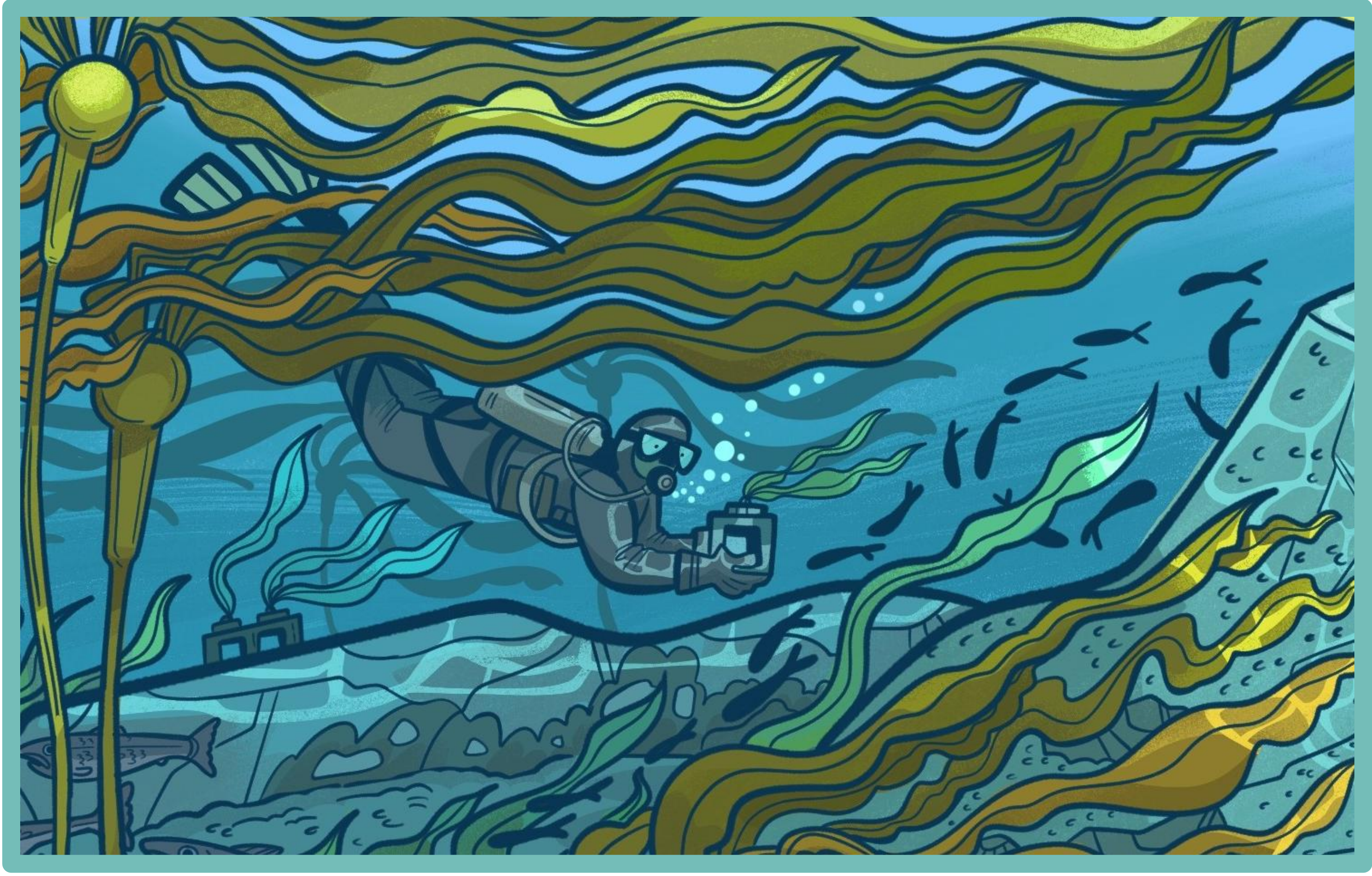

REVIEW OF KELP RESTORATION METHODOLOGIES USED IN THE SALISH SEA AND OTHER BRITISH COLUMBIA LOCATIONS

GREENING THE SALISH SEA: DECISION SUPPORT TOOLS FOR SUCCESSFUL PACIFIC SALMON HABITAT RECOVERY

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ABSTRACT

Bull kelp, *Nereocystis luetkeana*, is the dominant canopy-forming macroalgae in the Salish Sea, and the only one in the Strait of Georgia (SOG). *Nereocystis* is a fast-growing, annual species that is easily recognized by its structure. It is also considered an ecosystem engineer as it provides three-dimensional structure spanning up to 36 m in the water column, stalls water flow and entrains particulates, and provides habitat, food, shelter, and refuge to a trophic web of invertebrates, fish, and mammals. Salmonids, rockfish, Pacific herring, other forage fish, abalone, and sea urchins are some of the species known to depend on kelp forests for some time in their lives.

Unfortunately, *Nereocystis* has been noticeably disappearing from many areas in recent decades. The losses have been estimated from studies comparing historic occurrence records to modern imaging techniques and show warmer coastlines, enclosed inlets, and areas in the northern SOG as experiencing the greatest declines.

Since 2006, efforts have been made to restore bull kelp in places it was once known to flourish, beginning with concerned local groups of volunteers in areas of the northern SOG and expanding in recent years with the involvement of large organized groups collaborating with Indigenous Nations, conservation groups, and kelp nurseries. The method most used for outplanting kelp "seed" (propagules) is seeded lines. This method was adapted from aquaculture, where the string on which small kelp sporophytes have attached is wrapped around rope suspended off the sea bottom at a chosen site. Outplanting trials of "green" gravel, a newer technology developed for restoration work, have expanded restoration in the SOG and Barkley Sound on the west coast of Vancouver Island as proponents adapt the method for fast-growing bull kelp. Transplanting of young kelp from cultured substrates or wild ones that become drifters to a restoration site is the third most used method of kelp restoration in the region. The goal of these methods is to grow a cohort of sporophytes to maturity, have them reproduce successfully, and provide recruits to re-establish bull kelp forests at the location of outplanting. As sea urchin grazing on bull kelp impacts restoration trials, efforts to exclude them are being devised and implemented.

There have been some successes, many failures, and a lot of lessons learned over the almost two decades of trials to restore bull kelp in the Salish Sea and other locations in BC. Since attempts to restore kelp began in 2006, two major sources of stress have increased. There have been two major marine heat waves that have compounded the heat stress of the already increasing seawater temperatures in the Salish Sea; and the trophic relationships between bull kelp and herbivorous grazers, sea urchins and kelp crabs, have become unbalanced. While trials to match and adapt kelp restoration methods to new sites are ongoing, there is a push now to scale up restoration efforts and find ways to future-proof *Nereocystis* for a changing climate.

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GLOSSARY

Annual: An alga that dies after one growing season.

Gametophyte: Microscopic haploid (1N) stage in the life cycle of kelp, which are male or female and can grow vegetatively, developing to release sperm or eggs.

Germling: A young gametophyte produced by the germination of a zoospore; also, a young sporophyte.

Haptera: Part of the holdfast structure of kelp.

Macroalga: Alga which is multicellular and generally large enough at some stage of its life cycle to be seen with the naked eye.

Outplant: Term used in kelp restoration indicating the placement of kelp seed or young kelp sporophytes in position at the restoration site.

Perennial: An alga that lives for three or more years.

Propagule: May be either spore, gametophyte, a newly formed sporophyte, or a combination of these.

Salish Sea: In this report, three regions are identified in the Salish Sea: Northern Salish Sea, also known as the Strait of Georgia (SOG); the Southern Salish Sea, also called Puget Sound; and the Juan de Fuca Strait.

Seed: In the context of cultured kelp, seed refers to small sporophytes, sometimes in combination with gametophytes.

Sori: Singular form is sorus; reproductive tissue in the form of patches on the blades of kelp, which abscise from the blades and release zoospores.

Spore: Short form for a kelp zoospore, also called a meiospore.

Sporophyte: Macroscopic diploid (2N) stage in the life cycle of kelp which produces reproductive tissue called sori in patches on the blades.

Sporulation: Formation of spores by mature sporophytes of algae.

Transplant: The act of moving usually young sporophytes from one location to another, often requiring some temporary attachment to a substrate. The term is sometimes used for the individual being transplanted.

Zoospore: A flagellated, haploid cell capable of motility and limited photosynthesis; released from sori before and after abscission from sporophyte blades.

INTRODUCTION

Marine forests of large brown algae (Phaeophyceae) called kelp fringe the temperate and subpolar coastlines of the globe, where rocky substrates provide purchase. Kelp is a general name given to large brown macroalgae most commonly in the order Laminariales and often includes species of Fucales, and Desmarestiales in discussions of kelp forest ecosystems (Bolton, 2010; Wernberg and Filbee-Dexter, 2019). They form extensive marine ecosystems along one quarter of the world's coastlines, providing three-dimensional habitat, food, and shelter for juvenile salmon as well as a diverse array of other fish, invertebrates, marine mammals, and birds (Teagle et al., 2017). As primary producers, kelp contribute to gradients in carbon content, alkalinity, pH, and oxygen in the waters around them and contribute to carbon and nitrogen cycling by providing substrate for microbial metabolisms (Pfister et al., 2019). Canopy-forming kelp also protect shorelines by dampening waves and controlling erosion (Morris et al, 2020). When kelp dies, it may float for months, transporting and possibly dispersing many epiphytes and commensals, and when it washes ashore to form beach wrack, it provides habitat, shelter, and foraging for a different collection of species (Kidder, 2006). Kelp "highways" are thought to have facilitated the migration of humans along the coast of the northeast Pacific Ocean (Erlandson et al., 2007) and provide food and shelter to juvenile salmon migrating from freshwater out to sea (Shaffer et al., 2020; Shaffer et al., 2023). Coastal Indigenous people value kelp as a food and material, and for its role in providing food, habitat, and refuge for many of the fish and invertebrates they depend on, such as salmon, rock fish, herring, abalone, and sea urchins (Turner, 2001; Schweigert et al., 2018).

In the northeast Pacific Ocean, bull kelp (*Nereocystis luetkeana*) is a dominant canopy-forming macroalgae and the only canopy-forming kelp in the Strait of Georgia and Puget Sound regions of the Salish Sea. In kelp forests growing along the more exposed Pacific coast and the Strait of Juan de Fuca, where ocean salinity is generally higher and more stable, bull kelp can be found growing with giant kelp (*Macrocystis pyrifera*) forests, generally on the seaward edge (Mumford, 2007). *N. luetkeana* occurs from the Aleutian Islands to Point Conception, CA (Druehl, 1980; Miller and Estes, 1989). *N. luetkeana* is the only species in the genus *Nereocystis* (McGuiry, 2011).

Nereocystis luetkeana (K. Mertens) Postels and Ruprecht (1840), known as bull kelp or bullwhip kelp, is characterized by a large (up to 10 cm diameter) pneumatocyst (gas-filled bulb) at the terminus of a stipe that may be up to 36 metres long (Lindeberg and Lindstrom, 2024). Up to thirty long, flat blades sprout from the bulb, radiating up to 10 metres just below the surface. Under ideal conditions, this annual kelp species can grow 15 cm per day, faster than any other algae. Bull kelp typically colonizes semi-exposed coastlines or high current areas and can be found in sheltered areas with good water flow (Druehl and Clarkson, 2016). It attaches to substrates of rock boulders or large cobbles at depths from low intertidal to subtidal, generally shallower than 20 m, depending on water clarity. A firm attachment for this large kelp is provided by mucilaginous secretions from a holdfast complex of entwined haptera (Tovey and Moss, 1978).

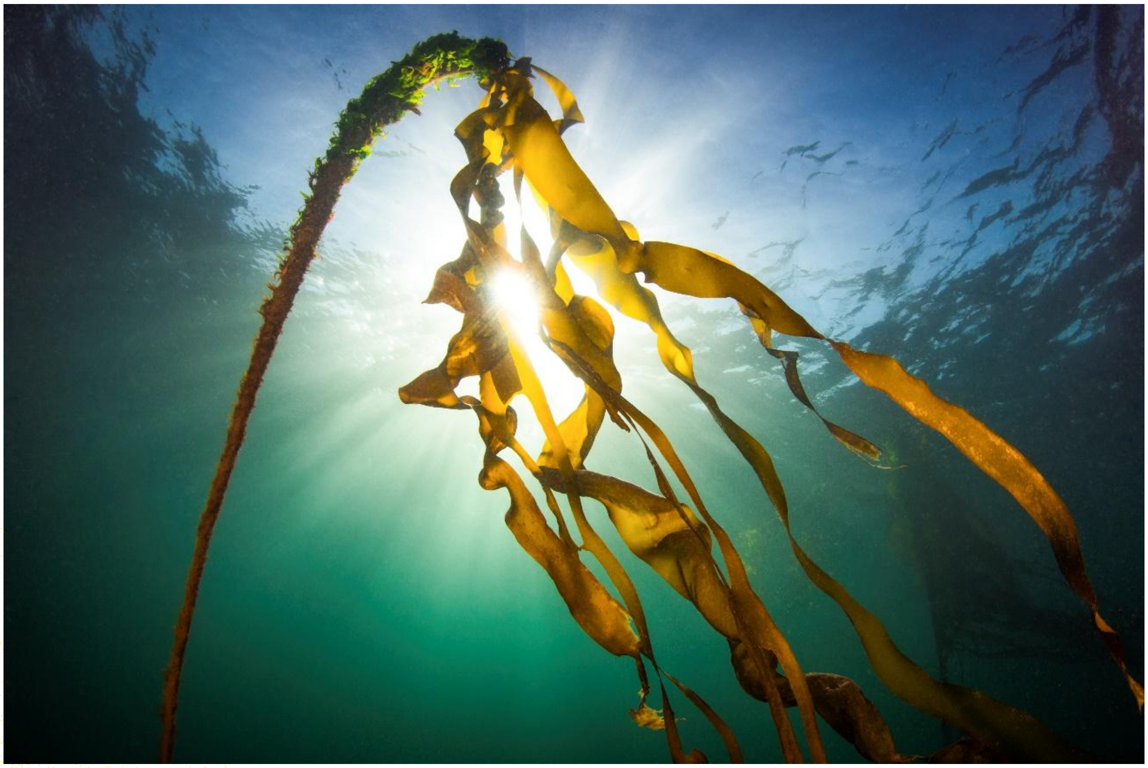
The annual life cycle of *Nereocystis* involves a macroscopic diploid stage called the sporophyte and a microscopic haploid stage, the gametophyte (John, 1994). In late summer and fall, patches of reproductive tissue called sori develop on blades of the sporophyte, where meiosis results in the formation of zoospores. Sori abscission follows a pattern of two hours before to four hours after sunrise, at two-to-four-day intervals (Amsler and Neushul, 1989). Some zoospores are released while sori are intact in the blade, others during descent, and almost all are released within four hours. A model of bimodal release of spores under ocean conditions predicted that a third of the spores would settle within 10 m of parent sporophytes and the rest would disperse more than 100 m, thereby enhancing dispersal (Burnett et al., 2024). Sporulation peaks in late summer and fall when *Nereocystis* blades are mature, but before storms and wave action tear them from their place of attachment, sending them adrift (Cameron 1916; Foreman 1984). Zoospores may not travel far, and the majority of abscised sori may deposit near adults, but due their buoyancy, rafts of bull kelp can be moved large distances on ocean currents, possibly dispersing spores a great distance (Kidder, 2006; Layton et al., 2022)

Zoospores settle on suitable substrate and develop into the microscopic gametophyte stage. Under low light and nutrient levels, gametophytes can grow vegetatively for extended periods even years in the lab, a capacity which allows overwintering in nature and the creation of clone cultures maintained in labs and kelp nurseries (Vadas, 1972, Redmond et al., 2014). Conditions in late winter, most likely increasing light levels (Vadas, 1972) trigger sexuality, the differentiation into male or female gametophytes, and the development of eggs and sperm. A female gametophyte with attached egg releases a pheromone to attract sperm to swim a short distance to fertilize the egg, creating a diploid zygote, which will grow into a sporophyte in the spring (Mamer et al., 1964). Restoration experiments have shown kelp propagules (a combination of tiny sporophytes, microscopic gametophytes, and possibly spores) cultured in a nursery lab and outplanted to the ocean bottom at a depth of 5-7 m in late December to mid-February, will show vigorous growth in March, reaching the surface by June (Heath et al., 2015; Hayford, 2025). In Puget Sound, WA, some *Nereocystis* recruits arise in every season, with the bulk appearing in the spring, though survival is low across seasons (Dobkowski et al., 2018). The length of time *Nereocystis* gametophytes remain viable in the wild is unknown, but in another annual brown macroalgae *Desmarestia*, they have been observed to survive for at least 15 months in the wild, contributing to recruitment in multiple years (Edwards, 2000). An unexpected observation by a graduate student studying the ecology of drift kelp in Oregon, and observed again in Alaska, was the development of sporophyte germlings on the sori patches of *Nereocystis*, suggesting another mode of dispersal (Kidder, 2006; Ulaski et al., 2023).

With its annual life history and fast growth rate, bull kelp is considered an opportunistic species, one that can quickly establish itself when favorable conditions arise, particularly after winter storms clear space in the nearshore (Foreman, 1984). It is also vulnerable to these storms, which can tear its attachment from the substrate, sending it adrift, often to become beach wrack where grazing by beach fauna and decomposition will transfer nutrients to the ecosystem (Kidder, 2006). In the Strait of Georgia, *Nereocystis* is also described as a successional species whose abundance prior to 2013 was controlled, in part, by the successional status of the community, particularly the green sea urchin (*Strongylocentrotus droebachiensis*) (Lamb et al., 2011).

Bull kelp is the dominant canopy forming kelp occurring in the Salish Sea because it is more tolerant to a relatively wider range of salinity and temperature than giant kelp (*Macrocystis pyrifera*), a perennial species (Foreman, 1984), but the optimal temperature range is less than 15 °C. This tolerance is being put to the test as the growth of bull kelp forests is influenced by many stressful environmental factors, both natural and anthropogenic. Natural factors are both physical, such as weather patterns, and biological, like grazing pressure. Nearshore construction and industrial activities such as log booming, as well as pollutants and sedimentation from urban, agricultural, and industrial sources all act as stressors on all stages in the life cycle of *Nereocystis* (for a review see Hollarsmith et al., 2022).

Nereocystis is known for the charismatic canopy it provides to nearshore areas, offering refuge from storms but also posing a hazard to navigation. The bull kelp canopy has been described as developing by May and lasting until winter storms tear their holdfasts from the bottom, sending them adrift. In more sheltered areas, the canopy may last a few months longer. In sheltered areas of the central Salish Sea today, the blades of *Nereocystis* begin deteriorating in late May, and by late August, only holdfasts with stipes remain (Heath et al, 2015). In other areas, the bull kelp canopy no longer appears (Berry et al., 2021; Mora-Soto et al., 2024; Starko et al., 2024).



Bull Kelp, photo by Eiko Jones.

Distribution Trends of *Nereocystis luetkeana* in the Northern Salish Sea (Strait of Georgia)

Initial investigations of kelp extent in BC were spurred on by its economic importance (Cameron, 1916), and in 1975, the Provincial Government of BC developed the Kelp Inventory Method (Kim-1) of Foreman (1975) to quantify biomass using infrared (IR) aerial photographs, combined with field-based information on bed structure, for kilometer-wide sections of the coastline. This method was employed in kelp inventory surveys through to 2007 with slight modifications (Coon et al., 1977; Field et al., 1977; Sutherland 1989, 2008).

Early surveyors of the kelp resources around Vancouver Island often noted fluctuations in biomass across spatial and temporal scales, attributing it to inconsistencies in survey methods like timing of the tides, tidal height, or seasons (Cameron, 1916; Anon., 1947; Scagel, 1961; Coon et al., 1981; Sutherland, 1989). Forman (1984) recognized the stochastic variability in yearly biomass of kelp forests while studying beds of bull kelp and giant kelp around northern Vancouver Island, relating it to clouds affecting light intensity and salinity by bringing rain, as well as changes in sea surface temperatures (SST). As an early successional species, bull kelp in some areas can be replaced by perennial understory kelp species over time (Duggins, 1987 in Mumford, 2007), and its distribution is also affected by grazing pressure from bands of green sea urchins that move about the Strait of Georgia in pursuit of their preferred food (Lamb et al., 2011). The fluctuating nature of many bull kelp forests has made it difficult to distinguish natural fluxes from more persistent losses until recently.

Historical records of canopy kelp occurrences from 137 British Admiralty (BA) charts created between 1858 and 1956, obtained from the Canadian Hydrography Service (CHS), were digitized to provide a historical baseline of kelp presence in coastal BC (Costa, 2020). These records provided cartographic interpretations of kelp as navigational hazards (drawn as dendritic images on maps). This information was combined with modern aerial photos (Field and Clark, 1978; Sutherland et al., 2008) and satellite imagery, to show persistence of continuous bull kelp beds during this time in the northern Salish Sea, in the Discovery Passage and around Quadra Island, and further south in southern Gulf Islands (Pender, Mayne, Salt Spring, Galiano, Penelakut, Thetis, and Gabriola, among others), Burrard Inlet, and the Strait of Juan de Fuca, with some persistent kelp patches near Texada and Lasqueti Islands (Costa et al, 2020; Mora-Soto et al, 2024b; Starko et al., 2024). The Strait of Georgia, from the southern Gulf Islands to Quadra Island, including the northern Gulf Islands (Denman, Hornby, Lasqueti, and Texada), was characterized by non-persistent kelp.

Researchers from Washington State assessed a 26-year history of canopy kelp from annual aerial surveys (1989 to 2015) using colour infrared photography (CIR) and compared it with estimates from 1911-1912 in the Strait of Juan de Fuca (Pfister et al., 2018). They found kelp to show relatively high aerial abundance and persistence throughout the (western) Strait of Juan de Fuca, and the exposed kelp beds appeared to decrease in abundance in the most easterly regions (in the vicinity of Port Angeles and Port Townsend).

Coastal sea surface temperature (SST) in the Strait of Georgia, measured daily at the network of British Columbia (BC) Lighthouse stations from 1973 to 2010, showed a statistically significant mean increase in SST of up to 0.56°C/decade, suggesting an approximately 3°C increase by the end of the 21st century (Amos et al. 2014). This rate of increase is higher than the outer shelf on the west coast of Vancouver Island and the global average. Global-scale oceanic conditions are thought to influence nearshore sea surface temperatures, marine heatwaves, and wind trends at the local level in the southern Salish Sea (Mora-Soto et al. 2024a). The combination of higher spring SST, more intense and frequent marine heatwaves (MHW) (maximum observed day intensity surpasses the day's seasonal climatology for more than 5 days), and fewer extreme winds were considered suboptimal for kelp resilience. These conditions prevailed during two recent time periods: 2002–2006; 2014–2019. During the 2014-2019 period, two warm water events in the North Pacific Ocean impacted nearshore SST. The first was an unprecedented MHW from 2013 to 2015 (Bond et al., 2015; Whitney, 2015) nicknamed "The Blob" which moved near the coastline in 2014, and the second was a strong El Niño event in 2015 to 2016 (Di Lorenzo and Mantua, 2016). Together they increased coastal SST from May 2014 through September 2016 (Gentemann et al., 2017). A heat dome in June 2021 brought further heat stress to kelp growing in the Salish Sea (White et al., 2023).

Kelp forest resilience to unfavorable climate conditions is highly variable throughout the Strait of Georgia, and the entire Salish Sea (Berry et al., 2021; Mora-Soto et al., 2024; Starko et al., 2024). On both a large scale, such as the Strait of Juan de Fuca, and a smaller scale, as in areas between islands, where resilience is associated with water flow. Prior to the marine heatwaves, which began in 2014, bull kelp forests in the northern Salish Sea formed relatively small and narrow but continuous beds at Discovery Passage and Quadra Island and further south at Galiano, Lasqueti, Texada, and Hornby Islands, whereas the more sheltered inlets had sparse kelp. Larger beds of kelp occupied the southern region along the coasts in the Strait of Juan de Fuca, in some semi-sheltered coasts in the southern Gulf Islands, and in Burrard Inlet.

In the classification of the Strait of Georgia coastline devised by Mora-Soto et al. (2024a; 2024b), the areas with the highest mean spring and summer temperatures, are where all the kelp restoration projects discussed in this review are located. Most of the locations facing the inner Strait of Georgia (Sunshine Coast, east and southeast sides of Denman and Hornby Islands, north and east coasts of Gabriola Island) are more exposed, resulting in higher fetch and wind speed. More sheltered locations, such as all coasts of Thetis Island, the western shores of Denman and Hornby Islands, Burrard Inlet, and Howe Sound, experience lower wind speeds and fetch, and the highest spring and summer temperatures.

Reassessment of kelp occurrences in the Salish Sea in 2022, after multiple years (2014-2016, and 2021) of marine heat waves, found an absence of kelp in the Strait of Georgia portion of the Salish Sea, particularly along the Sunshine Coast and around the northern Gulf Islands of Hornby, Lasqueti, and Texada, as well as the Discovery Passage and Quadra Island (Khangaonkar et al., 2021; Mora-Soto et al. 2024). In a comparison of kelp forests in BC during two time points, 2004–2007 and 2017–2021, parts of the inner Salish Sea were found to have experienced the highest temperatures and the greatest loss of kelp (Starko et al, 2024). Kelp forests on Valdes and Gabriola Islands declined by 74 per cent and the relatively persistent kelp beds around the nearby islands of Mayne and Saturna, saw declines in the northern parts of the islands facing the inner Salish Sea.

Local persistence of bull kelp beds in high current areas between the islands of Mayne, Valdes, and Gabriola suggests a role for water motion in moderating temperature (Starko et al., 2024). Kelp also persisted in small but continuous kelp beds further south in the southern Gulf Islands, Burrard Inlet, and the Strait of Juan de Fuca (Mora-Soto et al. 2024). The combination of temperature and current speed, and not fetch, best described kelp resilience in the southern region of SOG despite recurring MHWs (Starko et al., 2024).

The devastating impact of the 2014 MHW was recorded by a kelp restoration project conducting trials in Lambert Channel and Baynes Sound from 2011 to 2021 (Heath et al. 2015, Heath et al., 2017; Heath et al. 2022). Eagle Rock on the south end of Denman Island was initially chosen as a reference site because over a kilometre of fringing kelp reef had grown there as long as anyone remembered. Poor sori production in 2014 followed by poor recruitment of only 50 sporophytes the following year was attributed to high sea surface temperatures. In 2016, the kelp fringe failed to develop for the first time in memory, with no sign of recovery in subsequent years, until the project ended in 2021.

Northern portions of the SOG that experienced weaker summer winds and tidal currents and less freshwater inputs showed less resilient kelp than in the south (Mora-Soto et al, 2024a, Pena et al., 2016) A longer term trend of increasing SST may be associated with the decline in kelp forests around the more northerly Gulf Islands. *Nereocystis* presence in southern Puget Sound between 1873 and 2018 also declined mostly along sheltered shorelines where high temperatures and low nutrients aligned with little mixing from waves and current (Berry et al., 2021)

Concerned citizens sounded the alarm and scientist have provided empirical evidence of the decline in canopy-forming bull kelp in the Salish Sea on the Pacific Coast of Canada. These losses are reflected on coastlines around the globe, as countries report losses of kelp forests and the marine ecosystems they support. For a review of the many challenges to kelp survival in diverse countries including Australia, New Zealand, South Korea, Japan, Norway, France, Spain, Italy, Mexico, USA, Canada, and Chile, see the United Nations Environment Programme (2023) document "Into the Blue: Securing a Sustainable Future for Kelp Forest". The major threats include kelp overharvesting, increases in kelp grazing, increases in kelp encrustation by colonial zooids (bryozoans), loss of the predators of kelp grazers, reduced water quality from nutrient loading and other pollutants, increases in sedimentation and turbidity, increases in temperature, more frequent marine heatwaves, diseases, and invasive or range-expanding species of macroalgae (Eger et al., 2024).

Global hubs such as the Kelp Forest Alliance and the Green Gravel Group provide a tremendous service in bringing voices from around the world together to share stories of loss and successful restoration. While much can be learned by sharing experiences and knowledge from around the world, the *Nereocystis* forests of the Salish Sea are unique in many ways and require focused research and local experimentation. Concerns over the disappearance of the charismatic kelp canopy in the Salish Sea inspired concerned citizens to work together to restore bull kelp beds as early as 2006 in the areas first showing significant losses (NCES, 2009). As the effects of marine heat waves, a warming ocean, and other stressors affecting kelp expand to parts of the west and north coast of Vancouver Island, and the central and north coasts of BC, the local communities and Indigenous people reliant on them are collaborating with conservation groups, biologists, and resource managers to document the losses and consider restoration (AdminMaPP, 2019).

This review describes various methods used to restore, enhance, and rehabilitate kelp forests in the Salish Sea and other locations in BC. The level of success of these efforts is suggested by the extent of growth and reproduction by outplanted kelp seed and transplanted sporophytes. A timeline of the progression of these efforts is discussed in relation to environmental drivers, particularly sea surface temperatures. Lessons learned from these projects are summarized and some recommendations for future restoration methods and experiments, and directions for research are proposed.

"Literature" Review Methods

When few published scientific papers on kelp methodologies practiced in the northern Salish Sea/Strait of Georgia were found using various combinations of search terms ("kelp* OR macroalga* AND restor* AND Strait of Georgia OR Salish*) on Web of Science and the University of Vancouver Island Library system, the search turned to alternate sources. News articles and blog posts chronicling the amazing efforts of volunteer groups to restore kelp forests of coastal BC were important sources of information kelp restoration projects, as was the interactive Data Hub of the Kelp Forest Alliance. The most valuable source of practical information and insights came from personal communications with kelp restoration practitioners.

RESTORATION METHODS

Some resources are available to guide the practitioner in planning, designing, implementing, and monitoring kelp restoration. The chapter "Kelp forest restoration in action (methods)" (Eger et al., 2022a) in "Kelp Restoration Guidebook: Lessons Learned from Kelp Projects Around the World" (Eger et al., 2022bhttps://www.decadeonrestoration.org) describes the various methods used for restoring kelp practiced around the world including suggestions for a range of important topics from planning and obtaining permits to nursery and outplanting. A detailed graphic of kelp restoration procedures, from permitting to outplanting can be viewed on the "Mysterious World of bull kelp" website.

A protocol for producing and growing bull kelp sporophytes in a closed system, with the potential for temperature and flow experiments, has been developed at the University of British Columbia (Suprataya and Martone, 2023). The Puget Sound Restoration Fund (PSRF) has produced a step-by-step guide to nursery production of bull kelp seed: "Kelp Cultivation Handbook" The "Puget Sound Restoration Fund, Final Report. Bull Kelp Early Life History Study" by B. Allen (2018) provides insights into the best timing and life stage of kelp for outplanting through systematic experimentation at Tyee Shoal, outside of Bainbridge Island's Eagle Harbor, in Puget Sound.

South Korea is a world leader in kelp restoration, with 29,000 hectares of kelp forest under restoration, with a 50% success rate (Eger et al., n.d.). The Korea Fisheries Resource Agency (FIRA), responsible for implementing the ambitious plan to restore 30,000 ha of kelp forests by the year 2030 has made available "The Process for the Marine Forest Project" (2018) which describes planning site selection, artificial reefs, methods of outplanting and transplanting, herbivore control, monitoring, and evaluation. Although written for the Korean situation, many adaptable and thought-provoking methods are suggested.

The comprehensive description of nursery methods for growing a variety of kelp species can be found in the "Kelp Farming Manual: A Guide to the Processes, Techniques, and Equipment for Farming Kelp in New England Waters" (Flavin et al., 2013) and "New England Seaweed Culture Handbook: Nursery Systems" (Redmond et al., 2014) are readily adaptable to production of bull kelp seed for restoration purposes. A very detailed and well photographed description of the "green" gravel method of producing kelp seed on stones in a nursery has been written by Lamb et al (2023).

The goal of all the methods used in bull kelp restoration trials in BC is to grow a forest to restore a forest. By placing kelp seed (propagules) or transplanting small individual sporophytes near the seabed, a cohort of individuals will grow to maturity, enhancing recruitment of kelp to the area when spores are released, dropping to the seabed nearby, and developing to produce a new generation of juvenile sporophytes.

These are the various methods of kelp restoration trialed in the Salish Sea and other locations in BC:

1. Transferring sori in onion bags or perforated carboys

2. Seeded lines produced in a nursery, wrapped around pipes, ropes and deployed near the bottom and off-bottom
3. Seeded stones (green gravel) or tiles, produced in a nursery then deployed on the sea floor
4. Transplanting small sporophytes
5. Herbivore management
6. Site reclamation/rehabilitation

Note: Projects restore or enhance bull kelp (*Nereocystis*) unless stated otherwise

How each of these methods is used in kelp restoration in the Salish Sea and other regions of BC is briefly described in the following section. Find more details about each project and sources of information about them in Appendix I.

1. TRANSFERRING SORI IN ONION BAGS OR PERFORATED CARBOYS

Blades containing reproductive tissue called sori are collected from donor kelp sporophytes located from an area selected for its proximity to the enhancement site. They may be cleaned of debris, pre-treated with iodine, then dried out for about 36 hours, before stuffing into onion sacks or perforated plastic carboys. Each sack or carboy is attached at one end to an anchor, usually a concrete block, and at the other a float for suspension and recognition.

Two groups have reported using this method:

- Nile Creek Enhancement Society (NCES) near the Nile Creek estuary in Bowser (2007);
- Help the Kelp, Gabriola Island at Clark Bay (2013).

The Gabriola Island citizen science group Help the Kelp reported increased growth of bull kelp observed off the shores of Gabriola in 2013, but they weren't sure if it was the result of enhancement efforts earlier in the year. On a dive survey around Clark Bay the following year, the area of enhancement they saw had many times more bull kelp sporophytes than counted during kelp mapping in 2013, which also saw various other kelp species. No reports were found on the success of the sori transfer method used by NCES in enhancing bull kelp in the nearshore areas around Nile Creek in Bowser on Vancouver Island, although the cumulative effects of all the Society's efforts to rehabilitate the Nile Creek and estuary for Pacific salmon and cutthroat trout were successful.

The method of transferring sori for enhancing or restoring kelp to an area is a straightforward procedure that doesn't require specialized laboratory equipment. However, assessing the efficacy of the method is difficult because enhanced kelp sporophytes may not be distinguishable from naturally recruited ones.

2. SEEDED LINES

Anchoring ropes of seeded line or twine near the sea bottom is a method adapted from techniques used in seaweed aquaculture. The seeded line contains kelp propagules; a combination of small sporophytes and possibly some gametophytes. Juvenile kelp sporophytes may attach to the line at a density of 1-5 per centimetre (cm), with each sporophyte only a few millimetres (mm) tall or up to 1 cm, depending on how long they have grown in a nursery. Seeded lines of bull kelp may be deployed between late December and late February, depending on the site. Conventional wisdom once warned practitioners to get seed into the seawater before the winter solstice, but more recent findings suggest survival is better if seed are outplanted later to avoid some winter grazers, but before the diatom blooms arrive in spring (Allen, 2018).

Once an appropriate site for restoration is identified, reproductive tissue or sori from blades of mature sporophytes may be collected in the late summer-early fall, from nearby locations. Collection within a range of 50 km is currently recommended by the BC Ministry of Agriculture and Fisheries (Denley, 2025) and delivered to a nursery for production of seed spools. This usually takes place in the late summer or early fall of the year, a month or more prior to outplanting.

A full description of how to design and operate a seaweed nursery is available in the Kelp Nursery Manual by Flavin et al. (2013) and is summarized as follows. Containers for culturing kelp early life stages are most often glass aquaria, set up with lighting systems and housed in a cool chamber where temperature can be maintained around 10 °C. Seed spools are made from 25-30 cm lengths (depending on the height of the aquaria) of 5-8 cm diameter, polyvinyl chloride (PVC) pipe around which string or twine is tightly wound. Spools and string must be soaked and cleaned well to remove chemical residues. Multiple spools are placed standing upright in an aquarium and lights are generally set up on two sides.

Sorus tissue should be collected from at least 20 individual sporophytes. When sorus tissue arrives in the nursery, it is cleaned with an iodine solution, kept cool and semi-dry for up to 12 hours, then immersed in filtered seawater triggering spore release. Spore density is determined and containers, generally glass aquariums, are filled with spools of string or twine, filtered seawater, and an appropriate amount of spore and kept in the dark for 24 hours. During this time spores will settle onto the string and germinate to become male and female gametophytes. Alternatively, the nursery may use gametophytes selected from a “seed” bank, a collection of gametophytes maintained in a vegetative state by reducing nutrient and irradiance levels. Over the next four weeks, gametophytes grow and become reproductive, with males producing sperm, which swim a short distance to fertilize an egg attached to a female gametophyte. The fertilized eggs begin dividing, growing into young sporophytes that are visible as a brown film on the white string. Approximately four weeks after spore release, the spools are ready for transfer to the ocean.

Back at the restoration site, anchors, usually concrete blocks, are placed on the sea bottom at a depth at which sporophytes would still be covered by 1 m of water on a zero tide (ideally 5-8 m depth), and at a distance which will be spanned by a rope of desired length; 30 m lines are common. New 19 mm (about 0.75 in) diameter Polysteel™ rope is recommended, but used rope will suffice if well cleaned of old kelp holdfasts or heavy biofouling. The experimental restoration site established at Maude Reef at Hornby Island in 2011 was home to a grid structure, approximately 30 m x 40 m in size, at a depth of about 7 m, with up to 7 kelp culture lines, although 6 were usually deployed at one time (Figure 1). The intention was to build a structure that is robust enough to support a large population of mature kelp plants (with significant buoyancy and drag forces) and be usable for multiple years but can be removed when not further needed (Figure 2). The culture grid system is modeled after one used by Louis Druehl of Canadian Kelp Resources Ltd. for experimental trials at Bamfield, BC.

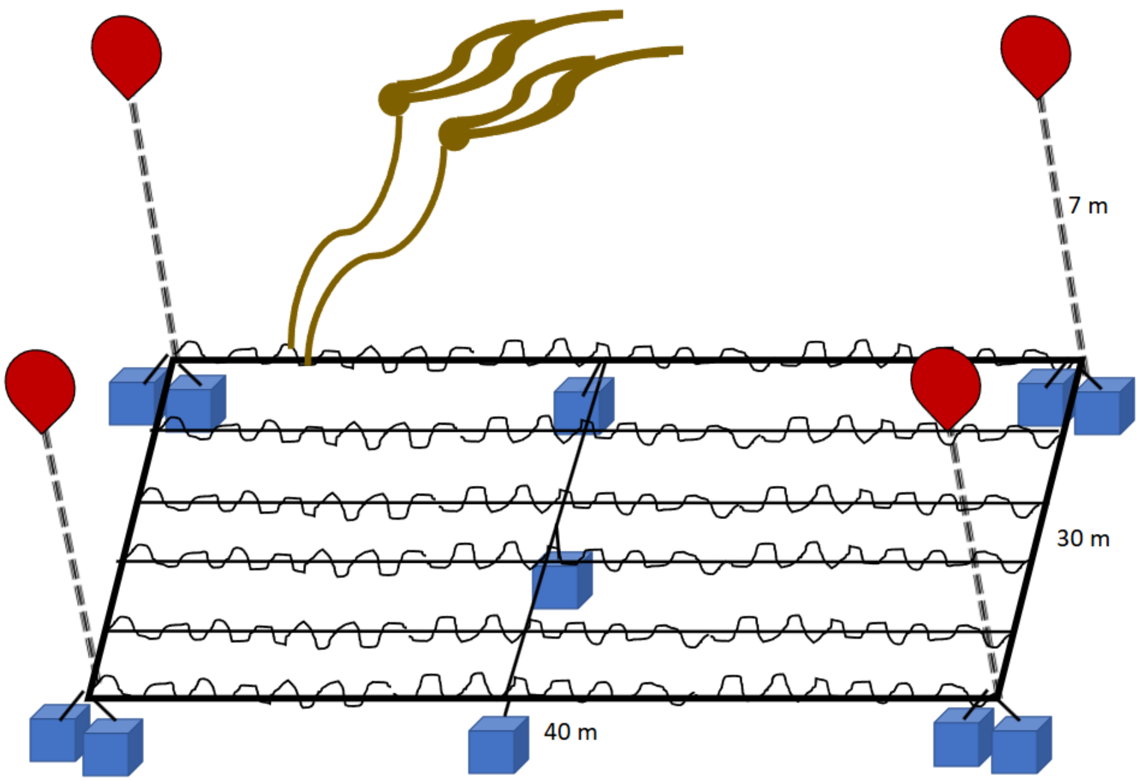


Figure 1. Sketch of bull kelp grid structure installed at Maude Reef, Hornby Island site (adapted from Heath, Zielinsky, and Zielinsky, 2015b; permission to use given).

Figure 2. Bull kelp growing up to reach the ocean surface at the experimental restoration site at Maude Reef, Horny Island (Heath, Zielinsky, and Zielinsky, 2018a; permission to use given).

Most of the groups involved in bull kelp restoration in the Salish Sea and other areas of coastal BC have used seeded lines in kelp restoration trials with bull kelp, *Nereocystis luetkeana*, unless otherwise stated.

- Nile Creek Enhancement Society (NCES), Hornby Island Diving, and Comox Valley Project Watershed Society (PWS) at Maude Reef in Lambert Channel near Hornby Island, Island Scallops lease near Bowser, Cape Lazo Shoal, and other sites in northern Baynes Sound (2011-2017)
- Project Watershed Society (PWS) and Hornby Island Diving at Maude Reef in Lambert Channel near Hornby Island (2018-2022)
- Help the Kelp, Gabriola Island (2011)
- Mount Arrowsmith Biosphere Region Research Institute (MABRRI) at the Winchelsea Islands and Northumberland Channel (2018, 2019)
- Independent, Lee-Ann Ellis at Nelson Island (2018-2019)
- Vital Kelp at Jeddah Point, Sunshine Coast (2021-2022)
- Thetis Island Marine Explorers (volunteer divers), Ocean Wise, & Canadian Kelp Research at North Cove and Pilkey Point on Thetis Island (2023, 2024)
- Archipelago Marine Research Ltd. for DND at Esquimalt Harbour, Esquimalt (2017) (results not available)
- Kelp Rescue Initiative (KRI), University of Victoria (UVic) Bamfield Marine Science Centre (BMSC), and Hornby Island Diving at Maude Reef near Hornby Island and Eagle Rock near Denman Island (2024-)

- Ausenco - Viterra-Cascadia terminal capacity expansion artificial reef at Second Narrows, Burrard Inlet (2021)
- Ocean Wise, Metlakatla Development Corporation, Ecotrust Canada, Ts'msyen Territory near Prince Rupert (2023)
- Toquaht First Nation, Redd Fish Restoration Society, and West Coast Kelp, intukʷaaʔatḥ (Toquaht) territory; Toquaht Bay and Mayne Bay, western Barkley Sound (2024) (results pending)
- Puget Sound Restoration Fund (PSRF), Central Puget Sound Kelp Forest Enhancement at Doe Kag Wats/Jefferson Head, Puget Sound, WA (2020-)
- Canadian Kelp Research (was Canadian Kelp Resources), Bamfield, Barkley Sound, original grid design adopted by NCES - CVPWS (experimental growth trials not for restoration; prototype) and provides seed and advice to many projects.

Of the 29 trials (site/year) that reported results, 20 (69%) reported growth reaching near the surface of the water, 17 (59%) saw bull kelp survive to produce sori (Table 1). Ten trials (34%) reported the presence of recruits (naturally-set young of the year), usually a small number (1-6); recruits were observed on long term mooring lines at the Maude Reef site in 2016 and 2017, one in 2019, and six were seen the following year (Figure 3) (Heath et al, 2017; Heath et al. 2022); 1-3 recruits were recorded each year at Doe Kag Wats/Jefferson Head, Puget Sound, except in 2024 when 33 were reported (Hayford, 2025; H. Hayford, PSRF, personal communication, March 26, 2025).

Figure 3 Bull kelp growing to reach the surface at the experimental restoration site at Maude Reef, Hornby Island, Lambert Channel (Heath, Zielinsky, and Zielinsky, 2018a; permission to use given).

Table 1. Growth and maturity of bull kelp outplanted as seeded lines at sites in the Salish Sea and British Columbia by year. The number and length (m) of lines outplanted, extent of growth, and presence of reproductive tissue (sori) or recruits (naturally sourced young sporophytes) observed. Restoration trials of bull kelp, *Nereocystis luetkeana*, unless otherwise stated.

SITE	YEAR	LINE AMOUNT (M)	RESULTS (GROWTH EXTENT)	SORI; RECRUITS	ISSUES
Maude Reef, Hornby Island	2013	Dec. 2012; 6 x 30 m	Few bull kelp plants grew to maturity. Deteriorated in June and July as the plants matured early and shed sori from fronds.	A few sori	Competition from laminarian kelps and hydroids. Lower light intensity on bottom. Kelp matured and decomposed early.
Maude Reef, Hornby Island	2014	Jan. 2014; 6 x 30 m	Huge crop of healthy bull kelp by May. Deteriorated in June and July as the plants matured early and shed sori from fronds	Sori	20 or more days at 15-16 °C in June 2014 saw kelp mature and begin deteriorating; prolonged high temperatures (18-20 °C) in late July and most of August proved lethal to the remaining bull kelp.
Maude Reef, Hornby Island	2015	Jan. 2015; 6 x 30 m	Heavy growth in May, reached the surface then began deteriorating due to heat and epiphytes and epizoans (bryozoans); done by August.	Small amount of sori	Bryozoans. 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 .
Northern Baynes Sound	2015	Jan. 2015; 1 x 15 m;	Grazed by kelp crabs before reaching surface	No	Kelp crab grazing.
Island Scallops, Bowser	2015	1 x 15 m; Jan. 2015	Some growth, 30 to 50 cm long, patchy distribution noted in July (only site visit).	Not Reported (NR)	
Maude Reef, Hornby Island	2016	6 x 30 m; Dec. 2015	Grew well and remained quite healthy into August Some recruits observed on long-term mooring lines.	Significant sori production	Some cooler periods in summer.

SITE	YEAR	LINE AMOUNT (M)	RESULTS (GROWTH EXTENT)	SORI; RECRUITS	ISSUES
				and release; Some recruits	
Maude Reef deeper site	2016	1 x 15 m; Dec. 2015	Grew well and remained quite healthy into October.	Significant sori production and release	Some cooler periods in summer.
Cape Lazo shoal	2016	1 x 15 m; Dec. 2015	Grew well.	Significant sori production and release	
Maude Reef, Hornby Island	2017	Dec. 2016; 6 x 30 m	Early on, reached the surface, then began deteriorating due to heat; done by August. Some recruits observed on long-term mooring lines	Some early sori; Some recruits	
Maude Reef, Hornby Island deeper site	2017	Dec. 2016; 1 x 15 m	Early growth reached the surface then began deteriorating due to heat; done by August. Some recruits observed on long-term mooring lines.	Some early sori	
Cape Lazo shoal	2017	Dec. 2016; 1 x 15 m	NR	NR	
Maude Reef, Hornby Island	2018	Dec. 12, 2017; 6 x 30 m	NR	NR	
Cape Lazo shoal	2018	Dec. 13, 2017; 1 x 15 m	Destroyed by storm.	No	
Maude Reef,	2018-2019	Dec. 27, 2018; 6 x 30 m	Sansum Narrows and Oyster River bull kelp seed.	One 2′ tall recruit;	Temperatures exceeded the 17 °C threshold for

SITE	YEAR	LINE AMOUNT (M)	RESULTS (GROWTH EXTENT)	SORI; RECRUITS	ISSUES
Hornby Island			Jun. 21, a well-developed canopy had formed. By mid-July, bull kelp was subject to widespread bryozoan colonization and blades were deteriorating from thermal stress (prolonged exposure to >17 – 18 °C). Nov. 15 all bull kelp floats gone.	Some sori in July	prolonged exposure. High green urchin density in 2018, almost none in 2019.
Maude Reef, Hornby Island	2020-2021	Dec. 24, 2020; 4 x 30 m, 1 x 30 m in exclosure	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. Aug. 27 some bull kelp still present but in poor condition, deeper kelp in relatively better condition.	Six bull kelp recruits; Some sori in Aug.	Rapid decline in bull kelp condition with arrival of a heat dome in late June 2021. Red urchin density high; small green urchins appeared in July.
Clark Bay, Gabriola Island	2011	2 x 30 m	Kelp failed to grow, and other kelp species colonized the lines.	No	Possible overgrowth by other kelp species.
Northum-berland Channel	2018	2 x 30 m Mar. 4, 5	No growth on seeded lines, possibly deployed too late.	No	Possibly deployed too late.
Winchel-sea Islets	2018	2 x 30 m Mar. 4, 5	No growth on seeded lines, possibly deployed too late.	No	Possibly deployed too late.
Northum-berland Channel	2019	Jan 13; 3 x 30 m	Good growth through to August then 50 % lost to urchin grazing; surviving kelp produced sori. 67 % (4/6) of the kelp transplants survived 76 days; 33 % survived to day 89. Grew on average 9.8 cm/day to 894.5 cm max average. Growth was much faster at the Northumberland site.	Sori	Urchin grazing.

SITE	YEAR	LINE AMOUNT (M)	RESULTS (GROWTH EXTENT)	SORI; RECRUITS	ISSUES
Winchel-sea Islets	2019	Jan 13; 3 x 30 m	Good growth through to August, then all lost to urchin grazing. 67 % (4/6) kelp transplants survived to Aug. 10 (76 days); none survived to day 89; growth to the surface on day 76; grew 0.7 cm/day to 99.8 cm max average; disappeared from surface on Aug. 23 (Day 89).	No	Urchin grazing.
Nelson Island	2018-19	Dec 2018; 13 x 15 m	Rapid growth in March; an epiphyte and fish community developed by July; kelp die-off occurred in the summer, possibly a natural process. In subsequent years some kelp was transplanted or weighted down.	Sori	Warm temperatures in summer lead to a die-off.
North Cove, Thetis Island	2023	Jan 28, 2023; 1 x 20 m	Kelp grew well on lines at Fraser Point, North Cove until spring/summer found it was decimated by northern kelp crabs.	No	Kelp crab grazing.
North Cove, Thetis Island	2023-24	Dec 23, 2023; 1 x 20 m	April 2024 Divers saw at most 10 kelp that had grown about 10 cm tall and had pneumatocysts. The rest of the line was clean. Next check in June all the kelp were gone and lines covered with kelp crabs.	No	Kelp crab grazing.
Pilkey Point, Thetis Island	2022-23	Dec 01, 2022; 1 x 20 m	Kelp grew poorly and sparsely for a short time. No history of bull kelp here.	No	No history of kelp.
Viterra-Cascadia terminal capacity expansio	2021	Date? 18 spools Dive team deployed the kelp seed lines	NR		

SITE	YEAR	LINE AMOUNT (M)	RESULTS (GROWTH EXTENT)	SORI; RECRUITS	ISSUES
n offset, Second Narrows, Burrard Inlet		onto in-house fabricated anchors and lines around an artificial reef, into 7°C ocean water.			
Ts'msyen Territory near Prince Rupert	2023	Mid-March 2023, Outplanted approximately 1.6 km of bull kelp seed spools on a disused oyster lease.	There was limited kelp growth on the lines	No	Possibly due to late outplanting (mid-March) or damage to spools during the long transportation from Bamfield to Prince Rupert.
Denman Island	2024	Feb. 24, 2024 Seeded twine in an urchin exclosure. *Also tiles and cobble that grew well*	?	?	
Maude Reef, Hornby Island	2024	Feb 26, 2024 Experimentally testing five *N. luetkeana* populations with different thermal histories and tolerances grown on a line array.	All populations grew, exhibited varying growth characteristics, but all showed signs of stress when high temperatures arrived in July.	Some produced sori.	Reduced lifespan due to high temperatures.
Smith Cove, Puget Sound	2021	Pyramidal anchor blocks were wrapped with kelp-seeded twine	Adult *Nereocystis* plants were successfully grown from outplanted juvenile sporophytes. None of the adult plants persisted very long and quickly lost all	No	Possibly due to low surface salinity

SITE	YEAR	LINE AMOUNT (M)	RESULTS (GROWTH EXTENT)	SORI; RECRUITS	ISSUES
		and installed	blades upon reaching the surface" possibly "due to low surface salinity		
Central Puget Sound Kelp Forest Enhancement at Doe Kag Wats0/Jefferson Head	2020	450 m of twine seeded with bull kelp onto longlines anchored to the seafloor, outplanted in late winter/early spring	Outplanted kelp has spanned seafloor to surface each year	Sori; 1-3 recruits	
	2021			Sori; 1-3 recruits	
	2022			Sori; 1-3 recruits	
	2023			Sori; 1-3 recruits	Surveys show wild bull kelp in Puget Sound also thriving into Sep./Oct.
	2024			Sori; 33 recruits	Increased amount of outplants and longer reproductive season in 2023

Some groups deployed seeded lines in unique ways:

- Nile Creek Enhancement Society (NCES) (2006-2010) deployed segments of seeded line attached to onion sacks of rocks from the Nile Creek north to Denman Island;
- Help the Kelp, Gabriola Island (2009) attached segments of line to rocks and dropped into Ford Cove, Gabriola Island;
- Puget Sound Restoration Fund (2019) wrapped seed line around pyramidal concrete anchor blocks at Smith Cove;
- KRI, UVic, Bamfield MS & VIU DBMFS placed seeded line within a fence exclosure on Denman Island 2024.

None of these groups reported successful growth to maturity, although Help the Kelp, Gabriola Island did note, "there appeared to be a small but non-measurable increase in bull kelp in the following years", which could indicate recruitment after enhancement.

3. SEEDED STONES ("GREEN GRAVEL") OR TILES

Green gravel, the name given to the practice of growing juvenile sporophytes from spores settled on small rocks in a nursery, is a relatively new approach to kelp restoration. The process of collecting sori from wild kelp and releasing zoospores is similar to seeded lines, only the procedures for inoculating the substrate and growing up the gametophytes, and very small sporophytes, differ. Basically, gametophytes are cultured on gravel, small cobble-sized rocks, or tiles, and once the sporophytes reach 2-3 cm, the rocks are dropped in the reef to grow out. Details on the nursery production of green gravel can be found in the Kelp Restoration Guidebook: Lessons Learned from Kelp Projects Around the World (Eger et al., 2022). As these methods were perfected for species in other parts of the world, they may need some adjusting to suit bull kelp and local needs. Learn more about green gravel and how and where it has been used at greengravel.org.

Cobble-sized rocks and tiles attached to large rocks or concrete blocks, are more effective for outplanting bull kelp than small rocks (3-5 cm) because of their fast growth rate (Good, 2024; Schuster, 2025). The stipe and pneumatocyst of *Nereocystis luetkeana* grow faster than the haptera that form the holdfast for attachment resulting in kelp sporophytes becoming buoyant and floating away before growing adequate attachment to the underlying stable substrate.

One advantage of the green gravel method is that the gravel/cobble/tiles can be deployed from a boat at the surface of the water removing the need for divers in the outplanting process. However, divers are used for deployment in some experimental trials to place substrate material within quadrats or along transects for quantitative analysis of results.

The use of the green gravel method for restoration of kelp species in BC began in Barkley Sound in 2021, with trials on bull kelp *Nereocystis luetkeana,* sugar kelp *(Saccharina latissima*), and giant kelp *(Macrocystis pyrifera*). Nursery methods and deployment techniques are being adapted for each species and expanded to project sites in the SOG.

- Ocean Wise Canada, Canadian Kelp Resources, Rendezvous Dive Adventures, Barkley Sound - bull kelp, sugar kelp, giant kelp (2021-2022)
- Neptune Terminals and UBC (Patrick Martone) - *N. luetkeana* on tiles in Burrard Inlet (2023-2024)
- Thetis Island Marine Explorers (volunteer divers), Ocean Wise, Canadian Kelp Resource - *N. luetkeana* at two sites near Thetis Island (2022-2023 and 2024)
- Ocean Wise Canada with the Tsleil-Waututh First Nation (TWN) - (*S. latissima*) on pebbles/cobble and oyster shells at False Narrows, Burrard Inlet (2024)
- Kelp Rescue Initiative (KRI) & Tsleil-Waututh Nation - *N. luetkeana* on seeded tiles, gravel, and cobble/rocks in Burrard Inlet (2023, 2024)
- KRI, UVic, BMSC & Hornby Island Diving - *N. luetkeana* on gravel, cobble, tiles, twine and direct seeding tested inside an urchin fence at Denman Island south (2024)
- KRI, UVic, BMSC - *M. pyrifera* and *N. luetkeana* on gravel and cobble in urchin cages at six sites in Barkley Sound (2024)

- Snuneymuxw First Nation and Cascadia Seaweed – *N. luetkeana* on fist-sized cobble at sites around Gabriola Island (2023, 2024-2025)

Of the 9 trials/year reporting results of bull kelp, five (40%) reported growth reaching the surface, and four of the eleven trials (30%) reached maturity with production of sori (Table 2).

Table 2. Locations where green gravel, cobble, or tiles were deployed for kelp restoration or enhancement in BC (NR, not reported).

LOCATION	DATE	METHOD	RESULTS (GROWTH EXTENT)	SORI: RECRUITS	ISSUE
Rainy Bay, Barkley Sound Nuu-chah-nulth territory, WCVI	2021-2022	*Nereocystis luetkeana, Saccharina latissima, Macrocystis pyrifera*. Sep. 2021, approximately 148,000 pieces of gravel seeded with bull kelp, sugar kelp, and giant kelp, dispersed over two, 100 m transects.	The giant kelp flourished while the bull kelp did not successfully establish.	Not bull kelp.	The green gravel planting process was considered simple, but transport of pebbles was not readily scalable.
Neptune's water lot Berth 2, Burrard Inlet	2023-2024	Lab-grown juvenile sporophytes on tiles were placed on Neptunes water lots	High survival of small bull kelp sporophytes six weeks after outplant. Sporophytes reached the surface and became reproductive.	Sori present	
Rocket Shoal, Clam Bay, Thetis Island	2023	Jan 31, 2023, Gravel	No growth	No	Not a site with previous kelp
Escape Reef, Thetis Island	2024	Dec 26, 2023, Gravel	No growth when checked in May 2024	No	
False Creek, Burrard Inlet	2024	Sugar kelp (*Saccharina latissima*) grown on pebbles/ cobble and	Growth and health of outplanted kelp	NR	Oyster shell proved to be too light weight for restoration.

LOCATION	DATE	METHOD	RESULTS (GROWTH EXTENT)	SORI: RECRUITS	ISSUE
		oyster shells. Outplanted February 2024 into False Creek in modified crab traps suspended in the water on ropes and transplanted in Burrard Inlet in early May 2024.	exceeded expectations despite the date of outplanting (February) being later than the recommended December.		
Burrard Inlet, 3 sites: New Brighton, Crab Park, and Nine O'clock Gun in	2023	Feb. 27-28, 2023 *N. luetkeana* Outplanted seeded tiles, gravel, cobble/rocks.	Kelp grew well from seeded tiles and larger cobble/rocks, reaching surface by June. Reached 3 to 4 metres at and Nine O'clock Gun in September. Did not survive to late summer.	Sori were found in 50% to 70% of individuals in September	By April, about 50% of green gravel was gone from plots possibly due to floating away as kelp grew. Steep slopes and larger boulders with crevices between create an environment where 3 to 5 cm gravel exposed to current could either fall between rocks or fall out of the depth range
Burrard Inlet	2024	Mar 01, 2024 *N. luetkeana* Outplanted seeded tiles, gravel, and cobble/rocks.	Kelp grew really well from seeded tiles and larger cobble/rocks. Reached surface by June with reproductive tissue observed on many individuals.	Many sori	
Maude Reef, Hornby Island	2024	Feb 26, 2024 Experimentally testing five *N. luetkeana* populations with different thermal histories and tolerances grown on a line array.	Differing growth patterns, all reached the surface.	Some were able to produce sori	All kelp showed signs of extreme tissue stress by July due to heat.

LOCATION	DATE	METHOD	RESULTS (GROWTH EXTENT)	SORI: RECRUITS	ISSUE
Denman Island, south	2024	Feb 26, 2024 Five different bull kelp restoration methods (gravel, cobble, tiles, twine and direct seeding) tested inside an urchin fence.	Kelp grew well; cobble and tiles performed best.	Produced sori	Protection from grazing
Barkley Sound	2024	Testing different kelp culturing and outplanting methods for *N. luetkeana* and *M. pyrifera* at six sites using two sizes of green gravel/cobble and urchin cages.	Giant kelp grew well; bull kelp was less successful.	No	Urchin cages were not super effective, got tossed around during storms
Taylor Bay, De Courcy Passage, Gabriola Island	2023	Several sites; outplanted early due to diatom problems in nursery	No growth	No	Outplanted too early
Taylor Bay, De Courcy Passage, Gabriola Island	2024-25	Nov-Dec 2024. Several sites; > fist-sized cobble plus tiles attached to concrete blocks	Pending		

Innovative methods of outplanting are being explored by collaborations with First Nations to incorporate Indigenous traditional knowledge to make restoration methods accessible to all (Martone, 2025). Collaborations with səlilwətaɬ (Tsleil-Waututh Nation) have trialed the use of oyster shell (Ocean Wise, Janke, 2024) and cedar rope (Martone, 2025) as substrates for bull kelp propagule collection.

4. TRANSPLANTING SMALL SPOROPHYTES

Small kelp sporophytes are collected from a donor site or found afloat after being dislodged by storm or current stress. Many methods have been tried to temporarily attach small sporophytes to a substrate without damaging the stipe until a permanent holdfast is grown. Multiple groups in the Salish Sea and other locations in BC have trialed temporary attachment methods with varying degrees of success, including combinations of natural rubber bands, nylon cord, cable ties, and surgical tape, hard plastic clips, and Epoxy resin, and other undisclosed methods.

- MABRRI at Northumberland Channel and Winchelsea Islands (2018)
- PWS at Maude Reef, Hornby Island (2020)
- Vital Kelp at Jeddah Point, Sunshine Coast (2021-2022)
- Neptune Terminals and Dynamic Ocean Consulting in Burrard Inlet (2023-2024)
- Ocean Wise Canada with the Tsleil-Waututh First Nation (TWN) in Burrard Inlet (2023)
- Ocean Wise, Tseshaht First Nation, and West Coast Kelp at southern Pinkerton Islands in Barkley Sound (giant kelp) (2024?)
- Toquaht Nation, Redd Fish Restoration Society, and West Coast Kelp - *Macrocystis* in Toquaht Bay (2024), results pending
- Carney et al. 2005, Friday Harbor (2003)
- Puget Sound Restoration Fund - Central Puget Sound Kelp Forest Enhancement at Doe Kag Wats/Jefferson Head in Puget Sound (2020-2024)

Of the six site/years of transplanting reporting results, four grew to the surface (67%), and all of these reported the presence of sori (Table 3).

Table 3. Locations where young bull kelp sporophytes were transplanted for kelp restoration or enhancement in the Salish Sea and other locations in BC (NR, not reported).

LOCATION	DATE	METHOD	RESULTS (GROWTH EXTENT)	SORI: RECRUITS	ISSUE
Northum-berland Channel	2018	June 6, 12 stray bull kelp sporophytes from the area were attached to the lines at the two sites using two methods: nylon cord and cable ties or surgical tape.	August 16, 2018, seven individuals remained between both sites; four individuals that were attached via nylon cord, and three individuals that were attached via cable ties and surgical tape.	Yes Between the two sites, five individuals were observed to have sori over the summer	The individuals that did not survive either snapped along their stipe, were grazed, or were completely absent from the site.
Winchelsea Islands	2018	June 6, 12 stray bull kelp sporophytes from the area were attached to the ropes at the two sites using two methods: nylon cord and cable ties or surgical tape			
Maude Reef, Denman Island	2020	Apr. 5, transplanted small kelp plants attached to individual rocks from the healthy Oyster River donor site to Maude Reef site "exclosure"	May 5, healthy condition with lots of sori patches. May 22, 9 transplants remain, loss due to current drag; lots of sori on larger sporophytes and ends of blades starting to break down. Jun 11, only 3 transplants remain along with one red urchin in enclosure. Jun. 16 kelp present on surface at 11' tide. Jul. 24, all bulbs and blades gone.	Sori present	Insufficient anchoring - bigger rocks needed. Temperature $\geq$20 °C for last two weeks of July.
Jeddah Point, Sunshine Coast	2021-2022	100 early sporophytes grown on lines at	Haptera developed in 2-4 weeks. Two thirds survived,	Sori; no recruits	

LOCATION	DATE	METHOD	RESULTS (GROWTH EXTENT)	SORI: RECRUITS	ISSUE
		aquaculture site were attached to rocks with rubber bands, deployed to sea bottom from kayaks	matured, produced sori.		
Neptune's water lot Berth 2, Burrard Inlet	2023-2024	Bull kelp was transplanted within Neptune's water lots	NR		
Burrard Inlet	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 (Burrard Inlet).	Kelp did not thrive	No	Probably due to poor site selection; site may be too deep and turbid for the bull kelp to survive.
Friday Harbor, San Juan Islands	2003, Mar-Jul	*N. luetkeana* thalli of <15 cm were transplanted from wild populations into restoration sites. Juveniles were inserted into rope sections, which were then threaded through a hard plastic clip. The clip was glued to the substrate with epoxy.	Twenty-eight percent of the transplants survived throughout the study period for at least 80 days.	Shed sori	Highest mortality rate (56 %) occurred in the first 24 days primarily due to method: 97% to a break in the epoxy bond between the clip and substrate. Stipe breakage due to grazing, primarily by *Lacuna vincta*, was also a problem.

5. HERBIVORE (SEA URCHIN, KELP CRAB, ETC.) MANAGEMENT

Some attempts have been made to combat lethal levels of grazing, primarily by sea urchins, although damaging levels of grazing from northern kelp crabs (*Pugettia productus*) and gastropod snails such as *Lacuna vincta* have also been reported. Northern kelp crabs caused kelp mortalities at Eagle Rock, near Denman Island and a restoration site in northern Baynes Sound was abandoned because of heavy grazing (Heath et al. 2015). Kelp restoration trials at North Cove, Thetis Island were also abandoned after two seasons of total decimation of kelp growing on lines by kelp crabs (A. Eriksson, personal communication, February 11, 2025; A. Lamb, personal communication, February 11, 2025). The Puget Sound Restoration Fund Squaxin Island Kelp Bed reported a decline in restoration success due to massive levels of grazing by kelp crabs resulting from a reduction in top-down predators such as rock fish and lingcod (PSRF and Toft, 2024). Kelp crabs are the main herbivore of concern at kelp restoration sites in Puget Sound, WA (Hayford, 2025). The only suggestion for reducing the impact of grazing by kelp crabs on kelp was to avoid the site (Heath et al., 2022).

Grazing of bull kelp stipes by *Lacuna vincta* caused breakage and loss for transplant trials around San Juan Island, WA (Carney et al. 2005), and grazer-related losses due to snails was also a problem for newly outplanted kelp around Gabriola Island (J. Clarke, personal communication, March 18, 2025). It was suggested new sporophytes outplanted in late winter were less susceptible to gastropod grazing because there were alternate food sources for them (B. Timmer, personal communication, February 25, 2025).

The most common cause of over-grazing of outplanted and wild bull kelp in the northern Salish Sea is green sea urchins (*Strongylocentrotus droebachiensis*) and red sea urchins (*Mesocentrotus franciscanus*), with the addition of purple sea urchins (*S. purpuratus*) on the outer coasts of BC and WA and the Strait of Juan de Fuca (Heath et al., 2022; Lamb et al, 2011). Overgrazing by sea urchins around Nelson Island in the northeast Salish Sea was considered the cause of the disappearance of bull kelp beds (Ennis, 2024) as was the disappearance of entire beds of kelp (*Neoagarum fimbriatum*) in Howe Sound after the mass mortality of sea stars since 2013 and the increase in green urchin abundance (Borden, 2018). Loss of top-down predation by sea otters (*Enhydra lutris*) around Haida Gwaii resulted in over-abundance of sea urchins, and sea urchin barrens left where bull kelp and giant kelp beds once flourished (Lee, 2024; Parks Canada, n.d.)

Heavy grazing by sea urchins caused losses at Eagle Rock, Denman Island due to increased abundance of green urchin grazing shallower than the usual red urchins, preventing colonization of the cooler depths below 6-7 m (Heath et al., 2017). After the disappearance of green urchins from the site in 2018, red urchins took over from the green urchins and there was lots of grazing pressure on sugar kelp (S*accharina latissima*) and other macroalgae (Heath et al., 2022). When sea urchin relocation/exclusion and thinning experiments were carried out at the Maude Reef, Lambert channel restoration site, an "exclosure" device proved very effective in excluding sea urchins and allowing a dense assemblage of kelps to develop (Figure 4). A Vexar™ fence strategically placed at the Eagle Rock, Denman Island site also prevented urchins from grazing on kelp restoration trials (Schuster, 2025).

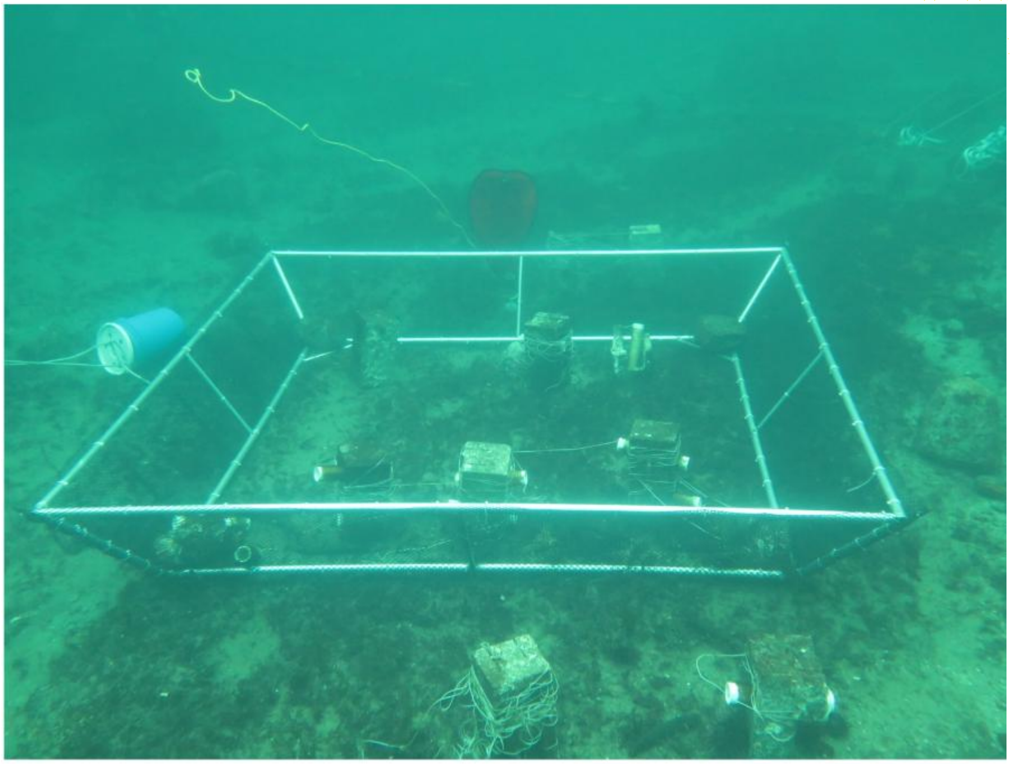


Figure 4. Sea urchin "exclosure" device deployed on the sea bottom at Maude Reef, Hornby Island (2017-2021) (Heath, Zielinsky, and Zielinsky, 2018a; permission to use given).

Different strategies have been trialed to prevent over-grazing by sea urchins in BC and WA:

- KRI, UVic, BMSC, and Hornby Island Diving at Denman Island – sea urchin fence (2024);
- KRI, UVic, BMSC in Barkley Sound – urchin cages (2024);
- Checko, R.F, and Saturna Island Marine Research and Education Society (SIMRES) at Saturna Island – sea urchin "exclosure" (2023);
- NCRS & CVPWS at Maude Reef, Hornby Island – sea urchin "exclosure" (2019-2022);
- Puget Sound Restoration Fund, Central Puget Sound Kelp Forest Enhancement at Doe Kag Wats/Jefferson Head, Puget Sound – some culling (2020-2024);
- The Haida Nation, Federal Government, Pacific Urchin Harvesters Association at Haida Gwaii – culled sea urchins (2017-2020).

Table 4. Locations where herbivore control has been used to aid in kelp restoration or enhancement in BC (NR, not reported)

LOCATION	DATE	METHOD	RESULTS
Denman Island	2024	Sea urchin fence of free-edge Vexar™ netting	Effective!
Barkley Sound	2024	Urchin cages	Not super effective, got tossed around during storms
Saturna Island Interim Sanctuary Zone	2023	Urchin "exclosure"	Effective but concern about acting as gillnet in long term
Maude Reef, Hornby Island	2019–2022	Sea urchin relocation/exclusion and thinning experiments. Seeding of bull kelp and *Saccharina latissima* on bottom in "exclosurers"	"Exclosure" was effective
Central Puget Sound Kelp Forest Enhancement at Doe Kag Wats/Jefferson Head	2020–2024	Some urchin culling	
3 kilometres of the Gaysiigas Gwaay (Murchison Island) shoreline, Haida Gwaii	2017–2020	Sea urchin culling. Greater than 90% of urchins (primarily red and green with some purple) were fished or cracked underwater along a 3 km stretch of rocky reef from 0–15 m chart datum" by Haida Fisheries Program divers and red sea urchin commercial fishery divers.	Effective. Within a year, kelp stipe density increased, notably in deeper areas, and urchin densities continued to be low. The following two years, kelp was less abundant than in summer of 2019, possibly because of different ocean conditions and also because of urchins moving into the area.

6. SITE RECLAMATION/REHABILITATION

Construction of artificial reefs to encourage kelp recruitment, restore habitat, and attract fish and invertebrates has been undertaken at industrial marine sites in Burrard Inlet, Roberts Bank, Esquimalt, and Puget Sound. Successful macroalgal colonization of the artificial reef substrates was reported for several project sites, *Nereocystis* was identified at two. It should be noted that monitoring for more than one year may be required to see the full scope of rehabilitation to a reclaimed site or artificial reef.

- Archipelago Marine Research Ltd. for the Department of National Defense (DND) - Esquimalt Harbour Sediment Remediation Program: Rehabilitation and sugar kelp transplant and seed outplant (2017) (Archipelago, 2021a).
- Archipelago Marine Research Ltd. in partnership with SNC Lavalin for Department of National Defense (DND), CFB Esquimalt and Formation Environmental (DND) - Esquimalt Harbour Marine Habitat Compensation Installation: Created three approximately 11,000 m^2 of rocky reef habitat (2012). Within less than a year, underwater dive surveys recorded a diversity of algae and kelp, invertebrates, and fish at home on the rocky reefs (Archipelago, 2021b).
- Ausenco - Viterra-Cascadia terminal capacity expansion in Burrard Inlet, outplanted sugar kelp and bull kelp (2021) (Ausenco, 2025).
- Delta Port Metro Vancouver - Delta Subtidal Reefs Compensation Monitoring Report, Deltaport Third Berth Project: 8 reef structures were created 2008-2009. Red and brown algae colonized reefs at moderate to abundant levels. Diversity of algae, epibenthic invertebrates and fish increased on all reef types from 2009-2010. However, the project was deemed not highly successful as abundance and diversity of regenerated sites was lower than control sites (Archipelago, 2021c).
- Vancouver Port Authority Subtidal Reef Construction at Roberts Bank, Delta, BC: Subtidal reefs were constructed beginning in 1983; two more were created in 1993 and 2000. Monitoring of the early sites over the following years showed recolonization by invertebrates and fish but not macroalgae, as the reefs were too deep. Dive transect surveys of the 1993/2000 reefs in 2004 reported an abundant fish and invertebrate community as well as subtidal macroalgae, specifically *Nereocystis luetkeana* and *Saccharina latissima* (Williams and Millar, 2006).
- Pacific Shellfish Institute, Puget Sound artificial reef construction (1990; monitored 1991-1994): Various kelp species, mainly *Nereocystis*, *Laminaria* and *Sargassum*, colonized the mitigation rock in all areas, with percent covers ranging with different tide heights, and increasing over time where space on suitable substrates was available (Cheney et al., 1994).

ADDITIONAL CONSIDERATIONS TO SUPPORT RESTORATION

Nurseries

Producing culture lines in a nursery provides time for juvenile sporophytes to grow and acquire some size before outplanting to an ocean site where they will be in competition with other macroalgae for light, subject to smothering by diatoms or sediment, and grazing by herbivores of various sizes.

Nursery procedures also provide opportunities for comparing growth, health, and resiliency of kelp from different locations with differing environmental conditions, as well as selective breeding.

Here is a list of nurseries providing seed and other services for bull kelp restoration in the Salish Sea and other locations in BC:

- Canadian Kelp Research (was Canadian Kelp Resources) in Bamfield, Barkley Sound, BC has been providing custom-grown seed and advice on restoration projects for many years. They now also offer biobanking;
- 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) nursery and biobank at Bamfield, Barkley Sound, BC;
- Vital Kelp at Lund, BC;
- Tla'Amin Nation at Cannery Bay, Okeover Inlet, BC;
- North Island College, Centre for Applied Research, Technology and Innovation (CARTI), Campbell River, BC has a training nursery with mini bioreactors and biobanking capability;
- Puget Sound Restoration Fund's (PSRF) conservation hatchery at NOAA's Manchester Research Station at Port Orchard, WA.

The development of technologies for keeping kelp gametophytes growing vegetatively while stalling sexual maturity has provided nurseries with the ability to supply seed "on demand" but also to act as seed banks (Le et al., 2022; Lüning and Dring, 1972; Redmond et al., 2014). Unlike flowering plants, kelp and other macroalgae don't produce true seeds capable of being stored for many years under cool dry conditions. However, gametophytes were found to survive at least 15 months in the ocean and capable of contributing to sporophyte recruitment over multiple years (Edwards, 2000) and are now held in nurseries for many years under low light or red light and with low nutrients. While gametophytes can be kept in culture for years, the cultures require regular maintenance and sub-culturing and are vulnerable to infections and genetic mutations over time as they continue to divide and grow. Some of the kelp nurseries in BC are organizing a biobanking network to safeguard the strains already in culture in the event of lab or culture failures (Kelp Node forum, February 2025). Cryogenic freezing techniques to store germplasm, or "seed" offer an alternative method of biobanking kelp seed to preserve local biodiversity in case some populations become extinct and possibly aid in future restoration and research projects. Cryopreservation techniques are in the final stages of testing at Simon Fraser University (Bisgrove, 2025).

Biodiversity observed at bull kelp at restoration sites

During monitoring of experimental sites and at natural kelp beds during sori collection, individuals and schools of juvenile salmon, Pacific herring (*Clupea pallasii*) (Figure 5), other forage fish, resident fish species such as shiner perch (*Cymatogaster aggregata*), rockfish (multiple species including juvenile copper rockfish (*Sebastes caurinus*), and invertebrates, including crabs and caprellid amphipods, were often observed in and around the kelp (Ennis, 2024; Heath et al., 2017; Tomlin et al., 2020). Eggs of tube-snout (*Aulorhynchus flavidus*) were observed on bull kelp (Ennis, 2024). Marine species occurrence and abundance surveys by REEF.org expert marine ID surveyors conducted at the Maude Reef grid in Lambert Channel each year from 2019 to 2021, recorded a total of 75 species within the and 67 species adjacent to it (Heath et al., 2022). These observations are important confirmations of the ecological service of kelp beds as refuge and feeding sites for many fish and invertebrate species in the Salish Sea.

Figure 5. School of herring above culture lines at Maude Reef restoration site in Lambert Channel on July 24, 2020 (Heath, Zielinsky, and Zielinsky, 2022; permission to use given).

HISTORY OF RESTORATION IN SOG (AND A FEW OTHERS IN BC)

For a more detailed description of the work of any of the restoration projects discussed here and sources of information see Appendix I.

Early in the 2000s, concerns about the disappearance of local bull kelp led individuals on Gabriola Island and in the Bowser area of the central east coast of Vancouver Island to take action: Nile Creek Enhancement Society (2006-2017) with Hornby Island Diving (2011-2022, followed by Savethekelp.org (2009-2013), and Comox Valley Project Watershed Society (2015-2022). The earliest attempts towards restoration began when volunteers collected and deployed perforated containers (mesh bags or buckets with holes) filled with sori, the reproductive tissue which develops on the blades of mature *Nereocystis* sporophytes. They also provided nurseries with locally collected kelp sori and received in return, string wound around plastic cylinders and seeded (inoculated) with tiny bull kelp sporophytes. The desired length of seeded string was cut, attached to an anchoring structure (e.g. mesh bag of stones), and dropped from boats to the sea bottom on rocky substrates identified by divers, at a depth that would be submerged under 1 m of water on a zero tide. The objective of these methods is to provide a source of spores to immediately, or in a new generation, re-establish bull kelp to an area. Monitoring the results of these trials is difficult and attributing any success to the method unequivocally requires careful experimentation and monitoring.

In 2011, Nile Creek Enhancement Society began a collaboration with Hornby Island Diving focused restoration efforts on Maude Reef on the southwest coast of Hornby Island in Lambert Channel, a site with a history of bull kelp. In 2013, with funding from Pacific Salmon Foundation's Community Salmon Fund, a more experimental approach was taken to testing restoration methods with the installation of an anchored line grid (Heath et al., 2015). The grid was modelled after an original design for experimental trials by Louis Druehl of Canadian Kelp Resources Ltd. A nearby fringing bed of bull kelp at Eagle Rock, near the southeast tip of Denman Island, was chosen as the reference site. The Comox Valley Project Watershed Society joined the effort and with funding from Pacific Salmon Foundation, Salish Sea Marine Survival Project (2012-2017) the Collaborative Bull Kelp Restoration Project expanded to trial new restoration sites in northern Baynes Sound, Cape Lazo shoal, and south of the Big Qualicum River Estuary (Island Scallops Ltd. aquaculture lease) (Heath et al, 2017).

Comox Valley Project Watershed Society continued their collaboration with Hornby Island Diving and with funding from the Fisheries and Oceans Canada (DFO), Coastal Restoration Fund (2017-2022) trials restoration trials proceeded on the Maude Reef seeded line grid from 2018 to 2021 (Heath et al., 2022). With the loss of the kelp forest at Eagle Rock, a healthy and persistent bed of bull kelp located near the mouth of the Oyster River was adopted as the new reference site for further restoration trials. The performance of kelp sporophytes grown from seed obtained from parent sori collected from the Oyster River kelp forest was compared to ones sourced from another persistent bull kelp bed at Sansum Narrows. The effectiveness of a sea urchin "exclosure" device at supporting growth of kelp sporophytes by preventing grazing was also tested.

The Mayne Island Conservancy has conducted the longest continuously running kelp mapping endeavor in BC, beginning in 2010. In the last five years, they were joined by groups of concerned citizens from other islands and the renamed Southern Gulf Islands Bull Kelp Monitoring Collaboration: Mayne Island Conservancy, the Pender Islands Conservancy Association, the Galiano Conservancy Association, the Saturna Island Marine Research and Education Society (SIMRES), and the Valdes Island Conservancy. The group has focussed efforts on mapping rather than restoration, and the kelp mapping and monitoring protocol employing kayaks they developed has been adopted by other conservation groups and can be downloaded from their website: Guidelines and Methods for Mapping and Monitoring Kelp Forest Habitat in British Columbia. In 2023, volunteers and staff recorded a total of 31.23 hectares of bull kelp at the 17 sites around the islands.

Mount Arrowsmith Biosphere Region Research Institute, (MABRRI), Vancouver Island University (VIU) conducted a study to re-establish kelp populations through deploying seeded lines on plots and monitoring growth, health, and biodiversity. Kelp seeded-lines were outplanted in 2018 and again in 2019 at two sites chosen at the Winchelsea Islets and in the Northumberland Channel, northwest of Dodds Narrows, both locations had a history of bull kelp presence. Individual young sporophytes were transplanted in 2018.

Concern over the loss of bull kelp along the Sunshine Coast in northeastern Salish Sea inspired the development of nursery procedures for producing bull kelp to restore beds lost over the previous ten years to overgrazing by sea urchins (Ennis, 2024). In the winter of 2018, seeded-lines were strung between oyster rafts on a shellfish lease near Nelson Island. Kelp grew rapidly in the spring, attracting many different fishes, and began to deteriorate in July. Continuing restoration efforts in the region, Vital Kelp was formed to restore floating canopy forming bull kelp to Jeddah Point near the entrance to Welcome Pass between South and North Thormanby Islands. In the winter of 2021, line grown bull kelp was transplanted onto fist-sized rocks and deployed by kayakers to the sea bottom. The method proved successful, and the kelp grew well.

More recent efforts on the Sunshine Coast region involve the Tla'amin Nation, shishalh Nation, and the British Columbia Conservation Foundation (BCCF), with funding from DFO's Aquatic Ecosystem Restoration Fund (AERF), to help restore and enhance 67,000 square metres of kelp forest at 25 sites in their territories. Lee-Ann Ennis of Vital Kelp is the project lead and kelp cultivation specialist for BCCF. In the fall of 2024, a kelp nursery was set up in Cannery Bay on the traditional territory of the Tla'amin Nation and a locally trained technician was hired. In its first season, the nursery produced seeded gravel, tiles, and spools using spore settled methods for outplanting in Okeover Inlet (L. Ennis, personal communication, April 02, 2025). Gametophyte cultures were established and with the acquisition of macroalgae bioreactors, the ability to produce a quick and reliable kelp gametophyte supply will be enhanced in the fall of 2025. In 2024, Tla'amin Nation Guardians surveyed present bull kelp extent and shared Indigenous knowledge of historical bull kelp extent in Okeover Inlet, a crucial step in identifying potential sites for bull kelp restoration. In mid April 2025, Tla'amin Glje (Land) Academy secondary students will assist with transplanting young sporophytes from line to rock. An early April survey of the out planted kelp showed survival of the line grown and transplanted kelp. A fundamental goal of this project is building capacity to steward and manage kelp resources and working together to incorporate Indigenous Knowledge and Western Science. Collaboration between First Nation Guardians, the BCCF, and other scientists to document past and present kelp resources, involving Nation Elders and students in restoration activities, building a kelp nursery within Nation's territory, and hiring an Indigenous kelp technician are all steps to building that capacity.

Disappearing bull kelp forests also motivated the Thetis Island Marine Explorers (TIME), a local group of divers, to attempt restoration at a few sites around Thetis Island (A. Lamb, pers. comm. February 11, 2025). With some help of Canadian Kelp Resources and Ocean Wise Canada they outplanted seeded lines at two sites, and green gravel at another site in 2023. Kelp grew well, reaching the surface at the Fraser Point site until northern kelp crabs, hiding in a nearby breakwater discovered the kelp line and grazed it completely. Another attempt was made to deploy green gravel the following year, with no success, and at Fraser Point a seeded line placed at a greater distance from the breakwater and with crab shields in place, but the crabs found the line earlier and grazed all the kelp while it was still small. Frustration with the lack of success drove the group to abandon the project after this (A. Eriksson, pers. comm. February 11, 2025).

An early restoration trial for Ocean Wise Canada was a collaboration with the Metlakatla Development Corporation and Ecotrust Canada on Ts'msyen Territory near Prince Rupert in 2023 (Ng, 2023). In mid-March 2023, approximately 1.6 km of bull kelp seed spools were outplanted on a disused oyster lease. There was limited kelp growth on the lines possibly due to late outplanting (mid-March) or damage to spools during the long transportation from Bamfield to Prince Rupert (S. Bohachyk, personal communication, March 05, 2025).

The advent of green gravel technology and heightened concerns about the increasing rate of kelp loss has spurred efforts to restore bull kelp forests. Larger organizations such and Ocean Wise Canada and the Kelp Rescue Initiative began collaborations with Indigenous Nations to trial new methods of outplanting kelp in their territories. In 2021, Ocean Wise Canada began kelp restoration in BC, in partnership with Canadian Kelp Resources and Rendezvous Dive Adventures trialing the "green gravel" method in Rainy Bay (Nuu-chah-nulth territory, Barkley Sound, on the west coast of Vancouver Island (Ocean Wise and Janke, 2024a; Schultz, 2023). Gravel seeded with *N. luetkeana, Saccharina latissima*, and *Macrocystis pyrifera* was dispersed over two transects within a 200 m^2 transect in the winter of 2021. Giant kelp flourished while the bull kelp did not. The green gravel outplanting process was deemed simple, but transporting the pebbles was considered a barrier to upscaling. Ocean Wise also tested the effectiveness of eDNA for monitoring biodiversity at the kelp restoration sites, concluding that the methodology "proved promising for the detection of species either alongside dive analysis or on its own" (Ocean Wise and Janke, 2024b). Ocean Wise also collaborated with Tseshaht First Nation and West Coast Kelp to bolster already existing *M. pyrifera* kelp beds in the southern Pinkerton Islands, Barkley Sound. Using a transplant process, known to First Nations in B.C., approximately 2,500 juvenile kelp sporophytes were removed from a farm or a nearby kelp forest, each holdfast was attached to a rock, and sunk to the bottom at the restoration site (Ocean Wise and Janke, 2024c). Ocean Wise also tested effectiveness and efficiency eDNA for monitoring biodiversity at the kelp restoration sites and compared the results to tests with dive transects (Ocean Wise and Janke, 2024). It proved promising for detecting species and providing baseline fish and invertebrate community composition.

In 2023, Ocean Wise began a collaboration with Tsleil-Waututh Nation with the goal of restoring kelp habitat in səl̓ilw̓ət (Burrard Inlet) in front of the Nation's reserve, where kelp beds were once historically well-established and thriving. Bull kelp was grown on a local farm to 35 cm then detached from the farm substrate and reattached to rocks, which were lowered into səl̓ilw̓ət (Burrard Inlet). The goal of restoring bull kelp habitat in front of the Tsleil-Waututh Nation's reserve, where kelp beds historically grew was not achieved, probably due to poor site selection, as the site may have been too deep and turbid for the bull kelp to survive.

Ocean Wise built a kelp nursery at the Pacific Science Enterprise Centre in West Vancouver to experiment with different substrates for settling sugar kelp to provide seed for restoration trials (Wolf, 2024). In another collaboration with Tsleil-Waututh Nation, sugar kelp was grown on both pebbles/cobbles and oyster shells (novel method trial), outplanted into False Creek in February 2024, and transplanted in Burrard Inlet in early May 2024. Despite what some consider a late outplanting in February, growth of sugar kelp exceeded expectations. Finding the best containers for transporting green gravel from the nursery to the outplant site was a problem.

An ongoing collaboration between the Squamish Nation, the Marine Stewardship Initiative, and Ocean Wise is attempting to restore sugar kelp beds in Átl'ḵa7tsem/Howe Sound to provide spawning habitat for Pacific herring (*Clupea pallasii*) as had previously been observed. Sugar kelp grown on various substrates in a kelp nursery will be outplanted to sites within the traditional territory of the Squamish Nation (Oceanwise and Janke, 2024).

The Kelp Rescue Initiative (KRI) is a project of the Western Canadian Universities Marine Sciences Society based at the Bamfield Marine Sciences Centre (BMSC, Bamfield, BC) with research support from Julia Baum's lab at the University of Victoria to lead and support kelp restoration projects with Indigenous Nations and other partners in coastal British Columbia, supported by a four year grant from Fisheries and Oceans Canada under the Aquatic Ecosystems Restoration Fund (Dal Monte, 2024). The KRI operates a kelp nursery and gametophyte bank at Bamfield, BC, with additional nursery facilities at Vancouver Island's Deep Vay Marine Field Station near Bowser, BC providing seed to restoration sites in Lambert Channel and Baynes Sound, and at the Pacific Science Enterprise Centre in West Vancouver, BC supplying seed to projects in Burrard Inlet.

In April 2024, KRI experimented with giant kelp seeded on two sizes of gravel/cobble and deployed in cages as protection from urchin grazing at six sites along an exposure gradient in Barkley Sound (KRI and Schuster, 2024). Urchin cages were not very effective as they were tossed around by waves.

Graduate student Camryn Good collaborated with KRI and the Tsleil-Waututh Nation in Burrard Inlet to restore bull kelp forest in urbanized areas of their territory in Burrard Inlet where it has been lost. From March 01, 2024, to July 25, 2024, seeded tiles, gravel, cobble/rocks were outplanted at three sites, and plots were monitored every 6 weeks from April to July (Good, 2024). Quantified numbers of tiles/gravel remaining in plots, number of sporophytes per tile/gravel, some sporophyte morphometrics, and temperature, light and current data were collected at each site throughout monitoring season. Kelp grew well from seeded tiles and larger cobble/rocks, reaching the surface by June, with reproductive tissue observed on many individuals.

In 2024, KRI began collaborating with Hornby Island Diving to test restoration success across five *Nereocystis* populations with different thermal histories and tolerances using a seeded line array at the experimental grid site at Maude Reef in Lambert Channel. Growth characteristics varied across the five populations, but all exhibited thermal stress under the warm conditions experienced in July. The experiment was planned to be repeated in 2025.

From February 26, 2024, to August 30, 2024, KRI and Hornby Island Diving conducted an experiment comparing five different bull kelp restoration methods and urchin exclosures in an area near the south end of Denman Island where bull kelp has been lost: gravel, cobble, tiles, seeded line, direct seeding. The kelp forest had been used as a reference site by the restoration project of Project Watershed Society and the Nile Creek Enhancement Society until it disappeared in 2015. Findings suggest cobble and tiles perform best. The urchin fence was effective at keeping grazers out of the restoration area. Kelp grew well and produced reproductive tissue. (KRI and Schuster, 2024). In 2025, restoration trials were scaled up with 1700 metres outplanted to a site in northern Baynes Sound.

From the records available, kelp restoration activities in the Salish Sea began in 2006 with community volunteers, most of whom only continued for a few years, after disappointing results for their efforts. With the help of dedicated funding, restoration trials became more experimental in 2013, with data collection and monitoring recorded and reported, and more sites included for bull kelp seed outplanting trials. Beginning in 2023, with the interest of larger groups made up of individuals with a broad range expertise and funding, in collaborations with Indigenous Nations and other groups involved in kelp restoration and marine conservation, and newly available restoration technologies, the number of sites undergoing experimental kelp restoration has grown quickly. The focus of some trials is now about scaling-up efforts to meet outplanting goals, while others continue to adapt site specific outplanting methods and explore techniques for reducing grazing pressure from herbivores. A timeline of the progression of the number of sites outplanted with kelp each year from 2006 to 2024 follows (Table 5).

Table 5. Timeline of the number of kelp restoration project sites in the Strait of Georgia, by outplant/grow out year.

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'ḵa7tsem/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'ḵa7tsem/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)

? Unconfirmed

TRADITIONAL ECOLOGICAL KNOWLEDGE

There is growing concern among Indigenous People about the state of bull kelp forests in the coastal areas of their traditional territories bordering the northeast Pacific Ocean. Traditional ecological knowledge recognizes the importance of kelp for cleansing the water and as food and habitat for young salmon, herring, abalone, crabs, octopus, sea urchins and many other species. All marine resources are integral to the lives of Indigenous people and the harvest of kelp as food for general consumption, and on which herring have spawned, also has cultural and ceremonial significance (Naar, 2020).

Most of the restoration projects undertaken in the Strait of Georgia and BC in recent years have been led by or are in partnership with First Nations in their traditional territories including: Haida Nation in Haida Gwaii; Metlakatla Development Corporation in Ts'msyen Territory, Prince Rupert; Tla'Amin Nation in Okeover Inlet; səlilwətaɬ (Tsleil-Waututh Nation) (TWN) in Burrard Inlet; c̓išaaʔatḥ (Tseshaht Nation) in Barkley Sound; t̓ukʷaaʔatḥ (Toquaht Nation) in Barkley Sound; Snuneymuxw Nation in Nanaimo/Gabriola Island; Sḵwx̱wú7mesh Úxwumixw (Squamish Nation) in Átl'ḵa7tsem/Howe Sound.

Many First Nations on the North Coast, Central Coast, and northern Vancouver Island regions of BC are working together through the Marine Plan Partnership for the North Pacific Coast, Marine Plan Portal (MaPP) initiative to survey and monitor kelp resources in their territories. At a "Kelp Summit" hosted by Ocean Wise and the Pacific Seaweed Industry Association held in October 2024 in Vancouver, BC, the importance of prioritizing Indigenous Rights and Title, and Traditional Ecological Knowledge was highlighted (Bohachyk, 2024). Effective resource management of kelp forests will require collaboration and genuine partnership to share knowledge and resources and "adaptation to local contexts, respecting the unique cultural and ecological landscapes of different Indigenous Nations" (Bohachyk, 2024). Consider for example, replacing the phrase "best practices" with "wise practices".

All restoration work conducted in the marine waters of BC requires consultation with all First Nations having claims to the location, and approval before a permit is granted by the BC Ministry of Food and Fisheries (MAF). Those interested in restoring kelp forests to an area can benefit by collaborating with local Indigenous Nations to learn from Indigenous knowledge holders and First Nation Guardians about the cultural significance of kelp, as well as the history and locations of bull kelp in the area, and changes seen over time (L. Ennis, personal communication, March 11, 2025; PSRF, n.d.b).

MANAGEMENT OF KELP RESTORATION

Information from restoration practitioners and researchers in the field and labs can be used to prioritize management and conservation actions. In northwest Washington State, the Northwest Straits Initiative coordinates seven county-based Marine Resources Committees (MRCs) for regional kelp conservation and recovery efforts in Puget Sound, under a framework defined in the Puget Sound Kelp Conservation and Recovery Plan (Calloway et al., 2020). It is a collaborative effort between tribes, nonprofits, state and federal agencies, universities, and local community stakeholders in Puget Sound, with additional collaboration with Canadian federal, provincial, and First Nation entities to support conservation and recovery efforts in the Puget Sound/Georgia Basin region.

Kelp restoration in BC has been carried out for almost twenty years (2006-2005) by concerned citizens with some help from biologists and sometimes funding from Fisheries and Oceans Canada (DFO) directly or through the Pacific Salmon Foundation (PSF) (Collaborative Bull Kelp Restoration Project 2013-2018 (Heath et al., 2018)). Through Canada's Oceans Protection Plan, DFO's Aquatic Ecosystem Research Fund (AERF) supports projects that help protect and restore aquatic habitat, such as the development of methods for culturing and out-planting giant and bull kelp in southern British Columbia by the Kelp Rescue Initiative in partnership with local First Nations. With funding under the AERF, PSF's Marine Science Program is leading a new project to create a Restoration Resource Hub of open-access informative resources and decision-support tools to guide and help co-ordinate adaptive nearshore habitat restoration approaches and strategies. No apparent overarching strategy for restoration of kelp in the Strait of Georgia or the rest of coastal BC was found.

While coastal aquatic ecosystems are managed by the Fisheries and Oceans Canada (DFO), aquatic plants (now recognized as algae) fall under the jurisdiction of the provincial Ministry of Agriculture and Seafood (MAS). Wild aquatic plant stocks in BC are managed under the Aquatic Plant Program which has conducted kelp inventories and mapping of aquatic plants in coastal region in the past and currently in partnership with coastal Nations through the Marine Plan Partnership (MaPP). It also regulates and licences the culture and wild harvest of aquatic plants for food, research, and any other purposes including in medicine and as fertilizer for gardens. A license is required to harvest wild aquatic plants, including kelp, for scientific purposes and to harvest more than 100 kg wet weight of aquatic plants, which is considered commercial scale. Regulation and licensing of the wild harvest and culture of aquatic plants fall under Fish and Seafood Licensing Regulation. Policy has been defined for managing culture and wild harvest, but a restoration policy has yet to be formalized. A forthcoming Restoration Policy under the Aquatic Plant Policy of MAF was presented by D. Denley at the Pacific Salmon Foundation's Kelp Restoration Symposium held in Victoria, BC on February 24-26, 2025 (Denley, 2025), and at the International Seaweed Symposium in Victoria, BC on May 5, 2025 (Romanin, 2025). The following points summarize the main concerns for kelp restoration:

- Ensuring integrity of aquatic plant beds
- 50 km or "ecozone" to be announced
- 30 source individuals
- 50 km radius/ ecozone
- No using reproductive plants from restoration area to grow new cultured material
- Genetic "modification" policy to be announced
- Series of best management practices, BMPs (restoration, biobanking, monitoring)

DISCUSSION

Increasing ocean temperatures, recurring marine heat waves, and other stressors associated with them, are having dramatic effects on *Nereocystis.* Overgrazing from a rapid increase in sea urchin densities due to the loss of an important predator, the sunflower sea star (*Pycnopodia helianthoides*) (Heath et al. 2015, 2022; Rogers-Bennett et al., 2019; Tomlin et al, 2020) and increasing epizoan load from organisms like bryozoans (Denley et al. n.d.; Heath et al., 2017) are impacting bull kelp survival. Although the marine heatwave of mid 2010s and the heat dome of 2021 have had devastating effects on some marine life in the Salish Sea, some kelp forests in the central Strait of Georgia had already been in decline, possibly due to suboptimal conditions during the period 2002-2006 (Mora-Soto et al. 2024a).

Local groups had noticed these earlier declines and have been fighting back since the mid-2000s with the Nile Creek Enhancement Society (NCES) attempting kelp restoration between Nile Creek, near Bowser on Vancouver Island, and Hornby Island in 2006, and the “Help the Kelp” group on Gabriola Island carried out trials beginning in 2009, and the Mayne Island Conservancy began mapping kelp occurrences in 2010. Restoration experimental trials continued in Lambert Channel (Maude Reef) and Baynes Sound areas until 2021 by the Comox Valley Project Watershed Society and were restarted in 2024 by the Kelp Rescue Initiative (KRI). The KRI and Ocean Wise Canada have taken the lead in kelp restoration since 2021, primarily testing and adapting “green gravel” technology to local kelp species and conditions at sites in the Salish Sea, Barkley Sound, and near Prince Rupert. KRI is expanding the amount of area undergoing restoration in Lambert Channel and Baynes Sound in 2025 (Schuster, 2025).

In the southern Salish Sea, the Puget Sound Restoration Society began experimenting in bull kelp restoration in 2011, but failure of early trials led studies to determine the best early life stage and timing of outplanting (Allen, 2018). Restoration trials resumed in 2020 and continue today to determine how seeding techniques, seed density, and timing of outplant affect kelp yield, and reproductive output at Doe Kag Wats/Jefferson Head and other sites in Puget Sound (PSRF and Toft, 20024; Hayford, 2025)

The most used method for restoring bull kelp in the Salish Sea prior to 2024 was seeded lines. It is effective in creating a prescribed stand of bull kelp sporophytes, and in a few cases, appears to have contributed to low levels of recruitment the following year (Hayford, 2025; Heath et al, 2022). The long-line cultivation approach can contribute to restoration “if the effort is diversified by developing a network of good sites spread over a large area of potentially resilient kelp forests” (Heath et al., 2022).

Green gravel technology arrived on the west coast of Vancouver Island in 2021, proving successful for outplanting *Macrocystis,* but less so for *Nereocystis*. The fast growth rate that provides *Nereocystis* an edge in the race to colonize freshly scoured rock substrates is detrimental for seed attached to small gravel (3-5 cm) because the stipe and bulb grow faster than the haptera, leading to increasing buoyancy before a permanent holdfast has formed. Practitioners report seeing the young sporophytes growing on the gravel one day and returning a month later to find them gone (Good, 2024). Cobble stones (fist-sized) have been found to be a more effective size of substrate for the technique (J. Clark, Cascadia Seaweed, personal communication, 2025; Schuster, 2025). The ability to deploy seeded gravel or cobble from a boat has an economic advantage over the deployment of transplants or seeded-tiles by divers. However, concerns have been expressed about the ease of deployment of the large amounts of gravel and cobble from boats required to scale up restoration efforts.

MEASURING SUCCESS

When site selection, time of outplanting, and environmental conditions are favorable, bull kelp propagules can grow vigorously from near the sea bottom to the sea surface in under three months. Growth to maturity, identified as the presence of reproductive tissue called sori (Figure 6), was often recorded, sometimes as early as May (Heath et al., 2015). However, the viability of spores released so early is questionable if water temperatures on the sea bottom exceed 17 °C (Korabik et al. 2023, Muth et al., 2019; Schiltroth et al., 2018; Weigel et al., 2023).

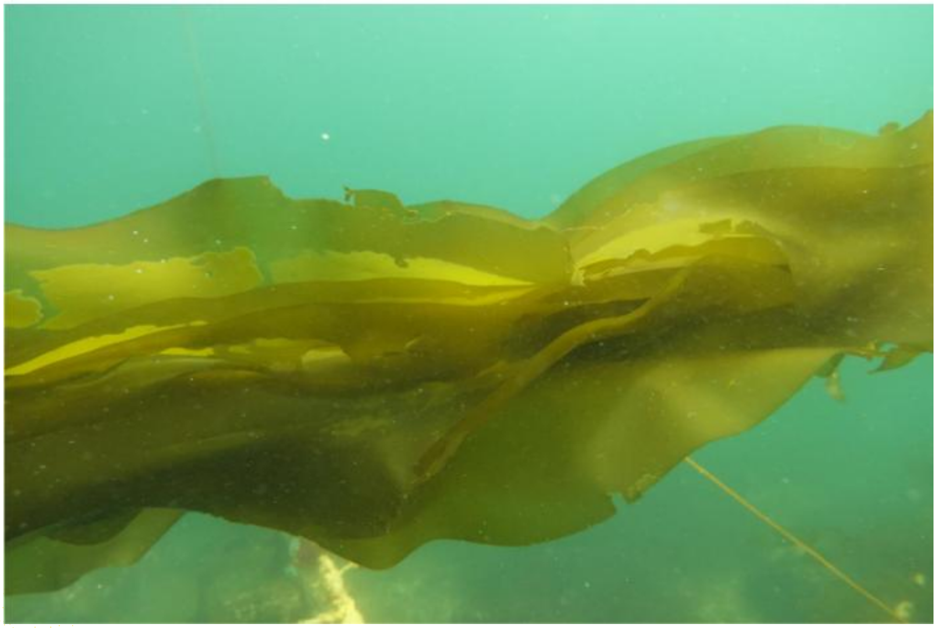


Figure 6. Sori (reproductive patches) on bull kelp blades at Maude Reef site on May 5, 2020 (Heath, Zielinsky, and Zielinsky, 2022; permission to use given).

The goal of kelp restoration is the establishment of a self-replenishing population of sporophytes evident as recruitment of young sporophylls derived from spores released from the previous generation. Of all the trials using seeded line, gravel/cobble/tiles, or transplants which reported results, two longer term restoration trials using seeded lines saw a few recruits over the years, and each had one exceptional year (Figure 7). The largest number observed at Maude Reef was six in 2021, in Lambert Channel in northern Strait of Georgia, in a year when very few green sea urchins were seen on the site (Heath et al., 2017, 2022). In 2024, divers counted 33 recruits within the restoration site at Doe Kag Wats/Jefferson Head in central Puget Sound, and at least one grew to reach maturity. (Hayford, 2025; H. Hayford, personal communication, March 26, 2025). Two factors that may have contributed to the success were an increase in the number of outplanted lines in 2023 and a longer growing season that year, which may have resulted in the release of greater number of zoospores under more favorable conditions.

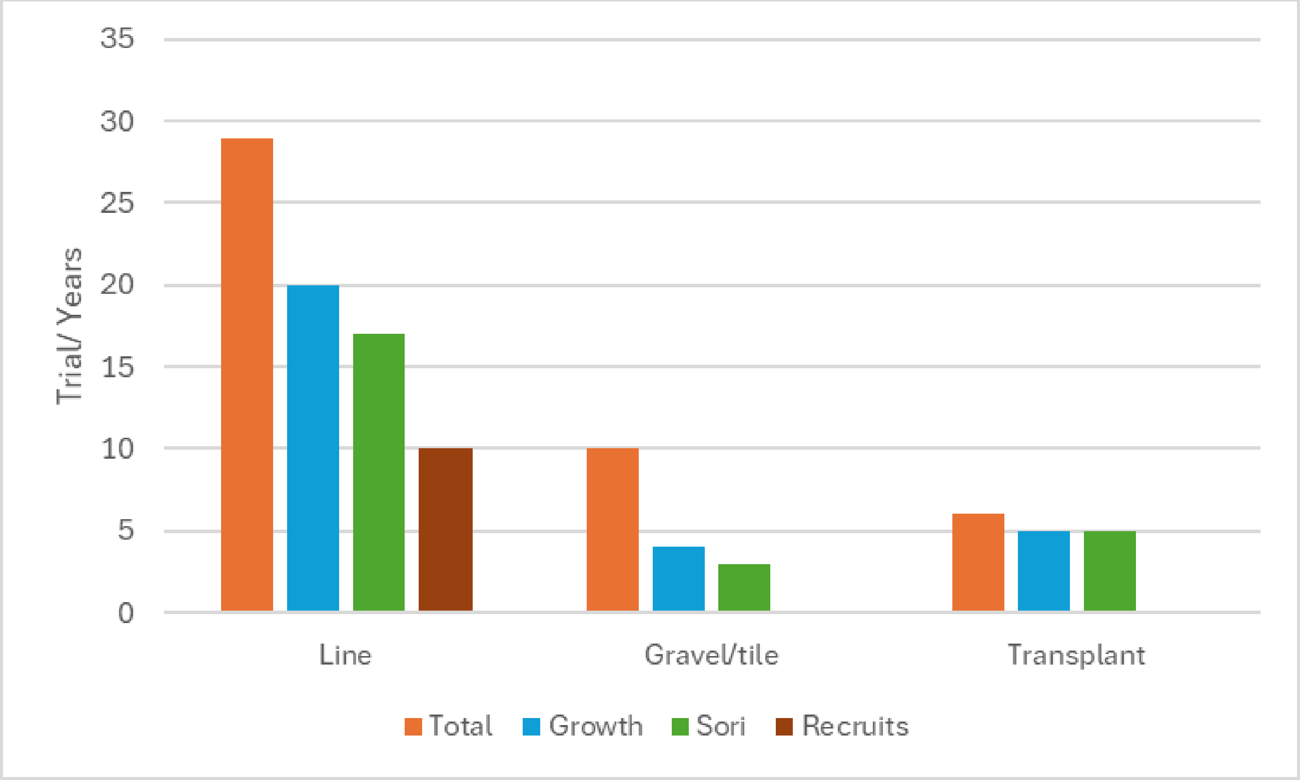


Figure 7. Comparing the three most common methods used in kelp restoration trials in the Salish Sea, Barkley Sound, Haida Gwaii, and Prince Rupert by total number of trials reporting results by year, the number of trials that reported growth to the surface, development of sori, and appearance of kelp recruits.

BARRIERS TO SUCCESS IN RESTORATION

The threats identified as negatively impacting growth, survival, and recruitment of bull kelp at restoration sites in the Salish Sea are increasing temperatures and marine heat waves, increased kelp grazing by sea urchins due to loss of predatory sun stars, grazing by kelp crabs and gastropods, increasing epiphyte and epizoan (bryozoans) loads, and competition from microalgae (diatoms) and other species of macroalgae including kelp.

Grazing by herbivores

In the Strait of Georgia, bull kelp was historically described as a successional species, where the existence of some forests fluctuated with the migrations of sea urchins (Forman 1984; Lamb et al., 2011). The relationship was disrupted in 2013, when sunflower sea stars (*Pycnopodia helianthoides*), a dominant predator in nearshore ecosystems, succumbed to an epidemic of sea star wasting disease, associated with the marine heat wave of 2014-2016 (Hamilton et al, 2021; Harvell et al., 2019, Miner et al, 2018). It appears the warming ocean temperatures and increasing marine heat waves are shortening the lifespan of the annual bull kelp, resulting in lower reproductive capacity and impacting re-establishment in areas after heavy sea urchin grazing. Unchecked growth of sea urchin populations led to overgrazing of bull kelp forests and the creation in some areas, such as Howe Sound and Haida Gwaii, of urchin barrens, where all or most kelp and other macroalgae were consumed (Borden, 2018; Watson and Estes, 2011). The restoration sites impacted by heavy sea urchin grazing were located at Maude Reef in Lambert Channel, as well as the reference site at Eagle Rock (Figure 8) (Heath et al., 2015, 2020), the Winchelsea Islets and Northumberland Channel (Tomlin et al., 2020), and sites in Barkley Sound (Schuster, 2024). A sea urchin "exclosure" deployed to the Maude Reef site was effective at preventing grazing pressure, which allowed outplanted bull kelp to flourish (Heath et al., 2022), as did a fence deployed at a south Denman location (Schuster, 2025).

Figure 8. Red sea urchins grazing brown and red algae around rocks at the Maude Reef restoration site in Lambert Channel on Feb. 24, 2020 (Heath, Zielinsky, and Zielinsky, 2022; permission to use given).

Northern kelp crab (*Pugettia producta*) have only recently been unveiled as devourers of kelp and have been shown to prefer *Nereocystis o*ver other kelp species (Dobkowski et al., 2017), to the frustration of kelp restorers and resulting in abandonment of sites for bull kelp restoration in northern Baynes Sound (Heath et al., 2015) and Thetis Island (A. Eriksson, personal communication, February 11, 2025). At the Doe Kag Wats/Jefferson Head site and most of Puget Sound, the main herbivores over-grazing bull kelp are kelp crabs rather than sea urchins (Berry et al., 2021; Hayford, 2025). The decline of top-down predators, such as rockfish and lingcod, has allowed kelp crab populations to explode, increasing grazing pressure on kelp (Berry et al., 2021; PSRF and Toft, 2024).

Grazing of outplanted substrates by gastropod snails has been mentioned as a possible source for loss of early life stages of bull kelp; evidence of grazing trails on substrates (Carney et al., 2005; J. Clarke, personal communication, March 18, 2025). Minor damage to the stipe of bull kelp from grazing by the snail *Lacuna vincta,* can increase mortality in high current areas (Duggins et al., 2001).

Epizoan and epiphyte burdens

In warmer years, the arrival of higher temperatures and the added stress of a heavy load of epiphytes and epizoans, mostly bryozoans, can lead to a decline in kelp condition beginning in late May, with complete deterioration of kelp by late August (Heath et al, 2015). The impact of heavy encrustations of the bryozoan *Membranipora* on wild giant kelp on the Central Coast of BC is being investigated (Denley et al., n.d.).

Other macroalgae and microalgae

Other species of macroalgae, including understory kelp, can interfere with the ability of bull kelp to reestablish forests where they once thrived by decreasing irradiance near the substrate to below levels required by bull kelp zoospores to germinate (Vadas, 1972). The non-indigenous red macroalgae, *Mazzaella japonica,* was considered a dominant competitor of bull kelp at the Eagle Rock reference site near Denman Island in Lambert Channel (Heath et al., 2015). *M. japonica* and an invasive brown macroalgae *Sargassum muticum,* were found to outcompete indigenous species of macroalgae in the Lambert Channel and Baynes Sound areas (Pawluk, 2016), and its removal from subtidal areas allowed colonization of native species of macroalgae. The perennial *S. muticum* has become established in areas of Puget Sound that were once home to *Nereocystis* forests (Berry et al., 2021).

Heavy settlement of microalgae, notably the diatom *Melosira*, in the spring can smother young sporophytes, preventing growth (Allen, 2018). This may have contributed to the lack of growth on a seeded lines outplanted at Fraser Point on Thetis Island in January 2023, where diatoms coated the line, while another line outplanted about one month before at the same site grew bull kelp successfully and lacked heavy diatoms (A. Lamb, personal communication, February 11, 2025). One suggestion for avoiding heavy settlement of diatoms on the substrate is to outplant prior to the beginning of the spring bloom, although the timing will be site specific.

Temperature effects on *Nereocystis luetkeana* life stages

Bull kelp sporophytes grow vigorously in the spring with increasing day length and warming temperatures, often reaching the water surface, and forming a canopy in June, depending on depth. Adult bull kelp sporophytes become reproductive, producing sori and releasing zoospores primarily from late spring throughout the summer and into early fall, with fertility peaking in July in some locations (Maxwell and Miller, 1996). In cooler years, sporophytes can persist until October and even November, extending the season of reproduction. Sori production near Maude Reef in the Lambert Channel area of the northern Salish Sea was found to occur from May to October in "cooler years", peaking in May-June, but not in hotter years, such as occurred in 2015 (Heath et al., 2015). When temperatures exceeded 18 °C over a 30 to 35 day period, sporophytes were observed to undergo tissue degeneration and mortality, causing the reproductive season of bull kelp to be shortened or absent (Heath et al., 2022). Blades of *Nereocystis* exposed to 21 °C over a shorter period of 8 or 9 days exhibited signs of thermal stress (Fales et al., 2023). The growth rate of *Nereocystis* blades and stipes were found to decline at temperatures above 10 °C on the Central Coast of BC, suggesting latitudinal/location-specific local adaptation to colder sea temperatures (Pontier et al., 2024). Laboratory experiments adjusting temperature and tension under simulated flow conditions demonstrated *N. luetkeana* sporophytes have a relatively wide range of thermotolerance around an optimum of 11.9 °C, with blades growing after exposure to higher temperatures of 13 to 20 °C for seven days (Suprataya et al., 2020). Thermally stressed individuals were unable to adjust their morphology to accommodate blade widening, in response to a low flow environment, as found in sheltered habitats where relatively high temperatures most often occurred in the Salish Sea (Starko et al., 2024).

Little is known about the effects of temperature on spore release in *Nereocystis*, although elevated temperatures were observed to increase rates of zoospore release in the giant kelp, *Macrocystis pyrifera* (Le et al., 2022). Early life history stages of *Nereocystis* show similar thermal tolerance as adults, with an upper limit of less than 17-18 °C for optimal settlement and germination of spores, and development of gametophytes and sporophytes (Muth et al., 2019; Schiltroth et al., 2018; Weigel et al., 2023). Schiltroth et al. (2018) reported temperatures around 20 °C resulted in mortality of nearly all spores. Another study obtained peak gametophyte densities at temperatures between 10 °C and 16 °C, while the range was narrower for sporophytes at 10–14 °C (Weigel et al., 2023). Sporophytes were produced at 16 and 18°C, but densities were 78% lower at 16°C and 95% lower at 18°C compared to cooler temperatures. Surprising results from experiments exposing sori of *N. luetkeana* to 18, 20, and 21°C for 3.75days found if zoospores were cooled to 10 or 16 °C then they would germinate and develop into gametophytes and sporophytes, though in lower numbers at the higher temperature. Increasing temperatures from 11.6 to 15.6 °C decreased gametophyte survival and sporophyte production and significantly impacted reproductive timing by causing female gametophytes to produce offspring earlier (Korabik et al. 2023). Tom Dieck (1993) reported survival threshold temperatures for *Nereocystis* gametophytes as 23°C for two weeks and -1.5 °C for 8 weeks. However, survival was measured as presence of living cells rather than competency to grow and mature. Temperatures recorded at the bottom of multiple kelp forests in Puget Sound reached the thermal limits of gametophyte growth (18°C) and sporophyte production (16–18°C (Weigel et al., 2023) limiting reproduction, and therefore recruitment, of adult kelp sporophytes, as was the case at the experimental restoration site near Maude Reef, in Lambert Channel, northern Strait of Georgia in July of 2021, where bottom temperatures reached an average of 17.5 °C (Heath et al., 2022).

Chrome Island lightstation, located approximately 700 m from Eagle Rock, near Denman Island south, and 3 km from the kelp restoration site on Maude Reef, Hornby Island has collected sea surface temperature (SST) since 1961 (2019, 2020 are incomplete) (Fisheries and Oceans, Canada, 2025). Sea surface temperatures for each of the months of May through August show an increasing trend (Appendix II) and average late spring/summer temperatures (May-August) follow an increasing trend of 0.127 degrees per year (Figure), for a total of 1.9 degrees Celsius between 1961 and 2021 (Figure 9).

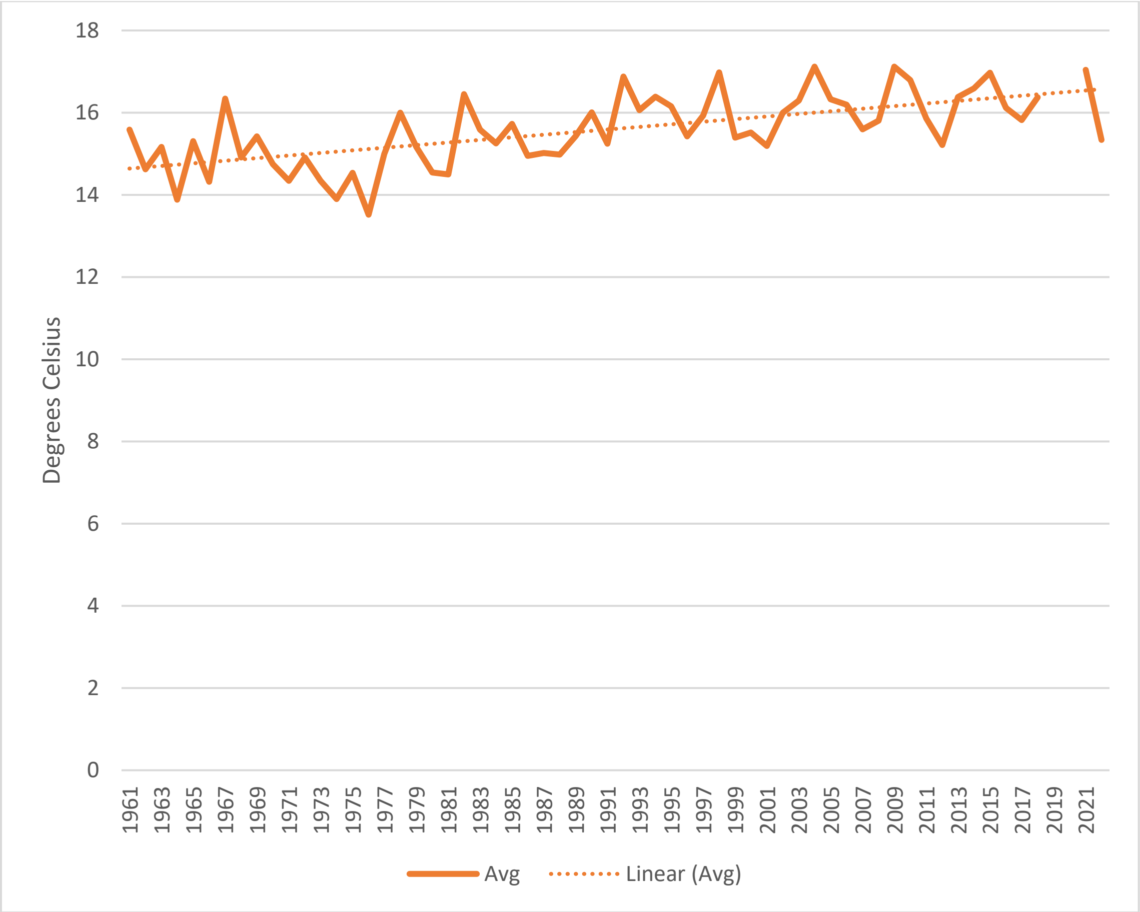


Figure 9. Average SST for late spring/summer (May-August) recorded at Chrome Island lighthouse 1961-2022 showing increasing trend line (DFO, Chrome Island Lightstation temperature data).

The average SST in July at Chrome Island Lighthouse was equal to or exceeded 18 °C in 45% of the years since 1990, and in August in 55 % of the years (Fisheries and Oceans, Canada, 2025). Prior to 1990, 10 % of years saw SST above 18 degrees in July and 7 % in August, possibly reflecting a climate shift in 1989 proposed by Hare and Mantua (2000), Litzow et al. (2020), and McFarlane et al. (2000). Rapid decline in bull kelp condition was observed at the Maude Reef, Hornby Island restoration test site with arrival of a heat dome in late June 2021, when temperatures ranged from 18 °C to 26.7 °C during June 23 to 30. The average SST recorded at the nearby Chrome Island Lighthouse in 2021 was 20.0 °C in July and 18.2 °C in August. If the upper tolerance of sporophytes is 18 °C over 30-35 days (Heath et al., 2022) then the SST experienced by mature *Nereocystis* sporophytes in approximately half of the years between 1990 and 2022 would lead to tissue degeneration and mortality, likely impacting sori production. Reproduction was even less likely in ten of those years when the average SST in both July and August exceeded 18 °C.

Successful growth of bull kelp sporophytes during long-term seeding experiments at Maude Reef in Lambert Channel in the northern Strait of Georgia and Doe Kag Wats/Jefferson Head in central Puget Sound indicates the environmental conditions at these sites can support bull kelp (Hayford, 2025; Heath et al., 2022). The continued need for input of kelp seed suggests that conditions that negatively impact microscopic life stages or reproduction and development might be contributing to kelp decline. Stressful temperatures at both the surface and bottom have been recorded at both sites, which may be a cause of poor success in reaching the goal of establishing self-sustaining bull kelp forests. Strategies for creating kelp forests that are resilient to climate change should be a priority.

Other water quality issues

Ocean temperature may be the dominant factor affecting biomass and distribution of *Nereocystis* but early life stages are also affected by levels of irradiance, sedimentation, nutrients, pollution, water movement, pH, and salinity. Lower salinity was shown to compound the negative response of *Nereocystis* early life history stages to increasing temperatures (Lind and Konar, 2017). A connection between ocean temperatures and nutrient availability has been postulated to explain the sensitivity of *Nereocystis* gametophytes and/or early sporophytes to winter oceanographic conditions in Northern California (García-Reyes et al., 2022). Warmer SST combined with the normally low nutrient levels of winter were found to predict poor summer *Nereocystis* canopy cover. Low nitrogen levels were less stressful than high temperatures to gametophytes or sporophytes in experiments, and additional nitrogen did not improve gametophyte or sporophyte survival at high temperatures (Weigel et al, 2023). Experimental lowering of pH level from 7.93 to 7.64 increased gametophyte survival and sporophyte production, but the effect was less than reducing temperature from 15.56 to 11.63 °C (Korabik et al. 2023). Investigating the role of cumulative effects on all life stages of bull kelp may lead to a better understanding of the factors that support resilience to increasing ocean temperatures, marine heat waves, and other ocean changes (Muth et al. 2019). Growth of bull kelp on the Central Coast of BC was found to slow at nitrate concentrations below 1 µm/L, and when light levels were lower or higher than the daily light interval of 20 to 40 mol/m^2/day (Pontier et al., 2024).

The only mention of turbidity issues at a restoration site was from an exploratory trial at Crab Park in Burrard, where poor growth of bull kelp on tiles was associated with high turbidity through the summer (visibility less than 1 m) possibly due to poor water flow and proximity to several urban waste outlets (Good, 2024), although a small bed of bull kelp had existed there within the last decade. Temperature and salinity measurements failed to explain poorer growth of bull kelp on gravel, cobble, and tiles outplanted at multiple sites compared to wild bull kelp at reference sites in Burrard Inlet. The author suggested also monitoring light, current, and nutrients in the future to better understand the requirements of bull kelp for growth (Good, 2024).

Freshwater at the surface was the suspected cause of blade loss in otherwise healthy bull kelp growing at a restoration site at Smith Cove in Puget Sound (PSRF and Calloway, 2024). A nearby storm water outfall and cruise ship terminal were suggested as possible sources.

Future-proofing kelp

Throughout the range of *Nereocystis luetkeana* in the northeast Pacific Ocean, populations display differences in genetic diversity via microsatellite markers, with the highest allelic richness levels found near the geographic fringes in California and Haida Gwaii (Gierke et al. 2023). Genetic relatedness was identified for four main groups: Alaska and Haida Gwaii; the outer coasts of Washington and Vancouver Island with Juan de Fuca Strait; the northern and southern Salish Sea; and Oregon with California. The relatively high genetic diversity in Northern California was associated with resilience to recent weather disturbances. The lowest genetic diversity was displayed in the inner reaches of the Salish Sea, in southern Puget Sound and northern Strait of Georgia. Further analysis of nucleotide diversity of *Nereocystis* occurring across BC and WA showed strong genetic structure (Bemmels et al., 2025), displayed in six clusters: Haida Gwaii and North coast of BC; west coast of Vancouver Island, Juan de Fuca Strait, southern Strait of Georgia, and northern Puget Sound; northern Vancouver Island (Broughton Archipelago); northern Strait of Georgia; and southern Puget Sound. Both studies emphasized the lack of genetic diversity exhibited in the northern Strait of Georgia and southern Puget Sound, where the highest ocean temperatures and greatest loss of bull kelp forests are occurring (Bemmels et al., 2005; Berry et al., 2021; Gierke et al., 2023; Mora Soto et al, 2024). The low genetic diversity found here is concerning, as it could make kelp forests more susceptible to marine heatwaves (Wernberg et al., 2018). The association between low genetic diversity with low effective population sizes, and high likelihood of inbreeding found in parts of the inner Broughton Archipelago, the Strait of Georgia, and Puget Sound suggests these populations suffer declining genetic fitness and increasing vulnerability to climate change (Bemmels et al., 2025).

Given the genetic differences identified in *Nereocystis* throughout its range, local adaptation or differential susceptibility to high temperatures could arise. Some studies have reported differences in thermal tolerance of kelp gametophytes from populations separated by large distances of 500 km to more than 2500 km (Becheler et al., 2022; Schimpf et al., 2022; Strasser et al., 2022). However, studies of *Nereocystis* from separate but not so distant locations have not shown differences in thermal tolerance. A comparison of the response of gametophytes and microscopic sporophytes cultured at seven different temperatures (10–22 °C) and two nitrogen concentrations found no difference in thermal tolerance across seven populations from locations around the southern Salish Sea, with different temperature profiles but only separated by 50 to 200 km (Weigel et al., 2023).

In a comparison of *Nereocystis* spores from a northern population (British Columbia/Washington State) to a central population (central California), both germinated at 12 °C but were intolerant of 18 °C for germination, development of gametophytes and sporophytes, although spore settlement did take place (Muth et al., 2019). Another study comparing bull kelp from three locations in California, located across approximately 500 km, saw a differential response in early life stages of bull kelp exposed to high temperatures, although few sporophytes derived from adults from any location developed at 18 °C (Fattori, 2024).

In a comparison of the development of early life history stages of *Nereocystis* from two locations in BC with different temperature profiles (summer SST was 5 °C lower at French Beach in the Strait of Juan de Fuca than at Stanley Park in Burrard Inlet), growth and development of healthy spores from each population was reduced when incubated in the lab at temperatures above ~ 17 °C, and temperatures of ~ 20 °C resulted in mortality of nearly all spores (Schiltroth et al. 2018). The only difference in response measured was in levels of reactive oxygen species (ROS) when exposed to the critical temperature of 17.5 °C. Gametophytes from the population growing in the warmer region were able to maintain low levels compared to ones collected from a population living at the cooler site, suggesting a physiological adaptation to a warmer environment. The two populations sampled for this experiment, French Beach and Burrard Inlet, possess different nucleotide diversity according to the designation of clusters by Bemmels et al. (2025).

When thermal tolerance is linked to genetic diversity, adaptation to high temperatures may be possible (Alsuwaiyan et al., 2021). When some offspring of Australian kelp *Ecklonia radiata* from different genotypes within the same population responded differently to marine heat waves, the authors concluded that some genotypes were more resistant and others more susceptible. In various trials determining the range of temperatures at which early life stages of *Nereocystis* thrive, there were often small numbers of individuals that survived under extreme conditions (Korabik et al., 2023; Muth et al, 2019; Schiltroth et al, 2018; Tom Dieck, 1993; Weigel et al., 2023). Future studies might combine genetic sequencing with temperature tolerance experiments to identify a possible genetic basis for susceptibility or tolerance to rising temperatures. Population genomics could be used to analyze gradients of kelp forest resilience with ocean temperatures to determine whether there is genetic adaptation to higher temperatures (Vranken et al., 2021).

One strategy suggested for selected breeding experiments is to study populations persisting at higher temperatures to determine whether tolerance to higher temperatures is a physiological adaptation or if there are additional environmental factors, which may affect tolerance. During the years the kelp restoration trials were conducted at Maude Reef in Lambert Channel, *Nereocystis* seed was obtained from adults in persistent beds in Sansum Narrows, Oyster River, and near Campbell River (Heath et al. 2015, 2017, 2022). The Oyster River site was only 54 km from the Maude Reef restoration site, yet in June and July of 2019, water temperatures at the Maude Reef site were more than 3.3 °C warmer at the bottom and 1 m below the surface than at the Oyster River site (Heath et al., 2022). Furthermore, vertical sonde casts and temperature logger data clearly showed the nearshore areas of Oyster River estuary provide a more stable thermal environment for bull kelp survival and persistence than at the Maude Reef site. Healthy natural bull kelp forests tend to persist in locations such as the Campbell River and Oyster River estuaries and Sansum Narrows because the waters are cooler, with average monthly temperature remaining below 15 °C. Transplants and seed for restoration trials sourced from these areas did not demonstrate any resilience to extended exposure to higher ocean temperatures (>18 °C) at the Maude Reef site in Lambert Channel, suggesting a lack of genetic adaptation to warmer conditions (Heath et al., 2022). Persistence alone does not equal resilience. Starko et al. (2024) suggests "restoration and conservation of kelp forests in these warmer regions will rely on the use of transformative and controversial tools that facilitate increased thermal tolerance in natural populations".

Past research priorities

The following were identified as research priorities at a workshop attended by regional experts in phycology, algal habitat mapping, kelp restoration, and fish habitat managers, to discuss research priorities and collaborative opportunities for nearshore macroalgae in coastal British Columbia, held at the Department of Fisheries and Oceans' Pacific Science Enterprise Centre on February 27, 2018 (Levings and Stewart, 2020).

- Natural limiting factors (e.g. urchin outbreaks as a factor for kelp restoration)*
- Anthropogenic effects, especially multiple stressors (e.g. contaminant mixtures with temperature) and cumulative effects
- Research on early life history stages (gametophytes)*
- Critical habitat linkages and maintaining connectivity within and between macroalgae ecosystems
- Research on forage fish ecology (e.g. herring) and their relations to macroalgae*
- Investigate use of Traditional Ecological Knowledge*
- Intensify efforts to educate citizens about the importance of ecological integrity, using macroalgal ecosystems as an example*
- Research on alternate productivity measures for macroalgae (i.e. in addition to carbon fixed) (fatty acids, stable isotopes) and information on amounts and timing for the measures to connect with consumer organisms
- Establish and/or maintain long-term monitoring programs and perform retroactive analyses on existing data as appropriate*
- Investigate genetic diversity of macroalgae communities*

Some progress has been made on the priorities marked with an asterisk*.

LESSONS LEARNED

Many trials in coastal BC and Puget Sound WA have demonstrated the resilient nature of bull kelp, *Nereocystis luetkeana,* to various methods of restoration. Some key messages come from the multiple practitioners attempting to restore bull kelp in the Salish Sea and other locations in BC around site selection, methods and timing of outplanting, and reducing grazing pressure from herbivores. Some future directions for restoration practices and research are suggested.

Site selection

Place-based knowledge is critical for site selection. Consult with local Indigenous people, communities, fishers, and others who have firsthand knowledge of the current and historical ecology of the area and human activities in it, as well as the cultural importance of bull kelp and potential restoration sites.

Restoration practices must be tailored to specific sites.

Almost all the sites chosen for restoration or enhancement in BC have a history of bull kelp presence, which indicates that the conditions at each of these sites once met all the requirements for bull kelp to grow, reproduce, and recruit. If restoration at these sites is going to be successful, then we need to determine what baseline conditions were like, find out what has changed, and whether conditions can be returned to what they were in the past, or find and breed bull kelp, which can grow under the new or changing conditions.

Site selection considerations (Heath et al, 2018):

- Substrate: Bedrock, boulder, cobble
- Moderate exposure to waves and/or currents
- Nutrients: Good sites are near source of upwelling or mixing of deep water to surface for sustained summer growth and good condition
- Depth: 6 to 12 m (if water clarity is reduced by plankton blooms or turbidity)
- Light intensity: Can be limiting in winter/ early spring so shallower is better (long-lines can be adjusted to be shallow for nursery phase)
- Temperature: <18 °C is best (avoid >18 °C for prolonged periods)
- Salinity: >20 PSU (stay away from large rivers)
- Herbivore density: Avoid areas with high densities of sea urchins, kelp crabs

Physical and environmental data that should be collected (Heath et al, 2018):

- Temperature: At or near bottom and mid-depth (range of kelp growth)
- Light intensity: As for temperature
- Turbidity / clarity: Secchi depth and/or turbidity probe
- Other parameters of interest: Salinity, Chl-a, pH, nutrients
- Herbivore species associated and their abundances
- Biodiversity associated with kelp via long-term monitoring

Monitoring water temperatures throughout the water column or at both the surface and bottom of restoration sites is important for understanding conditions under which all life stages of kelp grow.

Deploying green gravel from a boat is only recommended if the substrate is known to be rock and cobble, and even then, the efficiency may be reduced if the side with the least propagules is the one facing upwards (Good, 2024).

Comparisons of historic records and modern aerial photos and satellite imagery of bull kelp forests show the dynamic nature of kelp abundance, with populations exhibiting persistence and susceptibility to the increasing trend in ocean temperatures and frequency of marine heat waves, as well as imbalances in relationships with herbivore grazers (Mora-Soto et al., 2024b; Starko et al., 2024). All life stages of *Nereocystis* exhibit thermal stress to temperatures above 16 °C, with 18 °C an apparent upper limit (Heath et al. 2022; Schiltroth et al., 2018). These critical temperature points are exceeded at restoration sites at both the water surface where adult blades are most affected and at the bottom affecting zoospores, gametophytes, and early sporophytes, though less frequently (Heath et al., 2015, 2022; Weigel et al., 2023).

The following are ocean temperature related observations of bull kelp at the Maude Reef restoration site at Maude Reef in Lambert Channel.

- Too warm conditions lead to shortened or absent reproductive season for bull kelp.
- Upper tolerance of sporophytes appeared to be 18 °C over 30-35 days.
- Water temperatures at the Maude Reef site were more than 3.3 °C warmer at the bottom and 1 m below the surface, in June and July of 2019 than the Oyster River site, and exceeded the 17 °C threshold for prolonged exposure and leading to tissue degeneration and mortality.
- Rapid decline in bull kelp condition was observed at the Maude Reef test site with arrival of a heat dome in late June 2021 (18 °C to 26.7 °C, June 23 to 30) and a continuing heat wave in July.
- Sori production in the area was found to occur from May to October in “cooler years”, especially in May-June, but not in hotter years as seen in 2015.

Low but significant recruitment was observed at the two multi-year restoration sites in years following ones where the dominant stressor was reduced: Green urchins at Maude Reef in Lambert Channel (Heath et al., 2022) and cooler and longer growing season at Doe Kag Wats/Jefferson Head in Puget Sound (H. Hayford, PSRF, personal communication, March 25, 2025).

“Considering a marine heatwave hit in July 2024 and senescence of bull kelp in Puget Sound occurred notably earlier than normal (July, Aug), we are anticipating we will see fewer recruits this spring.” (H. Hayford, PSRF, personal communication, March 25, 2025)

Competition

Understory kelp can inhibit the recruitment of bull kelp, because low light levels beneath the canopy can inhibit gametogenesis in bull kelp (Vadas, 1972). Bull kelp conditions declined early, after some years, resulting in poor recruitment in subsequent years at the Eagle Rock, Denman Island site (Heath et al., 2015). Understory macroalgae, specifically the non-native *Mazzaella japonica,* became established, possibly preventing any further recruitment of bull kelp.

Elimination, or clearing of understory macroalgae was found to be more effective at encouraging recruits to a site than enhancement of propagules in the spring (Muth et al, 2019).

When conditions are favorable, microalgae, mostly diatoms, can settle on newly outplanted seeded lines, gravel, or tiles, dividing quickly to outgrow kelp propagules, blocking access to light and nutrients. This may have occurred on seeded lines deployed at Pilkey Point, Thetis Island in December 2023, where bull kelp only grew sparsely while spools of the same batch grew well at another site and in the nursery, which produced the seed (A. Lamb, TIME, personal communication, February 11, 2025). Time of outplanting may be a factor in avoiding diatom colonization of the lines, such as avoiding spring blooms of the chain-forming diatom *Melosira* (Allen, 2018).

Methods of outplanting

Care of seeded lines, gravel, or tiles is crucial during transport from the nursery until outplanting. It can be beneficial to have the nursery hold back some of the seed for comparison of growth with the outplanted kelp to be sure the seed was competent prior to travelling. Bull kelp failed to grow on a seeded line deployed at Ford Cove, Gabriola Island (Help the Kelp, n.d.) in January 2011, yet other species of kelp did grow on it voluntarily. The reason for the lack of bull kelp growth was not known, but may have been due to poor conditions for seeded line spools during transport rather than competition with the other kelp, since bull kelp is the faster growing species.

Bull kelp seed on cobble-sized stones and tiles were observed to perform better than the ones cultured on gravel-sized stones, seeded lines, and directly seeded in trials comparing growth of bull kelp settled on different substrates in the nursery and outplanted to the same site (KRI and Shuster, 2024).

Seed lines wrapped around concrete pyramids or concrete cylinders (8-gallon size) deployed on the bottom of restoration sites have been effective for producing clusters of bull kelp (H. Hayward, personal communication, March 25, 2025).

Size matters when choosing rocks for outplanting bull kelp seed or for transplanting small sporophytes. A large percentage of wild recruits will attach to rocks too small to anchor a larger, more buoyant individual, resulting in waves or current carrying them away. While small 3-5 cm gravel works well with giant kelp (Dawkins, 2024), the stipe and bulb of bull kelp grow faster than the haptera, resulting in the sporophyte becoming buoyant before the haptera have grown beyond the gravel to secure a more secure attachment by the holdfast. Use larger, fist-sized cobble as minimum, for bull kelp. KRI is running trials to find optimal size (Schuster, 2025) although the best size may be site specific.

Rocks used in the production of green gravel should be very clean or sun-bleached for high rates of spore settlement and germination in the nursery (Martone, 2025). Spores and/or gametophytes of bull kelp are found in higher density in the nursery when exposed to newly crushed rock or rocks from high in the intertidal zone and free of algal growth possibly due to competition for space and light (P. Martone, pers. comm., 2025).

Boat-deployed green gravel may be an inefficient method for restoration in high flow areas with steep slopes and larger boulders with crevices between them, as currents can carry 3-5 cm green gravel to places it cannot grow. It was estimated 60 to 70% of the seeded gravel outplanted from a boat at sites in Burrard Inlet would not land somewhere it could successfully become reproductive (Good, 2021; Schuster, 2024). Deploying gravel from a boat was also deemed unsatisfactory in Barkley Sound (Schuster, 2024).

Like green gravel, transplanted kelp sporophytes require sufficient anchor weight to prevent loss due to floatation (Heath et al., 2024). Recent transplanting trials have found that using natural rubber bands to attach each young bull kelp sporophytes to a fist-sized cobble stones was most effective, and dropping the transplants from the side of a boat to reach the sea bottom was an efficient method of deployment (E. Fulton, Redd Fish Restoration Society, personal communication, February 25, 2025; L. Ennis, Vital Kelp, personal communication, April 2, 2025). The search for a more biodegradable option for attachment is on.

Tiles work best if attached to a concrete block or rock substrate (Good, 2024; Martone, 2025). Epoxy can be used as an adhesive for this.

Deploying "conditioned" lines were effective at recruiting and growing *Saccharina* sp. but not bull kelp at the Maude Reef site near Hornby Island (Heath et al., 2022).

Explore place-based methods of kelp restoration and management by collaborating with First Nations to incorporate Indigenous traditional knowledge to make methods accessible to all. Collaborations with səlilwətaɬ (Tsleil-Waututh Nation) have trialed the use of oyster shell (Wolf, 2024) and cedar rope (Martone, 2025) as substrates for bull kelp propagule collection. Oyster shell was found too light weight to prevent bull kelp floating away as it grew (Ocean Wise and Janke, 2024).

In the hope of avoiding the use of spools of twine for outplanting bull kelp seed, experiments and trials are being conducted to produce a glue (alginate binder) resembling the natural adhesive material secreted by kelp for attachment to a substrate (A. Loudon, personal communication, January 10, 2025; M. Roy-Musor, personal communication, February 25, 2025).

Timing of outplanting

Should outplanting be done before the winter solstice or in late winter (February)? Late deployment can be more effective than early, possibly by avoiding predation, but must be early enough to avoid spring bloom. The best time for outplanting will be site specific.

Scaling-up

The long-line cultivation approach can contribute to restoration if the effort is diversified by outplanting potentially resilient kelp throughout a network of good sites spread over a large area (Heath et al., 2022).

KRI outplanted 1700 m of green gravel in 2024-2025 winter season.

Scaling up is logistically challenging, therefore evidence of return on investment (bigger outplant yielding more next-generation kelps) is an important validation of efforts (PSRF, n.d.b).

Herbivore culling or exclusion

Some exclusion devices are effective in preventing grazing by sea urchins, allowing kelp to grow. Vexar™ (1 cm) mesh attached to a PVC frame was effective at the Maude Reef, Hornby Island site (Heath et al. 2022) as was a Vexar™ fence with rebar deployed at Eagle Rock site near Denman Island (Schuster, 2025). Leaving the top edge of the mesh unsupported appears to discourage sea urchins from climbing over the edge. The drawbacks to using mesh in the ocean include the logistics of large-scale deployment and the requirement of maintenance by divers as fouling accumulates over time. There are also concerns about mesh acting as a gill net, trapping small fish (Checko, 2024).

Results from sea urchin surveys in kelp areas of concern suggest two urchins per m^2 is too many (Schuster, 2025).

Extensive culling of sea urchins in Gwaii Haanas was effective for one year, but then they began migrating back into the area (Lee, 2021). Management of herbivore grazing may require routine culling.

As noted above, some recommend outplanting in late winter rather than December to avoid hungry invertebrates such as gastropod snails looking for food (Allen, 2018; B. Timmer, personal communication, February 25, 2025).

Habitat reclamation/rehabilitation and artificial reefs

Building artificial reefs to encourage kelp, including *Nereocystis,* to settle, grow, and establish thriving beds has been attempted at several sites in the Salish Sea. The formation of artificial reefs and addition of rocky substrate to form habitat for kelp is reported to have been effective at one site in Roberts Bank, Delta, BC (Williams and Millar, 2006) and a location in Puget Sound, WA (Cheney et al., 1994) Like other restoration sites, water quality and oceanographic characteristics must be approporaite for the species of kelp, and monitoring may need to be long-term to see comprehensive results of colonization by kelp, fish, and invertebrates.

Future-proofing kelp

If ocean temperatures in the Salish Sea continue to follow the current increasing trajectory, or even if they continue at the current level, kelp forests lost in sheltered areas with low water flow in the northern Strait of Georgia and Puget Sound are unlikely to recover using current methods of restoration. Repeated, successful growth of a kelp bed at each of the long-term experimental restoration sites at Maude Reef in Lambert Channel and Doe Kag Wats in Puget Sound is evidence that environmental conditions at these sites can still support bull kelp. The continued need for input of kelp seed at these sites suggests that conditions that lead to a lack of microscopic forms or to interruptions to reproduction and development might be contributing to kelp decline. Stressful temperatures have been recorded at both sites, which may be a cause of variability in kelp success. This suggests the need for restoration strategies that are resilient to climate change such as assisted adaptation (Vranken et al, 2021).

The low genetic diversity and higher likelihood of inbreeding found in small populations of *Nereocystis* living in the northern Strait of Georgia could contribute to the vulnerability they have shown to increasing ocean temperatures and marine heat waves, as well as future changes in climate (Bemmels et al., 2025; Gierke et al., 2023). Large populations with higher genetic diversity, such as those found at the northern and southern fringes of its range, are suggested as the preferred genetic source for restoration over small populations with lower genetic diversity, unless the small population is locally adapted to a current and possibly future environment of an outplanting site (Bemmels et al., 2025). The authors suggest that offspring of crosses between small populations may perform better than offspring of crosses within a single small population and warn that out crossing with high or low diversity populations can lead to outbreeding impression. These strategies for sourcing and crossing populations require experimental validation (Bemmels et al., 2025). Future studies might combine genetic sequencing with temperature tolerance experiments to identify possible genetic basis for susceptibility or tolerance to rising temperatures (Vranken et al., 2021).

Selective breeding

Culture-based trials, which provided an opportunity to refine the kelp parental stock selection process and to learn more about factors limiting bull kelp restoration and rebuilding of local kelp forests, have and are being conducted in BC. Trials at the Maude Reef restoration site in Lambert Channel from 2013 to 2021, compared bull kelp seed and transplants sourced from persistent kelp forests in the northern Salish Sea, at Campbell River and Oyster River estuaries and Sansum Narrows, where average monthly temperatures remained below 15 °C near the bottom and surface of the water column (Heath et al., 2022). None of the kelp stocks exhibited tolerance to extended exposure to warmer conditions (>18 °C), suggesting a lack of genetic adaptation to higher temperatures.

“Finding kelp beds experiencing similar water quality parameters as lost beds, while exhibiting resilient to climate related stressors may lead to a genetic basis for resilience, one which may be selected for breeding trials” (Starko et al. 2024).

To investigate how different genetic compositions between populations influence growth and survival of *Nereocystis* in a shared environment, a common garden experiment was undertaken by the Kelp Rescue Initiative (KRI) and Hornby Island Diving, at the Maude Reef restoration site in

Lambert Channel in 2023 (Iselin and Above/Below, 2025). Bull kelp sourced from five separate locations in the Strait of Georgia that had persisted through recent marine heat waves showed differences in patterns of growth and maturity in response to warmer conditions at the site, but all exhibited signs of acute stress under the high temperatures of July. The study was repeated in 2024.

Thermal priming

KRI is investigating the potential for thermal priming in *Nereocystis* (Schuster, 2025). Thermal priming, a technique used in crop agriculture in which plants exposed to thermal stress acquire a stress memory that enhances performance under a second exposure to thermal stress, shows potential in enhancing resistance to rising ocean temperatures in kelp (Jueterbock et al., 2021). While few studies have investigated thermal priming in kelp to date, a preliminary study of sugar kelp, *Saccharina latissima* gametophytes exposed to 20 °C for 4 weeks gave rise to sporophytes tolerant of higher temperatures than individuals from non-exposed gametophytes (Gauci et al., 2024). Efforts to create more resilient sugar kelp involving priming with multiple environmental stressors (temperature and salinity) are progressing in Scotland (Scottish Association for Marine Science, 2025).

Alternate species

Evidence from long-term experimental restoration sites at Maude Reef in Lambert Channel and Doe Kag Wats/Jefferson Head in Puget Sound shows *Saccharina latissima* naturally recruited at sites where wild and outplanted *Nereocystis* struggled to establish self-sustaining beds (Hayford, 2025; Heath et al., 2022). *Saccharina* sp. recruited and grew a full cycle at the Maude Reef site during years when seawater temperatures were high and bull kelp failed to survive to reproduce, providing habitat that attracted a diverse community of fish and invertebrates (Heath et al., 2022).

Collaboration

Collaboration and knowledge sharing among restoration practitioners in nursery and field operations, and with stakeholder communities, Indigenous people, industries, and managers is crucial for developing strategies and directions for further research and developments in bull kelp restoration. Collaboration has been fundamental to the restoration projects undertaken in BC and has expanded with the involvement of large organisations, however an overarching strategy for restoration of bull kelp is lacking.

RECOMMENDATIONS

1. Use the remaining natural kelp beds as reference sites to compare differences in seasonality of growth, reproduction, and natural mortality with outplant sites to find clues to improving restoration techniques (Heath et al., 2022; PSRF, n.d.b).
2. 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)
3. Encourage growth of more heat tolerant laminarian kelp such as sugar kelp (*Saccharina latissima*) to create seabed understory, which can provide habitat for fish and invertebrates (Heath et al., 2022).
4. Avoid predators such as sea urchins and kelp crabs when selecting sites (Heath et al. 2022).
5. Continue research into site-specific timing within the year for outplanting, density of seed outplant, and outplant substrate (PSRF, n.d.b)
6. Investigate the role of cumulative effects on all life stages of bull kelp to better understand the factors that support resilience to increasing ocean temperatures, marine heat waves, and other ocean changes (Muth et al., 2019)
7. "Finding kelp beds experiencing similar water quality parameters as lost beds, while exhibiting resilience to climate related stressors may lead to a genetic basis for resilience, one which may be selected for breeding trials" (Starko et al., 2024).
8. Future studies might combine genetic sequencing with temperature tolerance experiments to identify possible genetic basis for susceptibility or tolerance to rising temperatures
9. "Scaling up is logistically challenging, therefore evidence of return on investment (bigger outplant yielding more next-generation kelps) is an important validation of efforts" (PSRF, n.d.b).
10. Building capacity within Indigenous communities (First Nations and Tribes) to manage and restore kelp forests in their territories is critical for a sustainable future.
11. Collaboration and knowledge sharing among restoration practitioners in nursery and field operations, and with local communities, Indigenous communities, industries, and managers is crucial for developing strategies and directions for further research and developments in bull kelp restoration (L. Ennis, personal communication, April 02, 2025; Martone, 2025; PSRF, n.d.a.)

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PERSONAL COMMUNICATIONS

Amy McConnel, personal communication, March 7, 9, 23, 2025 – Canadian Kelp Research

Andy Lamb, personal communication, February 11, 2025 - Thetis Island Marine Explorers (TIME) Dive club

Andy Loudon, personal communication, January 10, 2025 – Vancouver Island University

Ann Eriksson, personal communication, February 11, 2025 – (TIME) Dive club

Brian Timmer, personal communication, February 25, 2025 – University of Victoria, Kelp Rescue Initiative (KRI)

Dana Janke, personal communication, February 25, 2025 – Ocean Wise Canada

Diane Sampson, personal communication, March 14, 2025 – Nile Creek Enhancement Society (NCES)

Emily Fulton, personal communication, February 25, 2025 - Redd Fish Restoration Society

Hilary Hayford, personal communication, March 25, 2025 – Puget Sound Restoration Fund (PSRF)

Jennifer Clark, personal communication, March 18, 2025 – Cascadia Seaweed

Lee-Ann Ennis, personal communication, February 25, 2025; April 02, 2025 – Vital Kelp

Maisy Roy-Musor, personal communication, February 25, 2025 - KRI

Patrick Martone, personal communication, February 25, 2025 – University of British Columbia (UBC)

Scott Bohachyk, personal communication, March 05, 2025 - Ocean Wise Canada

APPENDIX I. RESTORATION PROJECTS 2006-2024

STRAIT OF GEORGIA, BC RESTORATION PROJECTS

1. Nile Creek Enhancement Society, Comox Valley Project Watershed Society, and Hornby Island Diving
2. Kelp Restoration Component of the Project Watershed Society Coastal Restoration Fund Project
3. Help the Kelp, Gabriola Island
4. Mount Arrowsmith Biosphere Region Research Institute (MABRRI), Vancouver Island University (VIU)
5. Independent, Nelson Island, Lee-Anne Ennis
6. Vital Kelp, Jeddah Point, Sunshine Coast
7. Thetis Island Dive Team Volunteers, Canadian Kelp Research, and Ocean Wise Conservation Association
8. Neptune Terminals & UBC (Dr. Patrick Martone)
9. Ocean Wise Canada
10. Kelp Rescue Initiative (KRI)

Other kelp restoration projects in BC and Puget Sound, WA

Nile Creek Enhancement Society, Comox Valley Project Watershed Society, and Hornby Island Diving

Bull Kelp Restoration Research Collaborative project of Project Watershed Society, Nile Creek Enhancement Society and Simon Fraser University, supported by Pacific Salmon Foundation (2012-2017) and Fisheries and Oceans Canada (2017-2022). Additional collaborations with University of Victoria, Vancouver Island University and University of Wisconsin-Milwaukee

The mission of the Nile Creek Enhancement Society (NCES), located in Bowser, includes enhancing and protecting the marine habitats that support salmonids and the habitat in which they live. They recognized that the kelp forests disappearing from around the mouth of Nile Creek are a part of the nearshore habitat ecosystem necessary for salmon to survive. According to their blog posts, the NCES began efforts to restore bull kelp to the area in 2006 (NCES, n.d.). Their first attempts involved sinking onion sacks filled with rocks and sori in reef areas, along with seeded strings of bull kelp juvenile sporophytes that was unwound from sections of PVC pipe and attached to sacks of rocks which were also placed on the sea bottom at depths that would be covered with a metre of water during the lowest tides. *Salmon and cutthroat trout runs returned but kelp follow-up was not reported (found).* In the next few years they changed their restoration methods by threading seeded kelp lines onto a grid-style planting structure at Maude Reef, located at the southwest end of Hornby Island.

> Nile Creek Enhancement Society (NCES). (n.d.). The Story of Nile Creek – Part II. YouTube clip. Available at https://nilecreek.org/youtube/

In 2011, Hornby Island Diving, teamed up with the NCES, and with support from the Pacific Salmon Foundation (PSF) Community Salmon Program, their efforts took a more experimental approach. These restoration investigations and findings have been reported over the years by William (Bill) Heath, past member of NCES and director of Cowichan Valley Project Watershed Society, and Rob Zielinski and Amanda Zielinski of Hornby Island Diving. They began to study local ocean conditions at a natural kelp bed at Eagle Rock near Chrome Island on the south end of Denman Island and at the kelp restoration site at Maude Reef where a kelp culture line grid (25m x 30m) of up to six lines was installed, based on that used by Louis Druehl of Canadian Kelp Resources Ltd in Barkley Sound near Bamfield, BC. Observations by divers and data-logged (Onset Hobo) temperature and light intensity measurements every 30 minutes at two depths (i.e. at the bottom and one metre below the surface (mid)) at each site were recorded.

In collaboration with Comox Valley Project Watershed Society (CVPWS) and with support from the PSF Salish Sea Marine Survival Program (SSMSP), efforts to restore and monitor kelp growth were expanded to include a second deeper experimental site in northern Baynes Sound and a site of the Island Scallops deep water lease near Bowser in 2015. Additional environmental data from multi-parameter sonde casts was collected at the study sites. The following year, a site was added at Cape Lazo shoal and they began obtaining sori and producing kelp "seed" from Sansum Narrows, in more southern Gulf Islands, to compare growth and survival with sori collected from the original source in Campbell River. Sea surface temperatures in the spring and summer of 2015 were some of the warmest recorded locally, providing an opportunity to study the effects of temperature stress and herbivore grazing as limitations to bull kelp distribution in the area. A collaboration with the Bisgrove Lab at Simon Fraser University Biosciences contributed to investigation of stress resiliency of kelp life stages (Schiltroth, 2021).

	
“Juvenile bull kelp plants on grow-line at Maude Reef site on February 24, 2015”	“Measurement of bull kelp plants at Maude Reef site on April 14. Wide range of sizes: vary from 8 to 14 cm stipe length... these larger sporophytes vary from 15 to 40 cm stipe length.”
	
“Heavy growth of bull kelp at Maude Reef site on May 22 despite epizoans and grazers”	“Deteriorating bull kelp plants on grow-line at Maude Reef site on July 8. Many plants have hardly any blades left.”

A1 Figure 1. Stages of bull kelp growth on the line grid at Maude Reef in Lambert Channel (Heath, Zielinsky, and Zielinsky, 2015b; permission to use given).

A1 Figure 2. Bull kelp with some sugar kelp growing on an experimental line at the Maude Reef line grid in Lambert Channel (Heath, Zielinsky, and Zielinsky, 2018; permission to use given).

Heath, W., Zielinski, R., Zielinski, A. (2018a). Bull Kelp Restoration Action in the Strait of Georgia. Slide show, available at https://www.nwstraits.org/media/2843/bill-heath_bullkelprestoration-straitofgeorgia_heath.pdf

Overall, these studies established: an experimental system for environmental sampling as well as planting and analysis of bull kelp performance in the field; the role of prolonged warm temperatures (>16 °C) and herbivore grazing in restricting bull kelp survival; and methods for assessing stress-resiliency of bull kelp populations.

Comparison of the performance and reliability of seed derived from sori collected from kelp at Campbell River and Sansum Narrows showed Sansum Narrows stock preferred for obtaining excellent quality sori for seed production.

Research and performance of the restoration trials during 2013 to 2017 were challenged by frequent and prolonged periods of warm water (>15°C) in spring and/or summer months in every year except 2016, when bull kelp was observed in good condition in September and October, providing an extended period for sori production and spore release. Demonstrating how resilient to disturbance the species can be when favourable growing conditions return.

Eagle Rock on the south end of Denman Island was initially chosen as a reference site because over a kilometre of fringing kelp reef had grown there as long as anyone remembered. High sea surface temperatures are thought to be responsible for decreasing abundance of wild kelp at the site, after poor sori production in 2014 was followed by years of poor recruitment. In 2015, only 50 sporophytes recruited to the site and the following year the kelp fringe failed to develop for the first time in memory. There was no sign of recovery by the end of the study in 2022. Compounding the effects of higher SST was competition with other algae, such as the non-native *Mazzaella japonica,* and increased abundance of green urchins grazing shallower than the usual red sea urchins (*Mesocentrotus franciscanus*), which prevented kelp from colonizing the cooler depths below 6-7 m. Grazing by kelp crabs also contributed to the loss of kelp from the reference site and decimated the deeper site in northern Baynes Sound, resulting in its abandonment as a test site. Despite challenges, the long-line cultivation approach proved itself as a method for restoration.

Conclusions about Temperature Effects

- Sori production occurs from May to October in “cooler years”, especially in May-June, but none in hotter years, such as occurred in 2015.
- Sporophyte upper temperature tolerance was found to be 18 °C over 30-35 days.
- Upper limit for spore formation is 17 °C, but revival can occur if lower temperatures return (Schiltroth, 2021).
- At 17 °C spore germination also decreases significantly, whereas 20 °C kills off spores (Schiltroth, 2021)
- Too warm conditions lead to a shortened reproductive season for bull kelp, potentially impacting recruitment.

Recommendations 2011-2018

Site Selection Considerations

- Substrate: Bedrock, boulder, cobble
- Moderate exposure to waves and/or currents
- Nutrients: Good sites are near source of upwelling or mixing of deep water to surface for sustained summer growth and good condition
- Depth: 6 to 12 m (if water clarity is reduced by plankton blooms or turbidity)
- Light Intensity: Can be limiting in winter/ early spring so shallower is better (long-lines can be adjusted to be shallow for nursery phase)
- Temperature: <18 C is best (avoid >18 C for prolonged periods)
- Salinity: >20 psu (stay away from large rivers)
- Herbivore density: Avoid areas with high densities of sea urchins, kelp crab

Physical and Environmental Data Collection

- Temperature: at or near bottom, mid-depth (range of kelp growth)

- Light intensity: as for temperature
- Turbidity / clarity: Secchi depth and/or turbidity probe
- Other parameters of interest: Salinity, Chl-a, pH, nutrients
- Herbivore species associated and their abundances
- Biodiversity associated with kelp via long-term monitoring

Kelp Restoration Component of the Project Watershed Society Coastal Restoration Fund Project

The restoration work of the CVPWS and NCES (2007-2017) culminated in a five year study as the Kelp Restoration Component of the Project Watershed Society Coastal Restoration Fund (CRF) Project, funded by Fisheries and Oceans Canada, and ended in 2022. Yearly progress reports were compiled by Heath, Zielinski, and Zielinsk (2019, 2020, 2021, 2022) and submitted to Fisheries and Oceans Canada, Coastal Restoration Fund and are the source of the following summary. These were the specific goals of the project:

- To conduct a seeded line outplant pilot study at Maude Reef grid site (7m depth), the reference site at Eagle Rock (9-10m), and at a second reference site at the Oyster River estuary where an extensive bull kelp population currently existed. The goal was for the seeded lines approach to provide sori (reproductive structures) for spore production and to enhance natural recruitment of bull and sugar kelps to the surrounding area.
- To conduct a bull kelp transplant by moving juvenile sporophytes from the Oyster River site to the Maude Reef site and following kelp growth, condition and survival in an enclosure.
- To test a sea urchin density control treatment by use of an urchin exclusion device designed to be relatively self-tending.
- To monitor the sites to provide information on: 1) utilization of kelp habitat by fish and invertebrate species; 2) the possible barriers to natural recruitment; 3) critical ecological and environmental interactions and ways to improve out-planting and 4) on overall habitat restoration performance
- To collaborate.

Procedures and Results

Water property profiles were created for the reference sites at the Oyster River estuary and Eagle Rock, and the Maude Reef grid site during June and July, from vertical casts of a YSI 6600 sonde recording temperature, salinity, turbidity, and chlorophyll. At the Oyster River reference site on July 29, 2020, water temperature declined with depth from 17.59 °C in a 2 m brackish layer to 12.67 °C at the bottom. On the same day, water temperature declined from 22.24 °C in a 1.5 m brackish layer to 14.31 °C at the bottom of the Maude Reef site. Salinity at the Maude Reef site was lower than at the Oyster River site at all depths and chlorophyll levels were elevated (3-6.5 ug/L) at depths of 2 m to 9 m at Oyster River.

The critical time for warming temperatures to affect bull kelp growth, condition and reproduction is during June, July and August at the Maude Reef restoration site. Results from data-logged temperature recordings for the Maude Reef grid site in 2020 and 2021 show a trend of prolonged stressful (>15 °C) and damaging temperatures (>17-18 °C), as summer progressed. Mean monthly temperatures at the Maude Reef site were consistently higher than at the Oyster River site at both bottom and mid-depth (1 m below the surface) during June through August 2021.

Red and green sea urchins were surveyed for relative abundance during the 2019 and 2020 kelp growing seasons at the Maude Reef and Eagle Rock study sites by divers experienced in species identification and in the REEF.org protocol. Sea urchin abundance and size distribution were also measured at the Maude Reef site. A major change in sea urchin distribution was observed in 2019 in comparison with earlier years at the Maude Reef site. While the density of red urchins remained similar to previous years at about 0.25 /m2, green urchins appeared to have moved from the site, resulting in the density plummeting from highs observed in 2018. Subsequently, grazing pressure also declined allowing a diverse assemblage of macroalgae to develop on the bottom, including kelps in the Laminariaceae family such as Saccharina sp.

Marine species and abundance surveys by REEF.org expert marine ID surveyors each year from 2019 to 2021 recorded a total of 75 species within the Maude Reef grid and 67 species adjacent to it. The average number of species observed by a surveyor ranged from 15 in April, 2021 to 37 in September, 2019. Species with the highest sighting frequency at the Maude Reef sites included copper rockfish (*Sebastes caurinus*), red sea urchins, blackeye goby (*Rhingobiops nicholsii*), buffalo sculpin (*Enophrys bison*), and kelp greenling (*Hexagrammus decagrammus*).

Culture lines seeded with kelp seed produced by Green Seas Kelp Co. of Comox, from sori collected from parent stock at Oyster River estuary and Sansum Narrows, were deployed at the Maude Reef grid site on Dec. 27, 2018. Both cohorts had excellent early survival, growth and condition through to June 21, 2019, forming a well-developed canopy. Sori development was observed in May. By mid-July the bull kelp was subject to widespread bryozoan colonization and blades were deteriorating from thermal stress (prolonged exposure to >17–18 °C). By mid-September most of the bull kelp plants at the Maude Reef site were gone but some blades were present with sori patches. At the Oyster River site, most bull kelp was in good condition into late October.

On several culture lines a dense understory of recruited kelp in the family Laminariaceae, hereafter called Laminarian kelp, (mostly *Saccharina* sp.) had developed by mid-June. In mid-July, when bull kelp was showing stress and deteriorating, the kelp understory remained in relatively good condition despite some bryozoan colonization.

2019 Kelp seed lines outplanted to Maude Reef site on Dec 27, 2018. Kelp showed good growth and density, observed reaching the surface June 21. F2 in 2019. Low green urchin abundance compared to 2018, while red urchins remained the same. The decrease in grazing pressure allowed a diverse assemblage of macroalgae, including laminarian kelp (Saccharina sp) to develop on the bottom. Sori observed in June, July, and September.

Six bull kelp F2 generation recruits were observed at the Maude Reef site in February of 2020, as well as many Laminarian kelp recruits (*Saccharina* sp., *Costaria* sp.). Unfortunately, the bull kelp juveniles were not firmly attached and didn't remain on site.

Twenty juvenile bull kelp sporophytes (size) attached to cobble-sized rocks were transplanted from bull kelp beds at Oyster River estuary to a sea urchin exclusion cage ("exclosure") on the seabed at the Maude Reef grid site on April 5, 2020. The plants were in excellent condition after the move, joining Laminarian kelp which naturally recruited inside the unit. One month later, the transplants showed good growth and condition, with sori present on some blades. A dense assemblage of kelps was present as the exclosure was effective in keeping sea urchins out. As the bull kelp transplants gained height over the next weeks a few were lost, possibly due to current drag. From late July, the remaining transplants deteriorated from stressful warm temperatures for a prolonged period (a month with >17 – 18 °C), and by mid-September most of the bull kelp plants at Maude Reef site were gone, although some blades with sori patches were present.

Survival of kelp recruits inside the exclosure while algal abundance outside the exclosure was affected by intense grazing pressure from the high density and biomass of red urchins, demonstrating its effectiveness at protecting kelp.

Four unseeded, conditioned kelp culture lines (30 m long) were deployed at the Maude Reef grid in 2020, with the aim of recruiting Laminarian kelp. Bull kelp failed to recruit onto culture lines, but a diverse kelp understory was established and maintained in both years, providing habitat for several species of fish and invertebrates.

Another four lines of bull kelp seed (two from Oyster River estuary, two from Sansum Narrows stock) on culture ropes and one spool in the exclosure at the Maude Reef grid site were outplanted in December 2020, for final monitoring of growing conditions. Bull kelp grew very well during winter and spring months (January through May and to mid-June) but rapidly declined in condition with rising water temperatures (18 to 26.7 °C) in late June. With the heat dome that occurred from June 23 to 30 and continuing heat wave in July, bull kelp disintegrated rapidly, ending sori development, and any chance of providing spores for the next generation. Despite the warm water temperatures, Laminarian kelps continued recruitment and development on the seabed and culture lines, maintaining a kelp understory which provided habitat for fish and invertebrate species.

The cultured line approach was based on the idea that by selecting resilient donor stock, producing a large biomass of reproductive plants it may be possible to "kickstart" the recruitment of new kelp plants on the seabed. During the study, there was some recruitment of bull kelp on mooring lines and over-wintered ropes at the site, but limited recruitment has been observed on the seabed, including inside the exclosure unit, possibly due to heavy grazing pressure from sea urchins and/or thermal stress from high summer temperatures at the restoration site.

The culture-based trials provided an excellent opportunity to refine the kelp parental stock selection process and to learn more about factors limiting bull kelp restoration and rebuilding of local kelp forests.

Saccharina sp. recruited and grew full cycle at the Maude Reef site during years when seawater temperatures were high and bull kelp failed to survive to reproduce, providing habitat that attracted a diverse community of fish and invertebrates. *Saccharina latissima*, has a higher temperature tolerance (temperatures between 21 and 24 °C seem lethal; Nepper-Davidsen et al. 2019) and may be better suited for wider and longer-term kelp restoration in areas such as Maude Reef where bottom temperatures remained well below 20 °C.

Combining vertical sonde cast and temperature logger data from Maude Reef and Oyster River estuary sites for 2019 and 2020 clearly shows that lower temperatures at nearshore areas of Oyster River estuary provide a more stable thermal environment for bull kelp survival and persistence than at the Maude Reef site. "Healthy natural bull kelp forest tend to persit in locations with cooler water (average monthly temperature <15 °C) such as the Campbell River and Oyster River estuaries and Sansum Narrows. However, kelp stocks from these areas don't appear to have strong genetic adaptation to extended exposure to warmer conditions (>18 °C) as was demonstrated by seeing transplant and growout trials at the Maude River grid site.

Key Findings

- The long-line cultivation approach 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."
- Sori production in the area was found to occur from May to October in "cooler years", especially in May-June, but not in hotter years (e.g. 2015).
- Too warm conditions lead to shortened or absent reproductive season for bull kelp.
- Upper tolerance of sporophytes appeared to be 18°C over 30-35 days.
- Water temperatures at the Maude Reef site were more than 3.3 °C warmer at the bottom and 1 m below the surface, in June and July of 2019 than the OR site, and exceeded the 17°C threshold for prolonged exposure and leading to tissue degeneration and mortality.
- Rapid decline in bull kelp condition was observed at the Maude Reef test site with arrival of a heat dome in late June, 2021 (18 °C to 26.7 °C, June 23 to 30) and a continuing heat wave in July.
- Lack of life cycle completion by bull kelp cohorts derived from kelp beds at Campbell River and Oyster River estuaries, and Sansum Narrows and outplanted to the Maude Reef grid site suggests favorable environmental conditions rather than any inherent ability to withstand higher temperatures underlie persistence of kelp beds in these areas.
- The "exclosure" was very effective in excluding sea urchins and allowed a dense assemblage of kelps to develop.
- Transplanted kelp sporophytes require sufficient anchor weight to prevent loss due to floatation.

- "Wild" set lines were effective at recruiting and growing *Saccharina* sp. but not bull kelp at the Maude Reef site.

Recommendations

- Avoid predators such as sea urchins and kelp crabs when selecting sites
- Encourage growth of more heat tolerant Laminarian kelp such as sugar kelp (*Saccharina latissima*) to create seabed understory which can provide habitat for fish and invertebrates.
- Continue to use the remaining natural kelp beds as reference sites to compare with experimental sites.

https://nilecreek.org/kelp-habitat/

https://projectwatershed.ca/2020/08/28/coastal-restoration-update/

Help the Kelp, Gabriola Island

Not long after the Nile Creek Enhancement Society began efforts to restore bull kelp, declining bull kelp abundance on some nearshore areas of Gabriola Island spurred individuals to action fearing the loss of the once flourishing kelp forests. In 2009, the group of volunteers established a citizen science project they named "Help the Kelp" with the goal of replanting bull kelp to areas on Gabriola Island. With help from NCES, the first kelp restoration was made in December with seeded ropes anchored by looping through pre-drilled rocks placed on the seabed. There appeared to be a small but non-measurable increase in bull kelp in the following years.

On their second attempt, made in January, 2011, they tried the commercial kelp growing method where two 30 metre ropes were attached to rocks on the bottom, and floats along the length to keep them off the bottom. Seeded strings were then wrapped around the ropes. These kelp failed to grow and other species of kelp colonized the lines. In the next couple of years, increased growth of bull kelp was observed off the shores of Gabriola but they weren't sure if it was the result of enhancement efforts.

Their next attempt trialled a third method of enhancement in the fall of 2013 . For the carboy protocol, approximately 40 treated and untreated sori were dried temporarily, then stuffed into each pre-drilled carboy. These were attached to anchors and placed near rocky areas in Clark Bay near the Surf Lodge. A survey dive of the area the following year saw various kelp species including many times more bull kelp sporophytes than was seen during mapping the previous year, the summer 2013.

In the summer prior to the third attempt at restoration, the group made a coordinated effort to map the entire island's bull kelp canopy based on a kayak procedure pioneered by the Mayne Island Conservancy Society. A follow-up mapping event took place the next year in the hopes that observations made over two seasons (August 3, 2013; July 29, 2014) would allow identification of areas that would benefit from replanting.

Two weeks after the first mapping session, almost all of the bull kelp between Lavender Bay and Entrance Island were observed to be bladeless, appearing to have been grazed on. The cause of the lost blades could not be identified since there weren't any sori evident on the blades during the survey and no suspect herbivores were seen.

While the primary goal of the Help the Kelp group was to restore bull kelp to areas suffering losses along the coast of Gabriola Island, they also hoped "to develop simple, cost-effective approaches and best practices for rebuilding kelp canopies that other communities might apply to their areas". Their efforts to restore bull kelp and map and monitor bull kelp beds around the island from 2009 to 2015 are reported in a blog at helpthekelp.blogspot.com.

Mount Arrowsmith Biosphere Region Research Institute, (MABRRI), Vancouver Island University (VIU)

https://mabrri.viu.ca/

To combat the decline in bull kelp in the Strait of Georgia in areas where it had once been abundant, MABRRI undertook a project to re-establish populations through deploying seeded plots and monitoring growth, health, and biodiversity. Progress on this project has been reported by Shaw et al. (2018), Mount Arrowsmith Biosphere Region Research Institute (MABRRI), VIU (2019), and Tomlin et al., (2020). Methods established by Comox Valley Project Watershed Society at their kelp enhancement plot at Maude Reef, Hornby Island (Heath, W., Zielinski, R., Zielinski, A. 2015) Shaw et al. (2018), were modelled at two locations chosen for placement of experimental enhancement plots: Northumberland Channel, northwest of Dodds Narrows and Winchelsea Islands, near the entrance of Nanoose Bay, located within the UNESCO designated Mount Arrowsmith Biosphere Region (Shaw et al. 2018). Both locations were identified by local divers and fishermen as having historical kelp beds which flourished until recently, and a small bed of bull kelp continued to survive near Dodds Narrows.

Starting in March of 2018, the enhancement plots were set up with two concrete anchors with a 19 mm diameter rope strung between them (Shaw et al. 2018). Strings seeded with kelp were wrapped onto the rope as it was lowered. Plots were inspected by divers to confirm the placement of lines parallel to the shore and suspended above the bottom. Bull kelp sporophytes were also collected and transplanted onto the rope. Two methods were used for attaching transplants: One method used nylon cord looped around the stipe of the bull kelp and multiple cable ties to attach to the cord to the rope (Carney et al., 2005). The second method involved wrapping veterinary tape around the holdfast and directly onto the rope (Shaw et al. 2018). The holdfast was then secured to the rope by attaching a cable tie on either side of the stipe and over top of the veterinary tape to minimize abrasion. Six individual sporophytes were attached using each method and evenly distributed along the rope for a total of twelve per plot. For more details and photos of the methods used to attach sporophytes, refer to Shaw et al. (2018) and Tomlin et al. (2020).

Monitoring of kelp growth and collection of baseline data regarding water parameters and species composition at each site. These involved swim-through video surveys, quadrat video surveys, YSIPro DSS sonde, temperature and light availability data loggers, identification of sori presence, and underwater time lapse cameras. Surveys of benthic species were also conducted using one metre square quadrats.

No growth was observed on the seeded lines in 2018, possibly because they were deployed late in the season. A total of seven of the transplanted individuals remained attached at the two plots and appeared to thrive. Some of the transplants that were lost left evidence of snapping off or being grazed while others were absent. Five individuals continued to grow over the summer and developed sori.

The same method was used the following year to deploy bull kelp seeded lines but an additional line was added to each site, and outplanting occurred in mid-January 2019, providing kelp sporophytes with a longer growing season (MABRRI, 2019).

Good growth was observed on both plots, and blades were seen at the surface in mid-August after 76 days at the plot, although less length was achieved at Winchelsea (Tomlin et al. 2020). From measurements taken that day, kelp at the Dodds Narrows site had reached an average maximum height of 894.5 cm (n=4.0), growing an average of 9.8 cm/day, whereas kelp off of the Winchelsea Islands reached a maximum average height of 99.8 cm(n=4), growing at an average of 0.7 cm/day. Greater sori development was observed in 2019 at the Dodd Narrow site than in 2018. Better growth this year may have been due to the earlier outplanting date and subsequent longer growing season, however, the water temperature was cooler overall during the summer 2019 compared to 2018. On a dive survey just 2 weeks later, no kelp was visible at the Winchelsea Islands plot and only approximately half of the kelp was visible at the surface at the Dodds Narrows site. On closer inspection, it appeared all the kelp at Winchelsea and 50% of the growth at Dodds Narrows was lost to grazing.

Once kelp appeared, overall fish biomass increased at both sites over time, but appeared to be less at the Dodds Narrows site in comparison to the Winchelsea Islands site. Species commonly observed using the bull kelp as habitat were schools of Pacific herring (*Clupea pallasii*), schools of shiner perch (*Cymatogaster aggregate*), and juvenile copper rockfish (*Sebastes caurinus*).

The most common invertebrates observed in Dodd Narrows quadrats during video surveys were ochre sea stars (*Pisaster ochraceus*), leather sea stars (*Dermasterias imbricata*), and giant California sea cucumbers (*Parastichopus californicus*), while at the Winchelsea Islands site there were red sea urchins (identified as purple sea urchin (*Strongylocentrotus purpuratus*) in the report), giant California sea cucumber, and frilled dog whelk (*Nucella lamellosa*) (Tomlin et al. 2020). No fish were observed in the Dodd Narrows quadrats while black eyed goby (*Rhinogobiops nicholsii*) were considered common at the Winchelsea Islands site. Common macroalgae species growing in quadrats at the two sites also differed, with turkish towel (*Chondracanthus exasperatus*) and sugar kelp (*Laminaria saccharina*) recorded at the Dodds Narrows site and rock weed (*Fucus vesiculosus*) and sea lettuce (*Ulva lactuca*) at Winchelsea Islands*. Possibly reflecting the higher current at the Dodds Narrows site*

This preliminary work showed that seeded kelp lines and transplanted kelp sporophytes will grow during the year it was outplanted, but it did not address the question of how it affected recruitment of bull kelp to the area or identify the factors that affected recruitment. The group had planned to carry on the enhancement studies and possibly expand the number and size of the plots with the objective of continuing to monitor bull kelp growth over time to know if it is able to replenish itself ,and to quantify its effects on the surrounding areas, but the project ended in 2020.

Independent, Nelson Island, Lee-Anne Ennis

Nelson Island KFI Map: 49.6568° N 124.1358° W, 20th Dec 2018 – 1st Jul 2019

As an "Independent", Lee-Ann Ennis (2024) set out "to restore *Nereocystis* in order to enhance biodiversity and ecosystem services and provide social outcomes". A site was chosen where kelp had been present a decade earlier, before disappearing due to overgrazing by sea urchins. Ennis cultivates three species of kelp, bull, sugar and ribbon kelp (*Alaria marginata*), in a licensed nursery, inoculating spools of twine with kelp spores, then growing the juvenile sporophytes in tanks over the fall (Beairsto, 2022). During winter of 2018/2019, twine seeded with bull kelp was outplanted to an aquaculture lease on Nelson Island where it was deployed to lines strung between docks. Thirteen 15 m long lines were strung, each 3m apart (Ennis, 2024). Rapid growth was observed in March, the sporophytes matured to produce sori, and an epiphyte and fish community developed by July. A die off of the kelp in summer was thought to be natural with kelp near the surface. Subsequent years of cultivation at this site, the kelp has been either harvested early, transplanted or weighted down during warm summer months.

Vital Kelp, Jeddah Point, Sunshine Coast

Near the entrance to Welcome Pass between South and North Thormanby Islands and the mainland Sunshine Coast, KFI Map (49.4932° N 123.9446° W), 21st Dec 2021 – 21st Jun 2022

Vital Kelp and BC Conservation Foundation partnered with numerous volunteers and funding from the Pacific Salmon Foundation's Community Salmon Program to cultivate and outplant kelp near a historical kelp bed in Welcome Pass (Beairsto, 2022). Continuing the work started on Nelson Island to restore floating canopy forming bull kelp to a site near the entrance to Welcome Pass between South and North Thormanby Islands and the mainland Sunshine Coast (Ennis, 2024). The historical kelp beds are thought to have suffered from multiple stressors including overgrazing by green sea urchins, warming ocean, imbalance of the ecosystem, and water pollution from coastal development. Bull kelp seed spools were produced in nursery, then out planted at an aquaculture lease in December of 2021, where they were suspended between floating docks and out of reach of sea urchins (Fischer, 2024). The young kelp grew quickly in early spring providing substrate for fish like the tube-snout (*Aulorhynchus flavidus)* to attach their eggs. Once the fish eggs had hatched, the 1-3m sporophytes were ready to be transferred from lines to rocks. Holdfasts of the bull kelp sporophytes were carefully removed from the line before their haptera had completely encircled it. A gentle "back and forth wiggle wiggle in the direction of the line" is recommended (Ennis, 2024). One hundred detached sporophytes were then attached to rocks using natural rubber bands and deployed to the enhancement site by kayakers. Within 2 to 4 weeks, haptera of the kelp holdfasts had regrown, providing physical attachment of each sporophyte to a rock. Two thirds of the kelp transferred to rocks and deployed to the sea bottom survived, matured and produced sori. Juvenile schooling salmonids and perch were observed taking cover in the transferred kelp in May. Subsequent recruitment of bull kelp to the enhanced area has not been seen.

Edited by Lee-Ann Ennis, Vital Kelp

Tla'amin & shishalh Nations, & British Columbia Conservation Foundation (BCCF)

Tla'amin & shishalh territories, Sunshine Coast: Nursery at Lund *(guess*) 4.983493° N, 767365° W; restoration sites in Okeover Inlet.

Lee-Ann Ennis of Vital Kelp is the Project Lead and Kelp Cultivation Specialist for BCCF

A December 2023 Fisheries and Ocean's AERF funding announcement: "Tla'amin Nation to partner and share … over the next four years for the (BCCF) to work in partnership with shíshálh Nation to help restore and enhance 67,000 square metres of kelp forest at 25 sites" (PEAK, 2023). In 2024, Tla'amin Nation (TN) Guardians surveyed present bull kelp extent and shared Indigenous knowledge of historical bull kelp extent in Okeover Inlet. TN harvested red urchins for a food fishery, and this helped remove urchins from one of the few remaining kelp beds. In the fall of 2024, a kelp nursery was set up in Cannery Bay complementing Tla'amin Nation's Oyster flupsy nursery and TN hired their first kelp technician building their capacity to steward and manage the resources in their territory. In its first season, the Cannery Bay Kelp nursery produced seeded gravel, tiles, and spools using spore settled methods for outplanting in Okeover Inlet. Gametophyte cultures were established and are being maintained under red light and refrigeration.

In mid April 2025, Tla'amin GIje (Land) Academy secondary students will assist with transplanting young sporophytes from line to rock. The young kelp will be deployed to sites identified as having lost kelp in the traditional territory of Tla'amin Nation. An early April survey of the out planted kelp has shown survival of the line grown and transplanted kelp.

TN's Cannery Bay nursery will employ a kelp technician for its second season and receive a 4 pack of SBR macroalgae bioreactors to produce reliable kelp gametophyte supply beginning fall 2025.

A fundamental goal of this project is building capacity to steward and manage kelp resources and working together to incorporate Indigenous Knowledge and Western Science. Collaboration between First Nation Guardians, the BCCF, and other scientists to document past and present kelp resources, involving Nation Elders and students in restoration activities, building a kelp nursery within TN territory, and hiring a kelp technician are all steps to building that capacity.

Sources:

Lee-Ann Ennis, Vital Kelp, personal communications February 25, March April 02, 2025

Neh Motl "us" (2025, February). Tla'amin Nation Launches Innovative Kelp Restoration Project. Ɫaʔəmen (Tla'amin Nation) Newsletter, February Edition 2025, p.4. https://www.tlaaminnation.com/category/nehmotl-newsletter/

PEAK. (2023, December 4). Grants to Tla'amin Nation will help protect ecosystems. PEAK *Voice of the Qathet Region*. https://www.prpeak.com/local-news/grants-to-tlaamin-nation-will-help-protect-ecosystems-7921385

PEAK *Voice of the Qathet Region* article posted on Dec 4, 2023, 10:50 AM, states the source as a funding announcement but doesn't identify the funding agency.

Thetis Island Dive Team Volunteers, Canadian Kelp Research, and Ocean Wise Conservation Association

Amy McConnell, Director/Operations Manager, Canadian Kelp Resources on behalf of Ocean Wise Conservation Association

More recently, another group of volunteers was motivated to restore bull kelp to the nearshores of an island in the central eastern side of the Strait of Georgia, this time it was the Thetis Island Marine Explorer (TIME) dive team. In cooperation with Canadian Kelp Resources and Ocean Wise Conservation Association, they set up a pilot project to restore bull kelp to Fraser Point at the NW end of North Cove (McConnel, 2024).

Divers with support vessels installed grow-line supporting structures composed of two cement or rock anchors, two vertical lines, each approximately 1 m long, and two pressure floats that remain 5-9 m below the surface of the water at 0 tide and positioned approximately 20 m apart (Navigation Protection Program Registry, 2023, April 03). The plan was to outplant bull kelp seeded lines on these structures in the fall, allow the kelp to grow to maturity in the summer, then die off naturally the following winter, when all the structures would be removed. The goal was for the kelp outplants to reach maturity, releasing spores that successfully develop, producing a new generation of bull kelp to the area.

Bull kelp "seed" was grown in the Canadian Kelp Resources nursery at Bamfield from sori of parent bull kelp collected near Thetis Island, in Porlier Pass (A. Lamb, personal communication. February 11, 2025). A seeded string from the nursery was outplanted to Fraser Point on Thetis Island in December 2022 by unwinding it around a 20 m grow-lines deployed horizontally and anchored to the support structures about 1 m off the bottom, in waters approximately 1 to 6 m deep below a zero tide (McConnell, 2024). Following the same procedure, another grow line was set up at Pilkey Point at depths of 5 to 6 m. Both sites were planted with a second line in January 2023. Rocks seeded with bull kelp, known as green gravel, were dropped to the bottom at the correct depth over Rocket Shoal, near the entrance to Clam Bay in January 2023. The substrate at Pilkey Point was described as sandstone and Fraser Point was large boulders.

Kelp sporophytes grew well on the first line deployed at Fraser Point, particularly in the shallower end of the range, and had reached the surface by mid-April. Divers found the kelp be decimated by northern kelp crabs by the spring/summer (Andy Lamb, personal communication February 11, 2025). A 30-foot rock jetty at the site provided habitat for the crabs. The early seeded line at Pilkey Point also grew well but more slowly probably because of the greater depth. Both lines outplanted later at Fraser Point and Pikey Point grew poorly and sparsely and were coated with diatoms. The green gravel at Clam Bay didn't produce any visible growth.

A second outplanting of a single seeded kelp line to Fraser Point occurred in December of 2023. This time the farm lines were anchored deeper and on the flat bottom rather than attached to the breakwater itself. Crab excluding shields were installed. When divers checked the line in April, most of the line was clean except for at most 10 kelp, about 10 cm tall, with pneumatocysts. The line was covered in kelp crabs in June, and no kelp were seen growing on the line.

The green gravel was deployed in December of 2023 near the marker on Escape Reef at 48° 56.423' N 123° 39.668' W. at depths ranging from 5 to 7 meters. No bull kelp was seen to be growing in the area when it was checked in May 2024.

After all of these attempts failed to establish any bull kelp in sites around Thetis Island, the group of volunteer divers decided they didn't want to proceed unless better protocols for predators could be found (A. Erikkson, personal communication, February 11, 2025). Takeaway: Site selection is important (A. Lamb, personal communication, February 11, 2025). While the sites chosen all met depth requirements for growth of bull kelp and had some rocky substrate, none had much current flow and the sites had no previous history of bull kelp presence, except possibly Clam Bay.

Neptune Terminals & UBC (Dr. Patrick Martone)

Neptune Terminals, a bulk shipping terminal located on the north shore of Burrard Inlet in the Port of Vancouver is funding a "Bull Kelp Restoration Program", examining bull kelp restoration and resilience in Burrard Inlet, with guidance from Dr. Patrick Martone at UBC and support from Dynamic Ocean Consulting (Neptune Terminals, 2023). The Bull Kelp Restoration (BKR) Program is one of the complementary measures prescribed for the Lynn Creek Estuary (LCE) Offset Project developed under the guidance of the Fisheries and Oceans Canada (DFO) (Neptune Bulk Terminals, 2023).

Despite the decline in bull kelp abundance in Burrard Inlet, recognised by Indigenous knowledge and Western science, some bull kelp continues to grow naturally within Neptune's water lots (Neptune Terminals, 2023). As the first practical step in an effort to better understand how to protect and enhance bull kelp populations in Burrard Inlet, restoration trials began at Neptune's water lots at Berth 2 in the Inner Harbour. Two techniques for restoration were employed: Bull kelp was transplanted within Neptune's water lots and lab-grown juvenile sporophytes on tiles were outplanted to the seabed of the lots. Methods developed for growing kelp in Dr. Martone's laboratory at Simon Fraser University are being applied to bull kelp outplants in field trials at the restoration site.

Preliminary success was reported, showing high survival of small bull kelp sporophytes six weeks after outplanting in the Neptune water lots (Neptune Terminals, 2023). Moving forward, Neptune hopes to expand restoration work to include the Lynn Creek Estuary, while Dr Martone's lab will attempt to identify strains of bull kelp which are tolerant of high temperature and low salinity providing greater resilience to climate change.

Ocean Wise Canada

Ocean Wise is "a global conservation organization on a mission to build communities that take meaningful action to protect and restore our ocean." The Seaforestation initiative works with communities, Indigenous groups, kelp farmers, and scientists on projects to restore and protect kelp ecosystems. Developing new kelp seeding methods in their nursery, novel restoration techniques for the field, along with consistent and effective monitoring to bring scalable, cost-effective, and collaborative efforts to reverse global kelp loss.

https://ocean.org/climate-change/seaforestation/

Ocean Wise Canada has been working with several groups in coastal British Columbia, wishing to restore kelp habitat to historic levels in areas of environmental and cultural significance. The restoration projects involving Ocean Wise and partners which have taken place in the Strait of Georgia up to and including 2024, are described here.

Ocean Wise Canada - Kelp Nursery Ocean Wise Launches Kelp Nursery to Restore Vital Ocean Habitats - Ocean Wise

https://kelpforestalliance.com/restoration-projects/ocean-wise-canada-burrard-inlet-1

Ocean Wise operates a kelp nursery located at the Pacific Science Enterprise Centre in West Vancouver to supply restoration projects (Ocean Wise, 2023). In 2023, the kelp nursery system was upgraded to a re-circulating process by adding filters, a UV sterilizer, and a reservoir to control and contain contamination (Ocean Wise, Janke, 2024). There were fewer contaminations than the previous year, resulting in successful growth of kelp seed for outplanting.

Ocean Wise Canada & Tsleil-Waututh First Nation
https://twnation.ca/twn-reserve-shoreline-adaptation-project/

https://kelpforestalliance.com/restoration-projects/ocean-wise-canada-burrard-inlet-1

Tsleil-Waututh First Nation (TWN) wants kelp habitat in səl̓ilw̓ət (Burrard Inlet), near North Vancouver, BC, in front of the TWN reserve restored in areas where bull kelp once thrived (KFA, 2025). With assistance from Oceanwise Canada, 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 at Whey-ah-wichen/Cates Park/Roche Point in April, 2023. No outcomes were achieved through to July, 2023, probably due to poor site selection, as the site may be too deep and turbid for the bull kelp to survive. They acknowledged gaining a better understanding of kelp transplant methods during the process.

In February, the following year, sugar kelp, (*Saccharina latissima*), grown on both pebbles/cobbles and oyster shells (novel method) was outplanted into False Creek and transplanted to Burrard Inlet in early May, 2024 (KFA, 2025). Due to difficulties in transporting green gravel, participants recommend being prepared with proper bins and equipment for transporting the green gravel from the nursery to the restoration site. Growth and health of outplanted kelp exceeded expectations despite the date of outplanting (February) being later than the recommended December.

Dana Janke (Seaforestation, Ocean Wise), Pers. Comm. February 2025. Gametophytes attached well to the oyster shells but they were found to be too light weight as the sporophytes grew and became more bouyant.

From Spore to Sporophyte: A Full Year of Growing Kelp blog post by Max Wolf, Ocean Wise Seaforestation Coordinator, posted August 22, 2024 by Kim Bricker

Ocean Wise with the Marine Stewardship Initiative & Squamish First Nation

Kelp Forest Alliance Map: Ocean Wise Canada - Átl'ḵa7tsem/Howe Sound - Kelp Forest Alliance

Ocean Wise is also working with the Marine Stewardship Initiative and the Squamish First Nation to restore sugar kelp beds in Átl'ḵa7tsem/Howe Sound to provide spawning habitat for Pacific herring, as had previously been observed. Sugar kelp, *Saccharina latissima,* was grown in the Ocean Wise kelp nursery on various substrates to plant within the Squamish First Nation traditional territory. No date or results noted in Kelp Forest Alliance entry.

Kelp Rescue Initiative (KRI) (UVic, Bamfield MSC), & Partners

https://kelprescue.org/

https://www.uvic.ca/news/topics/2024+kelp-restoration+news

The Kelp Rescue Initiative, based at the Bamfield Marine Sciences Centre (BMSC, Bamfield, British Columbia, Canada) leads and supports kelp restoration projects with Indigenous Nations and other partners in coastal British Columbia, supported by a four year grant from Fisheries and Oceans

Canada under the Aquatic Ecosystems Restoration Fund (Dal Monte, 2024). The team of researchers led by Julia Balm of the University of Victoria and Sean Rogers, director of BMSC, are testing different kelp culturing and outplanting method for the two canopy-forming kelp growing in BC coastal waters: *Macrocystis pyrifera* and *Nereocystis luetkeana*. At the kelp nursery at Bamfield, kelp from different locations can be grown selectively and ones with different thermal histories and tolerances can be tested. Projects with partners taking place in Burrard Inlet, Baynes Sound, and Barkley Sound, up to and including 2024 are described here.

Tsleil-Waututh Nation with KRI in Burrard Inlet, Vancouver, BC

Restoration Projects & Protection Areas – Kelp Forest Alliance

Tsleil-Waututh First Nation is leading efforts to restore *Nereocystis luetkeana* to their territory in Burrard Inlet, Vancouver, British Columbia (KRI, Shuster, 2025). In 2022, they began a 2.5 year partnership with KRI to test the feasibility of different restoration methods and their success in an urbanized environment. In the first year of the study, Good (2024) conducted environmental assessment and experimental seeding of three sites in Burrard Inlet with prior history of bull kelp presence: Nine o'clock Rock in Stanley Park, Crab Park, and New Brighton Park. Each site had a restored area and experimental plots. Sori from bull kelp growing in Burrard Inlet were transported to the Bamfield Marine Science Centre for production of gametophytes, which were taken to the Martone Lab at UBC for fragmentation and seeding of sporophytes on gravel, cobble/rocks, and tiles. These were then transferred to the Pacific Science Enterprises Centre for growing until sporophytes reached a visible size and were ready for outplanting, which took place at the end of February.

Seeded gravel and cobble/rocks were deployed from a boat (Good, 2024). Seeded rocks and tiles were placed on experimental plots by divers, with tiles epoxied into place along transects. Temperature and salinity were recorded by data loggers placed 0.5 m off the bottom. Water temperature remained below 18°C throughout the growing season and the average salinity was 23-24 PSU. When the first dive monitoring took place 58 days later, little survival of kelp was reported, and the only evidence for loss that could be identified was possible relocation of kelp outside of the study area.

The New Brighton Park site was considered to have potential for future restoration of bull kelp due to the presence of relatively strong current and substrate of mixed rock sizes, from pebbles boulders, with the caveat that larger rocks were needed for both seeding and tile attachment to prevent kelp from floating away as they became more buoyant with increasing size (Good, 2024). For future restoration at these sites, outplanting at depths of -1 to -2.5 m relative to chart datum and a late summer density of three sporophytes per metre squared was recommended. The Crab Park site experienced high turbidity in summer (i.e. reported as visibility less than 1 m) and was considered too heavily impacted by urban influences, such as sewer and stormwater outfalls and wastewater discharge, for further restoration efforts. Due to natural recruitment of *Nereocystis* observed during the study and a history of fluctuating kelp occurrence, the Nine o'clock Rock site was considered an important location for monitoring the effects of changing environmental conditions on bull kelp rather than for restoration at this time.

In early March, 2024, clay tiles (7.5 x 7.5 cm), large gravel 4.5 - 6.4 cm), small cobble (6.5 - 9.0 cm), and medium cobble (9.1 - 12.7 cm) were seeded with ***Nereocystis luetkeana*** following the same procedure as the previous year (Good, 2024). Some of the tiles were bolted to concrete blocks. These were deployed at depths of -0.9 to -2.3 m in Burrard Inlet at two sites: Whey-ah-wichen/Cates Park/Roche Point and New Brighton Park. From April to July, plots were monitored every six weeks. Abundance and some morphometrics of sporophytes were recorded at each plot every six weeks from April to July, and temperature, light and current data were collected at each site (KRI, Shuster, 2025). Kelp was observed to grow very well from seeded tiles and larger cobble/rocks, reaching the surface by June, and some individuals produced reproductive tissue.

KRI with Hornby Island Diving & VIU DBMFS, Lambert Channel

Maude Reef, Hornby Island https://kelpforestalliance.com/restoration-projects/kelp-rescue-initiative-hornby-island

KRI, with collaboration from Hornby Island Diving and Vancouver Island University's Deep Bay Marine Field Station, experimented with multiple techniques for restoring *Nereocystis luetkeana* in Lambert Channel in 2024. Trials were repeated in 2025 and outplanting was scaled up 1700 m at site(s) in Baynes Sound (Shuster, 2025).

The experiments at Maude Reef in Ford's Cove on Hornby Island tested restoration success across five *Nereocystis luetkeana* populations with different thermal histories and tolerances (KRI, Shuster, 2024). Kelp was grown on a seeded line array...See update here https://bullkelp.info/case-studies/hornby-island

Denman Island https://kelpforestalliance.com/restoration-projects/kelp-rescue-initiative-denman-island

Restoration experiments were also conducted on Denman Island from 26th Feb 2024 – 30th Aug 2024, comparing five different bull kelp restoration methods and an urchin exclosure. The site was chosen because there was suitable substrate for bull kelp growth and a historical bull kelp bed had recently been lost, possibly due to heat stress and increased grazing by sea urchins. Five different bull kelp restoration methods (gravel, cobble, tiles, twine and direct seeding) were tested inside an urchin fence. Growth and survival were monitored and biodiversity was surveyed. Findings suggest cobble and tiles were most effective at supporting growth of bull kelp sporophytes at this site and the urchin fence protected the kelp from grazers. "Kelp grew well and produced reproductive tissue. Monitoring will continue until die-off." (KRI, Schuster, 2024)

The site was an area where a fringing kelp bed had existed until 2015. It had previously been used as a reference site during restoration trials by NCEs and CVPWS until it disappeared (Heath et al. 2022)

Other Restoration Projects in BC and Puget Sound, WA

Ocean Wise Canada - Rainy Bay (Nuu-chah-nulth territory, Barkley Sound)

https://kelpforestalliance.com/restoration-projects/ocean-wise-canada-rainy-bay

Ocean Wise Canada collaborated with Canadian Kelp Resources & Rendezvous Dive Adventures from September 2021 to 2022 to conduct trials of the green gravel method for outplanting *Nereocystis luetkeana, Saccharina latissima, Macrocystis pyrifera* seed for restoration. Approximately 148,000 pieces of gravel seeded with giant kelp and bull kelp were dispersed over two, 100 m transects. The green gravel planting process was considered simple, but transporting of pebbles was not readily scalable. The giant kelp flourished while the bull kelp did not successfully establish. High biodiversity was observed in locations where giant kelp was planted.

Ocean Wise & Tseshaht First Nation and West Coast Kelp

https://kelpforestalliance.com/restoration-projects/ocean-wise-canada-barkley-sound

Tseshaht First Nation collaborated with Ocean Wise and West Coast Kelp to enhance existing giant kelp beds to prevent a marine community phase shift in the area and increase biodiversity, support fisheries in the area, and contribute to economic stability for the Nation. Using a transplant process known to First Nations in B.C., approximately 2,500 juvenile kelp plants were removed from a farm or a nearby kelp forest, holdfasts (roots) were attached to a rock, and dropped to the seafloor of the restoration site near the southern Pinkerton Island in Barkley Sound on traditional, unceded territory of the Tseshaht First Nation. *No date given.*

KRI - Barkley Sound

https://kelpforestalliance.com/restoration-projects/kelp-rescue-initiative-barkley-sound

To test the effectiveness of urchin cages to protect outplanted *Macrocystis pyrifera* seed, KRI researchers deployed two sizes of green gravel inside and outside of urchin cages at 6 sites in Barkley Sound in early April, 2024. Survival, size, sori production, bleaching etc. of sporophytes was monitored every 6 weeks from April to August to establish outplanting success. Temperature, light and current were also recorded at each site. The cages were placed along an exposure gradient, which all appeared to be too rough for the trial, as Jasmine Schuster (2024) reported, "Urchin cages were not super effective, got tossed around during storms.".

Ocean Wise Canada - Ts'msyen Territory near Prince Rupert

Ocean Wise Canada has been collaborating with Metlakatla Development Corporation and Ecotrust Canada, on a kelp regeneration project in Ts'msyen Territory near Prince Rupert to restore kelp forests (Ng, 2023). In March 2023, the Seaforestation team outplanted approximately 1.6 hectares of *Nereocystis* (bull kelp) seeded line in Ts'msyen Territory. The Metlakatla Guardians were involved in the outplanting process and will continue to monitor the project.

Scott Bohachyk, Director, Seaforestation, pers. comm. March 05, 2025

"The Metlakatla project was pretty early on in our kelp restoration journey, and I wasn't in this position as Director yet, so I'm not crystal clear on the details around project design, etc. From what I know though, we worked with Amy and Louis at Canadian Kelp Resources to grow bull kelp on spools in Bamfield to transport to Prince Rupert. We were using one of the aquaculture leases the Metlakatla had from a failed (oyster?) farm, I'm not sure what aquaculture operation they had there, but it wasn't successful. They expressed some interest in restoration and allowed us to use the lease. We had about 1.6km of bull kelp on line put in the water but the results were not great. I believe we outplanted too late, mid-March. The spools were also damaged in the long transportation from Bamfield to Prince Rupert and there was very limited growth. The infrastructure was removed in 2024.

I believe the Nation made an agreement with Cascadia Seaweed to take over their leases and we learnt they didn't have the capacity to pursue other restoration projects, so that was pretty much it. We've exchanged a few emails with them since them but have nothing active there.

Lessons learned were primarily about outplanting timing, limit distance for spool transportation, and engage much earlier with the Nation to ensure a more robust and collaborative project design.

Not the most inspiring story I'm afraid but let me know if you have any other questions."

The Haida Nation - "Chiix̱uu Tll iinasdll: Nurturing Seafood to Grow"

Lee, L. (2024). Parks Canada Gwaii Haanas - Haida Gwaii. Kelp Forest Alliance. https://kelpforestalliance.com/restoration-projects/parks-canada-gwaii-haanas-haida-gwaii

"Chiix̱uu Tll iinasdll is a collaborative project among the Haida Nation, federal agencies of Canada, academic and research institutes, and the Pacific Urchin Harvesters Association, aiming to restore kelp forests along three kilometres of the Gaysiigas Gwaay (Murchison Island) shoreline, covering approximately 20 ha (Lee et al. 2021). Forests of kelp, particularly *Macrocystis pyrifera, Laminaria* spp., *Pterygophora* sp, have been decimated by grazing of overabundant sea urchins, a population once controlled by predators such as the sea otter (*Enhydra lutris*), a key stone species now extirpated from the area. The restoration strategy was to mimic predation by sea otters on red sea urchins (*Mesocentrotus franciscanus*), green urchins (*Strongylocentrotus droebachiensis*), and purple sea urchins (*S. purpuratus*). The rationale for removing or cracking up to 95% of the urchins in the area was that by reducing grazing pressure on the macroalgae, more kelp would be able to have complete life cycles, providing natural recruitment of young kelp to areas previously overgrazed to become urchin barrens.

The project began in 2017 with pre-restoration activities including dive surveys of rocky reef marine life communities and tagging of red urchins to measure their growth rates in kelp forest (Parks Canada, n.d.). In 2017-2018, more than 90% of urchins were removed by harvesting or cracking underwater along a three km stretch of rocky reef from 0-15 m chart datum, by Haida Fisheries Program divers and red sea urchin commercial fishery divers (Lee 2024). Abalone, which are threatened by the loss of kelp, were tagged and a monitoring program established. Within a year, kelp stipe density had increased, particularly in deeper areas, and low urchin densities persisted. Monitoring and restoration activities continued in 2019-2020, with more urchins removed and more abalone tagged. A lower abundance of kelp observed the following year was attributed to different ocean conditions or the migration of urchins into the area. Restoration, research, and monitoring activities were projected to continue."

Toquaht Nation with Redd Fish Restoration Society, West Coast Kelp, and Parks Canada

Contact: Aline Carrier, Oceanographer

Location: Four different sites throughout tukʷaaʔatḥ (Toquaht) territory; Toquaht Bay and Mayne Bay, western Barkley Sound, BC

Year: 2024

Objective: Ongoing kelp surveys have shown that kelp forests are changing. Pilot project restoring giant kelp to four sites using different methods.

Methods: One 100 foot transect each of seeded line and transplants were outplanted at each of four sites in early March 2024. Natural rubber bands were used to attach young sporophytes to cobble stones. Transplants were dropped over the side of a boat travelling slowly in a straight line (transect).

Lessons Learned: Kelp grew better at some sites than others.

Project Outcomes: *Why choose these sites? Which method produced better growth of kelp? Are lines being left in place or retrieved?*

Future Plans: *2025?*

Note: Segments in italics are questions I posed to Alin. No answers were received.

Sources:

Emily Fulton, Red Fish Restoration Society, personal communication, February 25, 2025

Carrier, A. (2025). Toquaht's Kelp Stewardship. Presentation at Ha'oom Fisheries Society 2025 Knowledge Sharing Celebration, held online on March 05, 2025.

Toquaht Nation Newsletter Summer 2024 https://toquaht.ca/wp-content/uploads/2024/07/TOQUAHT-NEWSLETTER-final.p

Restoration Projects in Puget Sound

Carney et al. 2005 *San Diego State University-Friday Harbor, San Juan Archipelago, WA.*

The best kelp size for outplanting to restore kelp beds was the subject of research undertaken in Mar-Jul 2003 in the San Juan Archipelago, WA by L. Carney (Carney, 2003; Carney et al. 2005). The investigation compared growth and survival of bull kelp outplants (recently settled zoospores and microscopic sporophytes) (Method 1) to small juvenile transplants (<15 cm stipe length) (Method 2) and their potential in kelp restoration. Whether elevating outplants would improve survival by inhibiting exposure to sediment deposition and predation was also investigated. Outplant experiments were conducted at three locations: Saddlebag Island (48° 32.93′ N, 122° 33.41′ W) in Padilla Bay and Cantilever Point on San Juan Island (48° 32.84′ N, 123° 0.23′ W).

Method 1: *Nereocystis luetkeana* thalli of <15cm were transplanted from wild populations into restoration sites. Juveniles were inserted into rope sections, which were then threaded through a hard plastic clip. The clip was glued to the substrate with epoxy. Twenty-eight percent of the transplants survived throughout the study period and shed sori for at least 80 days Highest mortality rate (56%) occurred in the first 24 days primarily due to method: 97% to break in the epoxy bond between the clip and substrate. Also, stipe breakage by grazing, primarily by *Lacuna vincta*, was a problem. Spring was considered the best time for deploying transplants because of the small size of kelp sporophytes and lower abundance of snails.

Method 2: Experimental substrates were seeded either with recently settled zoospores or with microscopic sporophytes ("seed") and outplanted in the field. Control treatments consisted of experimental substrates with no seed material added. No recruitment was observed at either site on the dishes outplanted with zoospores and microscopic sporophytes possibly due to grazers, the 1 cm of sediment, or fouling by chain-forming diatoms, even when the dishes were elevated. Although the current study lacked any success with outplanting seed, authors suggest seeded twine could be deployed above the bottom in areas experiencing high sedimentation.

Due to the unpredictability of nearshore rock environments, an adaptive management approach employing different restoration techniques prior to large-scale planting, is recommended (Carney et al. 2005). This study recommends avoiding sites where sedimentation rates are high or plant juvenile transplants. Once a restoration method is chosen for large-scale deployment, don't expect complete success after a single year, as it may require several years of restoration to offset losses in some years.

Puget Sound, WA Restoration Projects

Puget Sound Restoration Fund (PSRF)Puget Sound Restoration Fund - Central Puget Sound Kelp Forest Enhancement at Doe Kag Wats/Jefferson Head

https://kelpforestalliance.com/restoration-projects/puget-sound-restoration-fund-central-puget-sound-kelp-forest-enhancement-at-doe-kag-wats-jefferson-head

https://restorationfund.org/programs/bullkelp/

A collaboration between the Suquamish Tribe and Puget Sound Restoration Fund

Beginning in March 2020, PSRF has been testing "how seeding techniques, seed density, and timing of outplant affect kelp yield, and reproductive output" at Doe Kag Wats/Jefferson Head, in central Puget Sound, a place of deep importance for the Suquamish Tribe (PSRF and Toft, 2024). They also monitor "for second generation kelp and compare outplanted kelp to wild kelp in adjacent areas".

"Specific techniques used at the Doe Kag Wats site from 2020–2024, encompass propagation and outplanting. Kelp seed on twine is propagated in PSRF's Kelp Lab, from either wild sporulation or germplasm archived in PSRF's seed bank. Approximately 1,500 ft (450 m) of seeded line is outplanted at the enhancement site by PSRF's scientific divers in winter, wrapped around a cultivation line that is anchored in place and suspended 1 to 2 ft (0.5 m) above the substrate. Anchor blocks are also occasionally wrapped with seeded line. Both the timing and the technique give the bull kelp a chance to grow above the substrate, before understory kelps have a chance to cover the substrate and bury the seeded line. Staggered timing of seasonal outplanting is part of the ongoing plan". Bull kelp Enhancement at Doe Kag Wats/Jeff Head in Central Puget Sound | The Mysterious World of Bull Kelp

Nylon twine seeded with bull kelp has been outplanted onto longlines anchored to the seafloor during winter/early spring, in each of the last six years (as of Feb. 2025). and monitors bull kelp growth, presence of sorus material, fish and invertebrate use. Outplant takes place in l with monitoring through kelp senescence (late summer). The main methodology is transplanting small sporophytes to lines, but we have also transplanted to blocks and, in one year, cleared competitors."

"From 2020 through 2024, bull kelp from the pilot-scale enhancement reached the surface and the outplanted kelp has spanned seafloor to surface each year since, making 2024 the 5th year of successful in-season bed regrowth. In 2024, we also observed reproductive second generation kelp."

Working on trial outplants at Washington sites with different characteristics, approaches to augmenting declining kelp beds, and assessing ecological functions provided by this type of restoration

“Key Findings [Bull kelp Enhancement at Doe Kag Wats/Jeff Head in Central Puget Sound | The Mysterious World of Bull Kelp]

Building a successful restoration project starts with co-developing goals to meet the needs of the community you are serving.

Restoration actions must be tailored to specific sites and place-based knowledge is critical.

Repeated, successful growth of a kelp bed at Doe Kag Wats is evidence that environmental conditions at this site can still support bull kelp. A continued input of kelp seed is needed at this site, suggesting that conditions that lead to a lack of microscopic forms or to interruptions to reproduction and development might be contributing to kelp decline.

Stressful temperatures at Doe Kag Wats have been recorded which may be a cause of variability in kelp success. This suggests the need for restoration strategies that are resilient to climate change.

In adapting aquaculture methods for use in restoration, careful lab practice, site-specific timing within the year, density of seed outplant, and outplant substrate are key components to consider.

Scaling up is logistically challenging, therefore evidence of return on investment (bigger outplant yielding more next-generation kelps) is an important validation of efforts.

Differences in seasonality of growth, reproduction, and natural death between the outplant site and wild sites might provide clues to improving restoration technique.”

Hilary Hayford, PSRF, pers. comm. March 26, 2025

“We generally found one or more recruits each spring following an enhancement. The big 2024 difference was magnitude. I think the record may have been three or four individuals prior to 2024. I'll highlight that not only did we have 33, but at least one of them made it to reproductive maturity before it disappeared.

2022 reproduction - 2024 recruitment were good years for bull kelp. I don't fully know what that means, however, DNR-led surveys of canopy area increased in 2023 relative to previous years at the majority of sites. We saw bull kelp in Puget Sound thriving later into the year (Sept, Oct) in 2023 than in other years.

2023 we had the greatest number of individuals in the outplant kelp bed, primarily due to outplant substrate (we did more long lines in this year). We suspect that the total number of potential parents increased the yield and that the need to have a kelp bed to get a kelp bed may be a key aspect of successful restoration.

Considering a marine heatwave hit in July 2024 and senescence of bull kelp in Puget Sound occurred notably earlier than normal (July, Aug), we are anticipating we will see fewer recruits this spring.

In 2024 we doubled the size of our dive team and they were able to track individual recruits over several weeks and really understand when individuals were new. While we are sure the divers didn't overlook dozens of recruits in years past, the extra care in 2024 should have given a more accurate, and possibly larger, count.

Yes, we've had great growth on seeded pyramids in different scenarios. In the first successful outplant at Doe Kag Wats/Jefferson Head (2020) all kelp was grown on seeded pyramids. Smith Cove doesn't have conditions we would predict are great for bull kelp, but we had other reasons for testing the site in spite of that. We also found that adult bull kelps transplanted to Smith Cove died (though it's an excellent sugar kelp site). This year we have outplants of seeded line onto concrete cylinders (7-gallon bucket-shaped, to be exact) at two different sites. Fingers are crossed."

Puget Sound Restoration Fund - Bull Kelp Early Life History Study at Tyee Shoal

Following several unsuccessful bull kelp enhancement trials, the PSRF conducted a reciprocal transplant experiment to determine the optimal life stage and timing for successful kelp enhancement (Allen, 2018). Four early *Nereocystis* life history treatments (sorus transfer / field-settled spores, lab-settled spores, 7-day gametophyte, 20-day sporophyte) were produced at the NOAA Manchester kelp nursery facility and then transferred to the field on a monthly basis. Tyee Shoal, outside of Eagle Harbor on Bainbridge Island was chosen as the study site because of a history of natural kelp canopy that recently disappeared (2015).

All of the outplanted early life history forms (zoospores, gametophytes and germling sporophytes) successfully produce juvenile sporophytes, with germling sporophytes consistently producing the highest densities (Allen, 2018). Outplanting in late winter (late January-early February) saw the most success if early enough for sporophyte size to be gained before the arrival of fouling by spring diatoms (March-April) and shading and scouring by understory kelp in summer (May-September). Grazing by mesogastropods in the winter months was seen to affect the outplanted substrates.

Puget Sound Restoration Fund - Smith Cove

https://kelpforestalliance.com/restoration-projects/puget-sound-restoration-fund-smith-cove

Early in 2018, PSRF undertook a pilot study to improve kelp restoration methodologies including enhancement of sea bottom to provide substrate for kelp attachment and recruitment (PSRF and Calloway, 2024). Boulder and cobble substrate was used to enhance a sandy bottom site before pyramidal anchor blocks seeded with kelp (*Nereocystis*) twine were deployed. Adult bull kelp grew successfully from outplanted juvenile sporophytes reaching the surface for a few weeks (Deweerdt, 2019). "Not for long as they lost blades when they reached the surface, possibly the result of exposure to low surface salinity from a nearby storm-water outfall or pollutants due to the site's proximity to a cruise ship terminal."

Puget Sound Restoration Fund - Squaxin Island Kelp Bed Restoration
https://kelpforestalliance.com/restoration-projects/puget-sound-restoration-fund-squaxin-island-kelp-bed-restoration

A bull kelp bed off Squaxin Island had been resilient in the face of anthropogenic influences despite being the innermost bed within Puget Sound, and the farthest from the Pacific Ocean (PSRF and Toft, 2024). This resilience has been tested since 2013, with annual surveys indicating that the kelp bed declined 97% up to 2022, when a heat dome brought high temperatures during very low tides in 2021, accelerated the decline. Fearing loss of these cultural and environmentally important kelp beds, Squaxin Island Tribe and the DNR worked together to select a site for enhancement and the PSRF assisted with planning bull kelp seed production for experimental outplanting annually in winter 2023 to 2026. The site chosen for seed enhancements is adjacent to, and northwest of the remaining bull kelp bed, at similar depths to the existing kelp, and within the footprint of the kelp bed that disappeared in 2022.

Increasing seawater temperature is a major stressor at Squaxin Island and throughout Puget Sound. A study on the effect of temperature on the early life stages of bull kelp from the Squaxin Island bed, conducted at the Friday Harbor labs by Weigel et a. (2023) showed gametophyte growth and sporophyte production thermal limits at 16° C. Temperature recorders for Squaxin Island Island show the water temperature exceeded the 16°C threshold for a total of 618 hours in 2021. A partial recovery was seen in 2023, following a year when water temperatures were lower.

Along with water temperature, degraded water quality is another stressor of concern in southern Puget Sound (Toft, PSRF, 2024). Inputs of fresh water, nutrients, and other pollutants may be contributing to the decline of top-down predators such as rockfish and lingcod, which allows kelp crab populations to explode, increasing grazing pressure on kelp.

SITE RECLAMATION/REHABILITATION

Department of National Defence (DND) - Constance Cove, Esquimalt Harbour Sediment Remediation Program

https://www.archipelago.ca/understory-kelp-salvage-recolonization-of-disturbed-sites-to-mitigate-temporal-habitat-loss

Archipelago Marine Research Ltd. in collaboration with SNC Lavalin and SLR Consulting for Defense Construction Canada implemented mitigation measures to salvage and restore understory kelp at Constance Cove, Esquimalt Harbour, on behalf of the Department of National Defense (DND), as part of DND's multi-year, harbour-wide sediment remediation program entitled, Western Constance Cove Remediation Project - Canadian Forces Base (CFB) Esquimalt (Archipelago Marine Research Ltd, 2021; Canadian Impact Assessment Registry, 2023). Beginning in 2017, salvageable rock substrate with at least 25% kelp cover was removed from within the area to be dredged, moved to a temporary storage area, then returned once construction was complete (Archipelago Marine Research Ltd, 2021). *Saccharina latissima* (sugar kelp) was the primary target species for salvage.

During storage of salvaged kelp and substrate, locally developed kelp enhancement lines were installed at the site to provide an additional source of spores to inoculate the salvaged substrate and provide temporary fish habitat during construction activities.

Vancouver Port Authority Subtidal Reef Construction at Roberts Bank, Delta, BC

Construction of subtidal reefs to offset unavoidable habitat loss related to the Roberts Bank port developments in Delta, BC, were initiated in 1983 by the Vancouver Port Authority (VPA) (Williams and Millar, 2006). Two hard surface subtidal reefs were constructed off the seaward margin of the Deltaport facilities at Roberts Bank. "One of the reefs is composed of 2.5 m long sections of 60 cm diameter concrete pipe loosely stacked on a silty bottom between –10 m and – 14 m water depth (tide and chart datum). A second reef was constructed with broken sections (i.e. 10 to 20 m length) of 90 cm diameter piling." (Williams and Millar, 2006, p. 26). Monitoring over the following years showed recolonization by invertebrates and fish but not macroalgae, as the reefs were too deep.

Two more reefs were constructed by the VPA in 1990s and 2000s at the site but in the shallow subtidal zone (Williams and Millar, 2006). "The reef was constructed in two sections using 0.9 m diameter quarry rock set on a pad of quarry tailings and crushed rock. The base elevation for the reefs ranged from –2.5 m to –3 m depth (chart datum) and rose to a 3 m wide crest at approximately –1 m elevation. Strong tidal currents flush the seaward margin of the Deltaport facility" (Williams and Millar, 2006, p. 26). Dive transect surveys of the reefs in 2004 reported an abundant fish and invertebrate community as well as subtidal macroalgae, specifically *Nereocystis luetkeana* and *Saccharina latissima*. The crest of the existing reefs now ranges from –4.0 m CD to 0.0 m CD, with the deepest reefs supporting the highest fish densities (Archipelago 2014).

Impact Assessment Agency of Canada (IAAC). (n.d.a). PORT METRO VANCOUVER | Roberts Bank Terminal 2. https://iaac-aeic.gc.ca/050/documents/p80054/101388E.pdf

Impact Assessment Agency of Canada (IAAC). (n.d.b). PORT METRO VANCOUVER | Roberts Bank Terminal 2. https://iaac-aeic.gc.ca/050/documents/p80054/101357E.pdf

Port Metro Vancouver - Delta Subtidal Reefs Compensation Monitoring Report, Deltaport Third Berth Project

Eight reef structures were created between 1st June 2008 and 12th September 2009 as compensation for destruction of subtidal habitat, including kelp habitat, due to construction of the large Deltaport container Terminal between 2007 and 2009 (Fehr et al. 2011). A pre (2007) and post construction monitoring (2015) plan was designed and implemented by Archipelago Marine Research Ltd. and GL Williams and Associates Ltd (Archipelago Marine Research Ltd., 2021). Monitoring included documenting macroalgae cover and distribution through intertidal biophysical surveys and photo documentation. Red and brown algae colonized created reefs at moderate to abundant levels. Diversity of algae, epibenthic invertebrates and fish increased on all reef types from 2009-2010. However, the project was deemed not highly successful as abundance and diversity of regenerated sites was lower than control sites.

Ausenco - Viterra-Cascadia Terminal Capacity Expansion, Eastern Burrard Inlet

https://ausenco.com/projects/viterra-cascadia-terminal-capacity-expansion/

Ausenco Pty Ltd. was hired to design and build an artificial underwater reef to mitigate construction impacts due to expansion of the at the Viterra-Cascadia terminal in Burrard Inlet. The outplanting of kelp seeding to augment the artificial underwater reef required incorporation into the federal *Fisheries Act* Authorization. "A "multi-faceted habitat complex, designed by Ausenco's coastal engineers and marine biologists, was finished in December with deep and shallow rock reefs, clam bench, and oyster shell enhanced mudflats, revitalizing the ocean habitat." (Ausenco, 2025).

Reproductive kelp patches (sori) were collected in Vancouver in 2021and transported to the Canadian Kelp Resources lab in Bamfield where 18 spools of bull kelp and 18 spools of sugar kelp were produced (Ausenco, 2025) A dive team outplanted the kelp seed lines on to in-house fabricated anchors and lines around the reef, into 7°C ocean water. Monitoring of the site is ongoing.

Pacific Shellfish Institute - Puget Sound

A remediation project in Puget Sound sought to install an artificial reef to mitigate the loss of important intertidal rearing habitat of juvenile salmon and marine resident fish caused by development of a large marina (Cheney et al., 1994). Approximately 5.2 hectares of rocky beach were constructed in three sections at varying depths between -2.5 m and +2.5 m in 1990-1991. Different sizes of aggregate were layered over pit-run aggregate on an existing mud-sand bottom. Monitoring the mitigation areas to evaluate the production of important food organisms (epibenthic zooplankton) for juvenile salmon and resident marine fish, and the micro- and macroalgal habitats they required, proceeded from 1991 to 1996. Various kelp species, mainly *Nereocystis*, *Laminaria* and *Sargassum*, colonized the mitigation rock in all areas, with percent covers ranging with different tide heights, and increasing over time where space on suitable substrates was available.

MAPPING AND MONITORING

Southern Gulf Islands Bull Kelp Monitoring / Collaboration Mayne Island Conservancy

2010- Mayne Island Conservancy began monitoring kelp. Since 2019 Southern Gulf Islands Bull Kelp Monitoring Collaboration: Mayne Island Conservancy, the Pender Islands Conservancy Association, the Galiano Conservancy Association, the Saturna Island Marine Research and Education Society (SIMRES), and the Valdes Island Conservancy.

Howe Sound Research Program

~1983- at the Vancouver Aquarium monitoring seabed biodiversity in Howe Sound

Tsleil-Waututh First Nation (2020). Kelp Mapping in Burrard Inlet.

<2018 Tsleil-Waututh First Nation (TWN) Abstract by Lindsey Ogston, Tsleil-Waututh First Nation (2020). Kelp Mapping in Burrard Inlet. ***Nereocystis*** **spp**. and other kelp species. Conducted kelp

mapping of the highly urbanized and busy port area of the south shores of Burrard Inlet by "adjusting kayak-based protocols and using novel technology".

University of BC (UBC), Patrick Martone lab. Girl in a Wetsuit Statue in Stanley Park, Vancouver

2021- to document year-round macroalgal biodiversity in a highly biodiverse urban intertidal zone: Stanley Park, Vancouver The Martone Labancouver

North Island College, NIC partners with Indigenous Nations on northern Vancouver Island and the adjacent Mainland BC to map and manage kelp resources and explore options for aquaculture and restoration.

Marine Plan Partnership for the North Pacific Coast, Marine Plan Portal (MaPP)
http://mappocean.org/helping-the-kelp/#:~:text=The%20project%20was%20initiated%20and,%2C%20and%20of%20course%2C%20kelp.

"Working together, many First Nations, the Province of British Columbia, and the Government of Canada have developed a plan for a Marine Protected Area Network in the Northern Shelf Bioregion, which extends from the top of Vancouver Island (Quadra Island / Bute Inlet) and reaches north to the Canada-Alaska border."

REEF Volunteer Fish Survey Project | Reef Environmental Education Foundation method used for biodiversity surveys in Lambert Channel

RESEARCH AND SUPPORTS

UVIC Remote Sensing and Spectral Lab mapping kelp https://uvicspectral.com/ Maycira Costa

UBC Martone Lab https://www3.botany.ubc.ca/martone/ Patrick Martone

Kelp Node - Quadra Data Centre https://kelpnode.org/

Canadian Kelp Research (was Canadian Kelp Resources)

Green Gravel Action Group

Kelp Forest Alliance

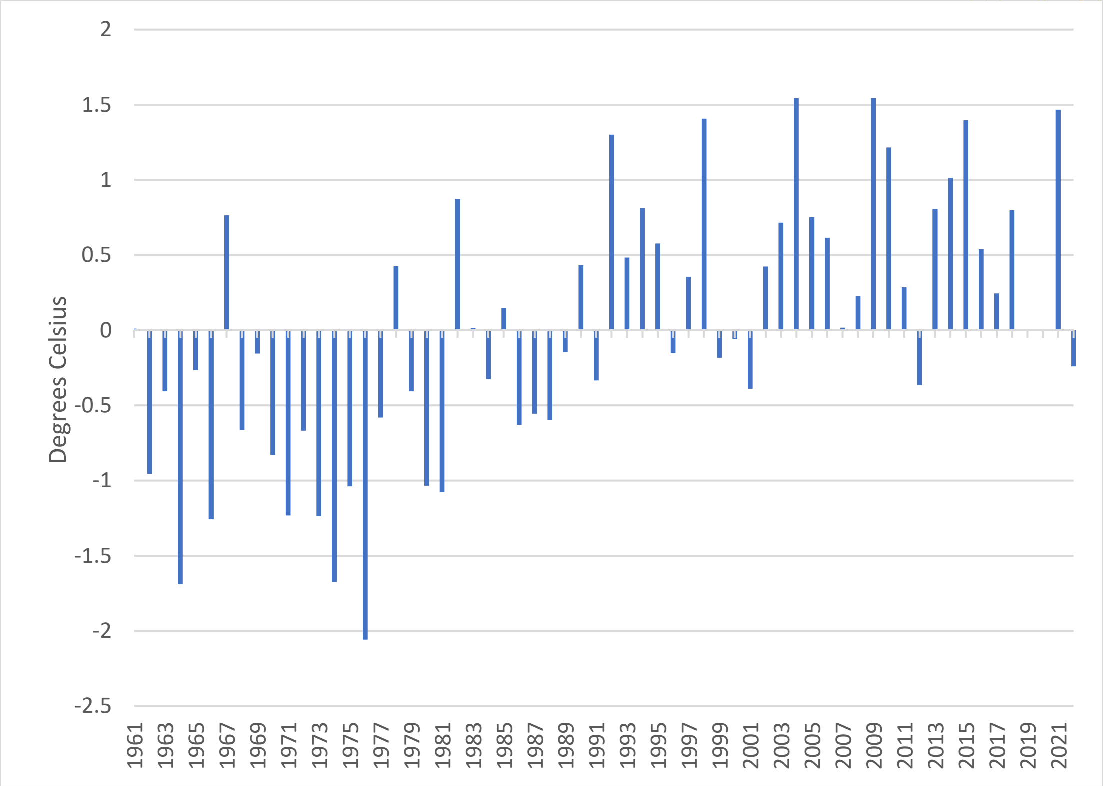
APPENDIX II. OCEAN TEMPERATURES AND KELP RESTORATION IN THE NORTHERN SALISH SEA

2007 Shifting baselines: Few remember the big kelp beds off Bowser. (Kelp returns to the octopus's garden. Hume, Mark The Globe and Mail; Toronto, Ont. 22 Jan 2007: S.1.) "Last fall, Ken Kirkby..."

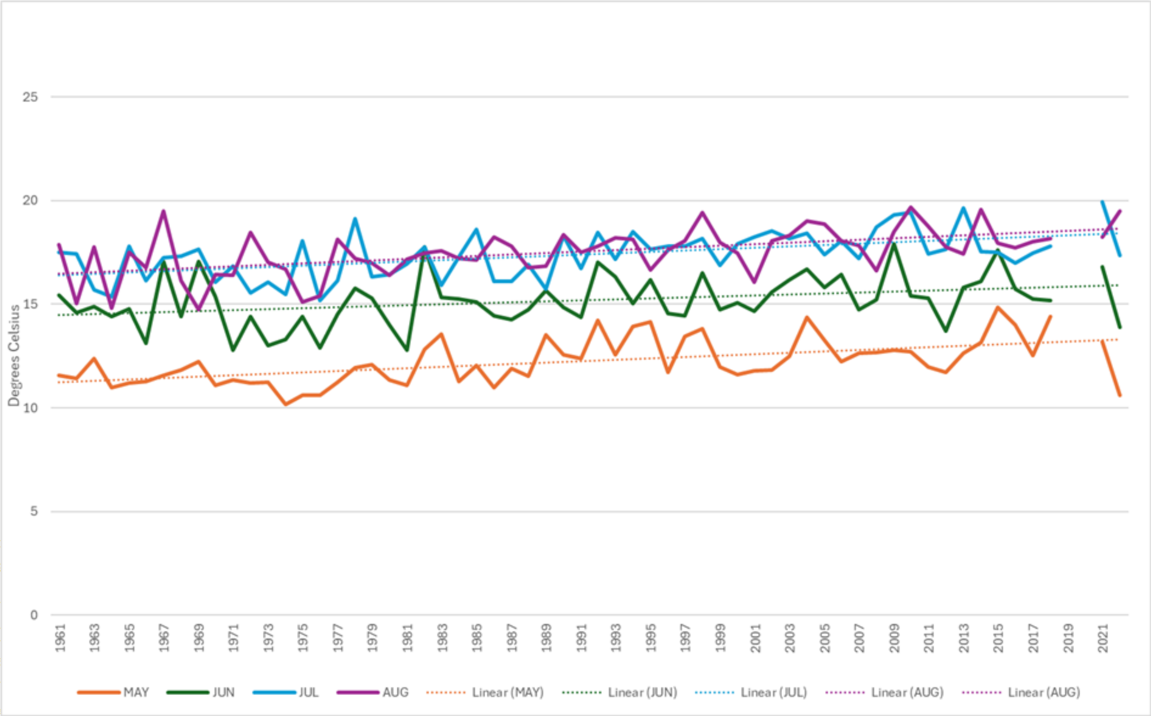
Although the marine heatwave of 2013 and the heat dome of 2021 have had devastating effects on some marine life in the Salish Sea, some kelp forests in the central Strait of Georgia had already been in decline, possibly due to suboptimal conditions during the period 2002-2006 (Mora-Soto et al. 2024a) and local groups were fighting back. The Nile Creek Enhancement Society began kelp restoration between Bowser on Vancouver Island and Hornby Island in 2006, the Help the Kelp group on Gabriola Island carried out trials beginning in 2009, and the Mayne Island Conservancy began mapping kelp occurrences around the island in 2010.

Chrome Island lighthouse located approximately 700 m from Eagle Rock, and 3 km from the restoration site on Maude Reef, Hornby Island in Lambert Channel has collected sea surface temperature (SST) since 1961 (2019, 2020 were incomplete) (Fisheries and Oceans, Canada, 2025). Sea surface temperatures for each of the months of May through August show an increasing trend and average summer temperature follow an increasing trend of 0.127 degrees per year (A2 Figure 1 and 2), for a total of 1.9 degrees Celsius between 1961 and 2021. A shift in this increasing trend appears in the records for 1989/1990, when the average cumulative temperature for May-Aug for the period 1961-1989 calculates to 59.9 °C compared to 64.5 °C for May-Aug for 1990-202.

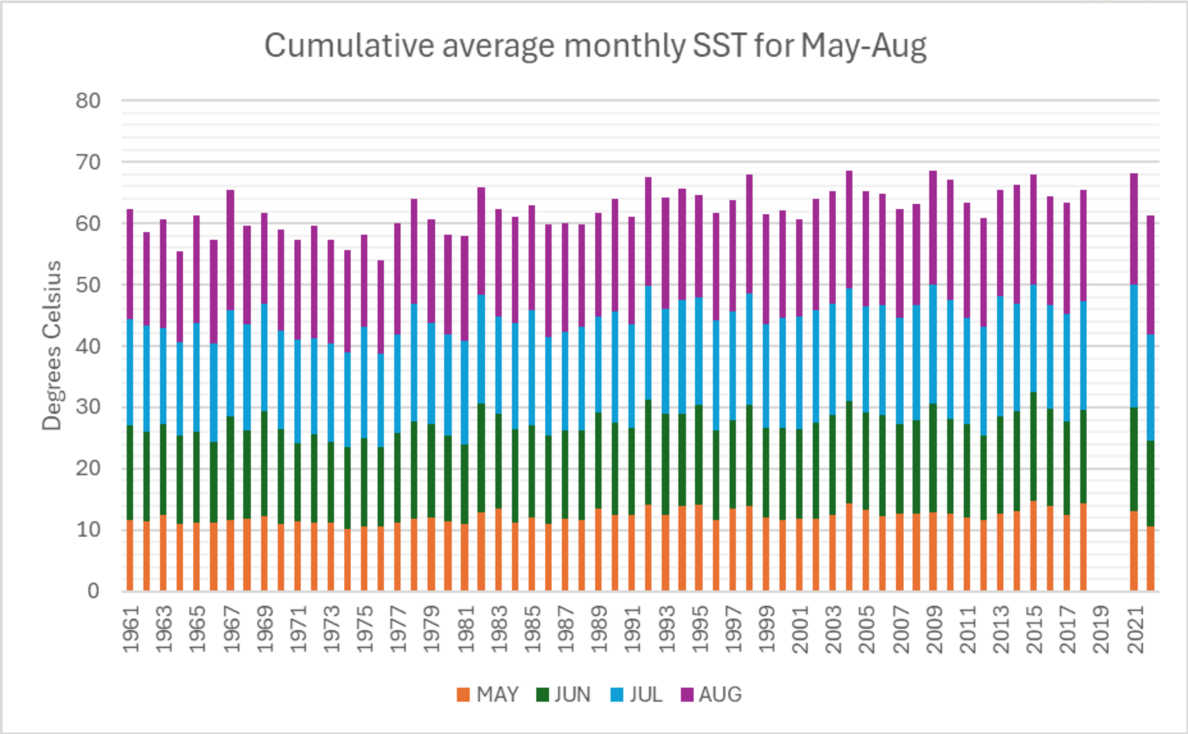
During the years restoration trials were conducted at Maude Reef, 2011-2021, cumulative SST (May-August) at Chrome Island were consistently higher than the average of 64.5°C for the time period from 1990 to 2022, which was already five degrees higher than three preceding decades. This upward shift in the already increasing SST in 1989 may reflect a regime shift in the North Pacific Ocean suggested by various indices for parts of the large marine ecosystems of the North Pacific by Hare and Mantua (2000), and climate–ocean changes associated with changes in the abundance and distribution of marine fishes including Pacific salmon (*Oncorhynchu*s spp.) suggested by McFarlane et al., 2000). A breakdown in the accepted relationship between North Pacific climate indices may have occurred 1989/1990 (Litzow et al., 2020).



A2 Figure 1. Temperature anomalies around the cumulative average SST June-August, 1961-2022 recorded at the Chrome Point Lighthouse.



A2 Figure 2. Average SST for each month of May-August recorded at Chrome Island lighthouse 1961-2022.



A2 Figure 3. Cumulative average SST temperatures for May-August recorded at the Chrome Island. light Station from 1961 to 2023. Data are missing for part of 2019 and all of 2020.

Entrance Island temps for Gabriola Island area average SST measured during July and August was equal to or greater than 18 °C, 13 times (2002, 2003, 2004, 2006, 2013, 2014, 2021, and 2022) since records began in 1936 (89 years, 3 missing data 2018, 2020, 2024)

Departure Bay average SST measured during July and August was equal to or greater than 18 °C, 11 times (2003, 2014, 2017, and 2021) since records began in 1914 (111 years, 7 years missing data including 2024).

Chrome Island average SST measured during July and August was equal to or greater than 18 °C, 11 times (2002-2004, 2009, 2010, and 2022) since records began in 1961 (64 years, 4 years missing data including 2019, 2000, 2023, 2024).

Compare Departure Bay to Burrard Inlet for 2023 or Departure Bay (no data for Chrome Island in 2023) Burrard Inlet 2023, Max 16 degrees for July to mid Aug. Brockton Pt N reached 18 degrees but this temp was not sustained continuously (Good, 2024, p63). Departure Bay was also relatively cooler in 2023 July avg 17.3 °C, Aug. 17.6 °C. Hilary Hayford, PSRF, said the summer of 2023 was also less warm in Puget Sound with kelp thriving into Sep/Oct.

The average SST in July at Chrome Island Lighthouse was equal to or exceeded 18 °C in 45% of the years since 1990, and in August in 55 % of the years. Prior to 1990, 10 % of years saw SST above 18 degrees in July and 7 % in August. If the upper tolerance of sporophytes is 18 °C over 30-35 days (Heath et al., 2022) then the SST experienced by mature Nereocystis sporophytes in approximately half of the years between 1990 and 2022 would lead to tissue degeneration and mortality, likely impacting sori production. Reproduction was even less likely in ten of those years when the average SST exceeded 18 °C in both July and August.

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PACIFIC SALMON FOUNDATION

Fisheries and Oceans Canada / Pêches et Océans Canada

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