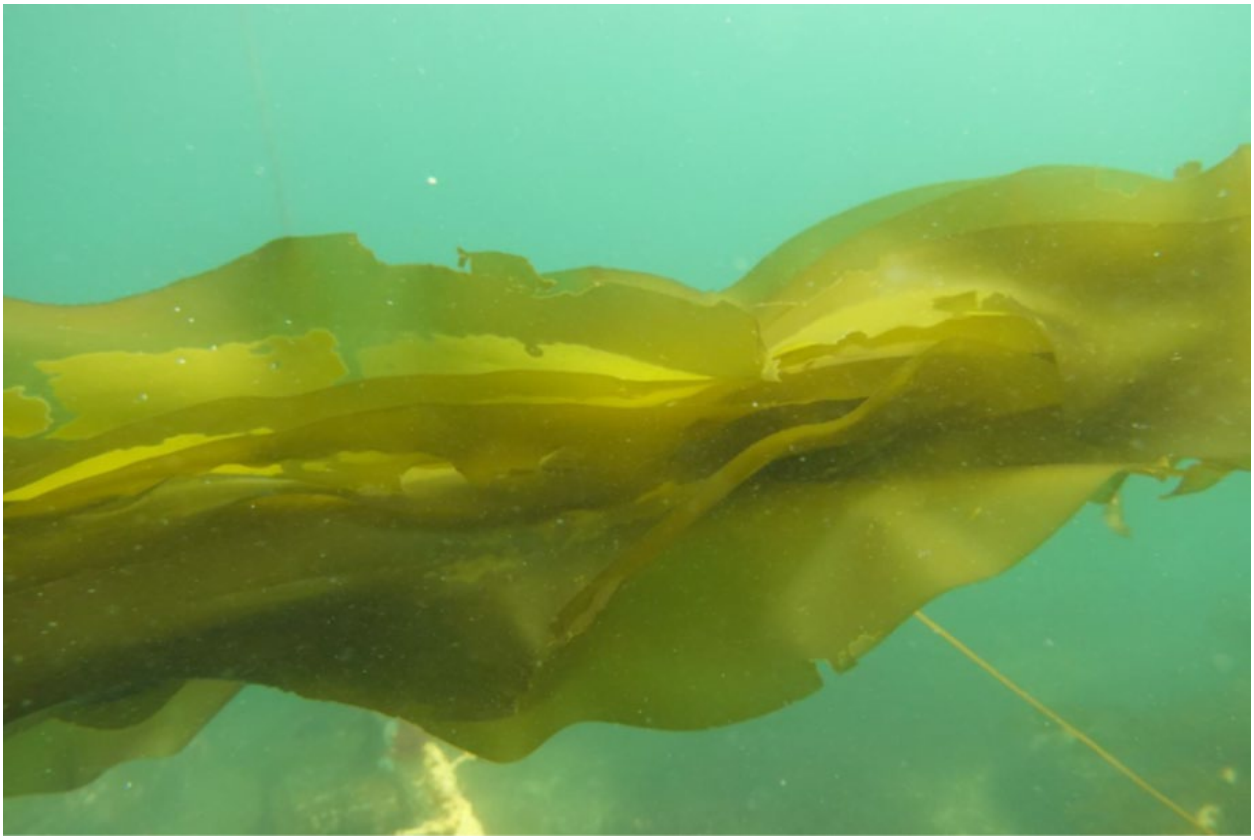


Figure 6.14 Sori (reproductive patches) on bull kelp blades at Maude Reef site on May 5, 2020 (Image from Heath et al., 2022).

Self-replenishing recruitment where sporophytes are derived from spores released from the previous generation has only been documented in two longer-term seeded line trials (Figure 6.14). The Maude Reef project reported up to six recruits in 2021, a year when very few green sea urchins were seen at the site (Heath et al., 2017, 2022), while a project at Doe Kag Wats/Jefferson Head in central Puget Sound recorded 33 recruits in 2024, with at least one growing to maturity (Hayford, 2025). Recruitment success can be attributed to the increase in the number of outplanted lines in 2023 and a longer growing season that year, which may have resulted in the release of a greater number of zoospores and more favourable conditions. A repeat of the recruitment success seen at Doe Kag Wats/Jefferson Head in the spring of 2024 was not expected in 2025 due to the arrival of a marine heatwave in July 2024 and senescence of bull kelp in Puget Sound earlier than normal (July, Aug) (H. Hayford, PSRF, personal communication, March 25, 2025). These and other results may indicate that seeded lines may prove to be the most effective kelp restoration method for use on bull kelp in BC and WA (Figure 6.15).

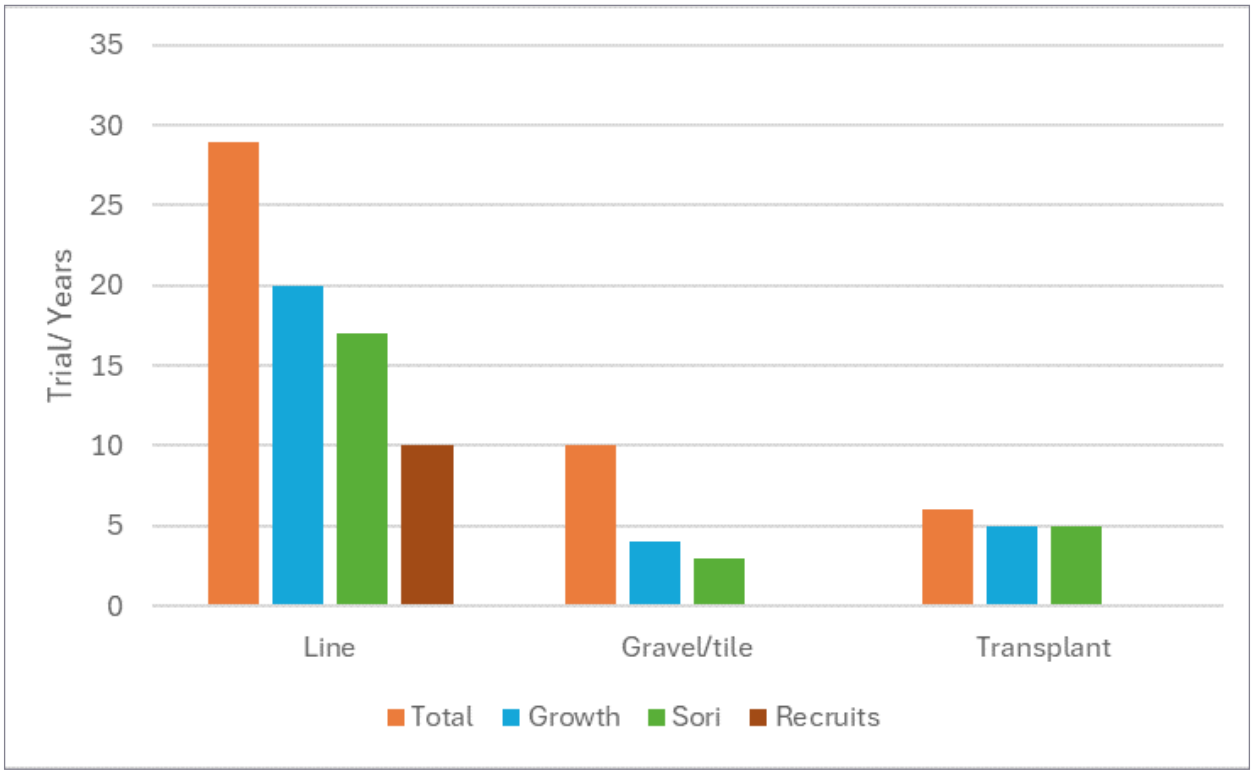


Figure 6.15 Comparing the three most common methods used in kelp restoration trials in the Salish Sea, Barkley Sound, Haida Gwaii, and Prince Rupert by total number of trials reporting results by year, the number of trials that reported growth to the surface, development of sori, and appearance of kelp recruits.

LESSONS LEARNED

- ☑ Use a place-based, climate-informed design when planning kelp forest restoration. Integrate Indigenous and local knowledge to assess site change, tailor methods, and monitor temperature; consider utilizing climate-resilient kelp strains where conditions have shifted.
- ☑ Substrate and deployment methods matter in kelp restoration. When utilizing the green gravel method, use clean/sun-bleached, larger than a fist-sized cobble; boat deployment can incur high losses in high-flow or complex habitats, ensure this technique is suitable for the site.
- ☑ Spread outplanting across multiple sites to buffer variability; evaluate success by recruitment given scaling constraints.
- ☑ Herbivory control is critical: sea urchin densities ≥ ~2 m^{-2} can suppress kelp growth and restrict restoration success. Combine exclusion and culling as needed, though consider the trade-offs inherent in each method.
- ☑ Habitat enhancement and construction of artificial reefs support establishment. Sugar kelp, (Saccharina latissima) may persist where bull kelp fails under warming (Heath et al., 2022; Hayford, 2025).
- ☑ The seeded line method of kelp restoration has shown a higher rate of success than either green gravel or transplantation as of time of writing.



Credit: Mitch Miller

CHAPTER SEVEN
CONSERVATION AND PROTECTION OF KELP FORESTS

INTRODUCTION

With all the challenges that kelp forests face, their future in the Salish Sea and BC depends on effective protection, management, and restoration (Figure 7.1) (Arafeh-Dalmau et al., 2024; Hollarsmith et al., 2022). While the federal government of Canada has made commitments to preserve and restore marine ecosystems and protect its biological diversity, there are gaps in the protection of kelp (Valckenaere et al., 2023). This chapter examines why that is, from the lack of protected status to the jurisdictional landscape, as well as the existing policies and area-based conservation measures that are levers to indirectly protect kelp. At the same time, many proactive organizations and networks are leveraging knowledge-to-action frameworks to advocate for urgent, large-scale planning, protection, and management of kelp forests in the northeastern Pacific region.

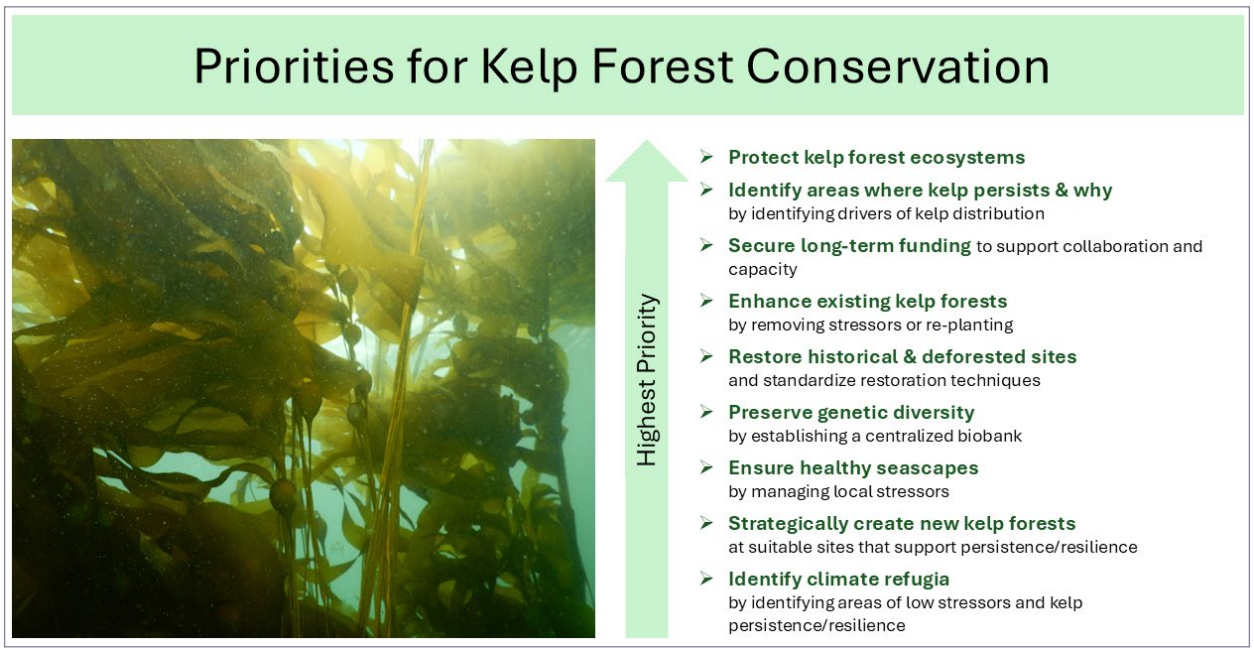


Figure 7.1 Kelp forests in BC are under threat, and protection should be the highest priority. Experts and practitioners identified several priorities during the PSF Kelp Symposium held in Victoria in February 2025 (Coleman, 2025; photo courtesy of C. Good).

CANADA'S COMMITMENT TO MARINE PROTECTION

Canada was the first industrialized country to ratify the landmark international treaty, the *UN 1992 Convention on Biological Diversity (CBD)*. The *Ocean's Act* (1996, amended 2026) is the foundational legal framework for protecting all areas of ocean under its jurisdiction, ensuring peaceful and equitable use of the ocean and its resources, and taking all measures necessary to prevent marine environmental pollution, especially of rare or fragile ecosystems (Hewson et al., 2023). It tasks Fisheries and Oceans Canada (DFO), Parks Canada Agency (PCA), and Environment and Climate Change Canada (ECCC) to collaboratively create a network of MPAs, which includes other area-based conservation. The *Oceans Protection Plan* (Transport Canada), supports projects that conserve and restore marine ecosystems, including kelp forests through DFO's *Aquatic Ecosystems Restoration Fund (2017)*. More recently, in 2022, Canada adopted the *Kunming-Montreal Biodiversity Framework (KMGBF)* along with 195 other countries. KMGBF is implemented through *Canada's 2030 Nature Strategy*, which sets 23 actionable national targets to protect and restore 30 per cent of the country's land and waters by 2030 (30 x 30). It aims to halt biodiversity loss, promote ecosystem restoration, ensure sustainable use of natural resources, and enhance the equitable sharing of benefits, while respecting the rights and title of First Nations. To this effect, First Nations-led conservation has been empowered by the most comprehensive statement of the rights of Indigenous Peoples in international law, the *United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP, 2007)*, which Canada implemented in 2016, and BC enacted through the *Declaration on the Rights of Indigenous Peoples Act (BC-DRIPA)* in 2019. Through the establishment of Indigenous Protected and Conserved Areas (IPCAs) and Guardian programs, First Nations, are reasserting their participation and authority through their traditional knowledge systems to restore (Figure 7.2) and steward the lands and waters. However, IPCAs are not yet recognized by Crown legislation in Canada.



Figure 7.2 Canopy-forming bull kelp forests in the Burrard Inlet, near the highly urbanized City of Vancouver, BC. The Tsleil-Waututh First Nation (TWN) are conducting kelp restoration here, in their unceded traditional territory (photo courtesy of C. Good and TWN).

EXPLORING GAPS IN PROTECTION – THE PROBLEM OF LEGAL STATUS

Currently, kelp forests lack dedicated legal protection under the federal Species at Risk Act (SARA). SARA provides species-specific protection in Canada and establishes Schedule 1, an official list that classifies species as being either extirpated, endangered, threatened, or of special concern. Once listed, measures are taken to protect listed species from being killed, harmed, harassed, and captured. Who carries out this protection? Listed aquatic species are protected, wherever they are found, by the *Fisheries Act* under the legislative authority of Fisheries and Oceans Canada (DFO). Some examples of protected aquatic species at risk in BC include the blue whale (endangered), killer whales (endangered), northern abalone (endangered), Olympia oyster (special concern), sea otter (special concern), stellar sea lion (special concern), rougheye rockfish (special concern), and yelloweye rockfish (special concern). In addition, species that are "significant to maintaining ecosystem structure and function" can be designated as Ecologically Significant Species (ESS), which provides enhanced protection measures. Eelgrass, for example, is an ESS in eastern Canada but not in BC (Eriksson & Clowater-Eriksson, 2026).

The loss of structurally complex critical habitats, such as kelp forests, drives species decline (Hogue & Breon, 2022). Through legal rulings, SARA requires that habitat "necessary for the survival or recovery of a listed species, and that is identified as the species' critical habitat", be identified to the extent possible and protected for all SARA listed species. Critical habitat can include aquatic or riparian components, spawning, rearing, feeding, and migration grounds. Critical habitat protection occurs through a Critical Habitat Order, which invokes prohibition against destruction of critical habitat. Note that while SARA prohibits the destruction of a critical habitat caused by human activities, it does not prohibit those activities (e.g., fishing, vessel traffic) within them.

While kelp forests support communities of species that are SARA listed (e.g., northern abalone, rockfish, and sea otters), they themselves are not listed as species at risk under SARA or as ESS, nor as critical habitat. This is also the case for eelgrass (*Zostera marina*), which similarly lacks legal status and protection in BC, despite high ecosystem value (Eriksson & Clowater-Eriksson, 2026). This is a policy 'blind spot', and this reactive, species-by-species approach misses the holistic interactions within an ecosystem, creating gaps in effective protection. A World Wildlife Fund-Canada assessment found that 84 per cent of habitats with high concentrations of at-risk species were either inadequately protected or not protected (as discussed in Daviet & Rachel, 2021). Also, while SARA uses strong language, implementation can be complicated by jurisdiction overlap. SARA applies to areas under federal jurisdiction, and for non-federal (provincial, municipal or private) areas, it is up to those jurisdictions to "effectively protect" critical habitat. For SARA to be effective, laws against critical habitat destruction need to be upheld, and cooperation needs to occur across all levels of government (Daviet & Rachel, 2021).

REGULATORY FRAMEWORK — THE PROBLEM OF OVERLAPPING JURISDICTIONS

The regulatory framework and lack of streamlined intergovernmental processes create jurisdictional gaps, which makes kelp conservation management and protection very challenging in BC. The regulatory framework is shared across four levels of government — Indigenous, federal, provincial, and local — in part, due to overlapping jurisdictions (Hewson et al., 2023; Martone et al., 2025). Federal jurisdiction typically includes the seabed from the low-water line to the seabed beyond 12 nautical miles (nm)/ 22.2 km), and extending out to 200 nm offshore, or the limit of Canada's Economic Exclusion Zone, as outlined in the *Ocean's Act (1996)* and the *United Nations Convention on the Law of the Sea* (UNCLOS; 1982). This is the case in other Canadian provinces and territories with a coastline, but BC is an exception (Hewson et al., 2023). In BC, provincial jurisdiction includes the seabed from the foreshore to the low-water line, and the seabed of the territorial sea out to 12 nm (22.2 km) from shore. This includes inland seaways between the mainland and Vancouver Island (i.e., the Salish Sea) "within the jaws of the land" (Hewson et al., 2023). Each jurisdiction takes responsibility over different activities and interests of BC's nearshore waters and species (Table 7.1; Figure 7.3; Hewson et al., 2023). This legacy goes back to the *Constitution Act* of 1876, which divided legislative powers over offshore-nearshore waters and resources between the federal and provincial governments, and historically, ignored the rights and titles of Indigenous Peoples (Hewson et al., 2023).

Overlapping jurisdictions become problematic when there is confusion about who is responsible for a particular marine decision, leading to delays and often inaction (Hewson et al., 2023). Also, governance tends to be siloed among jurisdictions (Atlas et al., 2020). Conservation and restoration work then often falls on the shoulders of non-profits, concerned citizens, and First Nations (e.g., clean-up of marine debris, abandoned boats, and fishing gear). Today, federal and provincial processes for marine planning and regulation are evolving and moving forward through commitments to Indigenous engagement and governance-related initiatives. A thorough review of marine conservation law, and the roles of different jurisdictions in BC can be found in Hewson et al. (2023).



Credit: Nicole Christiansen

Table 7.1 Five levels of government and their responsibilities and interests in relation to conservation and stewardship of aquatic, marine species and ecosystems. Note, that this is an open-ended list. (expanded from Hewson et al., 2023).

International	Indigenous	Federal	Provincial	Local
▸ United Nations Convention on the Law of the Sea (UNCLOS) ▸ Convention on Biological Diversity (CBD) ▸ International Convention for the Safety of Life at Sea (SOLAS) ▸ International Convention for the Prevention of Marine Pollution (MARPOL) ▸ United Nations Declaration on the Rights of Indigenous Peoples (UNDRIP) ▸ Pacific Salmon Treaty	▸ Aboriginal & treaty rights and responsibilities ▸ Coastal Guardian Watchmen & stewardship programs ▸ Research & monitoring ▸ Community planning ▸ Protected Areas, including Indigenous Protected & Conserved Areas (IPCAs) ▸ Community management of harvesting for food, social & ceremonies ▸ Oil spill response ▸ Restoration of marine habitats	▸ Fishing & fish habitat (DFO) ▸ Finfish & shellfish aquaculture ▸ Species at risk ▸ Shipping & navigation ▸ Oil spill response ▸ Search & rescue ▸ Migratory birds ▸ Environmental assessments ▸ Protected areas ▸ National defense ▸ Fisheries Act ▸ Ocean's Act ▸ Shipping Act ▸ Navigation Protection Act ▸ Salish Sea Strategy (part of the Oceans Protection Plan, OPP)	▸ Tenures over seabed & foreshore (i.e., aquaculture, including kelp) ▸ Tourism & recreation licensing ▸ Seafood safety ▸ Marine spatial planning ▸ Protected areas ▸ Aquatic plants ▸ Flood management ▸ Environmental emergency management (i.e., oil spill response) ▸ Waste management ▸ Heritage & cultural protection ▸ Cumulative effects management ▸ BC Declaration on the Rights of Indigenous Peoples Act ▸ BC Coastal Marine Strategy ▸ Islands Trust Act ▸ Wildlife Act ▸ Park Act ▸ Oil and Gas Activities Act ▸ Ecological Reserves Act ▸ Land Act	▸ Zoning (shoreline development regulation) ▸ Bylaws (permitted use in water zones) ▸ Parks and trails ▸ Public outreach, education & training

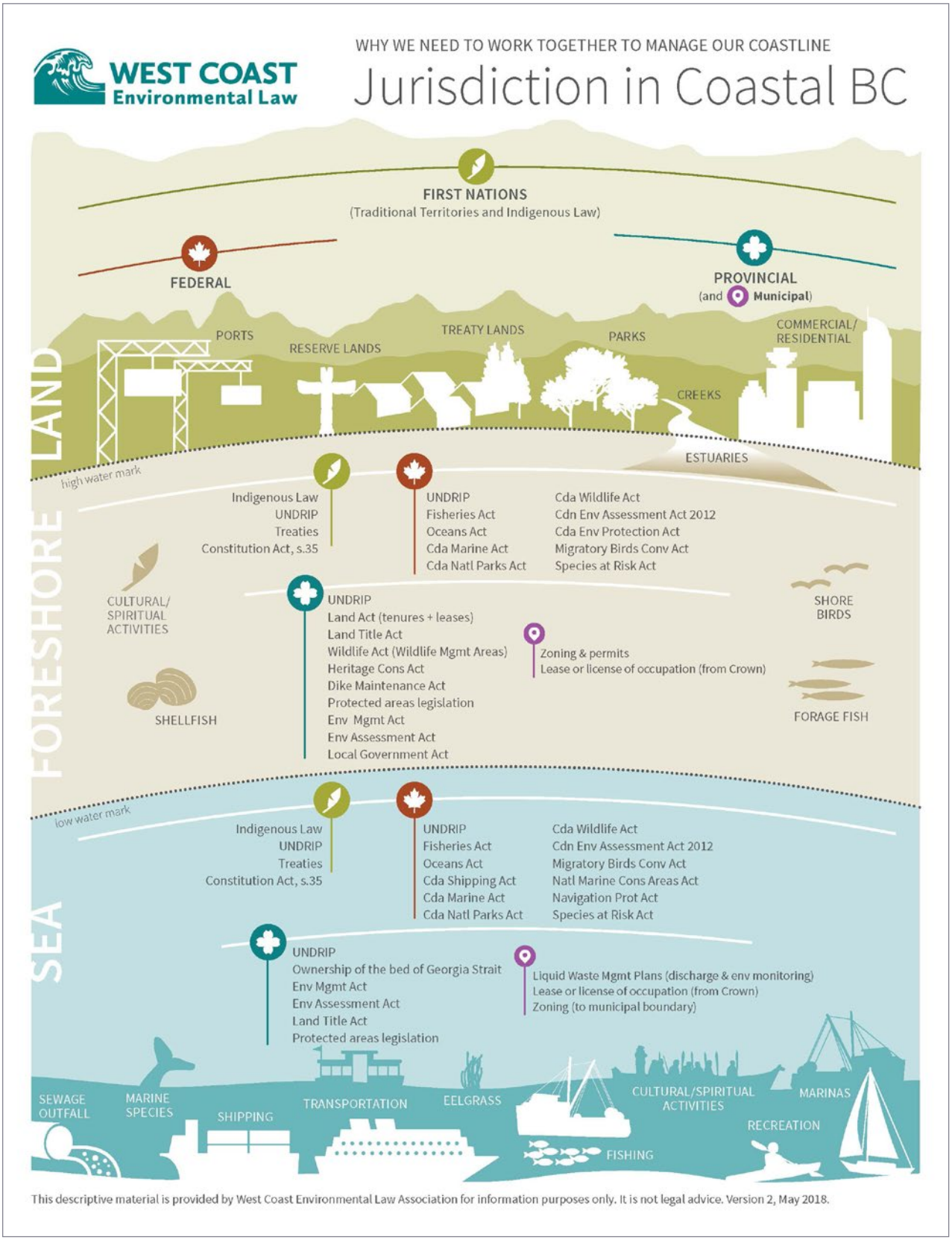


Figure 7.3 Overlapping jurisdictions – First Nation, federal, provincial, and municipal—and the regulatory framework for management of the terrestrial, foreshore and offshore areas in coastal BC (credit: West Coast Environmental Law Association, 2018).

SUMMARY OF POLICIES, REGULATIONS, AND INDIRECT PROTECTION

While kelp forests lack legal protection status, they have been identified as ecological conservation priorities in BC (Gale et al., 2018; Rubidge et al., 2024). As discussed in previous chapters, great efforts have been made in recent years to map, monitor, restore, and understand kelp resilience in the face of climate change. Currently, discussions have focused on leveraging kelp forests as an important climate mitigation solution for the establishment of MPA networks (Rubidge et al., 2024), with a strong need to verify their role in carbon drawdown and sequestration or blue carbon (McHenry et al., 2025). Currently, kelp forests may afford some indirect protection through existing government policies and regulations, and area-based conservation. Area-based conservation is the strategy of protecting species by managing and protecting the habitats where they live to restore ecological integrity, ecological processes, and sustainable use of resources. It involves establishing a legal framework to protect designated geographical areas such as MPAs, conservation areas, national parks and wilderness areas, and biosphere and biodiversity reserves (Hewson et al., 2023). Kelp forests may benefit from occurring within or near established conserved, managed and/or protected Marine Refuges, Indigenous Protected and Conserved Areas, or other effective area-based conservation measures (e.g., OECMs) (Table 7.2). Below, we focus on policies, regulations, and area-based conservation strategies that may provide some indirect protection for kelp forests in BC.

FEDERAL GOVERNMENT - FISHERIES AND OCEANS CANADA, PARKS CANADA, TRANSPORT CANADA

Fisheries and Oceans Canada (DFO) mandate the *Fisheries Act* and regulates environmental impacts on fisheries, and marine species at risk. It oversees conservation and protection of marine ecosystems and resources (Hewson et al., 2023). If a marine ecosystem needs protection, an MPA can be established under the *Oceans Act*, and mandated by DFO in consultation with provincial government, First Nations, and other stakeholders. Parks Canada also shares in the protection and recovery of listed species found in national parks, national marine conservation areas (NMCAs), and other historic and heritage areas (e.g., Gwaii Haanas National Park Reserve, National Marine Conservation Area Reserve and Haida Heritage Site; Table 7.2). Transport Canada mandates the *Shipping Act* and is responsible for shipping and navigation, and their related impacts on the marine environment (e.g., vessel anchorage, mooring, marine traffic, derelict vessels and vessel pollution). Kelps (as seaweed) are mentioned under the *Fisheries Act* (Section 44 Marine Plants), which regulates the commercial harvesting of aquatic 'marine plants' (including other seaweed or marine algal species). DFO and Transport Canada collaborate with First Nations and the BC Provincial Government on aquatic marine plant management, as discussed below.

In the Salish Sea of Washington State, dramatic loss of kelp and eelgrass has prompted legislation to create a statewide Kelp Forest and Eelgrass Meadow Health and Conservation Plan (2022).

The Fisheries Act

Kelp may receive indirect protection under the *Fisheries Act*. The *Fisheries Act* is a key piece of federal environmental legislation mandated by DFO, which provides protection for fish and fish habitats (Imhof et al., 2021). It prohibits the death of fish and the harmful alteration, disruption, or destruction (HADD) of fish habitat. Despite the implementation of the *Fisheries Act*, overlapping and competing jurisdictions across the different levels of government have led to regulatory gaps due to a lack of accountability or enforcement of regulations, which have resulted in environmental degradation (Ulaski et al., 2025). Ulaski et al. (2025, and references within) provide an assessment of the effectiveness of the *Fisheries Act*. However, codes of practice represent a tool for managing projects to avoid the death of fish and HADD (Imhof et al., 2021). DFO applies measures to mitigate risk, including the *Fish and Fish Habitat Protection Policy Statement* (2019), which encourages proponents to first avoid and mitigate impacts to fish habitat where possible, and where a HADD cannot be avoided, proponents are required to apply for a Fisheries Act Authorization prior to carrying out work. In addition, DFO's *Policy for Applying Measures to Offset Harmful Impacts to Fish and Fish Habitat* (2025) provides key guiding principles for developing offsetting measures. DFO can also identify ecologically significant areas (ESAs) that require enhanced protection by designating them through this regulation (Hewson et al., 2023). They are in the process of developing biodiversity protection regulations under the *Fisheries Act* (Hewson et al., 2023).

Marine protected areas

Marine protected areas (MPAs) are legally protected areas of the ocean as a conservation strategy used globally to address biodiversity decline (Gurney et al., 2023). While MPAs may allow for the recovery of species populations living in stable kelp forest ecosystems (Arafeh-Dalmau et al., 2025), they do not address the core drivers of kelp loss and degradation and have had limited success in protecting kelp against poor water quality, ocean warming, and MHWs (Filbee-Dexter et al., 2024). But their protections can help build resilience against human activity and climate impacts by increasing carbon-sequestering habitats and promoting genetic diversity (Arafeh-Dalmau et al., 2025; Rubidge et al., 2024).

MPAs and co-management

MPAs in BC have been co-developed and are being collaboratively managed by First Nations, the Province of British Columbia and the Government of Canada. The Endeavour Hydrothermal Vent MPA was redesignated as Tang.ɡwan – ḥačxwiqak – Tsiɡis (TḥT) MPA (2024), which means 'deep ocean' in the Haida language. It is located 150 km off the west coast of Vancouver Island and is the largest MPA in the Pacific region (the largest MPA in Canada is in the Arctic Ocean). A memorandum of understanding (MOU) was signed between Nuu-chah-nulth Tribal Council, Council of the Haida Nation, Pacheedaht First Nation, Quatsino First Nation, and the Government of Canada for the co-management and use of the TḥT MPA.

Approximately 10 per cent of Canada's coastal areas are protected by 16 Oceans Act MPAs, including three in the Pacific region. Those three MPAs were not designed with kelp or nearshore ecosystem connectivity in mind (Rubidge et al., 2024, and references cited within), but rather to protect and conserve unique open-ocean ecosystems and rare, endemic species of glass sponge and cold-water coral reefs, seamounts, and hydrothermal vent communities of the Pacific coast. Existing MPA frameworks, including the Great Bear Sea (Northern Shelf Bioregion) MPA Network, do set a strong precedent for planning future MPA networks in BC (Rubidge et al., 2024). Incorporating nearshore habitats like kelp forests and eelgrass meadows in future MPA planning will be vital for preserving ecological connectivity, protecting critical fish nurseries and migration corridors, and supporting sustainable fisheries management in BC.

MPAs are not the only area-based conservation tool, Parks Canada National Marine Conservation Area Reserves (NMCARs) and First Nations' Indigenous Protected and Conserved Areas are also area-based protections (IPCA; Table 7.2).

In parts of the world, kelp are well protected in MPAs, for example, in the Southern Ocean, 99.9 per cent of its kelp forests are within MPAs (11 per cent of the global distribution) (Arafeh-Dalmau et al., 2025). However, regions facing intensification of marine heatwaves (MHWs), have some of the lowest levels of effective protection of kelp forests, including the North American Fjordlands (2.5 per cent), Puget Sound Trough (0.09 per cent), and along the coast from Oregon to Vancouver (2.4 per cent) (Arafeh-Dalmau et al., 2025).

GOVERNMENT OF BC—MINISTRY OF WATER, LAND, AND RESOURCE STEWARDSHIP

As mentioned earlier, the Government of BC has jurisdiction over the foreshore to the low-water line and the seabed of the territorial sea, up to 12 nm (22.2 km) from shore, including inland waters—bays, fjords, inlets, and estuaries—so long as activities don't interfere with federally regulated activities, such as shipping and navigation. This gives BC legislative authority over several foreshore-related activities such as tenures for wharves and structures for aquaculture, finfish and shellfish aquaculture, aquatic plants (including kelp and other seaweed harvests), marinas, oil and gas development, and environmental emergency management, such as oil spills, with some exceptions e.g., Canada Port Authority lands that fall under the Canada Marine Act, such as the Port of Vancouver, public harbours, or national parks (Hewson et al., 2023). Kelp forests usually occur close to rocky shorelines in BC and therefore would fall under the jurisdiction of the province.

Aquatic Plant Program

The BC Provincial Ministry of Water, Land and Resource Stewardship (MWLRS) is the main provincial regulatory agency responsible for aquaculture management, while the Ministry of Agriculture and Food is responsible for fish, seafood, and seaweed processing. Permitting and licensing of aquatic plant licenses (as well as seafoods) for commercial harvesting and culturing of wild aquatic plants, and land tenures is managed by the MWLRS's Aquatic Plant Program under the Fish and Seafood Licensing Regulations of the BC Fish and Seafood Act (FSA), and the BC Land Act. The program regulates and licenses the culture and harvest of seaweed for food, research, herbal remedies, cosmetics, medical uses, and use as fertilizer for gardens. Its primary focus is on ensuring that aquatic plants are safe for consumption (Martone et al., 2025). Applications for seaweed aquaculture or co-culture are processed through a harmonized review process by federal (DFO and Transport Canada) and BC Provincial (MWLRS), in consultation with First Nations (Martone et al., 2025). A more thorough review of the legislation and regulations guiding seaweed aquaculture can be found in Martone et al. (2025) and Gregr et al. (2026).

Growing interest in kelp culture

Interest in kelp and seaweed harvesting and mariculture in BC is increasing. While this industry has been long established in Asia, it is still in its early stages in BC. Currently, commercial wild kelp harvesting and farming operations are small-scale, with low production, and are either First Nation-led or occur in collaboration with First Nations (e.g., NAAS Foods and Cascadia Seaweed). The lack of legislation and a fragmented regulatory framework, creates some uncertainty, and there are concerns about ecological risks (Gregr et al., 2026; Martone et al., 2025).

The cool temperate waters of the BC coast support over 600 seaweed species, and over a quarter of the world's known kelp species (Druehl, 1970; Druehl & Clarkston, 2016). The main species commercially cultivated here include sugar kelp (*Saccharina latissima*), winged-kelp (*Alaria marginata*) and giant kelp (*Macrocystis pyrifera*) (Martone et al., 2025). These three species are being wild-harvested by hand and/or cultivated in the ocean on anchored long-lines by small commercial initiatives that include First Nations' communities. The largest grower/harvester in BC is Cascadia Seaweed (and Acadian Seaplants on the Atlantic coast), which operates under a commercial license issued (in 2022) by the Tsawout First Nation of the Salish Sea region. They are also partnered with other First Nation groups and Tribes. They have cultivated a total of 65 hectares across nine farms, and as of 2025, hold 120 ha of tenured space comprised of 30 ha in cultivated area (Martone et al., 2025). The Kwakiutl First Nation, as another example, has been carrying out commercial wild harvest of kelp in their territory from the northern tip of Vancouver Island, into Knight Inlet and down Johnston Strait. They have been hand-harvesting giant kelp in their territory for ~28 years (Allchurch, 2023).

Coastal Marine Strategy

The forthcoming BC Coastal Marine Strategy (2024) is the first BC province-wide coastal marine policy co-developed with several First Nations, and input from federal and local governments, stakeholders, and the public. It aims to address the health and stewardship of marine ecosystems and resources and promises wider protection for species and habitats of importance to the Salish Sea. As part of its goals and actions, the strategy proposes to scale up monitoring of coastal habitats that are critical for maintaining biodiversity, including kelp beds, and to use this information to guide management decisions and planning initiatives. It also supports the mapping, conservation, and restoration of carbon-sequestering coastal ecosystems like eelgrass meadows, kelp forests, and salt marshes. This includes assessment of the rates of habitat loss and the development of a coast-wide aquatic plant research and monitoring network. This intersectional plan proposes to provide better coastal protection by taking a more proactive approach. It will be important as the seaweed mariculture industry advances in BC.

LOCAL GOVERNMENT

Municipal government boundaries can extend seaward beyond the normal high-water mark, allowing local government decision-making authority over coastal and marine protections and shoreline development through their land use planning authority, so long as it doesn't interfere with federal and provincial regulations and responsibilities (Hewson et al., 2023). Local governments can apply authority delegated from the provincial government through the *Local Governments Act*, the *Community Charter*, and the *Islands Trust Act* (Hewson et al., 2023). Therefore, they can enact land and water zoning for conservation purposes by creating restrictive Development Permit Areas (DPAs), and promoting long-term planning and policies, including protection of ecosystems through Official Community Plans and bylaws.

Islands Trust

The unique environments of the Salish Sea have been entitled to protective legislation by the Government of British Columbia under the *Islands Trust Act* since 1974. This is in cooperation with the municipalities, regional districts, the Government of BC, and Indigenous governments. The draft Islands Trust Policy Statement (2025) proposes directive policies for marine shorelines and nearshore areas, specifically to "identify and prioritize the preservation, protection, and restoration of eelgrass meadows, kelp forests, forage fish spawning areas, clam beds, estuaries, tidal marshes, mud flats, and coastal wetlands". Islands Trust provides mapped inventory of bull kelp, eelgrass, forage fish spawning, and sensitive ecosystems. The 26-member Islands Trust Council also aims to advance reconciliation through the *United Nations Declaration on the Rights of Indigenous Peoples Articles*, the *Truth and Reconciliation Commission Calls to Action*, the *Islands Trust First Nations Engagement Policy,* and *BC-Declaration on the Rights of Indigenous Peoples Act*, thereby actively involving First Nations in regional conservation and stewardship.

FIRST NATIONS' GOVERNANCE

First Nation groups have sovereignty over their territories, which includes the foreshore to offshore marine environment within Canada's EEZ. In BC and Canada, there is a movement towards Indigenous Peoples' rights to control their own lands, waters, and resources, or at least be meaningfully consulted about their use, and be provided an opportunity to participate in co-management (Dick et al., 2022). There is acknowledgement that post-colonial management approaches have been ineffective, and at times harmful to Indigenous People, and should be abandoned (Ban & Frid, 2018). This has led to Indigenous communities' revitalization of traditional fishing practices and systems of ecosystem management, including active stewardship of their coastal territories and waters. The BC Provincial Government enacted the BC *Declaration on the Rights of Indigenous Peoples Act* (BC-DRIPA) in 2019, as an act of Truth and Reconciliation. Its Action Plan identifies steps the province will take in consultation and cooperation with Indigenous Peoples (until 2027). The forthcoming BC Coastal Marine Strategy states that both the federal and provincial governments must consult with First Nations in areas deemed Crown Lands, which includes marine coastal environments. The federal government recognizes Indigenous jurisdiction in its *Principles Respecting the Government of Canada's Relationship with Indigenous Peoples*, including the right to self-determination and the inherent right to self-government, and the Province of BC followed suit in its *Draft Principles That Guide the Province of British Columbia's Relationship with Indigenous Peoples* (Hewson et al., 2023). Indigenous nations may declare Indigenous Protected and Conserved Areas (IPCAs) pursuant to their own laws and jurisdiction (Hewson et al., 2023). As discussed earlier, aside from IPCAs, MPAs in BC have been co-developed and are being collaboratively managed by First Nations, the province, and federal governments.

Indigenous-led area-based conservation

Indigenous Protected and Conserved Areas (IPCAs) uphold Indigenous title and land rights, while also monitoring, enhancing, and protecting biodiversity, and maintaining cultural values. IPCAs may differ in their governance, management styles, and goals as they are governed by Indigenous groups with differing laws, customs, and traditional knowledge. IPCAs often overlap with other area-based conservation areas. There are two main IPCAs in coastal BC (Table 7.2). The Tla-o-qui-aht Tribal Parks (www.tribalparks.com) were declared in 1984 to prevent clear-cutting of old growth temperate rainforests in Clayoquot Sound on the west coast of Vancouver Island; and the QEN'T Marine Protected Area was declared in 2023, by the Coast Salish Tsawaout First Nation in their territory. It encompasses an area of 155 km^2 of the Salish Sea, located 20 km north of Victoria on Vancouver Island (Saanich Peninsula). QEN'T, pronounced "qwant", refers to "caring for". The Tsawaout First Nation relies heavily on these nearshore waters for its food sources, and nearshore habitats are areas with kelp presence. Currently, Federal and Provincial governments lack the legal framework to formally recognize IPCAs, though they are supported through governmental and non-governmental funding sources e.g., Indigenous-Led Area-Based Conservation. IPCAs are an important step towards achieving Canada's 30 x 30.

Table 7.2 Examples of area-based conservation management and protection strategies in British Columbia (BC) and the Salish Sea (SS), across the different levels of government (Hewson et al., 2023). Note: DFO = Fisheries and Oceans Canada; CWS = Canada Wildlife Service; ECCC = Environment and Climate Change Canada; BC Parks = BC Ministry of Environment and Parks; BC-WLR = BC Ministry of Water, Land and Resource Stewardship.

Designation	Legal framework & authority	Purpose	Strengths	Weaknesses	Designated & example(s) of protected areas
INDIGENOUS					
Indigenous Protected and Conserved Area (IPCA) or tribal park	First Nations	"Lands and waters where Indigenous governments have the primary role in protecting and conserving ecosystems through Indigenous laws, governance and knowledge systems. Culture and language are the heart and soul of an IPCA."	▸ Long-term ▸ Indigenous-led ▸ Expression of Indigenous title ▸ Provides local oversight, increased "eyes-on-the-ground" ▸ Strong habitat protection ▸ Contributes to biodiversity conservation goals ▸ Funded through federal Nature Fund (2019)	▸ Lacks legal framework to guide federal and provincial governments to appropriately recognize IPCAs or share decision-making in a manner that upholds inherent Indigenous governance.	BC:14; SS:1 ▸ Tla-o-qui-aht Tribal Parks (1984), Clayoquot Sound ▸ QEN'T Marine Protected Area (2023), Salish Sea ▸ Mia-yaltwa Ha'lidzogm hoon (Central Coast of BC)



Credit: Liam Coleman

Designation	Legal framework & authority	Purpose	Strengths	Weaknesses	Designated & example(s) of protected areas
FEDERAL					
Marine Protected Area (MPA)	*Oceans Act* DFO	Designated to protect/maintain: ▸ Fish, marine mammals, and their habitats ▸ Endangered or threatened species and unique habitats ▸ Areas of high biodiversity or productivity ▸ Marine areas for the purpose of maintaining ecological integrity	▸ Long-term ▸ Safeguards biodiversity ▸ Protect species at risk ▸ Nature-based climate solution ▸ Allows recovery of fish stocks ▸ Increases commercial or recreational catches ▸ Support healthy coastal communities ▸ Opportunity for co-governance	▸ Regulates fisheries ▸ Require better/higher quality protection and management (e.g., via Indigenous co-management) ▸ Currently limited protection of species and habitats	BC:3; SS:0 ▸ SGaan K̲inghlas—Bowie Seamount MPA (2008) ▸ Hecate Strait and Queen Charlotte Sound Glass Sponge Reefs MPA (2017) ▸ Tang.ɢwan — ḥačxwiqak — Tsig̲is (TḥT) MPA (redesignated in 2024)
Rockfish Conservation Area (RCA)	*Fisheries Act* DFO	Establishes a marine refuge to allow long-lived rockfish stocks (up to 35 species) to rebuild in their natural home in rocky reefs	▸ Network of 164 RCAs (86 in Salish Sea) ▸ Prohibits fishing and bycatch ▸ Easily implemented ▸ May indirectly protect kelp forests also found in the rocky reef habitats of rockfish	▸ Not strictly regulated; not closed to all commercial fisheries ▸ Species (stock)-specific ▸ Not intended to enhance overall biodiversity nor do they have specific protections for habitat ▸ Lacks effective monitoring ▸ Research shows their ineffectiveness	BC:164; SS:86 ▸ Map of Pacific Fishery Management Areas

Designation	Legal framework & authority	Purpose	Strengths	Weaknesses	Designated & example(s) of protected areas
FEDERAL					
National Marine Conservation Areas (NMCAs)	*Canada National Marine Conservation Areas Act* Parks Canada	To benefit present and future generations, and to ensure the protection of the ecosystems within them. Subject to a claim of Indigenous title that has been recognized by the federal government and accepted for negotiation, but has not yet been settled.	▸ Strong baseline protections and prohibitions of water column and seabed e.g., exploration or exploitation of hydrocarbons, minerals, aggregates, or any other inorganic matter; disposal of any substances ▸ Intended to be managed in a particular way to ensure sustainability and intergenerational equity	▸ Not easy to implement, takes more time to establish and costlier (than MPAs) ▸ Fishing and shipping regulations have not yet been developed ▸ Weaker standards "sustainable use is an arguably weaker standard than marine protection"	BC:2; SS:0 ▸ Gwaii Haanas National Marine Conservation Area Reserve and Haida Heritage Site (Gwaii Haanas; 2010) ▸ Mia-yaltwa Ha'lidzogm hoon (Central Coast of BC)
National Park Reserve (NPR)	*Canada National Parks Act* Parks Canada	Benefits education and enjoyment of Canadians. It is managed like a national park but is subject to Indigenous land claims	▸ Long-term ▸ Strong habitat protection ▸ SARA, Fisheries Act, Rockfish Conservation Area prohibitions, and Transport Canada regulations all apply with enforcement supported by Park Wardens ▸ Can regulate fisheries (via fisheries closures) ▸ Regulate collection and removal of natural or cultural objects; feeding, harassing, or hunting wildlife; or camping outside designated areas or without a permit	▸ Increased human activity and overcrowding ▸ Habitat degradation & fragmentation ▸ Inadequate management ▸ Declining ecological integrity	BC:3; SS:1 ▸ Pacific Rim National Park Reserve (1970) (e.g., Broken Group Islands) ▸ Gulf Islands National Park Reserve (2003)

Designation	Legal framework & authority	Purpose	Strengths	Weaknesses	Designated & example(s) of protected areas
FEDERAL					
Migratory Bird Sanctuary (MBS)	*Migratory Birds Convention Act* CWS-ECCC	Protection and conservation of migratory birds and seabirds; Protects nests and eggs from direct threats: killing, harm, and harassment during a critical part of their life cycle	▸ Long-term ▸ Can be established anywhere ▸ Afford MPA protection standards (i.e., bottom trawl fishing, dumping, mining, and oil and gas activities will be prohibited in the marine components of future MBSs)	▸ Cover small coastal, marine areas ▸ Limited in application in marine conservation, except for seabirds ▸ Not regularly enforced; monitoring limited by funding	BC:3; SS:1 ▸ Victoria Harbour MBS (1923) ▸ Shoal Harbour MBS (1931) ▸ Esquimalt Lagoon MBS (1931) ▸ Christie Islet MBS (1962) ▸ George C. Reifel MBS (1967)
PROVINCIAL					
Ecological Reserve (ER)	*Ecological Reserve Act* & *Protected Areas of BC Act* BC Parks	Maintain biological diversity, protect genetic material, and support scientific research and education; represent special ecosystems in BC, including rare, endangered, or unique plant and animal species, and rare or unique natural phenomena.	▸ Long-term, permanent legal protections ▸ Strong protection standards ▸ Can be closed to public access ▸ High fines (up to $200,000) imposed for regulation violations ▸ Camping, hunting, fishing, and motorized vehicles generally prohibited ▸ Permits required for scientific research and educational activities	▸ Provincial government has no authority to prohibit federally regulated activities (i.e., fishing and shipping) ▸ May be overlaid with federal fisheries closures (i.e., Rockfish Conservation Areas) ▸ Open to recreational activities	BC:148; SS:4 ▸ Ballingall Islets Ecological Reserve (1963) ▸ Rose Islets Ecological Reserve (1971) ▸ Satellite Channel Ecological Reserve (1975) ▸ Race Rocks Ecological Reserve (1980)

Designation	Legal framework & authority	Purpose	Strengths	Weaknesses	Designated & example(s) of protected areas
PROVINCIAL					
Migratory Bird Sanctuary (MBS)	*Migratory Birds Convention Act* CWS-ECCC	Protection and conservation of migratory birds and seabirds; Protects nests and eggs from direct threats: killing, harm, and harassment during a critical part of their life cycle	▸ Long-term ▸ Can be established anywhere ▸ Afford MPA protection standards (i.e., bottom trawl fishing, dumping, mining, and oil and gas activities will be prohibited in the marine components of future MBSs)	▸ Cover small coastal, marine areas ▸ Limited in application in marine conservation, except for seabirds ▸ Not regularly enforced; monitoring limited by funding	BC:3; SS:1 ▸ Victoria Harbour MBS (1923) ▸ Shoal Harbour MBS (1931) ▸ Esquimalt Lagoon MBS (1931) ▸ Christie Islet MBS (1962) ▸ George C. Reifel MBS (1967)
Wildlife Management Areas (WMA)	*Wildlife Act* BC-WLR	Conservation management and protection of fish, wildlife, and their habitats	▸ Long-term ▸ Certain activities are prohibited ▸ Permission needed to use land or resources ▸ Government may regulate use and occupation	▸ Protective measures or tools often not used ▸ Out-of-date management plans	BC:31; SS:5 ▸ Boundary Bay WMA (1995) ▸ Parksville-Qualicum Beach WMA (1993) ▸ Sturgeon Banks WMA (1998) ▸ Skwelwil'em Squamish Estuary WMA (2007) ▸ Roberts Bank WMA (2011)
(Marine) Parks and Recreation Areas (PRA)	*Park Act* & *Protected Areas of BC Act* BC Parks	Preservation for a variety of purposes, including natural environment, for inspiration, use and enjoyment by the public	▸ Long-term ▸ Strong protection ▸ Includes marine areas ▸ Consumption prohibited ▸ Requirement for fees and permitting; public conduct; use of motor vehicles, boats, and aircraft; waste management; camping and picnicking; hunting and fishing, use of firearms etc. ▸ High fines (up to $200,000) imposed for regulation violations	▸ Small areas ▸ Lack coordination among levels of government ▸ No requirement for management	BC:630; SS:22 ▸ Discovery Island Marine Provincial Park (1972) ▸ Desolation Sound Marine Provincial Park (1973) ▸ Broughton Archipelago Provincial Park (1992)

KELP NETWORKS: MEETING CHALLENGES OF KELP MANAGEMENT

As regional interest in kelp grows, and as the consequences of kelp loss intensify due to human activities and climate change, several small and large-scale organizations have emerged and are being prompted to action. They call for urgent kelp conservation and protection reinforced by science-based management, policy support, and community engagement (Hessing-Lewis, 2025; Whitty, 2025). These individual organizations or associations made up of experts and stakeholders are working collaboratively with various research institutions, non-profits, community groups, Indigenous governments, policymakers, and businesses to form a network for innovation, data and knowledge. For example, the 83 kelp experts and practitioners who attended the 2025 PSF Kelp Symposium called for increased funding, legislative support, cross-border coordination and cooperation to further:

- address barriers and improve policy and regulatory frameworks;
- advocate for protection of kelp forests;
- reduce key kelp stressors through active management, and increase long-term monitoring;
- accelerate climate-resilient kelp restoration and genetic diversity preservation;
- increase capacity-building by strengthening Indigenous leadership and integrating Indigenous; knowledge with Western science, while expanding local monitoring capacity;
- promote kelps importance to the blue economy; and
- enhance data-sharing, knowledge transfer and integration through a centralized knowledge hub (Coleman, 2025a).

Many organizations exist, including First Nations groups that are working on research, restoration, nature-based climate solutions, and development of the seaweed sector in BC and beyond (Table 7.3). Of these, we highlight three regional organizations that have actively engaged in collaborative kelp initiatives in BC through collective action: MaPP, Kelp Rescue Initiative, and the Kelp Node.

MARINE PLAN PARTNERSHIP (MAPP) FOR THE NORTH PACIFIC COAST

Regionally, the Marine Plan Partnership (MaPP) for the North Pacific Coast (2011) confirmed giant kelp and bull kelp as valued ecosystem components under the MaPP Integrated Ecosystem-Based Management (EBM) Program of BC (2018-2019). This led to the Kelp Monitoring Project in partnership with 17 First Nations and the Province of BC, for the Northern Shelf Bioregion. It provided the impetus for increasing knowledge related to kelp, guided by questions around drivers of change, kelp status, associated pressures, and broader ecosystem effects of kelp change. MaPP initially developed standard protocols for kelp mapping and monitoring (Thompson, 2021, updated in 2026), and helped provide data and tools that could support future sampling designs.

KELP RESCUE INITIATIVE

The Kelp Rescue Initiative (2021) is a non-profit organization focused on advancing kelp restoration science and preserving resilient kelp forests in BC (Schuster, 2025). They work within a collaborative framework that includes multiple partners across academia, other non-profits, First Nations (Huu-ay-aht, Tsleil-Waututh, and Broughton Archipelago nations), federal (DFO), and provincial governments. Through their field research and restoration trials, they hope to advance and guide kelp restoration initiatives. They are developing best practice resources such as the Roadmap to Kelp Recovery for BC, and have completed projects in optimizing kelp restoration methods, kelp adaptation and thermal tolerance, sea urchin control, and alternative seeding methods, kelp genomics, and determining the status of kelp (historic changes, habitat suitability, and species distribution models). For example, a project in Burrard Inlet (Tsleil-Waututh Nation territory) tested whether kelp can persist in high-human-impact areas, while comparing the effectiveness of restoration methods, while another worked with the Maa-nulth First Nation to find ways to integrate sea urchin management strategies (Schuster, 2025). They also hope to expand community-led monitoring (Schuster, 2025).

KELP NODE

The Kelp Node (2022) is a diverse, collaborative transboundary network of researchers, educators, conservationists, Indigenous stewards, citizen scientists, marine managers, and policymakers (~more 250 members) in BC and Washington State (Hessing-Lewis, 2025). It emerged under the Northeast Pacific Biodiversity Action Network (BioActNet) and builds on initiatives endorsed by the UN Decade of Ocean Science for Sustainable Development. The networks' goals are to advance kelp conservation, management, and restoration in the transboundary waters of BC and WA, and facilitate data-sharing, policy integration, and restoration planning, ensuring coordinated action to protect kelp forests (Hessing-Lewis, 2025). The Kelp Node is organized into six interconnected working groups (WGs) that address specific goals through regular meetings (Figure 7.4). It is guided by a 'Knowledge-to-Action' framework that is fostered through inclusive collaboration. Transboundary networks are vital for species like bull kelp because marine environments (ocean currents, pollution, warming waters) occur across international borders (e.g., the Salish Sea between BC and WA State), and shared marine species and communities ignore political border lines (Hessing-Lewis, 2025).

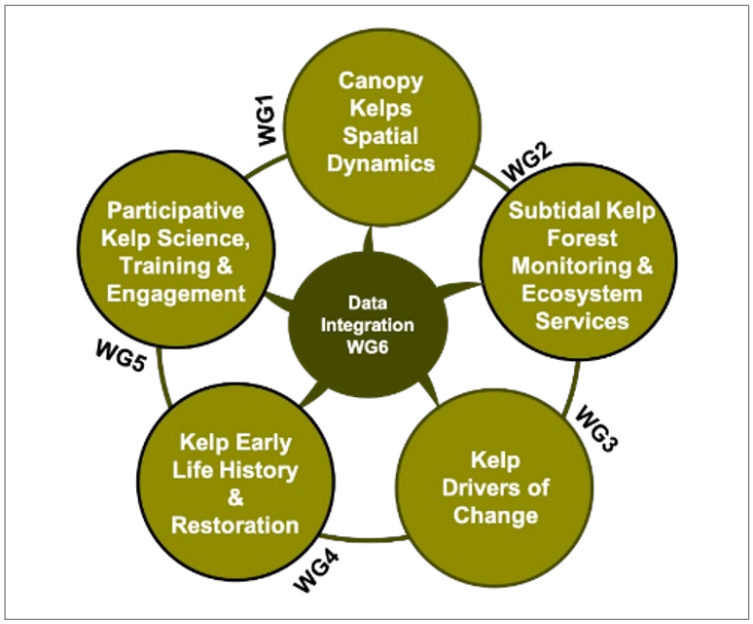


Figure 7.4 The six interconnected working groups that make up the Kelp Node (image from the Kelp Node).

Table 7.3 Kelp-focused organizations and networks working on collaborative research, consultation, restoration, protection, nature-based climate solutions, advocacy, and development of the seaweed sector. This list is not exhaustive, as there are many other organizations, including university research institutes and First Nation groups not listed.

Organization/institute	Description	Goals/scope
BRITISH COLUMBIA (LOCAL-REGIONAL)		
Canadian Kelp Research (previously Canadian Kelp Resources; 1982)	▸ Privately owned consulting company led by scientist Dr. Louis Druehl and Rae Hopkins, based in Bamfield BC ▸ Partnered with government, First Nations, research institutes, and non-profit organizations	▸ Research in kelp DNA; gametophyte banking ▸ Advise on aspects of kelp farming and nursery production, species selection, farm construction, production estimates, and permitting
Centre for Applied Research Technology and Innovation (CARTI), North Island College (2012)	▸ Applied research and education at North Island College, based in Campbell River, BC ▸ Location of the Seaweed Innovation Hub (with kelp bioreactor) ▸ Partnered with First Nations, industry, non-profit, and community organizations	▸ Provide education, training, applied research on seaweed and kelp cultivation, processing and marketing ▸ Hosts the Seaweed Series ▸ Optimize seaweed (kelp) nursery parameters and innovate new methods of seed production
Comox Valley Project Watershed (2010)	▸ Non-profit focused ecological restoration, research, and education, based in Courtenay, BC ▸ Partnered with First Nations, non-profit, and community organizations	▸ Actively restore and monitor eelgrass, kelp, and salt marsh habitats ▸ Grow kelp on seeded lines; urchin exclusion ▸ Study sites at Maude Reef (Hornby Island) and Cape Lazo shoal, with a reference site at Eagle Rock on SE Denman Island
Fisheries and Oceans Canada (DFO)	▸ Federal agency that mandates the Fisheries Act ▸ Partnered with government, First Nations, research institutes, and non-profit organizations ▸ Funds projects that help to restore aquatic ecosystems and mitigate human impacts on coastal and marine environments	▸ Kelp restoration project in collaboration with Tsleil-Waututh Nation (TWN) and Kelp Rescue Initiative (KRI), to provide techniques to reestablish bull kelp in urbanized Burrard Inlet, Vancouver, BC
Hakai Institute (2002)	▸ Non-profit research institute that creates specialized applications and tools to address issues and challenges facing BC's coastal margins, based in Campbell River, BC ▸ Collaborates with government, First Nations, research institutes, non-profit organizations, and international organizations	▸ Kelp Monitoring Program — provides research, and tools for mapping and monitoring of kelp forests ▸ Houses the Kelp Node

Organization/institute	Description	Goals/scope
BRITISH COLUMBIA (LOCAL-REGIONAL)		
Help the Kelp (~2009)	▸ Local citizen science project focused on mapping and restoration on bull kelp, based on Gabriola Island, BC	▸ To map and replant bull kelp around Gabriola Island, BC ▸ Carry out public education
Kelp Rescue Initiative (KRI; 2021)	▸ Non-profit focused on kelp restoration field research and trials, based in Bamfield, BC ▸ Partnered with government, First Nations, research institutes, non-profit organizations, and international organizations	▸ Advance kelp restoration science and preserve resilient kelp forests ▸ Restoration methods development, thermal tolerance and adaption, sea urchin control, alternative seeding methods, kelp genomics, kelp status, outreach, capacity building E.g., Development of best-practice resources such as the Roadmap to Kelp Recovery for BC
Marine Plan Partnership (MaPP; 2011) and Government of BC	▸ Government of BC and First Nations ▸ Partnered with government, First Nations, research institutes, non-profit organizations, and community organizations	▸ Implement marine use plans for the North Pacific Coast using an ecosystem-based management framework ▸ Regional kelp mapping on the North Pacific Coast
Mayne Island Conservancy (MIC; 2003) and partners	▸ Local community-based citizen science organizations, based on Mayne Island, BC ▸ Partnered with First Nations, research institutes, non-profit, and community organizations	▸ Annual mapping and monitoring of bull kelp around Mayne, Galiano, the Penders, and Saturna Southern Gulf Islands ▸ Provide public education and training ▸ Provide geospatial data (PSF Marine Data)
Nile Creek Enhancement Society (NCES; 1996)	▸ Non-profit of local citizen scientists committed to restoring, enhancing and protecting the habitat and ecosystems integral to the survival of salmonids in the Salish Sea/Strait of Georgia, based in Bowser, BC	▸ Trial bull kelp restoration methods along the East coast of Vancouver Island ▸ Provide public education
Ocean Wise — Seaforestation (2019)	▸ Non-profit focused on kelp restoration field research and trials, based in Vancouver, BC ▸ Partnered with government, First Nations, research institutes, non-profit organizations, and international organizations	▸ Kelp nursery for research and testing kelp seed production methods to advance restoration techniques ▸ Restoration projects in collaboration with kelp farmers, scientists, and First Nations ▸ Kelp forest ecosystem monitoring and methodologies in collaboration with Kelp Forest Alliance (International org.)

Organization/institute	Description	Goals/scope
BRITISH COLUMBIA (LOCAL-REGIONAL)		
Pacific Salmon Foundation (1987)	▸ Non-profit environmental organization focused on conservation, restoration, and enhancement of Pacific salmon and their ecosystems, based in Vancouver, BC ▸ Partnered with government, First Nations, research institutes, non-profit organizations, and community organizations	▸ Houses a marine data centre, and centralized repository ▸ Supports a kelp research at Simon Fraser University and University of Victoria ▸ Decision support tools for restoration (hub of data and knowledge) of kelp, seagrass, and tidal marsh ecosystems ▸ Developed a handbook for biobanking kelp
Pacific Seaweed Industry Association (2020)	▸ Non-profit, member-driven organization to raise awareness of seaweed's benefits and diverse uses, based in Port Alberni, BC ▸ Collaborates with stakeholders (Indigenous, research, businesses) to develop educational materials, policies, technologies, and innovations	▸ Promote and grow the seaweed sector ▸ Provide advocacy and policy support ▸ Support members through resources, and networking opportunities ▸ Lay out groundwork for a national seaweed network to unite Canada's growing seaweed sector
Redd Fish Restoration Society (1995)	▸ Non-profit focused on environmental consulting, ecological restoration, environmental monitoring, GIS, drone, and project management services, based in Ucluelet, BC ▸ Partnered with government, First Nations, not-for-profit organizations, industry	▸ Take a holistic approach to kelp restoration, integrate Indigenous knowledge and governance into their efforts to find the root cause of habitat degradation
University of Victoria's SPECTRAL Remote Sensing Lab (2004)	▸ Located at the University of Victoria, department of Geography and headed by Dr. Maycira Costa ▸ Partnered with government, First Nations, research institutes, non-profit organizations, and international organizations	▸ Carry out projects that include accessing historical and modern records of kelp bed size and presence to study climate change; and collecting environmental data that may affect kelp growth and resilience ▸ Provide education and training in remote sensing methods
Vital Kelp (2018)	▸ Offers consultancy (Lee-Ann Ennis), on kelp cultivation, monitoring, and project management, based in Pender Harbour, BC ▸ Partnered with First Nations, not-for-profit, and community organizations	▸ Cultivate and outplanting of bull kelp for restoration ▸ Provide training and education in setting-up kelp nurseries
West Coast Kelp (2022)	▸ Privately owned company, based in Bamfield, BC ▸ Offers ocean-ready kelp seed, kelp restoration and offsetting ▸ Partnered with coastal communities, First Nations, researchers and industry	▸ Provides kelp seed and nursery for commercial production and research ▸ Provides restoration and research support

Organization/institute	Description	Goals/scope
WASHINGTON STATE (REGIONAL)		
Coastal Watershed Institute (CWI; 1996)	▸ Non-profit formed by resource managers and scientists that promotes partnerships that foster understanding protection, and long-term management of natural ecosystems ▸ Partnered with government, First Nations, research institutes, not-for-profit organizations, community organizations, and international organizations	▸ Research on the dynamics of cold-water kelp forests, forage fish, and salmon, and how they are impacted by human activity in the Salish Sea ▸ Developed a handbook, in collaboration with PSF, of techniques for studying fish in kelp forests
Kelp Forest Monitoring Alliance of Washington State (WA; 2023)	▸ Collective of Washington State organizations (government, First Nations, research institutes, non-profits, and community organizations) working together to track floating kelp status and trends across WA ▸ Partnered with government, First Nations, research institutes, not-for-profit organizations, community organizations, and international organizations	▸ Track floating kelp status and trends across Washington State ▸ Advance understanding and conservation through coproduction of knowledge and information sharing ▸ Develop a statewide floating kelp indicator
Northwest Straits Commission (1998)	▸ Provides funding, training and support to marine resource committees, facilitates regional coordination and planning ▸ Partnered with government, First Nations, research institutes, not-for-profit organizations, community organizations, and international organizations	▸ Puget Sound Kelp Conservation and Recovery Plan, led by Jeff Whitty ▸ Identify priority stressors, monitor ecosystems, document kelp trends, and develop restoration strategies.
Puget Sound Restoration Fund (1997)	▸ Non-profit that works collaboratively to restore marine habitat, water quality, and native species in Puget Sound, WA, through on-the-ground projects ▸ Partnered with government, non-profit organizations, and community organizations	▸ Bull kelp restoration to reverse declines ▸ Developed the Puget Sound Kelp Conservation and Recovery Plan ▸ Public education and connecting people to marine resources
Washington State Department of Natural Resources (DNR) — Nearshore Habitat Program (~1989)	▸ Government organization carrying out kelp monitoring, research, and conservation in (Salish Sea) Washinton State ▸ Partnered with government, First Nations, research institutes, non-profit organizations, and community organizations	▸ Kelp Forest and Eelgrass Meadow Health and Conservation Plan (Senate Bill 5619, 2022) — Conserve and restore at least 10,000 acres of kelp forest and eelgrass meadow habitat by 2040, advancing high-priority strategies identified in both the Puget Sound Kelp Conservation and Recovery Plan

Organization/institute	Description	Goals/scope
TRANSBOUNDARY (BC-WA)		
Kelp Node (2022)	▸ A collective action network of over 150 individuals from partnered organizations, across six working groups; and Ocean Decade Project ▸ Partnered with government, First Nations, research institutes, non-profit organizations, and community organizations	▸ Advance kelp conservation, management, and restoration in the transboundary waters of BC (Canada) and WA (USA) ▸ Serves as forum for communicating information and knowledge; and organizing relevant research activities
INTERNATIONAL		
Kelp Ecosystem Ecology Network (KEEN; 2011)	▸ Collection of marine scientists interested in assessing the impacts of global change on kelp forests	▸ Find and unify past kelp forest monitoring datasets, for assessment of drivers of global change ▸ Conduct parallel experimental manipulations to determine how kelp forests will change in the future. ▸ Create a standardized kelp forest observational sampling protocol for public use
Kelp Forest Alliance (2022)	▸ Network of global scientists, conservationists, and communities interested in restoring and protecting kelp forest ▸ Partnered with government, First Nations, research institutes, non-profit organizations, industry, and community organizations	▸ Facilitate global knowledge exchange through its knowledge hub ▸ Raise the profile of kelp forests and strongly advocates protection ▸ Provides tools and guidelines for monitoring and restoration ▸ Formed the Kelp Forest Challenge
International Seaweed Association (ISA) (1953)	▸ First international organization connecting industry and academia seaweed stakeholders, dedicated to the encouragement of research and development of seaweed and seaweed products ▸ Partnered with government, First Nations, research institutes, non-profit organizations, industry, and international organizations	▸ Promote applied phycology on a global basis ▸ Stimulate interactions among researchers, industrialists and government ▸ representatives in all relevant institutions, organizations and industries and in all countries ▸ Organizes the International Seaweed Symposium, runs every three years

LESSONS LEARNED

- ☑ Surface canopy-forming kelp species and kelp forest habitats are not directly protected under any legal legislation, which makes them vulnerable.
- ☑ Kelp forests as fish habitats, receive indirect protection and benefits under Indigenous, Federal and Provincial governments under various statutes such as the *Oceans Act*, *Fisheries Act*, *Canada National Marine Conservation Areas Act*.
- ☑ In BC, there are some regulations for kelp associated with commercial harvesting and culturing of marine "plants" (including kelp), which falls under the primary jurisdiction of the BC Provincial Ministry of Water, Land and Resource Stewardship (MWLRS), with responsibilities shared with DFO and Transport Canada, and in consultation with First Nations.
- ☑ Jurisdictional gaps in the protection of kelp and kelp forests may be addressed through the implementation of Indigenous Conserved and Protected Areas (IPCAs), and the forthcoming BC Coastal Marine Strategy (2024).
- ☑ Several dedicated individuals, institutions and organizations are working collaboratively on kelp research, monitoring, restoration, and conservation and facilitating active knowledge sharing to improve efficiency and outcomes.



Credit: Nicole Christiansen

CHAPTER EIGHT
SUMMARY, GAPS AND RECOMMENDATIONS

INTRODUCTION

Interest in kelp in British Columbia has never been greater due to its vital role in marine ecosystems, climate resilience, and an emerging blue economy. Coastal communities, First Nations, non-profits, and researchers are increasingly focusing on kelp for habitat restoration, carbon capture/storage, and sustainable aquaculture. They are catalyzed into action by rapidly changing conditions and growing concerns over warming and loss of kelp forests worldwide. The era of climate change has made it critical to take immediate action to protect coastal ecosystems and implement nature-based climate solutions. For this to occur effectively, several knowledge gaps need to be addressed, including the complexities inherent in the existing legal regulatory framework, which do not provide direct protection of kelp forests in BC. Pathways to protection and management may come through meaningful healing (reconciliation) with First Nations and acknowledgment of their rights and titles. Empowering First Nations and collaborative leadership can bridge some of the knowledge gaps, counter historical governmental inaction and incapacity, introduce solutions through western science and TEK, and drive effective Indigenous-led marine conservation and stewardship.

For many of the reasons stated above, kelp focused work and research in BC must continue to fill in knowledge gaps, while advocating for protection. More information is needed to steer the environmentally responsible development of a new industry and safeguard kelp from warming oceans and other anthropogenic and climate-related pressures. To aid in this, we have identified several recommendations for kelp research and action to ensure that kelp continues to win BC for generations to come. The knowledge gaps and recommendations were informed by our review of scientific and other relevant literature as well as by communications with experts and practitioners.

GAPS AND RECOMMENDATIONS

PROTECT AND MANAGE EXISTING KELP ECOSYSTEMS

- **Gaps:** Kelp forests in BC lack dedicated protection. Their persistence, decline, and resilience in the Salish Sea are shaped by interacting stressors that remain poorly understood. There is no coordinated framework for sea urchin management and limited prioritization of climate-resilient kelp forests or refugia. While warming and marine heatwaves are dominant stressors, their cumulative impacts combined with grazing and other factors, and kelp's ecological connectivity with adjacent systems such as eelgrass and tidal marsh, remain insufficiently understood, constraining recognition of kelp's role in coastal food webs.
- **Recommendations:**
  - Consider implementation of sea urchin management in priority restoration areas, integrating Indigenous harvesting practices and urchin predator recovery strategies.
  - Identify natural climate refugia, such as areas of high water motion or deep-water buffering (Mora-Soto et al., 2024a; Starko et al., 2022), to focus conservation and restoration efforts.
  - Address land-based pollution sources, particularly sediment runoff and excess nutrients, which negatively impact kelp growth and survival.
  - Identify knowledge gaps in food-web interactions between kelp and ecologically, culturally, and commercially important species.
  - Determine the functional role of kelp forests as migration corridors, nursery habitat, and feeding grounds, particularly for salmonids.

INDIGENOUS LEADERSHIP AND GOVERNANCE

- **Gaps:** Cultural loss of oral histories and Traditional and Ecological Knowledge (TEK) related to kelp ecosystems presents a significant challenge for restoration and stewardship. Coordination between First Nations and government agencies remains limited, and stronger collaboration, legislation, and funding support is needed to enable Indigenous leadership in kelp protection and conservation, including implementation of initiatives such as the BC Coastal Marine Strategy Program.
- **Recommendations:**
  - Support Indigenous sovereignty over marine resources by ensuring First Nations and Tribes are central to monitoring, restoration planning, permitting, and policy development.
  - Expand and provide funded support for Indigenous-led monitoring and stewardship programs integrating TEK with scientific research (e.g., Indigenous Guardians programs).
  - Continue with developing co-managed Marine Protected Areas (MPAs) and support Indigenous Protected and Conserved Areas (IPCAs) that prioritize kelp habitat conservation.
  - Support long-term place-based restoration approaches through collaboration with First Nations (Martone, 2025).

Knowledge sharing and Indigenous engagement

To empower Indigenous Guardians with skills and confidence for monitoring kelp forests in their territories, divers from six coastal First Nations took part in a five-day Indigenous Guardian dive workshop at Calvert Island hosted by the Hakai Institute. Working with expert trainers, participants sharpened their kelp survey and species identification skills to support ecosystem monitoring efforts.



Figure 8.1 Indigenous Guardian divers from coastal First Nations learn techniques for kelp monitoring from kelp research experts at a five-day workshop on Calvert Island in 2025.

MONITORING, DATA, AND KNOWLEDGE SYSTEMS

- **Gaps:** A lack of continuous, long-term monitoring limits our understanding of the drivers of kelp forest variability, persistence, and decline. Monitoring efforts remain fragmented, with insufficient support for Indigenous-led and citizen science initiatives, and there is currently no centralized data repository or standardized set of protocols to enable consistent data collection, comparison, and knowledge sharing across regions and programs.
- **Recommendations:**
  - Expand coast-wide remote sensing and satellite-based kelp monitoring, integrating historical and real-time datasets.
  - Standardize data collection methodologies across regions and research groups.
  - Leverage AI and machine learning tools for automated biodiversity assessments.
  - Develop centralized, accessible kelp data platforms and georeferenced tools to support knowledge sharing.

CONTINUE KELP RESTORATION EFFORTS; OPTIMIZE SCALE AND METHODS

- **Gaps:** Effective kelp restoration in the Salish Sea is constrained by the absence of a coordinated framework to guide site selection and implementation, including identification of suitable sites with higher likelihoods of success and clearer guidance on site-specific practices such as substrate conditions, deployment timing, and herbivore management. At the same time, limited understanding of pre- and post-restoration biological conditions restricts the ability to evaluate restoration effectiveness and to determine how restored kelp habitats are used by salmon, forage fish, and other invertebrate species.
- **Recommendations:**
  - Protect the remaining natural kelp beds and use them as reference sites to compare differences in seasonality of growth, reproduction, and natural mortality with outplant sites to improve restoration techniques (Heath et al., 2022; Calloway et al., 2020; Northwest Straits Initiative et al., 2023).
  - Continue using the long-line cultivation approach, as it can contribute to restoration "if the effort is diversified by developing a network of good sites spread over a large area of potential resilient kelp forests" (Heath et al., 2022).
  - Encourage growth of more heat tolerant kelp such as sugar kelp (*Saccharina latissima*) to create seabed understories, which can also provide valuable habitat for fish and invertebrates (Heath et al., 2022).
  - Avoid selecting sites with grazing herbivores such as sea urchins and kelp crabs, or pair restoration with grazer management (Heath et al. 2022).
  - Continue research into site-specific conditions for outplanting, including timing, density of seed outplants, and substrate (Northwest Straits Initiative et al., 2023), with increased standardization across sites where possible.
  - Research the impact of cumulative effects on the different life stages of bull kelp to better understand factors that support resilience to increasing ocean temperatures, marine heat waves, pollution and runoff, overgrazing, and other coastal ocean changes (Muth et al. 2019).
  - Prioritize studies combining genetic sequencing with stress tolerance experiments to identify possible genetic basis for susceptibility or tolerance (Starko et al. 2024).
  - Scaling-up restoration efforts can be logistically challenging, planning and design should consider habitat suitability (Barbosa et al., 2026) and the potential for successful next-generation kelp yields from increased outplanting efforts (Hayford, 2025).
  - Collaboration and knowledge sharing among restoration practitioners in nursery and field operations, and with Indigenous and other stakeholders, remain critical (Calloway et al., 2020; Martone, 2025).

CLIMATE ADAPTATION AND GENETIC RESILIENCE

- **Gaps:** Strategies to climate-proof kelp restoration remain underdeveloped, and current understanding of thermotolerant kelp strains is still in its early stages. Genetic research programs aimed at enhancing thermotolerance of local kelp species require further advancement, while limited biobanking capacity constrains the ability to preserve existing genetic diversity and support future breeding or restoration efforts under changing ocean conditions.
- **Recommendations:**
  - Determine genetic mechanisms of kelp thermotolerance.
  - Develop thermally tolerant kelp strains through selective breeding (Liu et al., 2014) or thermal priming (Gauci et al., 2024).
  - Explore the practical, scientific, and legal feasibility of using thermotolerant kelp strains in restoration projects.
  - If kelp forests continue to decline or are lost completely from warmer regions, thermotolerant strains may become necessary for restoration.
  - Build capacity to store kelp biodiversity long-term, including funding strategies, optimized protocols, facilities, and personnel.
  - Continue to investigate cryopreservation as a method for kelp biobanking (Coleman et al., 2025).
  - Advance biobanking efforts urgently to minimize loss of kelp biodiversity.

POLICY, FUNDING, AND COORDINATION

- **Gaps:** Bull kelp habitat is not explicitly protected within existing policy frameworks in the Salish Sea or BC, and multiple overlapping governmental jurisdictions contribute to inefficiencies, regulatory complexity, and inaction. At the same time, limited long-term funding, weak cross-sector coordination, limited coordination with Indigenous stewards, and low public awareness constrain the scale and effectiveness of kelp conservation and restoration efforts.
- **Recommendations:**
  - Develop a streamlined permitting process for kelp research and restoration projects, distinct from commercial aquaculture.
  - Integrate kelp conservation into fisheries and coastal management policies.
  - Formalize legal recognition of IPCAs to support co-management.
  - Strengthen transboundary coordination between BC and Washington State.
  - Develop public-private partnerships to support long-term funding.
  - Expand citizen science, outreach, and ocean literacy initiatives to build public support.
  - Marine planning and regulation should continue to move forward through commitments to long-term Indigenous engagement and governance-related initiatives.

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Funding for the project is provided by the Aquatic Ecosystem Restoration Fund by Department of Fisheries and Oceans Canada.

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