Collaborative exploration of novel bull kelp (*Nereocystis luetkeana*) restoration techniques in an urban ecosystem

by

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Declaration of Committee

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Title:	**Collaborative exploration of novel bull kelp (*Nereocystis luetkeana*) restoration techniques in an urban ecosystem**
Examining Committee:	**Chair: Dr. Shawn Chartrand** Supervisor Assistant Professor, School of Environmental Science
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Abstract

This applied research project serves as the first year of a collaborative project between the Tsleil-Waututh Nation and Kelp Rescue Initiative aimed at tailoring bull kelp (*Nereocystis luetkeana*) restoration methodologies to Burrard Inlet. This research characterized abiotic and biotic conditions at reference sites, compared these conditions to three identified restoration sites to determine their viability for larger-scale restoration, and trialled the green gravel and kelp-seeded tile restoration methods. This study concluded New Brighton Park has sufficiently large substrate to be a restoration site in future years. Naturally recruited *N. luetkeana* was found from the low intertidal to a maximum depth of 3 metres below chart datum at an average sporophyte density of ~3 sporophytes per m^2 in the late summer. The restoration trials saw limited success past April; however, lessons learned suggest outplanting larger kelp-seeded rocks and attaching kelp-seeded tiles to larger substrate could increase restoration success.

Keywords: macroalgae; kelp; *Nereocystis luetkeana*; restoration; green gravel

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I am privileged to conduct research and restoration in səl̓ilw̓ət (Burrard Inlet and Indian Arm) and acknowledge these lands and waters are within the traditional, ancestral, and unceded territory of the səl̓ilw̓ətaʔɬ (Tsleil-Waututh), Sḵwx̱wú7mesh Úxwumixw (Squamish), and ʷməθkʷəy̓əm (Musqueam) Nations.

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Bull kelp (*N. luetkeana*) growing in Burrard Inlet. Photo credit: Fernando Lessa.

Chapter 1. Introduction

1.1. Background

Kelp forests are highly productive ecosystems providing habitat to many, invertebrate, fish, and mammal species (Steneck et al. 2002). Kelps (Order Laminariales) provide numerous ecosystem services that contribute to carbon sequestration, nutrient cycling, tourism, and fisheries (Bennett et al. 2015; Krause-Jenson & Durarte 2016). Additionally, they offer food security to First Nations by providing critical habitat for migrating salmon and traditionally harvested invertebrates (Shaffer 2004; Marushka et al. 2021). However, kelp forests have experienced significant declines globally (Krumhansl et al. 2016), and in British Columbia (Starko et al. 2019), due to increasing ocean temperatures and overgrazing by sea urchins (Filbee-Dexter & Scheilbling 2014; Wernberg et al. 2019; Starko et al. 2022) Marine heat waves are increasing in frequency due to climate change and impact much of BC's coastline (Starko et al. 2019; Wernberg et al. 2019). Kelp forests in wave-sheltered regions, like Burrard Inlet, are at a higher risk for decline compared to exposed coastlines due to decreased wave splash and local water motion that alleviate thermal stress (Starko et al. 2019). Critically, there are estimated economic losses of $1,000,000 per year for every one kilometre of coastline experiencing kelp forest loss (Filbee-Dexter & Wernberg 2018).

Burrard Inlet is an urban centre home to over 2.6 million people and has experienced 1,214 hectares of intertidal and subtidal shoreline loss to development since European contact in 1792 (Taft et al. 2022). Many fisheries such as herring, smelt, and salmon have significantly declined since the 19th century with declines in Burrard Inlet being more severe than in surrounding areas (Morin & Evans 2022). In 2017, the Tsleil-Waututh Nation (TWN) released the Burrard Inlet Action Plan with the overarching goal of providing a roadmap to improving environmental conditions in Burrard Inlet (Tsleil-Waututh Nation & Kerr Wood Leidal 2017).

As stated in a letter from Chief Maureen Thomas:

> Tsleil-Waututh, like our Musqueam and Squamish relatives, has a long-held legal obligation to steward the water, land, air, and resources in Burrard Inlet. This stewardship responsibility includes restoring conditions that provide the environmental, cultural, spiritual, and economic foundation for our communities to thrive (Tsleil-Waututh Nation & Kerr Wood Leidal 2017).

Trends in kelp forests in Burrard Inlet have not been monitored closely; however, according to observations from TWN community members, areas which once were abundant have seen significant declines since European contact (Tsleil-Waututh Nation & Kerr Wood Leidal 2017). There have also been recent kelp declines in Burrard Inlet since 2017 highlighting the need for urgent restoration and research (ShoreZone 2017; Figure 1). The limiting factors for kelp forests in Burrard Inlet remain unclear and were identified as a knowledge gap in the Burrard Inlet Action Plan (2017). Understanding the drivers of kelp loss is essential for the persistence and restoration of both kelp and the many associated species to which kelp provide refuge in this impacted inlet (Tsleil-Waututh Nation & Kerr Wood Leidal 2017).

The main canopy-forming kelp species within Burrard Inlet is *Nereocystis luetkeana* (bull kelp), an annual species with a unique life history. Knowledge of the timing and stages of this life cycle is essential for restoration methodology and research efforts. *N. luetkeana* has two main life stages: a macroscopic sporophyte stage and a microscopic filamentous gametophyte stage (Springer et al. 2010). The sporophyte stage forms canopies and grows primarily from early spring through fall (Springer et al. 2010). Sporophytes produce sori (reproductive tissue) in the summer and fall from which spores are released (Springer et al. 2010). These spores swim and settle on the seafloor and germinate into gametophytes (Springer et al. 2010). By late fall and early winter, most of the sporophytes have died off, and the predominant stage in winter months is the gametophyte stage (Springer et al. 2010). Starting in the late winter and early spring, gametophytes undergo sexual reproduction to form juvenile sporophytes that grow into adults forming the foundation of kelp forest ecosystems in Burrard Inlet (Springer et al. 2010; Dobkowski et al. 2019; Schenk et al. 2022).

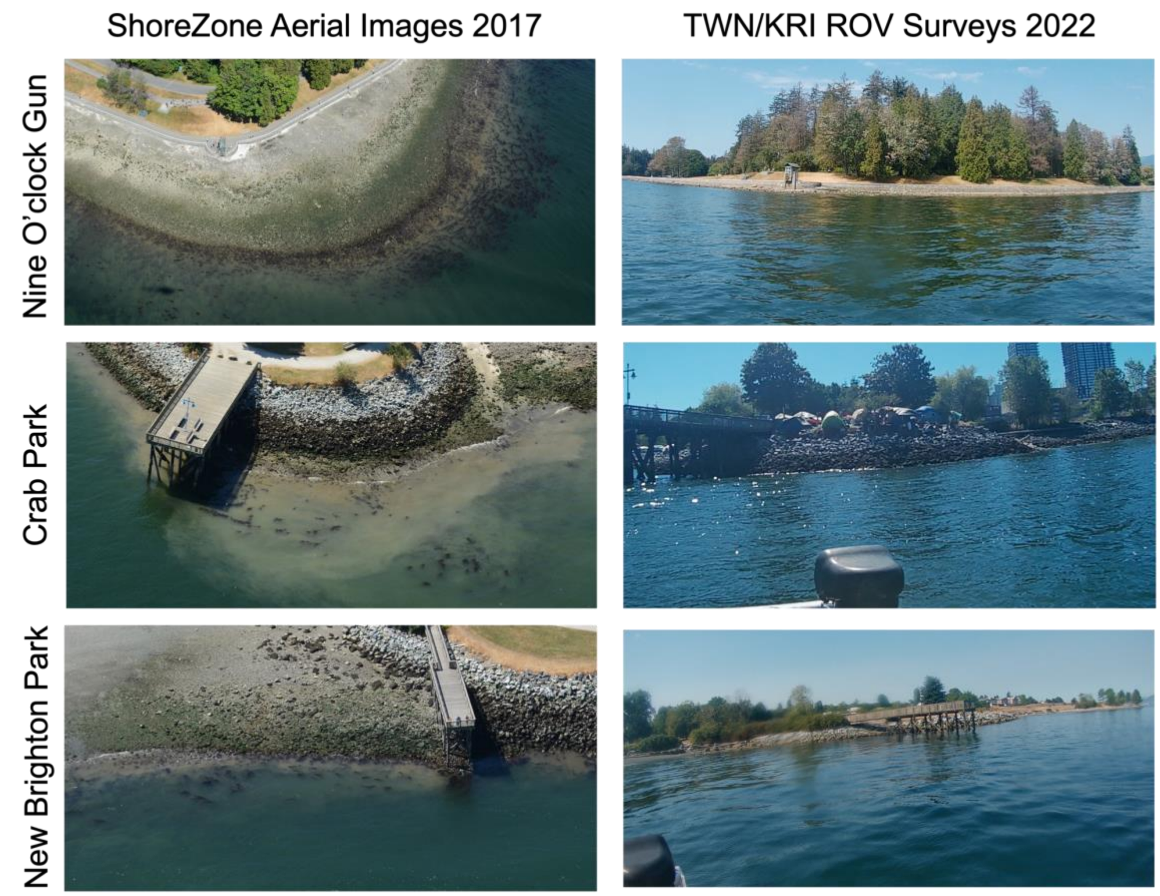

Figure 1 Decline of *N. luetkeana* in Burrard Inlet between 2017 and 2022.

ShoreZone (2017) aerial images (left panels) show *Nereocystis luetkeana* growing as dark patches along shore in July of 2017 at the Nine O'clock Gun in Stanley Park, Crab Park, and New Brighton Park. Images from Tsleil Waututh Nation (TWN) and Kelp Rescue Initiative (KRI) ROV surveys in August of 2022 (right panels) depict the absence of *N. luetkeana* in the same sites 5 years later. These are the sites selected for restoration in this project.

Previous methods for kelp restoration have been expensive due to reliance on divers and shown mixed results (Eger et al. 2021); however, the emergence of the green gravel technique has shown early success (Fredriksen et al. 2020; Alsuwaiyan et al. 2022). Green gravel reintroduces kelp to a site by collecting reproductive tissue (sori) from nearby populations, culturing the microscopic (gametophyte) life stage, growing the macroscopic (sporophyte) life stage on gravel substrate in a nursery, and outplanting kelp-seeded gravel to a restoration site where kelp outplants grow and attach to natural substrate (Fredriksen et al. 2020; Alsuwaiyan et al. 2022; Figure 2). This novel method offers a promising cost-effective option for kelp restoration that does not rely on divers, as kelp recruits can be outplanted by dispersing kelp-seeded gravel from a boat (Fredriksen et al. 2020; Alsuwaiyan et al. 2022). Another method that is being trialled in this project is the kelp-seeded tile restoration technique; this is adapted from a method being used by the Martone Lab at UBC (Supratya & Martone 2023). In this approach, gametophyte fragments are sprayed onto ceramic tiles and affixed underwater by divers.

Conserving critical near-shore habitat complexes is a priority action within the Burrard Inlet Action Plan (Tsleil-Waututh Nation & Kerr Wood Leidal 2017), and TWN is addressing local declines by co-leading a 2.5-year pilot project with the Kelp Rescue Initiative (KRI) to restore 450 m^2 and 900 m^2 of *N. luetkeana* habitat using the green gravel and kelp-seeded tile restoration techniques in 2023 and 2024, respectively.

1.2. Objectives

The first year of the TWN/KRI Bull Kelp Restoration Project is the focus of this applied research project. This project aims to (a) characterize the biotic and abiotic conditions of the persisting Burrard Inlet kelp beds to help select suitable restoration targets for future work; (b) compare these conditions to three identified restoration sites to determine their viability for larger-scale restoration; and (c) trial restoration methods for *N. luetkeana* in local waters of Burrard Inlet. This led to one overarching research question: What are the site-specific conditions that characterize Burrard Inlet kelp forests and how do they compare to possible restoration sites? For example, what combination of temperature, salinity, and substrate conditions determine the presence of *N. luetkeana* in Burrard Inlet? At what depths and densities does *N. luetkeana* grow?

Specifically, there are two objectives which address this question: (1) characterize the substrate, understory kelp and seaweed diversity, temperature, and salinity conditions that characterize two current *N. luetkeana* beds and three possible restoration sites in Burrard Inlet; and (2) determine the depth range, density, and growth characteristics of *N. luetkeana* at two reference kelp beds. A third objective (3) is to trial the green gravel and kelp-seeded tile method to inform future kelp restoration efforts in Burrard Inlet.

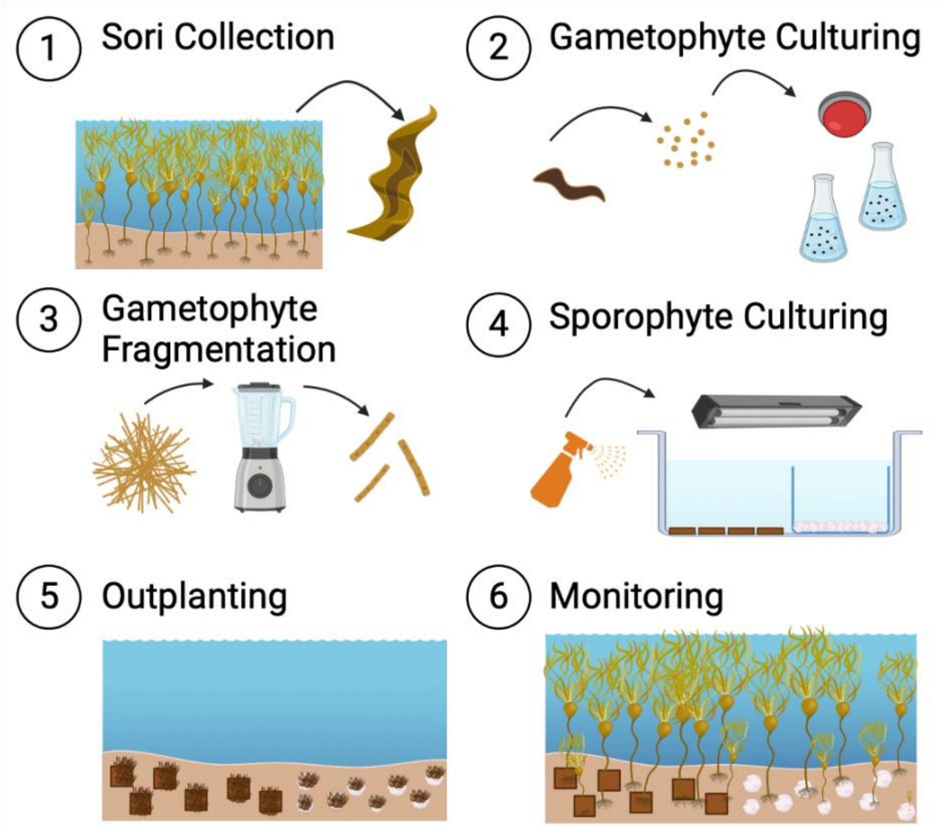

Figure 2 **Conceptual diagram of the green gravel and kelp-seeded tile restoration techniques.**

(1) Blades with sori (reproductive tissue) were collected from reference *N. luetkeana* populations. (2) Spore release was induced from sori. The spores germinated to form gametophytes (microscopic filaments) where they were vegetatively grown in a red-light tumble culture. (3) Gametophytes were blended into short (4-10 cell) fragments and placed in solution. (4) The gametophyte fragment solution was sprayed onto ceramic tiles and gravel in flow-through seawater tanks. The gametophytes attached to the gravel and tiles and were grown in white-light. The sporophyte (macroscopic) phase developed and began early growth. (5) The sporophyte-seeded gravel and tiles were outplanted to restoration sites. (6) The sporophytes grew larger and attached to the underlying hard substrate in some cases. This diagram was created in Biorender, and the *N. luetkeana* illustration was downloaded from Dreamstime.

Chapter 2. Methodology

2.1. Timeline

The objectives outlined above were met by culturing local *N. luetkeana* gametophytes at Bamfield Marine Sciences Centre in the fall of 2022, culturing *N. luetkeana* sporophytes at the Pacific Science Enterprise Centre in January and February 2023, outplanting kelp-seeded gravel and tiles to selected restoration sites February 27th and 28th, and monitoring restoration success and reference sites in the spring and summer of 2023.

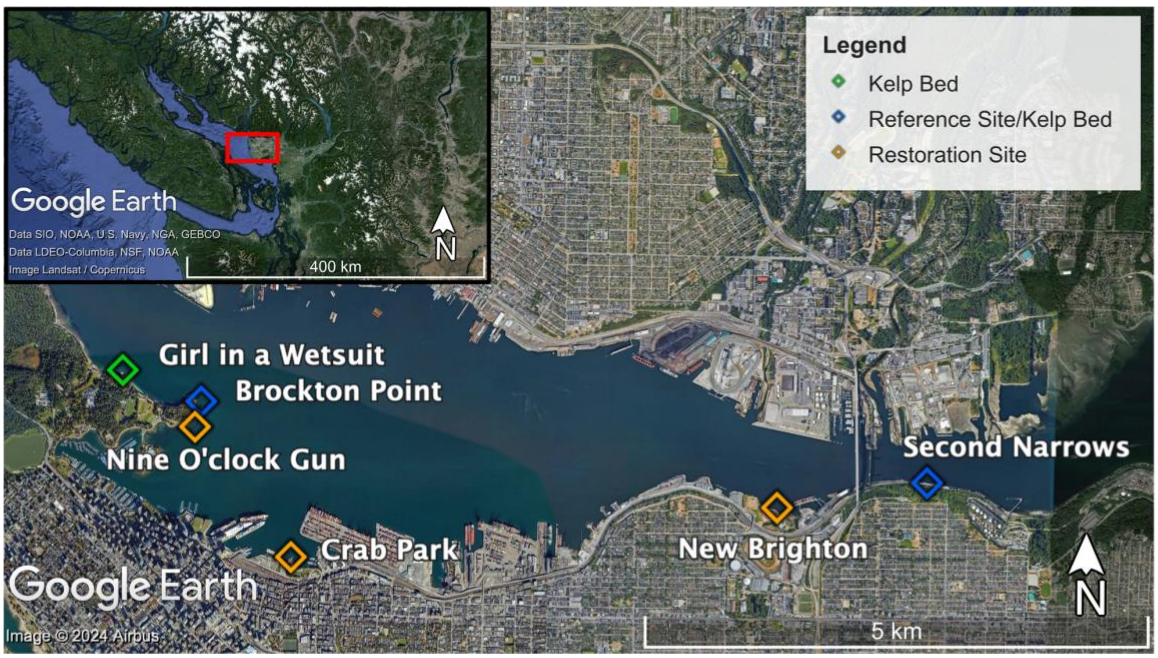

Figure 3 Map of the study area within Burrard Inlet.

2.2. Study Area and Site Selection

səl̓ilw̓ət (Burrard Inlet and Indian Arm) is a fjord situated in the Salish Sea and extends east from the Strait of Georgia. It is within the traditional, ancestral, and unceded territory of the Sḵwx̱wú7mesh Úxwumixw (Squamish), səl̓ilw̓ətaʔɬ (Tsleil-Waututh), and ʷməθkʷəy̓əm (Musqueam) Nations. It is also the location of the Port of Vancouver which is one of the busiest and largest ports in Canada (Vancouver Fraser

Port Authority 2024). The colonial place names of the main cities surrounding the inlet are Vancouver and Burnaby to the south, North Vancouver and West Vancouver to the north, and Port Moody and Coquitlam to the east. Girl in a Wetsuit (49.302924°N, -123.126386°W), Brockton Point (49.300185°N, -123.115656°W), and Second Narrows (49.293324°N, -123.016642°W) are the locations of the three main remaining *N. luetkeana* beds in Burrard Inlet (Figure 3). Brockton Point and Second Narrows were selected as reference sites.

Attempting restoration work in Burrard Inlet is complex due to the high boat traffic and extensive shoreline development within the Inner Harbour (Vancouver Fraser Port Authority 2023b). For this project, potential restoration sites were limited to areas zoned for recreation. Nine O'clock Gun (49.297924°N, -123.116485°W), Crab Park (49.286404°N, -123.103295°W), and New Brighton Park (49.291058°N, -123.037081°W) were selected as restoration sites because they 1) fall within recreation boundaries, 2) had *N. luetkeana* present in ShoreZone surveys in July 2017, but have since seen declines (ShoreZone 2017; Figure 1), and 3) are located near healthy persisting *N. luetkeana* beds (Figure 3).

2.3. Study Design

The restoration sites can broadly be separated into a 1) restoration area and 2) experimental area. At Crab Park and New Brighton Park, there was both a restoration area and experimental area, and Nine O'clock Gun had only an experimental area. Within the restoration area, 'green gravel' was deployed from the surface (i.e., deployed from a boat) thereby testing the efficacy of this technique at scale. Within the experimental area, two rows of plots were set up, to test the effectiveness of different green gravel sizes. The gravel size experiment had three small gravel (20 to 30 mm), three large gravel (35 to 50 mm), and three control 1 m x 1 m plots. There were 20 pieces of gravel in each treatment plot. Depth for the gravel size experiment was centered on 1.5 m below chart datum. This depth was determined from analyzing ShoreZone aerial images of the previous kelp beds at the sites in 2017. In addition, a tile transect was set up near the experimental plots, running perpendicular to shore with 20 to 28 tiles installed along a depth gradient from 0 to 6 m below chart datum (Figure 4). The tile transects trialed the restoration potential of ceramic tiles epoxied to natural rock.

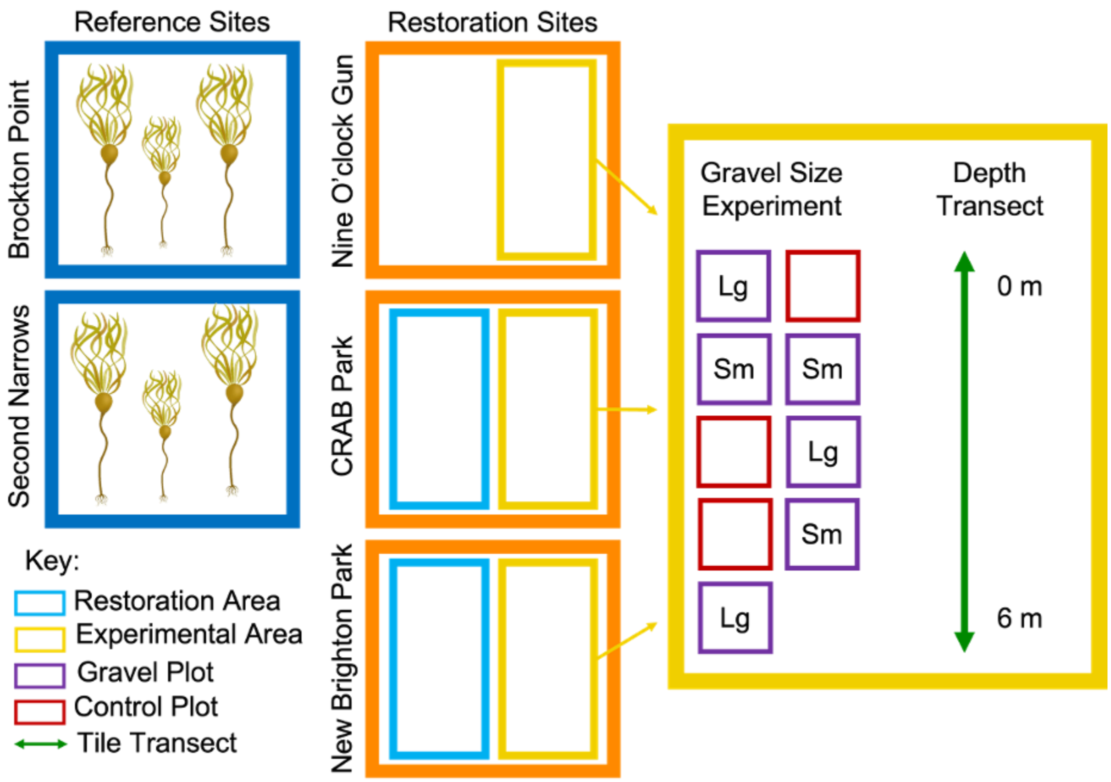

Figure 4 Conceptual illustration of the experimental design for the Burrard Inlet Restoration Project.

Restoration sites are divided into restoration areas (light blue) and experimental areas (yellow). In each experimental area, there was two distinct experiments: the outplanting depth transect and the gravel size experiment. There were two gravel size treatments: large (Lg) and small (Sm). The average depth of the gravel experiment was -1.5 m, and the depth range of tile transect was 0 to -6 m relative to chart datum. This diagram was created in PowerPoint; *N. luetkeana* images were downloaded from Dreamstime.

2.4. Sori Collection, Spore Release, and Gametophyte Culturing

All sori collection, spore release, and gametophyte culturing was led by Clay Steell, the Kelp Rescue Initiative Lead Culture Technician. Sori were collected from Girl in a Wetsuit, Brockton Point, and Second Narrows by the KRI and TWN field crew on

August 31, 2022. A sampling distance of at least 2 m between individuals was used to ensure each sample was a different genetic individual. One sorus per collected individual was prepared for spore release at the Deep Cove Marina following collection on August 31, 2022, and stored at 6 °C overnight. Sori were transported to Bamfield Marine Sciences Centre on September 1, 2022, in a 10 °C cooler. On September 1, 2023, spores were released using a protocol adapted from the Kelp Farming Manual (Flavin et al. 2013). A total of ten individuals released spores: six from Second Narrows and four from Stanley Park. Spores were diluted to 10,000 spores per mL and stored at 10°C in red light to prevent gametogenesis. They were cultured in red light at 10 to15 μmol photons · $m^{-2} \cdot s^{-1}$ using f/2-enriched seawater and a 16:8 day:night photoperiod in 20 mL falcon tubes for 6.5 weeks (Supratya & Martone 2023). Gametophytes were then fragmented and moved to two 1,000 mL flasks with aeration for biomass magnification for 11 weeks. On January 3, 2023, the gametophyte cultures were transported to the Martone Lab at the University of British Columbia in 20 mL falcon tubes in coolers maintaining their temperature at 7 to10.5°C. They were re-established in two 1,000 mL flasks with aeration at 10°C in red light at 10 to 15 μmol photons · $m^{-2} \cdot s^{-1}$ and a 16:8 day:night photoperiod for 13 days (Figure 5A).

2.5. Sporophyte Nursery Design and Set-Up

All sporophyte culturing was completed at the Pacific Science Enterprise Centre (PSEC) in a covered outdoor tent. The tent was plumbed and set-up in November 2022 through January 2023 by the Kelp Rescue Initiative with the support of contracted plumbers and PSEC staff. Seawater was sourced by PSEC from below the thermocline and ran through a sand and UV filter prior to entering the nursery tent. Once in the nursery, seawater was filtered with a 1-micron filter and UV filter before entering eight 200 L tanks in a flow-through system. Each tank maintained 20 cm of water depth and had 5000K white LED lights overhead. Each tank had 30 to 35 ceramic tiles (7.5 cm x 7.5 cm) and three 61 cm x 40 cm trays that each held a single layer of gravel. Two trays of small gravel (20 to 30 mm) and 22 trays of large gravel (35 to 50 mm) were spread across the eight tanks. The gravel was marble and sourced from a local landscaping supplier.

2.6. Gametophyte Fragmentation and Seeding

Gametophytes from the two 1,000 mL flasks were fragmented on January 16, 2023, at the University of British Columbia in the Martone Lab. Fragmentation was completed using a bullet-style kitchen blender in three to five second bursts to produce fragments as small as approximately 10 cells (Figure 5B). The gametophyte cultures were incrementally poured in the blender, fragmented, and poured into two spray bottles until most of the biomass was removed from the flasks. This resulted in a total fragment solution volume of 1,180 mL. The density of the fragment solution was determined from two 10 uL samples and approximated to be 14,000 fragments per mL which results in approximately 17 million total fragments.

The fragment solutions were stored in a 7 to 9 °C cooler and transported to PSEC. The gravel and tiles were placed in the tanks and soaked in seawater for 24 hours prior to seeding. Then, tanks were drained prior to gametophyte seeding and fragmented gametophytes were sprayed onto the gravel and tile lined tanks ensuring as even of a distribution as possible (Figure 5C). The total area that was sprayed was approximately 5.4 m^2 resulting in a seeding density of 315 fragments per cm^2. The seeded gravel and tiles were exposed to 9 °C air for one hour following seeding to facilitate attachment of the gametophytes to the gravel and tiles. The tanks were then slowly filled with seawater and left in static seawater for 24 hours under 15 to 30 μmol photons $\cdot$ $m^{-2} \cdot s^{-1}$ to further allow for gametophytes to settle (Supratya & Martone 2023).

The nursery set-up was completed in mid-January, and the seeding timing was determined based on the readiness of the tanks for sporophyte culturing.

2.7. Sporophyte Culturing

After 24 hours, gentle flow was introduced at flow rate of less than <0.1 L min^{-1}. After one week in culture, the light intensity was increased to 30 to 60 μmol photons $\cdot$ $m^{-2} \cdot s^{-1}$ using a 16:8 day:night photoperiod (Supratya & Martone 2023). The temperature in the tanks ranged from 5 to 9°C; the temperature in tanks fluctuated with changes in the air temperature in the tent. Seeded microscope slides were checked weekly for developmental milestones. A stereoscope was used to view gametophytes and sporophytes on gravel as well.

Nine days post-seeding, gametophytes had developed discernable oocytes (female reproductive structure). After 14 days, microscopic sporophytes were detected, and 23 days post-seeding sporophytes were approximately 200 cells, but still microscopic (Figure 5D). At 30 days post seeding, sporophytes were confirmed macroscopic. Sporophytes remained in culture for an additional 12 days and then were outplanted to restoration sites (Figure 6A).

Fifteen tiles and 21 large gravels remained in culture in the tanks until May 1, 2023. On May 1st the stipe length, pneumatocyst diameter, and holdfast radius were measured for nursery-grown kelps.

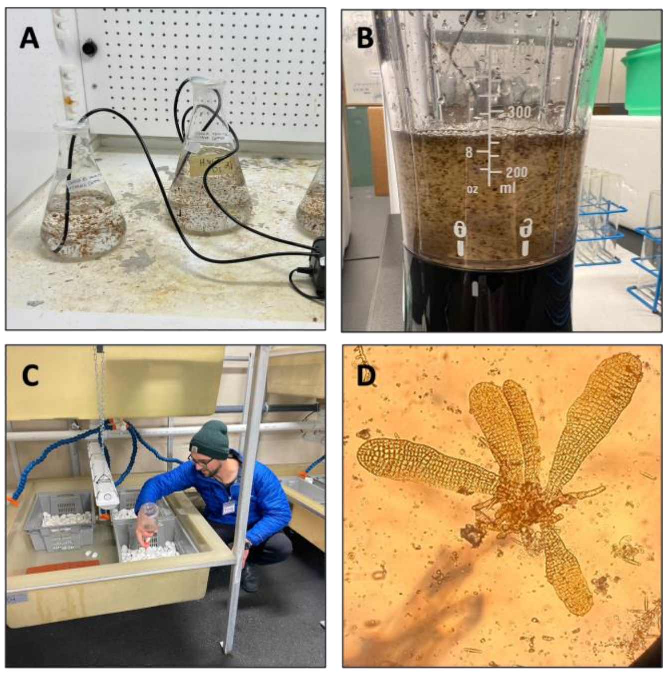

Figure 5 Gametophyte culturing, fragmentation, and seeding.

(A) Gametophytes in tumble culture at UBC prior to fragmetation (pictured in white light briefly during installation). (B) Gametophytes being fragmented in a blender in the Martone Lab at UBC. Photo Credit: Clay Steell. (C) Fragmented gametophytes being sprayed onto gravel and tiles by Clay Steell at the Pacific Science Enterprise Centre. (D) Microscopic sporophytes growing in tanks at the Pacific Science Enterprise Centre.

2.8. Sporophyte Outplanting

Outplanting occurred on February 27 and 28, 2023, and was completed by the TWN and KRI field team. This timing was chosen because it was approximately six weeks post seeding which ensured the sporophytes would be macroscopic. Juvenile kelp was present in the intertidal at Girl in a Wetsuit (Stanley Park) in February 2022 and 2023 suggesting this outplanting timing is consistent with the natural timing of sporophyte production in Burrard Inlet (Schenk et al. 2022).

2.8.1. Preparation and Transport

Gravel trays and tiles were removed from the tanks and stored in basins for transport ensuring the sporophytes remained submerged. The outplants were picked up from the PSEC by the TWN field boat and transported 10 to 16 km to restoration sites (Figure 6B). The SeaChange Marine Conservation Society dive boat met the crew at the restoration sites.

2.8.2. Experimental Areas

Numbered 10-pound orange sandbags, 60 pieces of large gravel (35 to 50 mm), 60 pieces of small gravel (20 to 30 mm), and 30 tiles were lowered from the boat at each restoration site. Divers established three large gravel plots, three small gravel plots, and three control plots using numbered orange sandbags as markers at each site. A treatment was randomly assigned to each plot number using a random number generator. Twenty pieces of gravel were hand-placed per plot, and plots were installed from 0.5 to 2.6 m below chart datum (Figure 6C). Areas with substrate that are predominantly cobble or bedrock were targeted; however, this was difficult to achieve due to the natural substrate at restoration sites. The best suited locations for plot installation were determined by the divers. Tiles were attached to the marine benthos using marine epoxy along a transect running perpendicular to shore from 0 to 6 m below chart datum (Figure 6D). Tiles were placed roughly 0.5 to 1 m apart along a 2 to 3 m wide swath of shoreline. Splash Zone A-788 epoxy was mixed on the boat and carried to the site by divers. Twenty tiles were installed at Nine O'clock Gun, 28 tiles were installed at New Brighton, and 28 tiles were installed at Crab Park.

2.8.3. Restoration Areas

The TWN field boat was positioned at the predetermined GPS coordinates for outplanting at a target depth of 1.5 m below chart datum. Accounting for the tide height on outplanting days, this corresponded to a water depth of approximately 4 to 6 m. A GPS waypoint was recorded to mark the starting point of the gravel deployment. A GPS track was started to follow the boat outplanting path. Three people deployed the gravel from the front of the boat targeting a combined deployment width of 3 m for outplanting at Crab Park and New Brighton (Table 1). The boat operator drove slowly to ensure that gravel cleared the hull and approximately parallel to shore targeting a constant depth. Direction was adjusted as needed to keep the outplanting depth constant. This process was repeated for each restoration (boat-outplanted) area.

Table 1 Summary of the number of green gravel outplants and length of shoreline seeded at each boat outplanting area.

Location	Approximate Number of Outplants (count)	Estimated Linear Shoreline Seeded (m)
Crab Park West	570	49
Crab Park East	470	28
New Brighton West	797	142
New Brighton Central	507	120
New Brighton East	492	37

2.9. Monitoring

2.9.1. Timing

There were three monitoring periods throughout the spring and summer to track the success of outplanted kelp and characterize reference and restoration kelp beds: April 26 to 28, 2023, June 5 to 8, 2023, and September 6 to 9, 2023. These were all completed via SCUBA surveys by the SeaChange Marine Conservation Society commercial divers. A summary of all monitoring activities is provided in Table 2.

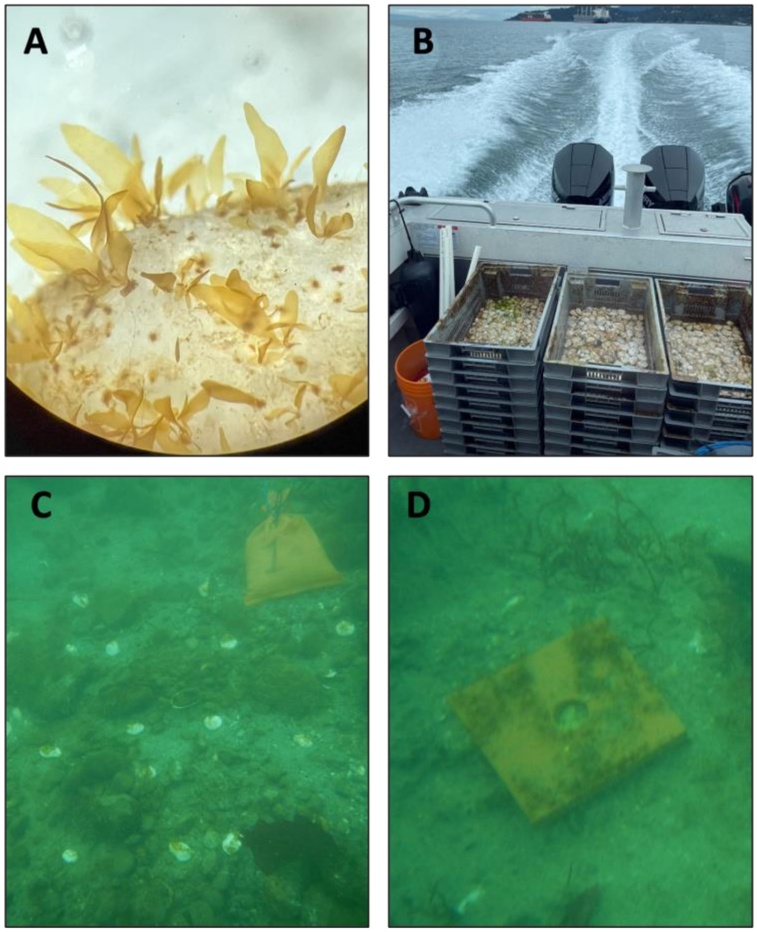

Figure 6 Sporophyte outplanting.

(A) Sporophytes growing on gravel prior to outplanting. (B) Gravel and tiles in trays on TWN SNKY vessel in transport to outplanting sites. Photo Credit: Jonathan Page. (C) Twenty pieces of gravel installed by SeaChange divers in an experimental plot. (D) Tile expoxyed by SeaChange divers on natural substrate along a tile transect.

2.9.2. Transects

Monitoring transects were established at reference sites to characterize the substrate composition, understory seaweed composition, *N. luetkeana* density, stipe length (cm), and pneumatocyst diameter (mm) along a depth range from 1 m above chart datum to 3 m below chart datum during the first monitoring period, April 26th to 28th. There were two transects at Brockton Point North and two transects at Second Narrows. Each transect length varied based on the steepness of the slope (13 to 50 m); divers placed 1 m x 1 m quadrats equidistant along this depth gradient to achieve 10 to 15 plots per transect. Transects were marked with an onshore and offshore GPS point and were re-established by placing temporary floats and transect tape at these points in subsequent monitoring periods (Table C.1).

During the second and third monitoring period, additional transects were established at Brockton Point South and the restoration sites. Sori, bleaching, and bryozoan presence was also added to the monitoring program. There was a total of four transects at Brockton Point (two at Brockton Point North (BP N) and two at Brockton Point South (BP S)), two transects at Second Narrows (SN), three transects at Nine O'clock Gun (NOG), two transects at Crab Park (CR), and three transects at New Brighton (NB) (Figure 7; Figure 8).

Substrate composition is measured as the percent cover of fine sediment (less than 2mm), pebbles (2 mm to 16 mm), gravel (16 to 64 mm), cobble (64 to 256 mm), or boulders (greater than 256 mm) to the nearest 1% as defined in a United States Geological Survey guide (Valentine 2019). Understory seaweed composition of common seaweed species in Burrard Inlet was determined by measuring the percent cover to the nearest 1%. The species list used included *Ulva fenestrata, Saccharina latissimia, Alaria marginata, Costaria costata, Sargassum muticum, Desmarestia herbacea,* and the phylum Rhodophyta.

Divers randomly selected up to five *N. luetkeana* sporophytes per quadrat and measured stipe length and pneumatocyst diameter. Stipe length is the length from the top of the holdfast to the base of the pneumatocyst and was measured in cm. Pneumatocyst diameter is the diameter around the widest part of the bulb and was measured in mm using calipers.

2.9.3. Experimental Plot Area

During each monitoring period, the gravel size experiment was monitored by assessing the gravel density, kelp survivorship, stipe length, pneumatocyst diameter, holdfast attachment, substrate composition, and understory seaweed composition in each plot at each restoration site. Gravel density is the count of all experimental gravel present in the plots. Kelp survivorship is the count of experimental gravel with kelp growing on them. Divers measured the longest growing sporophyte on each gravel.

Holdfast attachment is the presence of at least one haptera attaching to the underlying substrate.

2.9.4. Tile Transects

During each monitoring period, the tile transect was monitored by assessing the number of tiles found and the number of tiles with kelp growing. For each tile with kelp growing, the stipe length, pneumatocyst diameter, holdfast radius, and holdfast attachment of the largest sporophyte was measured. During the second and third monitoring period, sori, bleaching, and bryozoan presence were also monitored. Holdfast radius is the distance from the base of the stipe to the end of the longest haptera and measured in mm.

2.9.5. Restoration Area

There were no monitoring objectives to assess the success of boat outplanted areas. Divers conducted meander surveys at the New Brighton boat outplanting restoration areas to determine if there were any successful outplants during the April 26 to 28, 2023 monitoring period. Divers started at the western edge of a boat outplanting area and zigzagged along the shore from depths of 0 to 4 metres below chart datum for the length of the boat outplanting area.

2.9.6. Temperature and Salinity Loggers

Star Oddi CTD loggers were installed at Brockton Point N, New Brighton, Second Narrows, and Nine O'clock Gun during the April 26 to 28, 2023 monitoring period and removed during the September 6 to 9, 2023. A Star Oddi CT logger was installed at Crab Park during the June 5 to 8, 2023 monitoring period; however, it detached from the copper pipe and was not recovered in September. The loggers were attached to a 1 m copper pipe which was pounded ~0.5 m into the substrate and anchored with two 10-lbs sandbags at 1.5 m below chart datum. Temperature (°C) and salinity (PSU) were recorded hourly from April 29th at 12:00 AM PDT to approximately 3:30 PM PDT on September 18th when the data collection was stopped, and the data was downloaded in the Martone Lab at the University of British Columbia.

Table 2 **Summary of monitoring completed at each site throughout the study period. Reference sites are italiczed.**

Dates	**Sites Surveyed**	**Monitoring Completed**
May 1st- August 31st	*Brockton Point North, Second Narrows*, Nine O'clock Gun, & New Brighton	Temperature Salinity
April 26th- 28th	*Brockton Point North & Second Narrows*	Substrate and seaweed cover *N. luetkeana* depth and density *N. luetkeana* growth characteristics
	Nine O'clock Gun Experimental Area, New Brighton Experimental Area, & Crab Park Experimental Area	Substrate and seaweed cover Experimental plots monitoring Tile transect monitoring
	New Brighton Restoration Areas: West, Central, & East	Meander surveys of boat-outplanted areas
June 5th-8th	*Brockton Point North*, Nine O'clock Gun, & *Second Narrows*	Substrate and seaweed cover *N. luetkeana* depth and density *N. luetkeana* growth characteristics
	Brockton Point South	Substrate and seaweed cover *N. luetkeana* depth and density
	Crab Park & New Brighton	Substrate and seaweed cover
	Nine O'clock Gun Experimental Area & Crab Park Experimental Area	Seaweed cover Experimental plots monitoring Tile transect monitoring
September 6th-9th	*Brockton Point North, Brockton Point South*, Nine O'clock Gun, & *Second Narrows*	Substrate and seaweed cover *N. luetkeana* depth and density *N. luetkeana* growth characteristics
	Crab Park & New Brighton	Substrate and seaweed cover
	Nine O'clock Gun Experimental Area, New Brighton Experimental Area, & Crab Park Experimental Area	Substrate and seaweed cover Experimental plots monitoring Tile transect monitoring

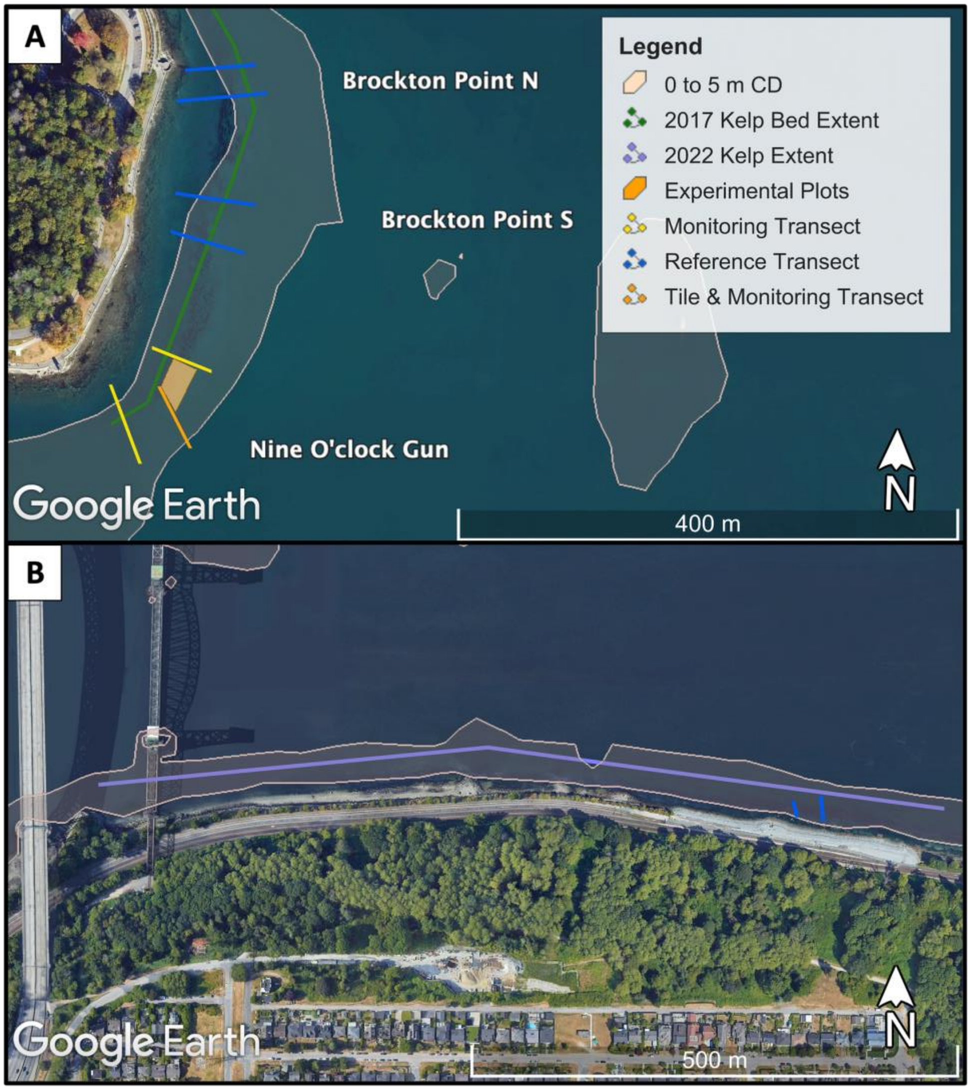

Figure 7 **Brockton Point, Nine O'clock Gun, and Second Narrows site maps.**

(A) The Brockton Point *N. luetkeana* bed (green line) extended from the Brockton Point Lighthouse to approximately 350 m south at the Nine O'clock Gun in 2017 (ShoreZone Imagery 2017). Four reference transects were established in 2023 at Brockton Point. Nine O'clock Gun was establised as a restoration site and experimental plots (orange polygon), a tile transect (orange line), and monitoring transects (yellow and orange lines) were installed. (B) Second Narrows bed (purple line) is roughly 900 m long extending east along the shoreline from Iron Workers Memorial Bridge (shown at the left of the map). Two reference transects (blue lines) were established near the eastern edge of the bed. CD refers to chart datum.

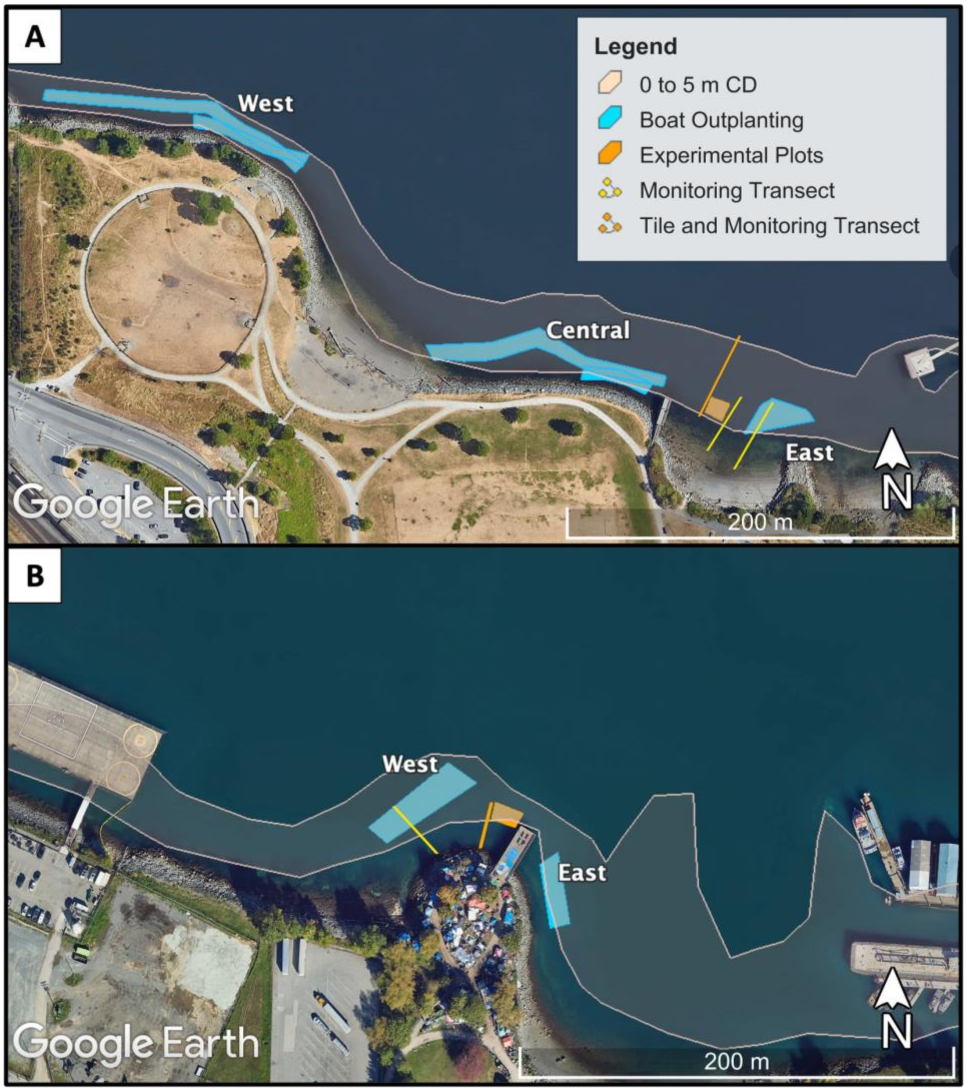

Figure 8 New Brighton and Crab Park site maps.

(A) New Brighton Park is situated approximately 900 m west of the 2022 extent of the Second Narrows reference kelp bed and 140 m west of the Viterra Cascadia Terminal. (B) Crab Park is located approximately 550 m east of Canada Place and 200 m west from the Port of Vancouver Centerm Container Terminal. It is approximately 1.75 km southeast of Brockton Point and 6 km west of Second Narrows. This site was selected for boat outplanting (blue polygons), experimental plots (orange polygon), a tile transect (oragne line), and monitoring transects (yellow and orange lines). CD refers to chart datum.

2.10. Data Analysis

To compare abiotic and biotic conditions between restoration and reference sites, a nonparametric Kruskal-Wallis test and pairwise Wilcoxon rank sum test were conducted in R programming language (R Core Team 2022). Specifically, temperature, salinity, substrate, understory seaweed, and understory kelp were compared between Brockton Point N, Brockton Point S, Second Narrows, Nine O'clock Gun, Crab Park, and New Brighton. In addition, *N. luetkeana* density, *N. luetkeana* depth range, and stipe length measurements were compared at Brockton Point N, Brockton Point S, Second Narrows, and Nine O'clock Gun. The stipe lengths of outplanted kelp, nursery kelp, and reference kelp were compared for the April 26 to 28 monitoring time point.

The temperature, salinity, substrate, understory seaweed, understory kelp, *N. luetkeana* density, *N. luetkeana* depth range, and stipe length data did not meet the assumptions for a one-way ANOVA. Thus, a nonparametric Kruskal-Wallis test was used to test for differences between sites. If a significant difference was detected, a pairwise-Wilcoxon rank sum post-hoc test was used to determine which sites were significantly different from each other. A continuity correction and Bonferroni adjustment were used for the pairwise Wilcoxon rank sum test to account for the ties in the data and adjust for multiple comparisons, respectively. A significance level of 0.05 was used for all tests. Temperature and salinity data were analyzed across the entire period of data logger deployment, and hourly measurements from each day were averaged across each 24-hour period to obtain the daily average. For the experimental plot and monitoring transect data, each time point was analyzed separately to determine differences between sites rather than differences across time points.

Percent cover estimates for substrate and understory seaweed were placed in the following cover classes: 0%, 1 to 5%, 5 to 25%, 26 to 50%, 51 to 75%, 76 to 95%, 96 to 100%. The midpoint of each class was used for analysis. Substrate data was standardized, so the maximum substrate value is 100% representing complete cover. The understory kelp and seaweed percent cover data were not standardized, and the maximum cover value can be higher than 100% in cases where there is overlap between seaweed species.

Chapter 3. Results

3.1. Environmental Data

3.1.1. Water Temperature

There was no significant difference in the average (Kruskal-Wallis test: χ^2(df = 3, n = 123) = 2.05, p = 0.56) and maximum (Kruskal-Wallis test: χ^2(df = 3, n = 123) = 4.14, p = 0.25) daily water temperatures between sites throughout the entire study period (Table B.1). The warmest month on average was July with average daily water temperatures of 14.74 ± 0.09°C (mean ± SE), 14.61 ± 0.15°C, 14.43 ± 0.13°C, and 14.54 ± 0.13°C at Second Narrows, Brockton Point North, Nine O'clock Gun, and New Brighton, respectively (Figure 9; Figure 10; Table A.1). The average daily maximum in July was 16.13 ± 0.06 °C, 16.10 ± 0.21°C, 15.83 ± 0.81°C, 15.69 ± 0.17°C at Second Narrows, Brockton Point North, Nine O'clock Gun, and New Brighton, respectively (Figure 10; Table A.1). There was a significant difference between sites in the minimum daily water temperature (Kruskal-Wallis test: χ^2(df = 3, n = 123) = 15.47, p = 0.001; Table B.1). Specifically, the minimum daily water temperature at Second Narrows is significantly higher than Brockton Point North and Nine O'clock Gun (Table B.2). The average minimum daily water temperatures in July were 13.88 ± 0.12°C, 13.25 ± 0.15°C, 13.22 ± 0.15°C, and 13.67 ± 0.11°C at Second Narrows, Brockton Point North, Nine O'clock Gun, and New Brighton, respectively (Figure 10; Table A.1).

3.1.2. Salinity

There was a significant difference in average (Kruskal-Wallis test: χ^2(df = 3, n = 123) = 84.57, p < 0.001), maximum (Kruskal-Wallis test: χ^2(df = 3, n = 123) = 106.8, p < 0.001), and minimum (Kruskal-Wallis test: χ^2(df = 3, n = 123) = 74.36, p < 0.001) daily salinities between sites throughout the entire study period (Table B.1). For the average daily salinity, all sites were significantly different from each other (Table B.2). The average daily salinities from May 1st to August 31st were 21.30 ± 0.29 PSU, 23.20 ± 0.14 PSU, 24.22 ± 0.17 PSU, 23.62 ± 0.15 PSU at Second Narrows, Brockton Point North, Nine O'clock Gun, and New Brighton, respectively (Figure 11; Figure 12; Table A.2). For the maximum daily salinity, all sites were significantly different from each other except for Brockton Point North and New Brighton (Table B.2). The maximum daily salinities from May 1^{st} to August 31^{st} were 23.84 ± 0.12 PSU, 24.76 ± 0.11 PSU, 25.66 ± 0.13 PSU, and 24.90 ± 0.08 PSU at Second Narrows, Brockton Point North, Nine O'clock Gun, and New Brighton, respectively (Figure 12; Table A.2). For the minimum daily salinity, all sites were significantly different from each other except for Nine O'clock Gun and New Brighton (Table B.2). The minimum daily salinities from May 1^{st} to August 31^{st} were 18.75 ± 0.38 PSU, 21.27 ± 0.19 PSU, 22.87 ± 0.28 PSU, and 22.07 ± 0.22 PSU at Second Narrows, Brockton Point North, Nine O'clock Gun, and New Brighton, respectively (Figure 12; Table A.2). Second Narrows experienced low salinities in July and August with average daily salinities of 18.94 ± 0.73 PSU and 19.97 ± 0.53 PSU, respectively (Figure 11; Figure 12; Table A.2). The lowest recorded salinity at Second Narrows was 9.13 PSU in August (Figure 12; Table A.2).

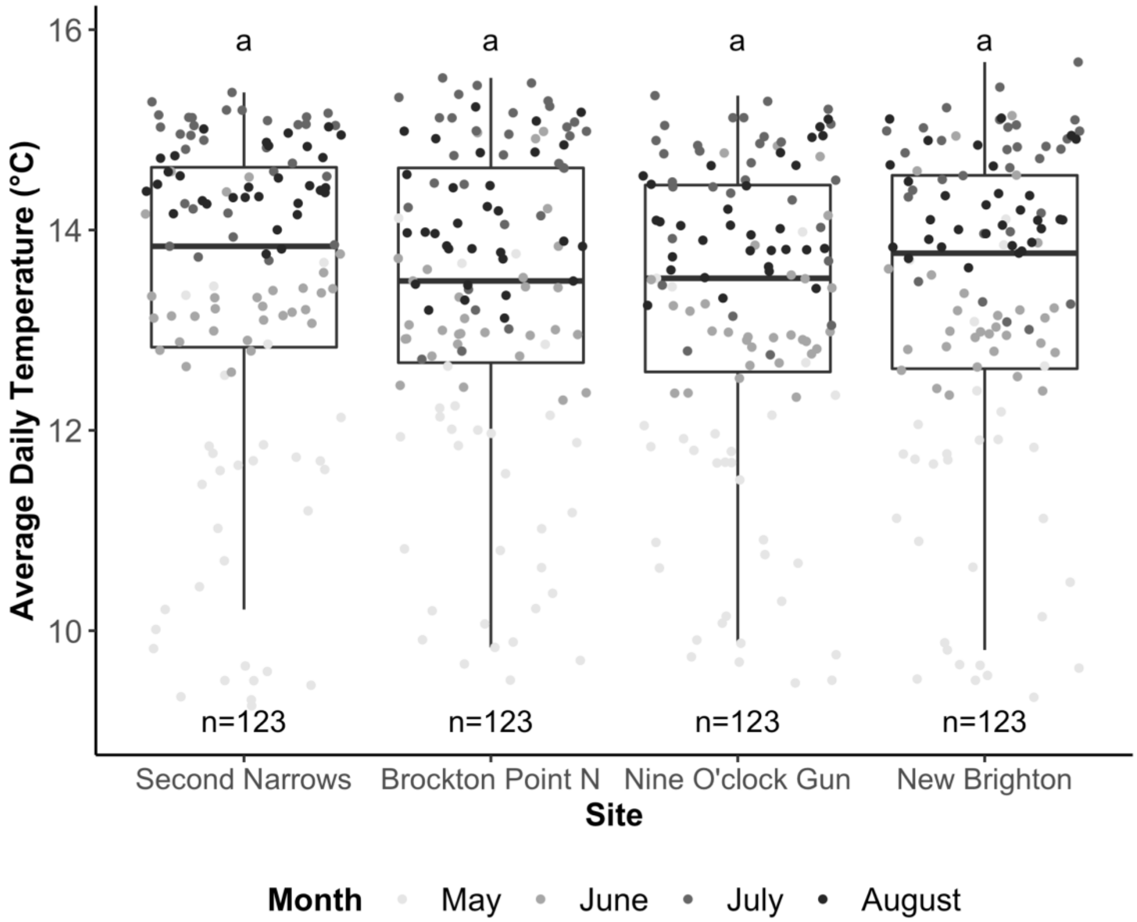

Figure 9 **Average daily temperature at four sites in Burrard Inlet from May 1st to August 31st, 2023.**

There are two reference sites (Brockton Point and Second Narrows) and two restoration sites (Nine O'clock Gun and New Brighton). The hinges extend from the 1st quartile to the 3rd quartile with the median indicated by the bold line within the hinges. The raw data is overlayed and separated by month using different grey colors. The "a" annotation indicates there are no significant differences in average daily temperature between sites.

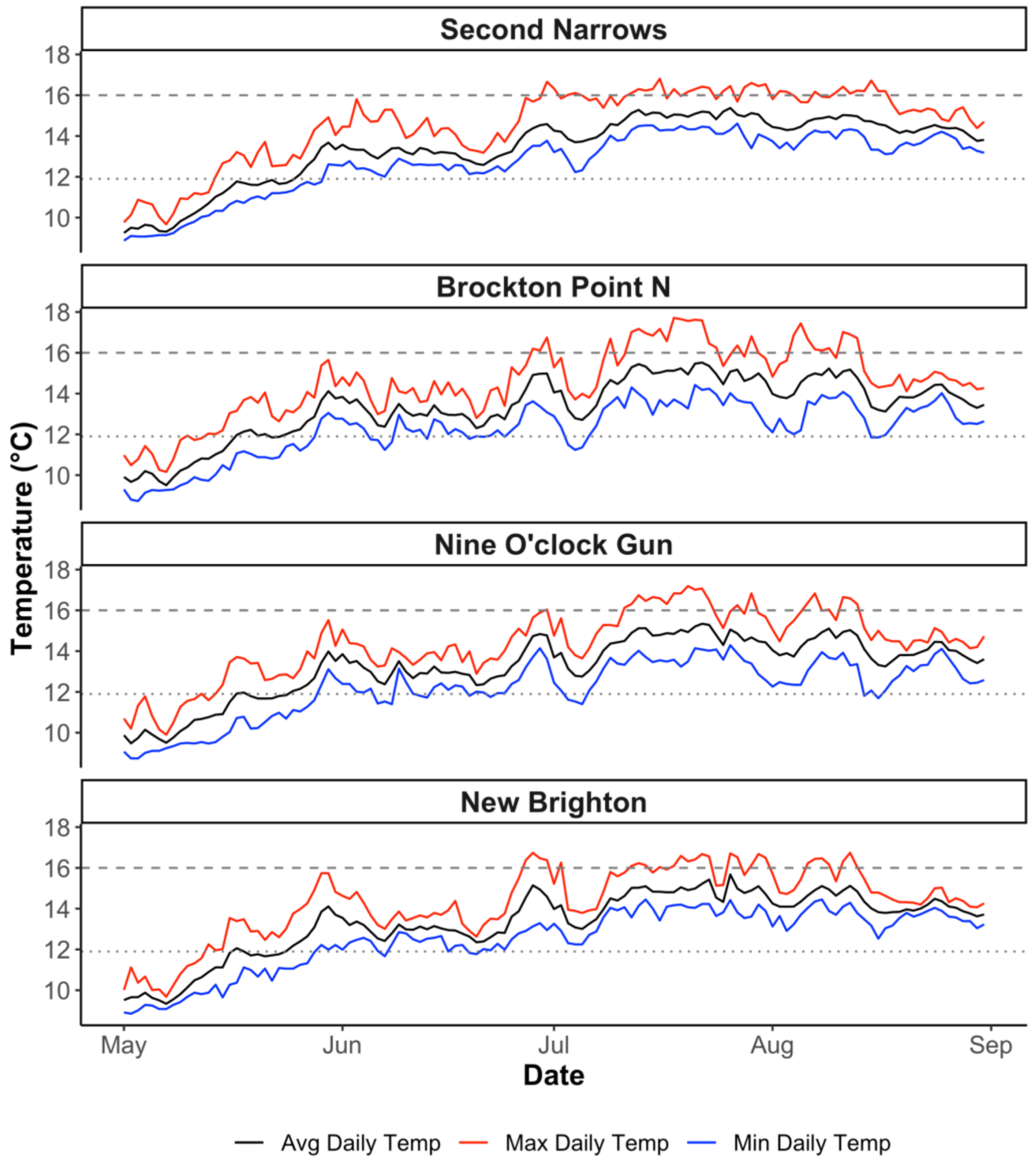

Figure 10 **Time series of the average, minimum, and maximum daily temperatures at four sites in Burrard Inlet from May 1st to August 31st, 2023.**

There are two reference sites (Brockton Point and Second Narrows) and two restoration sites (Nine O'clock Gun and New Brighton). The dashed lines indicate the temperature (16 °C) at which sporophyte production is reduced 78% (Weigel et al. 2023) and the dotted line at 11.9°C indicates the optimal blade elongation temperature (Supratya et al. 2020).

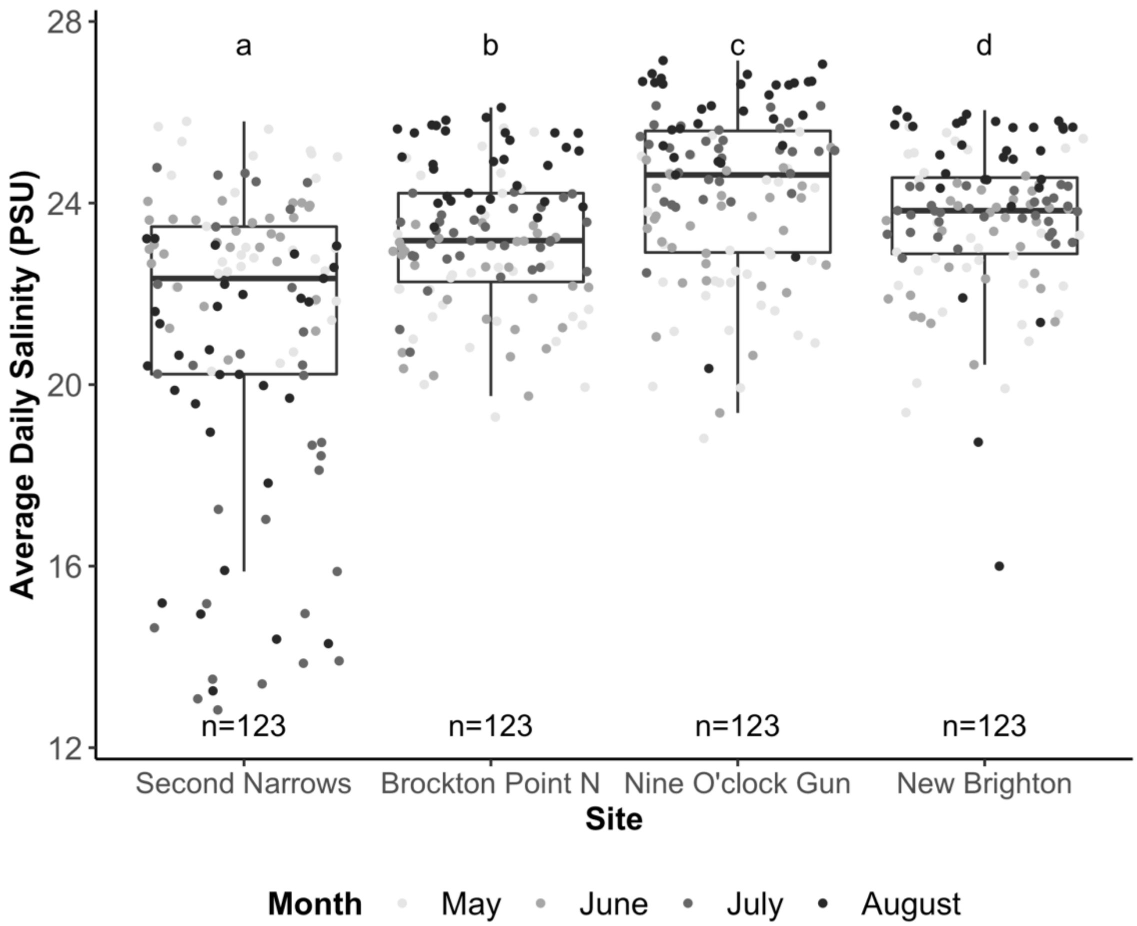

Figure 11 **Average daily salinity at four sites in Burrard Inlet from May 1st to August 31st, 2023.**

There are two reference sites (Brockton Point and Second Narrows) and two restoration sites (Nine O’clock Gun and New Brighton). The hinges extend from the 1st quartile to the 3rd quartile with the median indicated by the bold line within the hinges. The raw data is overlayed and separated by month using different grey colors. The letter annotations at the top of the plot indicate which sites are significantly different from each other with the same letters indicating no difference and different letters indicating a significant difference.

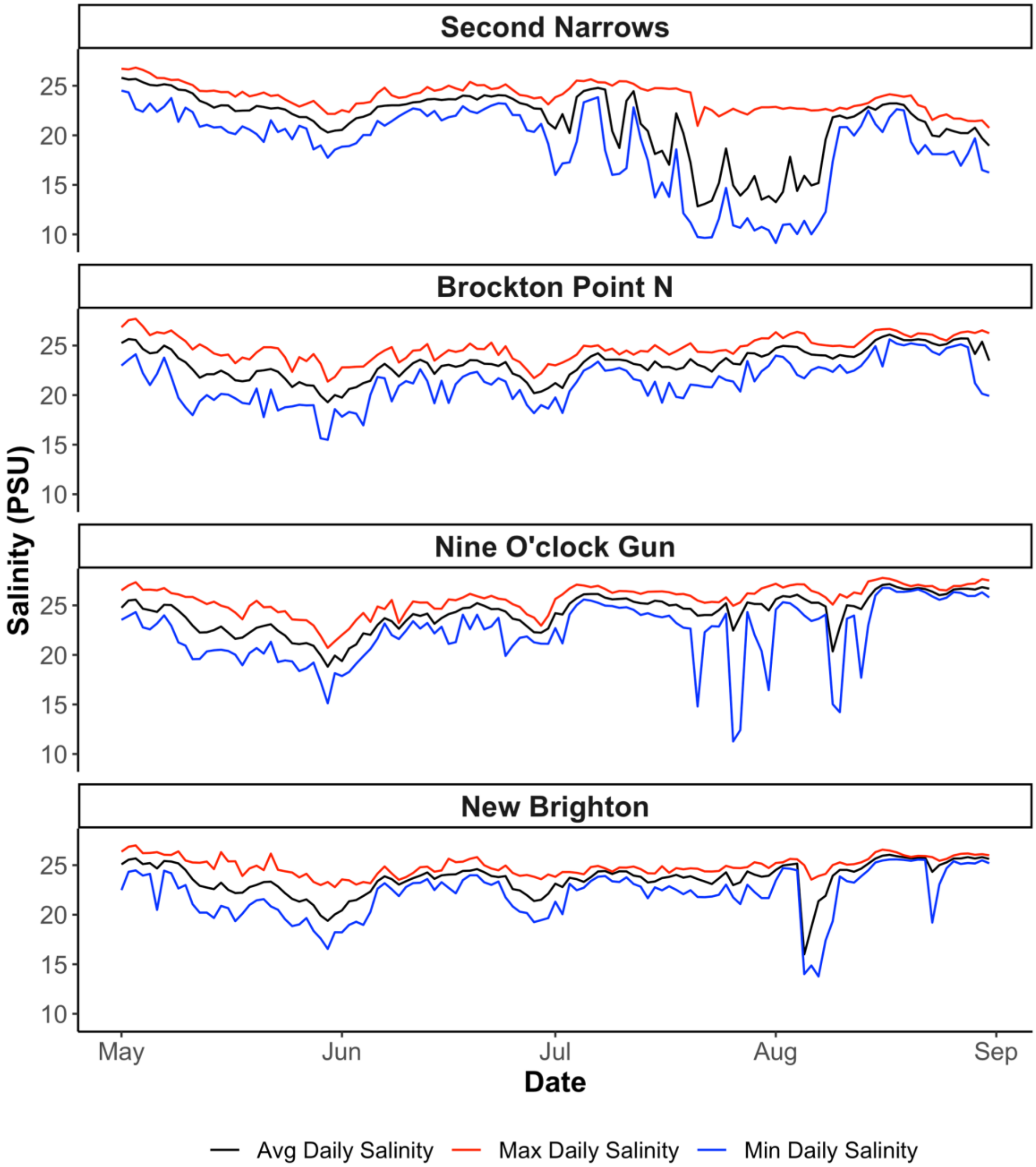

Figure 12 **Time series of the average, minimum, and maximum daily salinities at four sites in Burrard Inlet from May 1st to August 31st, 2023.**

There are two reference sites (Brockton Point and Second Narrows) and two restoration sites (Nine O'clock Gun and New Brighton).

3.2. Substrate

3.2.1. Reference Sites

The percent cover of cobbles and boulders was significantly higher at Second Narrows compared to Brockton Point North in April (Kruskal-Wallis test: χ^2(df = 1, SN: n = 21, BP N: n = 25) = 5.62, p = 0.02) but not in June or September (Table B.2). On average, Brockton Point North ranged from 53 ± 5% to 57 ± 6% cobbles and boulders, and Second Narrows ranged from 63 ± 6% to 77 ± 7% cobbles and boulders (Figure 13; Table A.3). There was no significant difference in the amount of fine sediment between Brockton Point North and Second Narrows at any time point (Table B.1; Table B.2). The average percent cover of fine sediment ranged from 9 ± 2% to 18 ± 3% at Brockton Point North and 14 ± 4% to 24 ± 5% at Second Narrows (Figure 13; Table A.3).

On average, the percent cover of cobbles and boulders in June and September at Brockton Point South was 43 ± 5% and 24 ± 4%, respectively (Figure 13). There was no significant difference between Brockton Point South and Brockton Point North in the percent of cobbles and boulders in June; however, Brockton Point South had a significantly lower percent of cobbles and boulders in September (Table B.2). Brockton Point South had significantly lower percent cover of cobble and boulders in both June and September compared to Second Narrows (Table B.2). The percent cover of fine sediment was significantly higher at Brockton Point South compared to Brockton Point North and Second Narrows in June and September (Table B.2.). The average percent cover of fine sediment was 39 ± 6% and 48 ± 4% at Brockton Point South in June and September, respectively (Figure 13).

3.2.2. Restoration Sites

Substrate was characterized along monitoring transects in June and September at restoration sites, and there were significant differences between sites in the percent cover of cobbles and boulders in June (Kruskal-Wallis test: χ^2(df = 5, SN: n = 22, BP N: n = 27, BP S: n = 29, NOG: n = 42, CR: n = 31, NB: n = 45) = 30.86, p < 0.001) and September (Kruskal-Wallis test: χ^2(df = 5, SN: n = 27, BP N: n = 27, BP S: n = 29, NOG: n = 39, CR: n = 26, NB: n = 36) = 33.06, p < 0.001). There were also significant differences between sites in the percent cover of fine sediment in June (Kruskal-Wallis test: χ^2(df = 5, SN: n = 22, BP N: n = 27, BP S: n = 29, NOG: n = 42, CR: n = 31, NB: n = 45) = 63.33, $p < 0.001$) and September (Kruskal-Wallis test: χ^2(df = 5, SN: n = 27, BP N: n = 27, BP S: n = 29, NOG: n = 39, CR: n = 26, NB: n = 36) = 41.21, $p < 0.001$; Table B.1).

Specifically, Crab Park, New Brighton, and Nine O'clock Gun on average had a significantly lower percent of cobbles and boulders than Second Narrows in June, and Crab Park and New Brighton has a significantly lower percent of cobbles and boulders in September (Table B.2). Brockton Point North had significantly higher percent cover of cobbles and boulders compared to Crab Park in June and significantly higher percent cover of cobbles and boulders compared to New Brighton in September (Table B.2). The average percent cover of cobbles and boulders was 27 ± 4% and 36 ± 5% at Crab Park, 38 ± 5% and 33 ± 5% at New Brighton, and 42 ± 5% and 40 ± 5% at New Brighton in June and September, respectively (Figure 13; Table A.3). Crab Park and Nine O'clock Gun had significantly more fine sediment compared to Brockton Point North in June and September (Table B.2). Crab Park had significantly more fine sediment compared to Second Narrows in June (Table B.2). In September, there was no significant difference in fine sediment between Second Narrows and the restoration sites (Table B.2). The average percent cover of fine sediment was 52 ± 6% and 52 ± 6% at Crab Park, 8 ± 3% and 22 ± 3% at New Brighton, and 38 ± 5% and 41 ± 4% at Nine O'clock Gun in June and September, respectively (Figure 13).

3.2.3. Experimental Plots

In April, the average percent cover of cobbles and boulders was 32 ± 7%, 24 ± 5%, and 23 ± 3% at Crab Park, New Brighton, and Nine O'clock Gun, respectively (Figure 13; Table A.5). In September, the average percent cover of cobble and boulders was 38 ± 11%, 17 ± 3%, and 10 ± 4% at Crab Park, New Brighton, and Nine O'clock Gun, respectively (Figure 13; Table A.5). The average percent cover of fine sediment 72 ± 8%, 30 ± 11%, and 79 ± 3% in April and 59 ± 11%, 34 ± 9% and 54 ± 8% in September at Crab Park, New Brighton, and Nine O'clock Gun, respectively (Figure 13; Table A.5).

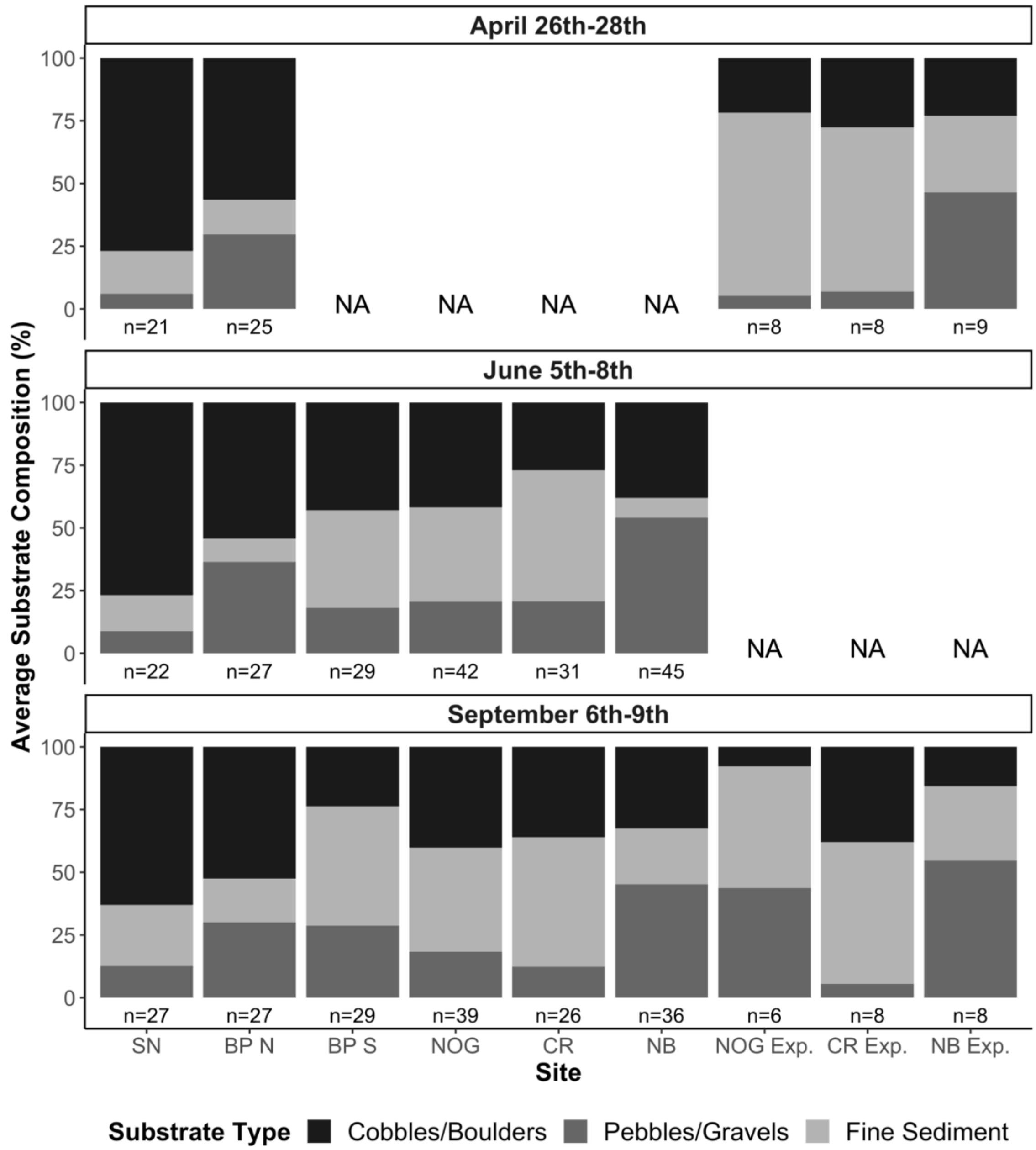

Figure 13 **Average substrate percent cover at 2 reference and 3 restoration sites at 3 time points in 2023.**

The percent cover values are the average of the percent cover in 'n' number of plots. Second Narrows (SN), Brockton Point North (BP N), and Brockton Point S (BP S) are the reference transects. Nine O'clock Gun (NOG), Crab Park (CR), and New Brighton (NB) are the restoration transects. The substrate percent cover was also sampled in the experimental plots and reported with the "Exp." distinction.

3.3. Understory Seaweed

3.3.1. Understory Kelp

There was no significant difference in the percent cover of understory kelp between Brockton Point North and Second Narrows in April (Kruskal-Wallis test: χ^2(df = 1, SN: n = 21, BP N: n = 25) = 2.13, p = 0.14). On average, Brockton Point North had 40 ± 6% and Second Narrows had 30 ± 7% total understory kelp cover in April (Figure 14; Table A.4). There was a significant difference in understory kelp between sites in June (Kruskal-Wallis test: χ^2(df = 5, SN: n = 22, BP N: n = 27, BP S: n = 29, NOG: n = 42, CR: n = 31, NB: n = 45) = 12.68, p = 0.03) and September (Kruskal-Wallis test: χ^2(df = 5, SN: n = 27, BP N: n = 27, BP S: n = 29, NOG: n = 39, CR: n = 26, NB: n = 36) = 39.02, p < 0.001; Table B.1).

Specifically, Crab Park had significantly more understory kelp cover than New Brighton with 56 ± 6% compared to 33 ± 3% at New Brighton (Figure 14; Table A.4; Table B.2). The average understory kelp cover in June was 36 ± 5%, 45 ± 5%, 45 ± 4%, and 37 ± 6% at Brockton Point North, Brockton Point South, Nine O’clock Gun, and Second Narrows, respectively (Figure 14; Table A.4). In September, Crab Park had significantly higher understory kelp cover (75 ± 6%) compared to all sites (Figure 14; Table A.4; Table B.2). Second Narrows has significantly less understory kelp cover compared to New Brighton in September (Table B.2). The understory kelp cover in September was 29 ± 5%, 47 ± 7%, 42 ± 5%, 34 ± 6%, and 21 ± 5% at Brockton Point North, Brockton Point South, New Brighton, Nine O’clock Gun, and Second Narrows, respectively (Figure 14; Table A.4).

3.3.2. Total Understory Seaweed

There was no significant difference in total understory cover between sites in April (Kruskal-Wallis test: χ^2(df = 1, SN: n = 21, BP N: n = 25) = 3.52, p = 0.06) or June (Kruskal-Wallis test: χ^2(df = 5, SN: n = 22, BP N: n = 27, BP S: n = 29, NOG: n = 42, CR: n = 31, NB: n = 45) = 10.07, p = 0.07; Table B.1). There was a significant difference in September (Kruskal-Wallis test: χ^2(df = 5, SN: n = 27, BP N: n = 27, BP S: n = 29, NOG: n = 39, CR: n = 26, NB: n = 36) = 14.23, p = 0.01; Table B.1); however, the post-hoc test did not detect a significant difference between any specific sites (Table B.2). The average total cover at reference sites was 72 ± 6% in April and June and 71 ± 5% in September at Brockton Point North, 78 ± 5% and 76 ± 4% at Brockton Point South in June and September, respectively, and 86 ± 6%, 93 ± 6% and 75 ± 4% at Second Narrows in April, June, and September, respectively (Figure 14; Table A.4). The total seaweed cover at restoration sites was 80 ± 6% and 87 ± 5% at Crab Park, 80 ± 4% and 84 ± 4% at New Brighton, and 73 ± 5% and 66 ± 6% at Nine O’clock Gun in June and September, respectively (Figure 14; Table A.4).

3.3.3. Experimental Plots

In April, the average understory kelp cover was 16 ± 4%, 41 ± 9%, and 14 ± 3%, and the average total seaweed cover was 33 ± 7%, 74 ± 10%, and 49 ± 6% at Crab Park, New Brighton, and Nine O’clock Gun, respectively (Figure 14; Table A.5).

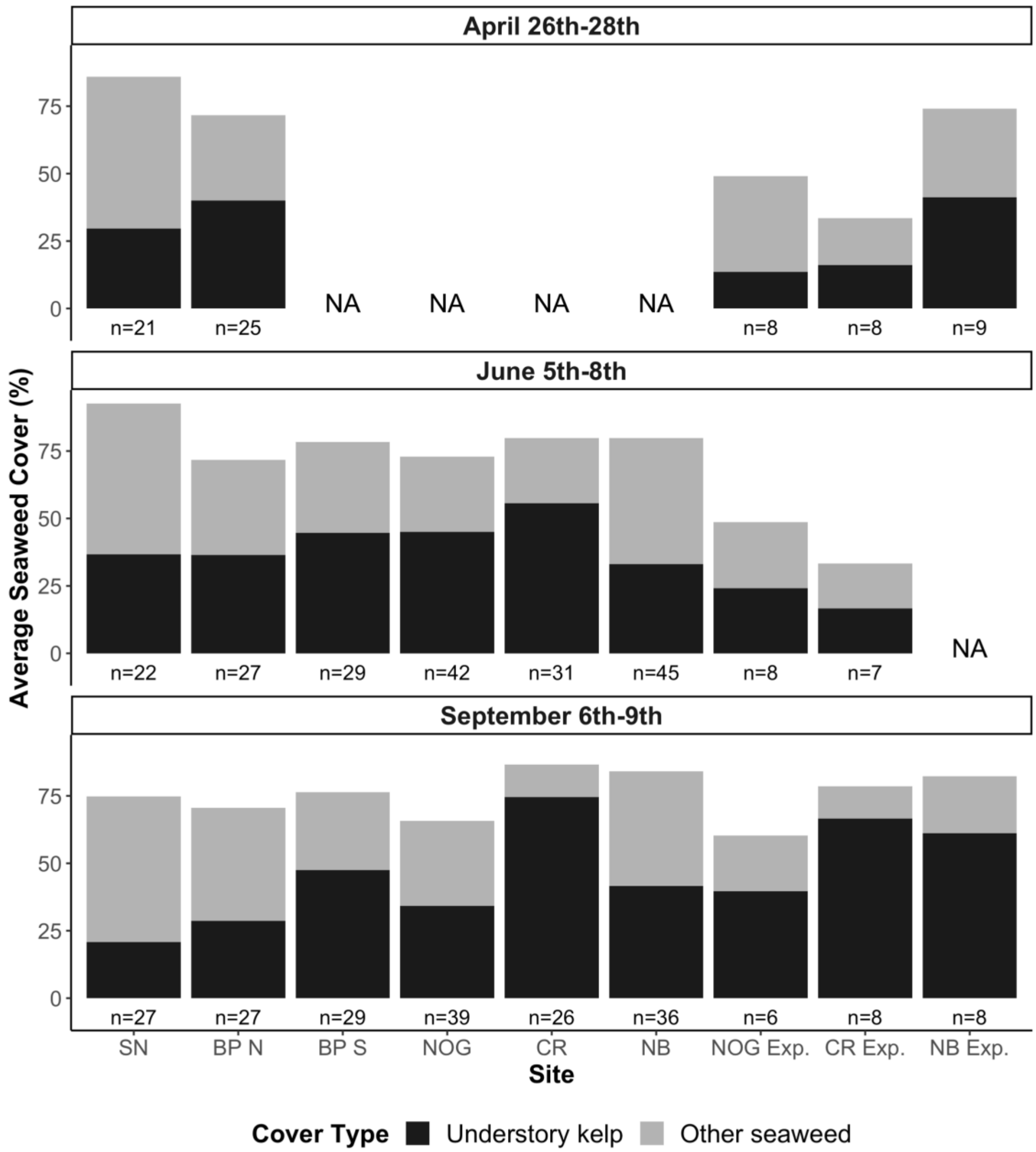

Figure 14 **Average seaweed percent cover at 2 reference and 3 restoration sites at 3 time points in spring and summer 2023.**

The percent cover values are the average of the percent cover in 'n' number of plots. Second Narrows (SN), Brockton Point North (BP N), and Brockton Point S (BP S) are the reference transects. Nine O'clock Gun (NOG), Crab Park (CR), and New Brighton (NB) are the restoration transects. The seaweed percent cover was also sampled in the experimental plots and reported with the "Exp." distinction.

3.4. *N. luetkeana* Bed Characteristics

Naturally recruited (i.e. not outplanted) *N. luetkeana* sporophytes were found growing at Brockton Point North, Brockton Point South, Nine O'clock Gun, and Second Narrows consistently throughout the monitoring periods. Anecdotally, there were few (approximately 10 or less) naturally recruited *N. luetkeana* sporophytes found at New Brighton in the April and June monitoring periods.

3.4.1. *N. luetkeana* Depth

There were no significant differences in the depth in which sporophytes were found across sites in April (Kruskal-Wallis test: χ^2(df = 1, SN: n = 21, BP N: n = 25) = 0.12, p = 0.73), June (Kruskal-Wallis test: χ^2(df = 3, SN: n = 22, BP N: n = 27, BP S: n = 29, NOG: n = 42) = 5.18, p = 0.16), or September (Kruskal-Wallis test: χ^2(df = 3, SN: n = 27, BP N: n = 27, BP S: n = 29, NOG: n = 39) = 7.07, p = 0.07; Table B.1).

The average depth sporophytes occurred relative to chart datum in April was -0.5 ± 0.4 m and 0.0 ± 0.2 m at Brockton Point North and Second Narrows, respectively (Figure 15; Table A.6). Sporophytes were found in the intertidal at both sites up to 1 m and down to -2.8 m and -1.0 m relative to chart datum at Brockton Point North and Second Narrows, respectively (Figure 15; Table A.6). In June, the average depth was -1.4 ± 0.3 m, -0.6, ± 0.2 m, -0.6 ± 0.2 m, and -0.9 ± 0.3 m at Brockton Point North, Brockton Point South, Nine O'clock Gun, and Second Narrows, respectively (Figure 15; Table A.6). Sporophytes were found to a depth of approximately 3 m below chart datum across all sites in June (Figure 15; Table A.6). In September, the average depth was -1.3 ± 0.5 m, -0.9 ± 0.4 m, -1.2 ± 0.3 m, and -0.1 ± 0.2 m relative to chart datum at Brockton Point North, Brockton Point South, Nine O'clock Gun, and Second Narrows, respectively (Figure 15; Table A.6). The maximum depth sporophytes were found ranged from -2.1 m to -2.5 m relative to chart datum at all sites except for Second Narrows which had a maximum depth of -0.5 m relative to chart datum (Figure 15; Table A.6). Brockton Point North, Brockton Point South, Nine O'clock Gun, and Second Narrows had sporophytes growing in the low intertidal at depths of 0.3 m, 0.2 m, 0.4 m, and 0.9 m, respectively (Figure 15; Table A.6).

3.4.2. *N. luetkeana* Distribution

In June, 56%, 69%, 60%, and 59% of plots surveyed within the depth range in which *N. luetkeana* sporophytes were found had sporophytes present at Brockton Point North, Brockton Point South, Nine O'clock Gun, and Second Narrows, respectively (Table 3). By September, sporophytes were only found in 19%, 17%, 21%, and 22% of plots at Brockton Point North, Brockton Point South, Nine O'clock Gun, and Second Narrows, respectively (Table 3).

3.4.3. *N. luetkeana* Density

There were no significant differences in the density at which *N. luetkeana* sporophytes were found across sites in April (Kruskal-Wallis test: χ^2(df = 1, SN: n = 21, BP N: n = 25) = 1.12, p = 0.29), June (Kruskal-Wallis test: χ^2(df = 3, SN: n = 22, BP N: n = 27, BP S: n = 29, NOG: n = 42) = 6.40, p = 0.09), or September (Kruskal-Wallis test: χ^2(df = 3, SN: n = 27, BP N: n = 27, BP S: n = 29, NOG: n = 39) = 0.97, p = 0.81).

In April, the average density was 5 ± 1 and 7 ± 2 sporophytes per m^2 at Brockton Point North and Second Narrows, respectively (Table A.6). By June, the average density was 4 ± 1, 4 ± 1, 3 ± 1, and 2 ± 0 sporophytes per m^2 at Brockton Point North, Brockton Point South, Nine O'clock Gun, and Second Narrows, respectively (Table A.6). In September, the average density was 3 ± 1 at Brockton Point, 2 ± 1 at Brockton Point South, and 2 ± 0 sporophytes per m^2 at Nine O'clock Gun and Second Narrows (Table A.6).

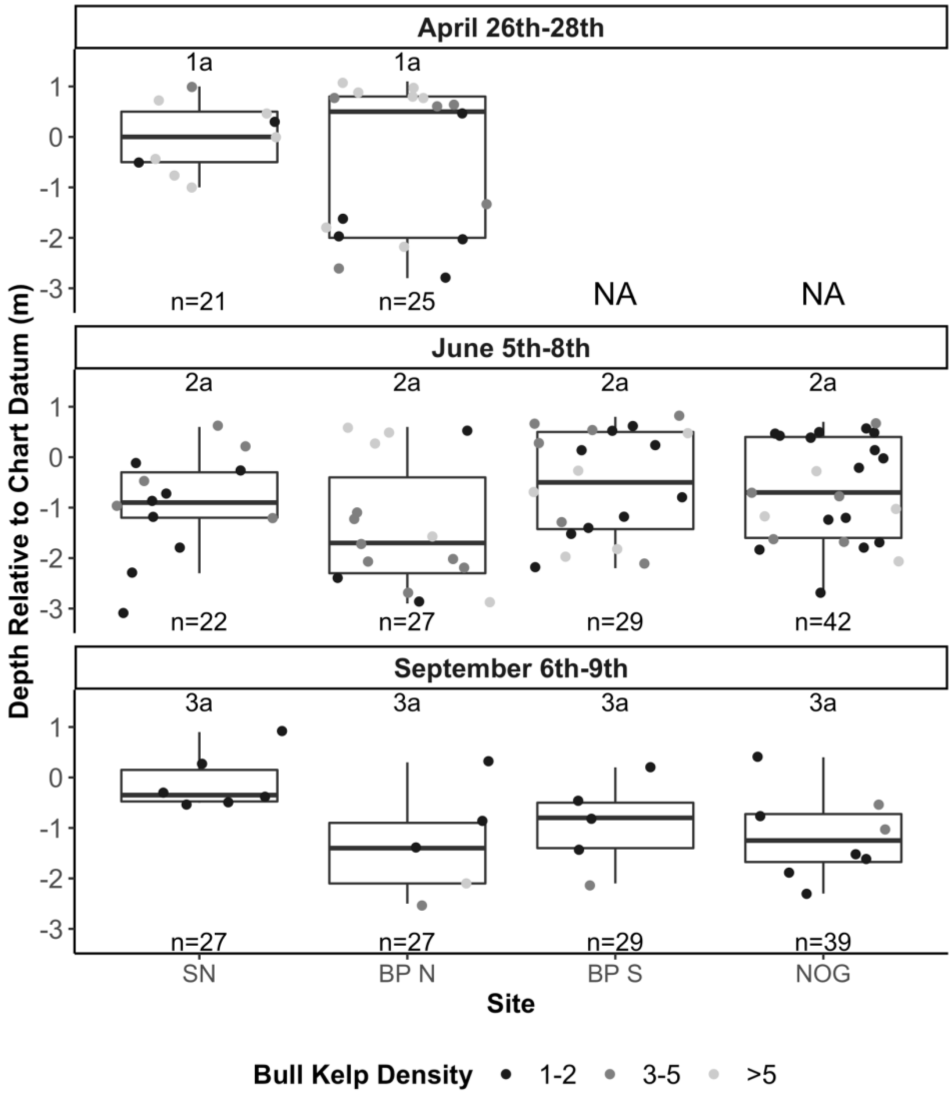

Figure 15 ***N. luetkeana*** **sporophyte depth at 4 sites at 3 time point in the spring and summer 2023.**

The number of plots surveyed is 'n' and indicated at the bottom of each panel. The jitter overlay is the number of plots in which sporophytes were found. The annotation at the top of each panel indicates the results of a Kruskal-Wallis test; a separate test was conducted for each timepoint and is indicated by the number. The same letter indicates sites that were not significantly different from each other. Second Narrows (SN), Brockton Point North (BP N), and Brockton Point S (BP S) are the reference sites. Nine O'clock Gun (NOG) is a restoration site.

Table 3 ***N. luetkeana*** **sporophytes percent presence. This is the percent of plots with sporophytes found of the total number of plots sampled within the depth range of *N. luetkeana* in Burrard Inlet. Reference sites are italicized.**

Date	Site	n (plots)	Sporophytes present (%)
April 26-28	*Brockton Point N*	25	68
	Second Narrows	21	43
June 5-8	*Brockton Point N*	27	56
	Brockton Point S	29	69
	Nine O'clock Gun	42	60
	Second Narrows	22	59
Sept. 6-9	*Brockton Point N*	27	19
	Brockton Point S	29	17
	Nine O'clock Gun	39	21
	Second Narrows	27	22

3.5. Naturally Recruited Sporophyte Growth and Health Characteristics

3.5.1. Stipe Length

The stipe length at Second Narrows was significantly longer than Brockton Point North in April (Kruskal-Wallis test: χ^2(df = 1, SN: n = 21, BP N: n = 25) = 33.23, $p < 0.001$). The average stipe length in April was 18 ± 2 cm and 52 ± 5 cm at Brockton Point North and Second Narrows, respectively (Figure 16; Table A.7). There was no significant difference in stipe length between sites in June (Kruskal-Wallis test: χ^2(df = 2, SN: n = 22, BP N: n = 27, NOG: n = 42) = 0.53, p = 0.77) or September (Kruskal-Wallis test: χ^2(df = 3, SN: n = 27, BP N: n = 27, BP S: n = 29, NOG: n = 39) = 6.74, p = 0.08; Table B.1). The average stipe length was 59 ± 5 cm, 61 ± 5 cm, and 54 ± 6 in June at Brockton

Point North, Nine O'clock Gun, and Second Narrows, respectively (Figure 16; Table A.7). In September, the average stipe length was 415 ± 34 cm, 367 ± 48 cm, 308 ± 41 cm, and 282 ± 40 cm at Brockton Point North, Brockton Point South, Nine O'clock Gun, and Second Narrows, respectively (Figure 16; Table A.7).

Table 4 ***N. luetkeana*** **sporophyte reproductive and health characteristics. The sample size (n) is the number of sporophytes surveyed at each site for a given monitoring. Reference sites are italicized.**

Date	Site	n (count)	Sori Presence (%)	Bleaching Presence (%)	Max. Bleaching Depth (m)	Bryozoan Presence (%)
April 26-28	*Brockton Point N*	85	NA	NA	NA	NA
	Second Narrows	64	NA	NA	NA	NA
June 5-8	*Brockton Point N*	63	5	27	0.3	100
	Brockton Point S	73	1	14	-0.7	81
	Nine O'clock Gun	76	23	49	-1.2	92
	Second Narrows	30	12	14	-0.5	85
Sept. 6-9	*Brockton Point N*	14	71	0	NA	40
	Brockton Point S	10	72	0	NA	100
	Nine O'clock Gun	14	50	13	-0.5	44
	Second Narrows	9	83	0	NA	67

3.5.2. Sori, Bleaching, and Bryozoan Presence

Sori were rarely found on the sporophytes surveyed in June with exception of the sporophytes surveyed at Nine O'clock Gun which had sori present on 23% of the individuals surveyed. However, by September, sori were present on 50% to 83% of sporophytes surveyed (Table 4). There was bleaching in blade tissue as well as stipe and pneumatocyst tissues in some more extreme cases in June. Generally, bleaching was found to a depth of 1.2 m below chart datum at the June time point, and by September, there was only one individual found at Nine O'clock Gun with evidence of bleaching (Table 4). Bryozoans were present on most individuals in June across all sites. In September, they were found on a lesser percent of individuals at all sites except for Brockton Point South where they were found on 100% of individuals sampled (Table 4).

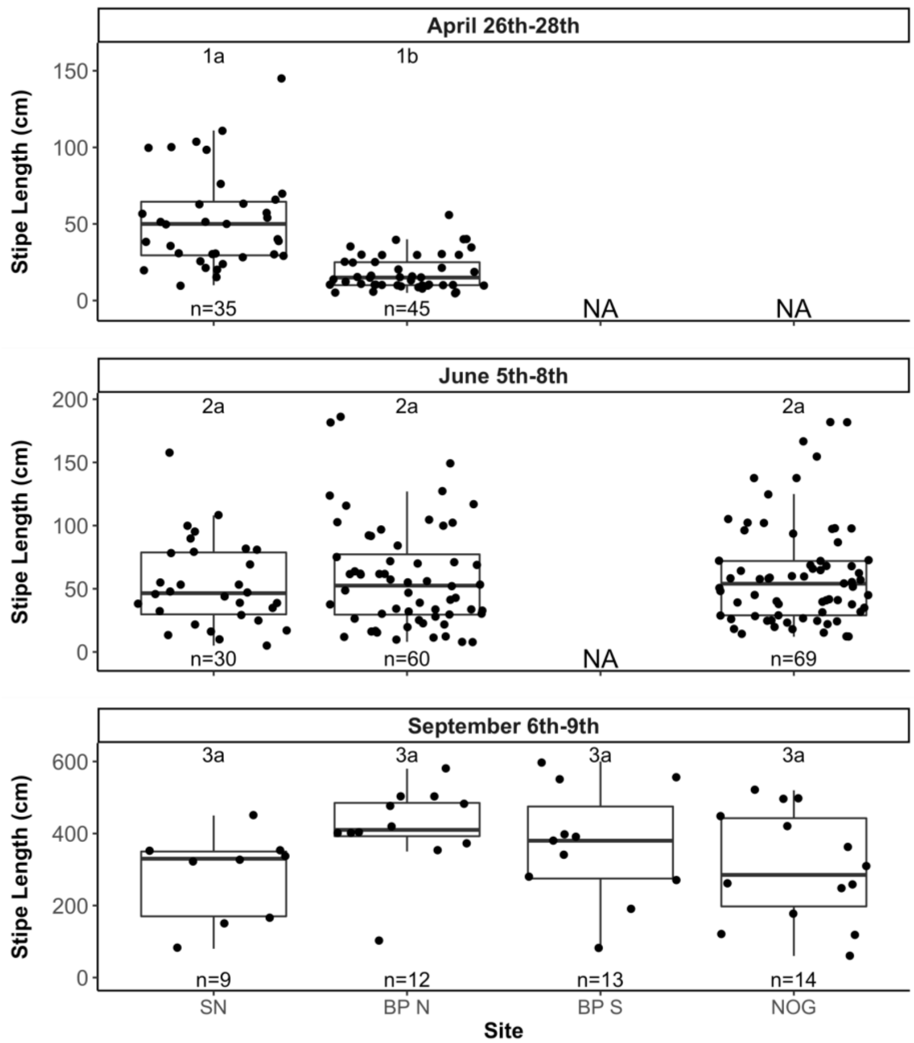

Figure 16 **Average stipe length at 4 sites at 2 time points in the spring and summer of 2023.**

The number of sporophytes (n) sampled is indicated at the bottom of each panel. The annoation at the top of the panel indicates the results of Kruskal-Wallis test. The number indicates the time point for which the test was conducted, and different letters indicates a significant difference between sites. The overlayed jitter shows the individual measurements. Second Narrows (SN), Brockton Point North (BP N), and Brockton Point S (BP S) are the reference sites. Nine O'clock Gun (NOG) is a restoration site.

3.6. Restoration Trials

3.6.1. Restoration (Boat-Outplanting) Areas

There were no quantitative monitoring activities associated with the boat-outplanted green gravel; however, the divers completed meander surveys along the boat-outplanting transect areas at New Brighton in April. They found 10 gravels with outplanted *N. luetkeana* growing and many gravels deeper than the target depth in sandy substrate with no kelp growing in the eastern and central areas of New Brighton.

3.6.2. Experimental Plots

In April, six of the large gravel plots were located and all nine of the small gravel plots were located. Of the 20 gravels per plot outplanted, there was on average 10 ± 2 large gravels and 6 ± 1 small gravel were found per plot across all sites (Figure 17; Table A.8). In April, four large gravels at Nine O'clock Gun and six large gravels at New Brighton were found with outplanted kelp growing for a total of 10 large gravel with sporophytes successfully growing across all sites. One small gravel was found with sporophytes growing at New Brighton; however, anecdotally it was more buoyant compared to the sporophytes growing on the large gravel. Each gravel found with sporophytes had multiple sporophytes growing per gravel (Figure 18A; Figure 18B). There was evidence of holdfast attachment to the underlying substrate by sporophytes growing on two of the large gravels at New Brighton.

At the June monitoring time point, the New Brighton plots were not located due to poor visibility. Five of the nine installed plots were located across the region for both the large and small gravel treatments. On average, 9 ± 1 large gravels and 9 ± 2 small gravels were found per plot (Figure 17; Table A.8). There were no sporophytes growing on the gravel found. While the New Brighton plots were not located, the divers found no *N. luetkeana* sporophytes growing in the general area of the plots.

In September, five large gravel and three small gravel plots were located across the study area. On average 2 ± 1 large gravels and 0 ± 0 small gravels were found (Figure 17; Table A.8).

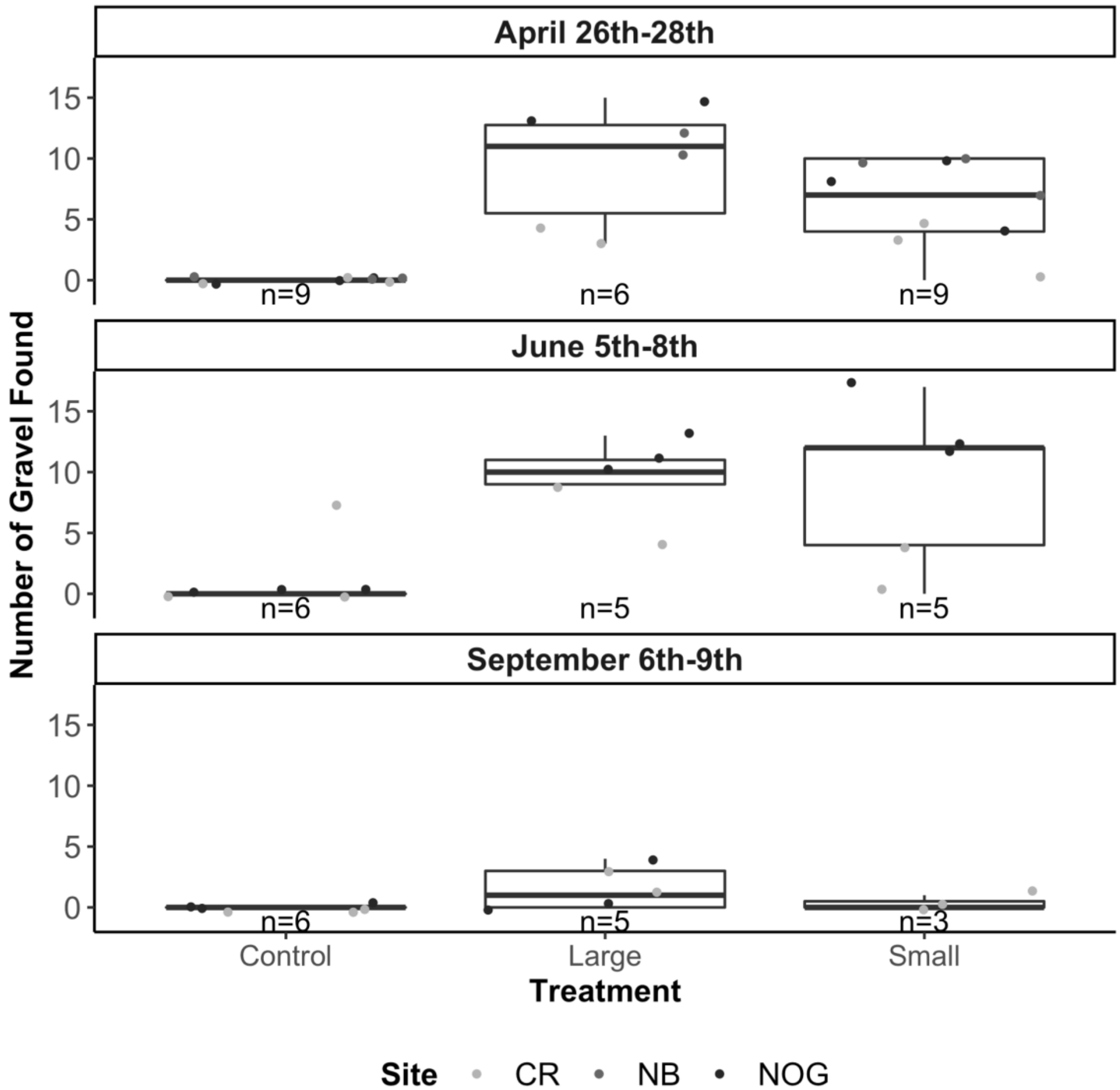

Figure 17 **Number of gravel found in experimental areas.**

Nine O'clock Gun (NOG), Crab Park (CR), and New Brighton (NB) are the restoration sites. The treatments are large gravel, small gravel (, and control plots. The sample size (n) is annotated on the bottom of each panel. The jitter overlay shows each sample size, and the site is indicated by the color of each point.

3.6.3. Tile Transects

In April, 10 tiles at Nine O’clock Gun, four tiles at Crab Park, and zero tiles at New Brighton were found with kelp growing (Table 5). All tiles with kelp growing had multiple sporophytes growing per tile, and one tile at Crab Park and two at Nine O’clock Gun had holdfast attachment to the underlying substrate. (Figure 18C; Table 5).

In June, six tiles at the Nine O’clock Gun and two tiles at Crab Park were found with kelp growing (Table 5). Two tiles at the Nine O’clock Gun and two tiles at Crab Park had holdfast attachment to the underlying substrate (Figure 18D; Figure 18E; Figure 18F; Table 5). Kelp was found growing on tiles from -2.7 m to -0.3 m relative to chart datum (Table 6).

Table 5 Tile transect monitoring results. Tiles with kelp indicates the number of tiles found with outplanted kelp growing. Tiles with holdfasts attached indicates the number of tiles where outplanted kelp had holdfasts attached to the underlying substrate.

Monitoring Period	Site	Tiles outplanted (count)	Tiles found (count)	Tiles with Kelp (count)	Tiles with Holdfasts Attached (count)
April 26th-28th	Crab Park	28	17	4	1
	New Brighton	28	13	0	NA
	Nine O’clock Gun	20	13	10	2
June 5th-8th	Crab Park	28	36	2	2
	New Brighton	28	4	0	NA
	Nine O'clock Gun	20	55	7	2

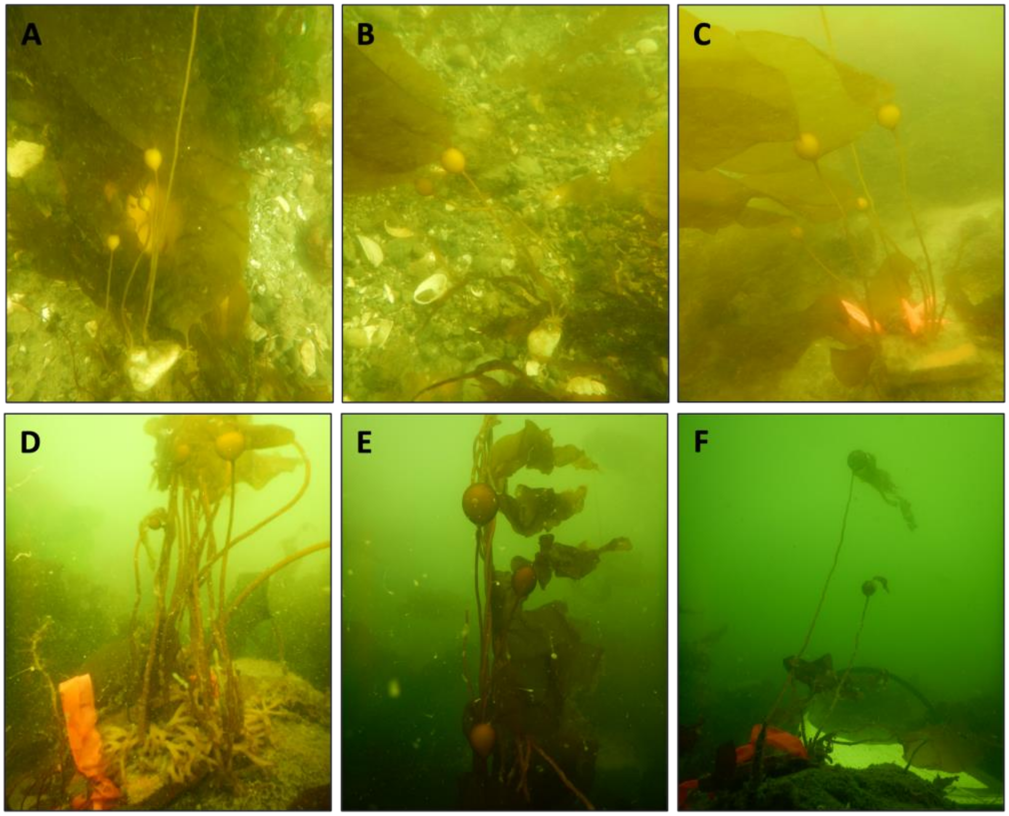

Figure 18 Experimental plot and tile transect monitoring.

(A,B) Outplanted *N. luetkeana* sporophytes growing on experimental gravel at New Brighton in April 26th to 28th. (C) Outplanted *N. luetkeana* sporophytes growing on clay tiles epoxied to natural substrate at Nine O'clock Gun April 26th-28th. (D, E, F) Outplanted *N. luetkeana* sporophytes growing on clay tiles epoxied to natural substrate at Nine O'clock Gun June 5th-8th.

Table 6 Summary statisitics for the depths *N. luetkeana* sporophytes were found on the tile transect.

Monitoring Period	Site	n	Min	Median	Max	Mean	SE
April 26th-28th	Crab Park	4	-1.0	-0.8	-0.5	-0.8	0.1
	Nine O'clock Gun	10	-2.5	-1.5	-0.3	-1.5	0.2
June 5th-8th	Crab Park	2	-1.9	-1.4	-0.8	-1.4	0.6
	Nine O'clock Gun	7	-2.7	-2.1	-0.5	-1.9	0.3

3.6.4. Stipe Length Comparison

In April, there was a significant difference in stipe length between naturally recruited sporophytes growing at reference sites, naturally recruited sporophytes growing at restoration sites, nursery grown sporophytes at PSEC, and outplanted sporophytes at restoration sites (Kruskal-Wallis test: χ^2(df = 5, SN: n = 35, BP N: n = 45, Tile: n = 14, Large gravel: n = 10, Lab gravel: n = 21, Lab tile: n = 15) = 43.02, $p < 0.001$; Table B.1). Specifically, naturally recruited sporophytes at Brockton Point North were significantly shorter than sporophytes grown on gravel and tiles in tanks at the PSEC and naturally recruited sporophytes at Second Narrows (Table B.2). The average stipe lengths for the sporophytes grown in tanks were 42 ± 4 cm and 34 ± 4 cm for large gravel and tiles, respectively (Figure 19; Table A.9). The average stipe length of outplanted sporophytes growing on large gravel was 43 ± 7 cm and 9 ± 2 cm at New Brighton and Nine O'clock Gun, respectively (Figure 19; Table A.9). The average stipe length of outplanted sporophytes growing on tiles was 40 ± 11 cm and 30 ± 6 cm at Crab Park and Nine O'clock Gun, respectively (Figure 19; Table A.9). The one small gravel with outplanted kelp growing had a stipe length of 18.5 cm and a pneumatocyst diameter of 18 mm.

In June, there was no significant difference in stipe length between naturally recruited sporophytes and outplanted sporophytes growing on tiles (Kruskal-Wallis test: χ^2(df = 2, SN: n = 30, BP N: n = 60, Tile: n = 8) = 1.25, $p = 0.53$). The average stipe lengths of outplanted sporophytes growing on tiles were 98 ± 48 cm and 68 ± 19 cm at Crab Park and Nine O'clock Gun, respectively (Figure 19; Table A.9).

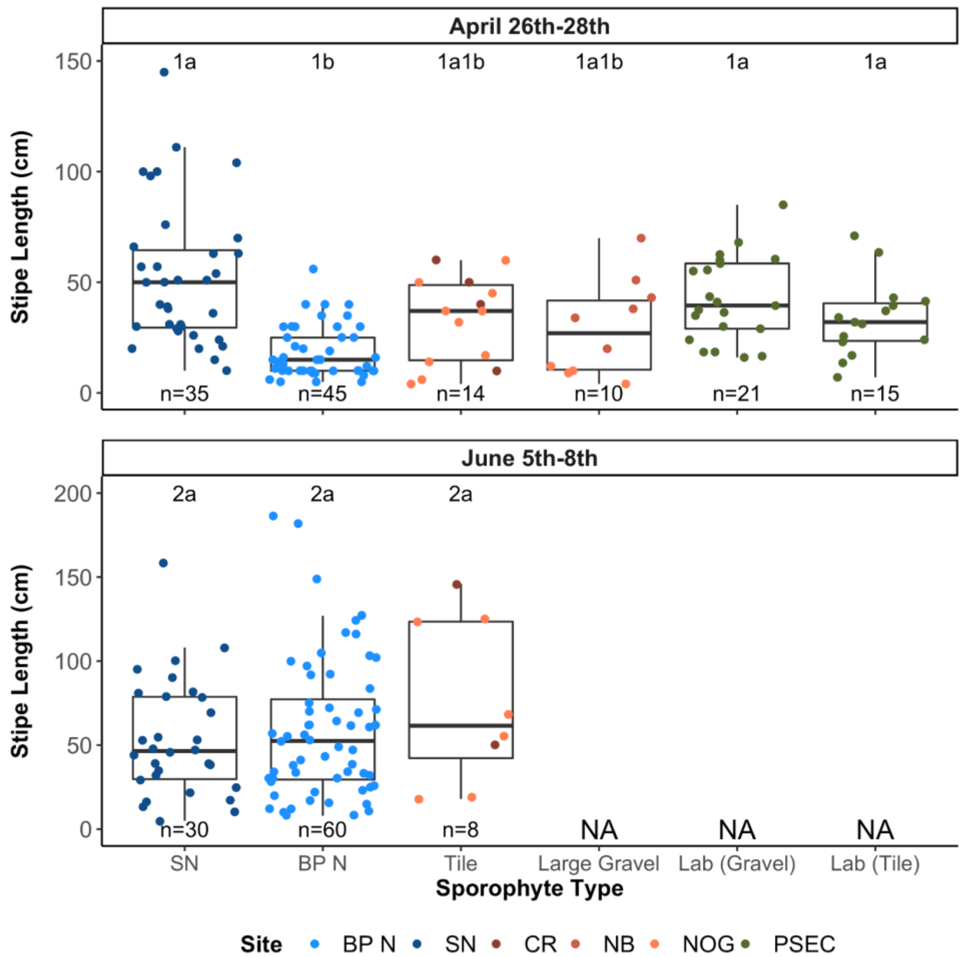

Figure 19 **Comparison of stipe length across sites and treatments.**

The number of sporophytes sampled (n) is indicated at the bottom of each panel. The annoation at the top of the panel indicates the results of Kruskal-Wallis test. The number indicates the time point for which the test was conducted. Different letters indicate a significant difference between sites. The overlayed jitter shows the individual measurements, and the color indicates the site from which the measurement was taken. Second Narrows (SN) and Brockton Point North (BP N) are the reference sites, and Nine O'clock Gun (NOG), Crab Park (CR), and New Brighton (NB) are the restoration sites. Pacific Science Enterprise Centre (PSEC) is the nursery. Tile and large gravel are measurements from the experimental area, and lab gravel and tile are measurements from the nursery.

Chapter 4. Discussion

4.1. Reference and Restoration Site Conditions

4.1.1. Second Narrows as a Reference Site

The Second Narrows kelp bed grows along the Canadian Pacific Railway right-of-way. In the fall of 2019, there was an expansion project that involved the permanent alteration of the marine intertidal and subtidal within a kelp bed (Vancouver Fraser Port Authority 2019). The project involved excavation and the installment of riprap fill down to chart datum and into the subtidal in part of the project area. The 2023 monitoring transects fell within the 2019 Canadian Pacific Railway project area. There is a current Canadian Pacific Railway expansion project that started in the fall of 2022 and is adjacent to the 2019 project extending east (Vancouver Fraser Port Authority 2023a). This project also involves permanent alternation to the marine intertidal and subtidal in some locations within the project area (Vancouver Fraser Port Authority 2023a). All data collected at Second Narrows in 2023 occurred in an area that was heavily disturbed 3.5 years prior to measurements, and the transects were located 100 metres west of an area that was heavily disturbed less than a year prior to monitoring.

The data collected from Second Narrows is less representative of a reference site and more representative of a site that has experienced recent and nearby ongoing disturbance. Due to this, information from Brockton Point North, Brockton Point South, and Nine O’clock Gun will be used for reporting reference targets related to *N. luetkeana* growth characteristics.

4.1.2. Water Temperature and Salinity

The similarity in water temperature between both reference and restoration sites suggests that temperature, at least for the 2023 growing season, was not a main contributing factor in determining where *N. luetkeana* can grow. It is promising that there are little differences in the temperature between reference and restoration sites and suggests that the restoration sites have suitable temperatures to support *N. luetkeana* at present. Throughout the outplanting and monitoring season, local water temperatures remained below 18°C with daily averages of 14 to 15°C in July which is within the thermal range of *N. luetkeana* sporophytes and gametophytes based on values from Supratya et al. (2020) and Weigel et al. (2023).

Brockton Point N, Nine O'clock Gun, and Crab Park had an average salinity of 23 to 24 PSU across the measurement period; lower salinities are common in Burrard Inlet due to input from the Fraser River (Davidson 1979). There were significant differences in salinity with Second Narrows having lower salinity compared to other sites particularly in July and August. Second Narrows data logger was installed between the monitoring transects in a recently disturbed area along the Canadian Pacific Railway tracks at 1.5 m below chart datum. There are 5 municipal stormwater outfalls along the south shoreline of the inlet within 400 m of the transect locations (Tsleil-Waututh Nation 2022), and the outlet of the Seymour River is 650 m across the inlet from the monitoring transects. While it is difficult to conclude the cause of the decreased salinity at Second Narrows, it is possible one of these freshwater sources contributed to decreased salinity in the surface layer of water at Second Narrows in July and August.

While collecting temperature and salinity is important to understand the baseline conditions at restoration sites, there were no differences between reference and restoration sites that could explain why *N. luetkeana* is able to grow at reference sites but not restoration sites. Other environmental measures such as light, current, and nutrients may be required to better understand what conditions are limiting for *N. luetkeana* growth in Burrard Inlet.

4.1.3. Understory Seaweed Cover

Total seaweed cover hovered around 75% for most sites in June and September. While it is useful to have a baseline of the understory kelp and other seaweed cover and species at both reference and restoration sites to establish seaweed biodiversity targets, it is a less important measure in terms of determining where *N. luetkeana* could possibly grow.

Understory kelp and total seaweed cover could be important at restoration sites during outplanting. The outplants for this project and other Kelp Rescue Initiative projects are typically quite small (i.e., ~ 2 cm). If an area already has a high percent cover of understory kelp or other seaweed blanketing the substrate, the small outplants could be outcompeted for light and nutrients while acclimating to the ocean environment. While not an essential measure to include at every monitoring time point at restoration sites, characterization of the understory kelp and seaweed is important to consider when outplanting or in early monitoring.

4.1.4. Substrate

Variation in substrate classifications between time points is likely due to differences in the plot area surveyed. Each transect was marked by GPS points and re-established by placing the transect line in a similar but not exact location. The substrate values are representative of the substrate at the specific site and depth, but do not represent the same 1 m x 1 m area from time point to time point leading to variation in the measurements.

N. luetkeana does not attach to fine sediment, and hard substrate is required for growth. As *N. luetkeana* grows larger, the pneumatocyst size, stipe length, and blade tissue increases; this increases the buoyancy and drag force each sporophyte experiences. For *N. luetkeana* to persist to adult size, attachment to larger substrate such as cobbles and boulders is required.

Brockton Point North had higher percentages of cobbles and boulders compared to restoration sites at most time points. However, the percent cover of cobbles and boulders at Brockton Point South and Nine O’clock Gun were consistent with the other restoration sites, yet these sites supported *N. luetkeana* of the same size and similar density to Brockton Point North. This suggests that while the presence of cobbles and boulders is required, a mix of fine sediment, small pebbles and gravel, and larger substrate can support *N. luetkeana* beds in Burrard Inlet that are consistent with reference sites.

4.1.5. Nine O’clock Gun

The area surveyed at the Nine O’clock Gun had naturally recruited *N. luetkeana* present at each time point surveyed, and the depth, density, percent presence, stipe length, and sori production of the *N. luetkeana* surveyed was consistent with reference transects. This suggests that while there were declines noted in the 2022 ROV surveys, this area actively supports a *N. luetkeana* population and should not be used as a restoration site at this time. Annual kelp beds in this region naturally experience bed expansions and reductions year to year depending on many environmental factors; additional years of data at this site are required to better understand if restoration is required here (Pfister et al. 2018).

4.1.6. Crab Park

While Crab Park did see some limited growth of outplanted kelp on tiles, has cobbles and boulders present, and recently supported a small population of *N. luetkeana* (ShoreZone 2017), this site is situated in a completely urbanized area between Canada Place cruise ship terminal and the main container port in Vancouver Harbour. The area between the terminals is approximately 24 hectares and contains a total of 1 provincially authorized wastewater discharge, 1 combined sewer overflow outfall, and 14 municipal stormwater outfalls (Tsleil-Waututh Nation 2022). While visibility was poor and plots were difficult to locate at all sites in the summer, anecdotally, Crab Park had visibility of less than 1 m which made it near impossible to monitor experimental areas.

Additionally, wave-sheltered and lower current areas are at higher risk for *N. luetkeana* decline as temperatures warm due to an inability of sporophytes to adapt in low flows (Supratya et al. 2020). Crab Park is located further from the direct path of the main tidal flood and ebb current in Burrard Inlet compared to reference and other restoration sites which could make it more difficult for outplanted kelp to persist in the later summer months. This would place any restored *N. luetkeana* at higher risk for decline at this location compared to other proposed restoration sites. Due to these factors, Crab Park is not an ideal restoration site for *N. luetkeana* in Burrard Inlet.

4.1.7. New Brighton Park

This site saw kelp growth on seven outplanted gravel, and anecdotally divers saw a handful (less than 10) naturally recruited individuals at the site at the April and June time points, but none fell within the transect sampling area. This area is near the Second Narrows reference site and is near the direct path of the main tidal flood and ebb current. Anecdotally, divers found cobbles with tiles epoxied that were turned over suggesting the currents are strong enough to tumble cobbles. This could also explain why no tiles were found with kelp growing at New Brighton. Based off monitoring transects from this year, this site was dominated by pebbles and gravels with on average approximately 35% of the area covered with cobbles and boulders.

The growth of both outplanted and naturally recruited *N. luetkeana*, location near a reference bed, presence of relatively high currents, and presence of cobbles and boulders suggests that *N. luetkeana* restoration is possible at this site.

4.2. Restoration Targets

This is one year of monitoring data and cannot be used for establishing restoration targets, as year-to-year variability in conditions and *N. luetkeana* growth is common (Pfister et al. 2018). However, this project can serve as the first year of monitoring data that can help to establish more realistic averages of site and *N. luetkeana* bed conditions. This information can also be used as a benchmark to inform future years of restoration work prior to more robust targets being developed.

Due to the location of the Second Narrows transects within a relatively disturbed site, values from the Second Narrows transects will not be used for restoration targets. Additionally, since the Nine O'clock Gun had *N. luetkeana* characteristics consistent with Brockton Point N and Brockton Point S, values from the Nine O'clock Gun transects will be used for restoration targets. It is important to note that the values for these targets come from Brockton Point N, Brockton Point S, and Nine O'clock Gun which are located adjacent to each other along the same stretch of shoreline (Figure 3; Figure 7A). Therefore, these restoration targets come from one *N. luetkeana* bed and may not be representative of all areas in Burrard Inlet.

These restoration targets are specific to Burrard Inlet and do not consider the conditions of *N. luetkeana* beds that grow in other areas of British Columbia. This is due to the highly unique and extensive urban conditions in Burrard Inlet that makes it difficult to apply values from other regions. These unique conditions also makes pre-restoration monitoring of local *N. luetkeana* beds essential for restoration work in Burrard Inlet.

4.2.1. Biodiversity Targets

This study did not look at invertebrate, fish, bird, or mammal biodiversity at reference sites, but biodiversity is an important indicator of ecological function and should be included in further monitoring.

There were no noticeable differences in the understory kelp and total seaweed cover as well as seaweed species present between reference and restoration sites despite *N. luetkeana* being present at some sites and not present at others. Therefore, it appears that algal assemblages are similar and relatively consistent across sites in Burrard Inlet, and they appear independent of *N. luetkeana* cover.

4.2.2. *N. luetkeana* Outplanting Depth

Throughout the study period, *N. luetkeana* was found from a depth of 3 m below to 1 m above chart datum. To determine the optimal depth range for restoration the maximum and average depth where *N. luetkeana* was found at different time points, as well as and depths where bleaching occurred, must be considered. Ideal outplanting depth should balance maximising light availability and minimizing heat stress. For example, light may be limiting for sporophyte growth at deeper depths early in the year (e.g., Jan-Feb) when kelp typically gets outplanted. Yet, if kelp is planted too shallow, heat stress near the surface can lead to lethal bleaching during summer. Based on the data available from this project, the April time point is best suited to indicate the lower outplanting depth limit. In April, *N. luetkeana* was growing healthily in the intertidal to a maximum depth of -2.8 m and average depth -0.5 m at Brockton Point North.

Previous work demonstrates that above-average air temperatures paired with mid-day low tides create heightened thermal stress for intertidal organisms in the Pacific Northwest (Helmuth et al. 2002). In Burrard Inlet, such a thermal stress period coincided with the June monitoring, and extensive bleaching was observed in the intertidal at Brockton Point North, Brockton Point South, and Nine O’clock Gun. Bleaching was even found on some individuals in the subtidal at Brockton Point South and Nine O’clock Gun to a depth of -0.7 m and -1.2 m, respectively. Notably, these bleaching events occurred even before peak summer temperatures were reached in July and August of 2023. Additional and more severe bleaching to deeper depths may have occurred later in the summer but was not captured by monitoring. In September, *N. luetkeana* was found from 0.4 to -2.5 m relative to chart datum at Brockton Point and Nine O'clock Gun indicating that the *N. luetkeana* persisted at a relatively constant depth range throughout the summer. The average depth at Brockton Point and Nine O'clock Gun was -1.1 m in September.

When considering the information from all three monitoring periods, a target outplanting depth of -1 to -2.5 m relative to chart datum is sufficiently shallow to support growth in the late winter and early spring and should be sufficiently deep to avoid lethal bleaching.

4.2.3. *N. luetkeana* Sporophyte Density Targets

Since *N. luetkeana* is an annual species, an important aspect of restoration success is the production of sori and release of spores to "seed" the subsequent year of sporophytes. Sori production was first detected in June with highest sori production detected at the beginning of September for the 2023 monitoring season. Typically, sori production is more prevalent in late summer and fall when *N. luetkeana* is transitioning from the sporophyte stage to the gametophyte stage for winter (Springer et al. 2010). These life cycle patterns suggest that for outplanted sporophytes to best contribute to the natural recruitment of sporophytes in the subsequent year, outplanted sporophytes must persist to the late summer.

The average sporophyte density was 2 to 3 sporophytes per m^2 in September at Brockton Point N, Brockton Point S, and Nine O'clock Gun. To achieve sori production and spore release consistent with reference sites, an outplanted sporophyte density of ~3 sporophytes per m^2 should be achieved at restoration sites in late summer. This describes the target sporophyte density at the end of summer; however, further research is required to determine how many sporophytes must be outplanted per m^2 in February to achieve this target.

It is also important to note that these density estimates were calculated only using plots where *N. luetkeana* was found. In June, 31% to 44% of plots did not have *N. luetkeana*, and 79 % to 83% of plots did not have *N. luetkeana* present in September. This suggests that *N. luetkeana* naturally grows in a relatively patchy distributions with some areas having clusters of sporophytes and others having no sporophytes. The sporophyte density across the entire area surveyed at the reference site in September is 0.55 sporophytes per m^2. For the green gravel method, only one sporophyte on one gravel would need to persist to September in approximately every two plots to meet a sporophyte density consistent with the reference transects. Restoration monitoring methods that holistically look at an entire restored area will be required to accurately assess the success of restoration efforts compared to reference beds.

4.2.4. Sporophyte Length and Reproductive Targets

Stipe length is an important measure for comparison earlier in the season while sporophytes are still growing toward the water surface. Each restoration season, stipe lengths can be compared between reference sites, restoration sites, and restoration treatments to gauge early success and health of outplanted sporophytes.

Once sporophytes reach the surface and become reproductive, sori production becomes an important measure of restoration success. This is an indication of spores being released and "seeding" the surrounding area which can lead to the natural recruitment of sporophytes the following season.

For 2023, the average stipe length was 0.6 metres at Brockton Point N and Nine O'clock Gun in June and 3 to 4 metres at Brockton Point N, Brockton Point S, and Nine O'clock Gun in September. Sori were found on average on 50% to 70% of individuals in September.

Both stipe length and sori production are highly variable and should be directly compared to a reference site each season to control for variation in environmental conditions between years that could affect sporophyte growth and reproduction. However, these data are useful benchmarks that can contribute to the development of restoration targets for *N. luetkeana* restoration in Burrard Inlet.

4.3. Lessons Learned from Restoration Trial

While the restoration trial was somewhat unsuccessful when considering the above criteria for success, we learned a lot of important lessons that will directly inform and improve future restoration efforts.

4.3.1. Stipe Length

The stipe length of surviving outplanted sporophytes was generally consistent with the stipe length of naturally recruited sporophytes. This suggests that culturing and outplanting methodology used can produce kelp that grows consistently with reference sites in Burrard Inlet.

4.3.2. Monitoring Timing and Frequency

The first monitoring period was two months after outplanting. At this point, most of the kelp had died, been outcompeted or eaten, or drifted away. It is impossible to know what the main stressor was that led to limited outplanted kelp found in plots. Monitoring time points must be scheduled sooner and occur more frequent after outplanting to establish: 1) the proportion of outplants that survive outplanting; 2) the proportion that are eaten by grazers or outcompeted by other seaweed; and 3) the proportion that become too buoyant and are subject to sufficient drag force from current to drift out of the plot area. From this, it can then be determined if the main limiting factor to restoration success is outplanting methodology, herbivory or competition, or rock size.

There was a three-month gap between the June monitoring and September monitoring. In this time, the remaining outplanted kelp growing on the tiles died off, but there is no specific information as to why. We also do not know if any of the outplants became reproductive which is a key indicator of success. A monitoring time point that occurred earlier in the peak temperature and reproductive period in July and August would be helpful to better characterize reference kelp beds as well as determine if any outplants are successful in becoming reproductive.

SCUBA surveys are expensive and time consuming, so strategizing the most important time points for monitoring and supplementing dive surveys with permanent cameras or ROV surveys could help to better evaluate restoration success.

4.3.3. Green Gravel: Boat-outplanting

This project trialled the efficacy of boat deploying green gravel which is one of the main benefits of the green gravel method at scale, as it does not depend on divers for deployment. In Burrard Inlet, there is a narrow depth range in which *N. luetkeana* grows and many of the shorelines, including the areas selected for boat outplanting in 2023, have been reinforced with riprap creating relatively steep slopes. This creates a narrow area close to shore where a boat must operate to remain over the desired depth range. To deploy the gravel at sufficient density, boat operators must also drive as slowly as possible while battling currents and wind that make staying at the desired depth very challenging.

Additionally, outplanting green gravel (either by boat or by divers) in an area that has larger boulders with crevices between or steep slopes creates an environment where 3 to 5 cm gravel exposed to current could either fall between rocks or fall out of the depth range where *N. luetkeana* can grow. Outplanting green gravel in an area that has a more gradual slope and substrate that does not have large crevices between such as cobbles or bedrock could be better suited to boat-outplanting green gravel in Burrard Inlet.

Another consideration is most of the restoration sites we surveyed have mixed substrate with on average 30 to 40% being cobbles or boulders. If using boat outplanting in an area like this, on average 30 to 40% of the outplants would land on substrate that is large enough to support an adult sporophyte. It is unlikely that all gravel outplanted by boat will land with the sporophytes facing the surface, so there would be an additional percentage unable to reach adulthood due to landing with the sporophytes facing the substrate. Before any outplants are lost for reasons related to outplanting survival, such as herbivory, competition, or drifting away, less than 30 to 40% of the gravel outplanted would be in a location or orientation viable for survival and growth to a reproductive age.

Space for culturing gametophytes and particularly sporophytes is limited and requires time and effort from culturists and researchers. Given the conditions found in Burrard Inlet so far, boat-deploying green gravel would be an inefficient method for restoration, as more than 60 to 70% of the gravel cultured would not land somewhere it could successfully become reproductive. If a site with a relatively gentle slope and cobble dominated substrate is identified in Burrard Inlet, that would be more suitable to boat-outplanting green gravel.

4.3.4. Green Gravel: Rock Size

There was one small gravel (2 to. 3 cm) found with kelp growing in April at New Brighton. The divers noted that this gravel was quite buoyant compared to the large gravel with kelp growing. The longest sporophyte on the small gravel did not have holdfast attachment to the underlying substrate, and it was smaller than the kelp found growing on the large gravel at New Brighton. If there were kelp growing on other small gravel at the same rate as the kelp on the large gravel, the small gravel would likely be too buoyant to remain in the plots. At New Brighton, less than 50% of outplanted small gravel was found in plots in April. While it is very challenging to know, this piece of anecdotal evidence suggests that it is possible that there were sporophytes growing on the small gravel that became large and buoyant and floated away. This suggests that the 2 to 3 cm gravel size is likely too small to be used for restoration efforts at New Brighton.

In the large gravel treatment at New Brighton kelp was growing on six total gravels in April, and there was some evidence of holdfasts beginning to attach to the underlying substrate. The specific plots were not located in June due to poor visibility, but there was no *N. luetkeana* growing in the area. While it is possible there was a die-off at New Brighton, it is more likely the gravels with sporophytes became too buoyant and experienced too much drag from the currents causing the gravels to drift out of the plots.

At Nine O’clock Gun in a large gravel plot there were four pieces of gravel with sporophytes growing and 11 pieces of gravel without sporophytes growing. In June, only 11 pieces of gravel without sporophytes growing remained; this provides evidence that the four gravels with sporophytes floated away sometime between the April and June monitoring. This suggests that 3.5 to 5 cm gravel may be too small at New Brighton and Nine O’clock Gun.

The rock size needed to retain gravel with sporophytes in the plots is highly dependent on the currents experienced at each site. For results to be applicable beyond the study site, current data must be collected at the study site and compared to the current data at other possible restoration sites.

It is possible that gravel sizes may not be large enough for restoration in areas in Burrard Inlet; cobbles could be used for restoration to increase the probability of retention of outplanted *N. luetkeana* in plots. If increasing to a cobble size, the distance from the top of the rock, where the juvenile sporophytes are growing, to the underlying substrate would likely increase in some cases. This means the cobbles used need be large enough to support larger sporophytes, as holdfast attachment to the underlying substrate would be delayed.

4.3.5. Kelp-Seeded Tile Restoration Method

While this method had somewhat mixed success with sites like Nine O'clock Gun seeing outplanted sporophytes growing on half of the tiles outplanted and New Brighton seeing no growth. One main benefit of this method is the ability for the divers to select the exact location outplants will grow and reduce the probability of outplants floating away. One of the possible issues at New Brighton was the tiles were not epoxied to large enough substrate, and as a result, there was evidence of tumbling which likely would have abraded and killed young sporophytes.

While this method relies on divers for installation, it reduces the issue of outplanted kelp floating away and the possibility of outplants landing in a location or orientation that is not suitable for survival. In this method, there is the possibility of 100% of cultured and outplanted materials to be placed in an area where they can survive and grow. Tile size could be adapted to best fit a culturing space or potential outplanting substrate, and both natural and non-natural substrate could be used for this method providing versatility to best fit a specific restoration project. This approach does introduce non-natural materials, ceramic tiles and epoxy, to the marine environment which would require removal by divers at the end of the growing season.

Green gravel provides a method that could potentially not rely on divers, but the efficiency of the method in Burrard Inlet would likely be low compared to the kelp-seeded tile restoration method. A cost-benefit analysis comparing the expenses required for restoration would determine if the green gravel method is a more cost-effective option in practice.

4.4. Future Directions

Given the results of the first year, it is unlikely the initially proposed target of a total of 1,350 m^2 of restored area will be met. However, using the knowledge gained from the first year of the project, in the second year, the project can generate reliable data evaluating the most appropriate restoration approaches in Burrard Inlet.

The following improvements or changes are recommended for future years of the project:

Focus on site selection:

Plot areas were selected the same day as outplanting giving divers limited time to establish plots. In some cases, plot areas had higher fine sediment covers compared to monitoring transects at the same site. To better locate areas of ideal substrate (i.e., cobbles or boulders), substrate surveys could be conducted in advance to locate specific areas with higher cover of cobbles and boulders that can be relocated when establishing restoration plots.

Use larger gravel and cobble sizes:

While there is limited evidence from the plots, it seems that 2 to 3 cm and 3.5 to 5 cm gravel may not be large enough for green gravel restoration in Burrard Inlet. The use of larger gravel sizes and cobble sizes could be explored to try to establish a threshold rock size required for retention of outplanted sporophytes at a specific restoration site.

Add light and current monitoring:

These are two important environmental factors that were not monitored in 2023 that impact where *N. luetkeana* can grow. Light can be used to compare differences in conditions between the upper and lower limit of the *N. luetkeana* depth range. Current is particularly important for characterizing the conditions at green gravel restoration sites. Current data could allow these results to be applied to other areas of similar current conditions.

Monitor earlier and more frequently:

The initial success or failure of restoration efforts seem to occur shortly after outplanting. Monitoring the site through permanent cameras or dive surveys within the first month of outplanting will help answer some of the questions related to what stressors are the limiting factor in outplant growth and survival.

Expand the kelp-seeded tile restoration and use it on larger substrate:

This method has the potential to work on larger boulders and riprap that are prevalent along Burrard Inlet's shorelines. Epoxying tiles to larger substrate that does not have the possibility of tumbling or being covered in sediment could provide a better chance for successful outplant growth.

4.5. Preliminary Observations from the 2024 Outplanting Season

The second year of restoration activities for the project are currently underway in Burrard Inlet and have seen encouraging preliminary results that support some of the above recommendations.

4.5.1. 2024 Project Overview

Similar gametophyte and sporophyte culturing methods were utilized in the 2024 season to grow *N. luetkeana* on large gravel (4.5 to 6.4 cm), small cobble (6.5 to 9 cm), medium cobble (9.1 to 12.7 cm), and clay tiles (7.5 x 7.5 cm). New Brighton and Whey-ah-Wichen (49.304480°, -122.947707°) were selected as restoration site for the 2024 outplanting season. Large gravel, small cobble, medium cobble, and tiles bolted to concrete blocks were outplanted in experimental plots at New Brighton, and large gravel and tiles bolted to concrete blocks were outplanted at Whey-ah-Wichen on February 14, 2024. Bolting kelp-seeded ceramic tiles to concrete blocks is a novel restoration method that was presented by Dynamic Ocean Consulting Ltd. and the Martone Lab from UBC at the Burrard Inlet Kelp Symposium on November 22, 2023.

There are four plots per treatment per site, and the plots range from -0.9 m to -2.3 m relative to chart datum. Fifteen large gravels, small cobbles, and clay tiles were installed per plot; 10 medium cobbles were outplanted per plot. Tiles were epoxied to natural substrate (boulders at Whey-ah-Wichen and riprap at New Brighton) along transects ranging from -1 to -2.5 m relative to chart datum on February 15 and 16, 2024.

The first monitoring period occurred March 25 and March 26, 2024. For each experimental plot, the number of rocks or tiles with outplanted sporophytes growing was recorded. Within each plot, five rocks or tiles were randomly selected, and the number of sporophytes growing was recorded. For each rock or tile selected, the stipe length, pneumatocyst diameter, and blade length was recorded for the longest sporophyte.

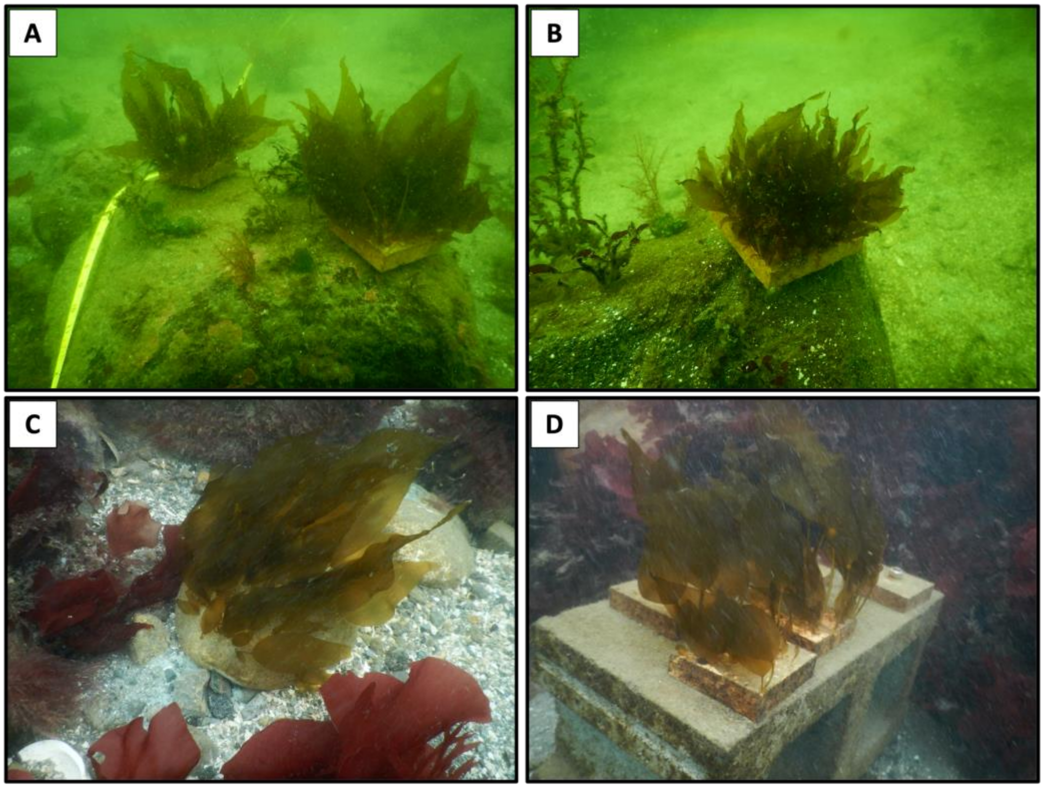

Figure 20 2024 Outplanted sporophytes at Whey-ah-Wichen and New Brighton on March 25, 2024.

(A, B) Outplanted sporophytes growing on clay tiles epoxied to boulders at Whey-ah-Wichen. (C) Outplanted sporophytes growing on a small cobble at New Brighton. (D) Outplanted sporophytes growing on clay tiles bolted to concrete blocks at New Brighton (Note: this is an example of a less successful tile plot, but allows for the viewing of the tiles and bolts).

4.5.2. Preliminary Results from First Monitoring

The longest sporophyte on each rock or tile in the experimental plots ranged in size from small blades with a stipe length of 1 cm and blade length of 4 cm with no pneumatocyst to sporophytes with a stipe length up to 16 cm, blade length up to 24 cm, and pneumatocyst diameter up to 13 mm. The average sporophyte length (sum of blade length and stipe length) was 20 ± 1 cm (mean ± SE). The largest sporophytes found were still a single blade, and there was no evidence of holdfast attachment to the underlying substrate. Of the rocks and tiles with sporophytes growing, there was an average of ~30 ± 2 sporophytes per rock or tile with a minimum of 1 and maximum of 80 sporophytes per rock or tile.

There were no outplanted *N. luetkeana* growing on the tiles epoxied to the riprap at New Brighton despite most of the tiles being relocated. At Whey-ah-Wichen along the tile transect, 92% of outplanted tiles were found, and 93% of tiles found had epoxy that was intact. Of the tiles found, 86% had outplanted sporophytes successfully growing (Figure 20A; Figure 20B). In the experimental plots at New Brighton, outplanted sporophytes were growing on 83 ± 14%, 83 ± 5%, 32 ± 16 %, and 43 ± 18% of outplanted tiles, medium cobble, small cobble, and large gravel, respectively (Figure 20C; Figure 20D; Figure 21). At Whey-ah-Wichen in the experimental plots, 13 ± 2 % of large gravel and 93 ± 6% of tiles had outplanted sporophytes successfully growing (Figure 21).

While it is too early to draw any conclusions from the 2024 data, it is encouraging to see growth in all experimental treatments at both sites. This highlights the importance of early monitoring, as the 2023 first monitoring period occurred 58 days post outplanting, and the 2024 first monitoring occurred 40 days post outplanting. In 2023, only 7 ± 4% of large gravel and 1 ± 1% of small gravel outplanted across sites survived to the first monitoring period. If there was an earlier monitoring period in 2023, it is possible a higher percentage outplant survival would have been recorded.

Despite the fact it is not a direct comparison due to the difference in monitoring timing, there is a stark difference in outplant survival between the years that is partially attributed to improved outplant survival at sites in 2024 compared to 2023. In particular, the high percentage of sporophyte growth on the tiles bolted to concrete blocks and medium cobbles shows improvement that will likely continue to subsequent monitoring periods.

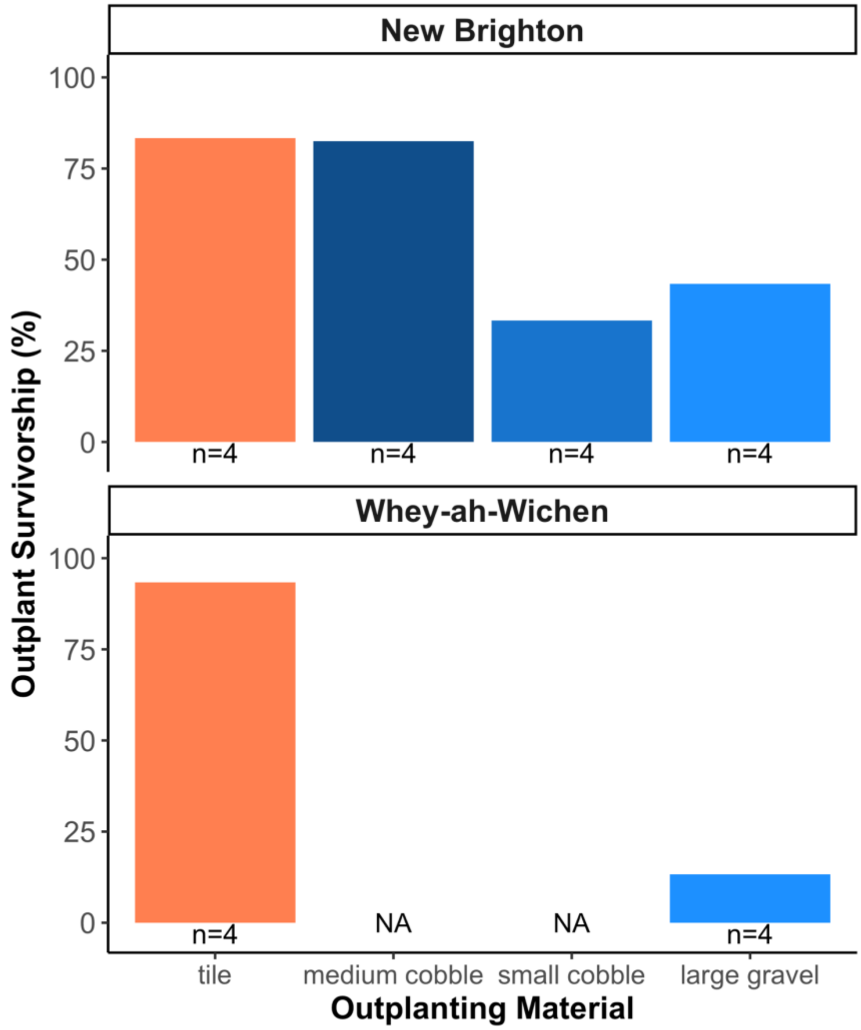

Figure 21 **Percentage of outplanted rocks or tiles with outplanted *N. luetkeana* growing in March 25, 2024, at New Brighton and Whey-ah-Wichen.**

4.6. Water Temperature in the Context of *N. luetkeana* Thermal Tolerances and Climate Change

The thermal optimum for *N. luetkeana* adult sporophytes in Burrard Inlet is ~11.9°C; however, sporophytes will still grow well at temperatures above and below this optimum (Supratya et al. 2020). Gametophytes have been shown to survive at temperatures of 5 to 21°C (Vadas 1972; Lind & Konar 2017; Muth et al. 2019; Schiltroth 2021). However, in populations from the Southern Salish Sea (i.e., Washington), declines in gametophyte density were shown at temperatures above 16°C with 20°C being lethal (Weigel et al. 2023). The production of sporophytes in the Salish Sea populations was optimal between 10°C to 14°C with a 78% reduction in density at 16°C and 95% reduction at 18°C (Weigel et al. 2023). No sporophytes were produced at temperatures above 18°C in these experiments on Salish Sea populations (Weigel et al. 2023).

In Burrard Inlet, all sites reached 16°C at the beginning of July, and the maximum daily temperature often reached 16°C from July to mid-August. At Brockton Point North, the maximum daily temperature approached 18°C in mid-July. While these stressful temperatures were reached, they were not sustained continuously, as the average daily temperature ranged from 14 to 15 °C across sites in July. At 15 °C, adult sporophytes are above their thermal optimum; however, sporophytes are still growing at around 90% of the optimum (Supratya et al. 2020). This also falls within optimal range for gametophyte germination and survival. While the many sporophytes are produced earlier in the growing season, any sporophytes recruiting later in the season could experience some stress as the average temperatures were above 14°C in July. When considering the 2023 temperatures, the current thermal conditions in Burrard Inlet can support *N. luetkeana*.

However, the Salish Sea is predicted to increase in mean ocean temperature by 1.5 to 3°C by 2100 (Riche et al. 2014; Amos et al. 2015; Khangaonkar et al. 2019). If this were to occur in Burrard Inlet, it would push the July average daily temperatures at 1.5 metres below chart datum to 16.5°C to 18°C using the 2023 temperature data. At 18°C, adult sporophytes would grow at 75% of the optimum, gametophytes would survive at reduced densities, and few sporophytes would be able to recruit. Critically, these temperatures only represent the averages, where the maximum temperatures experienced could move into the lethal range.

Trialling and determining the optimal methodology for restoration work is essential; however, it does not address climate resilience of restored kelp. In future years of this project and other restoration projects in Burrard Inlet, the development and use of heat-tolerant or other stressor tolerant strains should be a priority to ensure any *N. luetkeana* that is restored is able to persist in the changing inlet.

4.7. Conclusions

While it is difficult to draw specific conclusions related to both restoration targets and methodology based on the data collected, this project serves as the first year of data that can be combined with subsequent years to inform restoration targets and methodology for future projects.

The reference and restoration site monitoring resulted in three key takeaways: (1) there is less cobble and boulder substrate at restoration sites, but there is still enough to support *N. luetkeana* growth based on values from the reference transects; (2) New Brighton has sufficient current and large substrate to act as a restoration site in future years, whereas the conditions at Nine O'clock Gun and Crab Park are less suitable for restoration at present; and (3) based on the available *N. luetkeana* sporophyte depth and sporophyte density data, an outplanting depth range of -1 to -2.5 m relative to chart datum and a target late summer sporophyte density of 3 sporophytes per m^2 have been identified for future restoration.

There was no difference detected in stipe length between, naturally recruited and surviving outplanted sporophytes; this suggests that outplanted sporophytes have the potential to survive and grow consistently with reference sporophytes. However, the methodology needs to be improved to increase the number of outplanted sporophytes that survive. Specifically, in Burrard Inlet, increasing the rock size outplanted and affixing tiles to larger boulders could increase the chance of retaining outplanted kelp in restoration areas. While the restoration trials in 2023 did not yield sporophytes that persisted to the late summer, preliminary data from the 2024 outplanting season suggest improvement in early outplant survival. It is encouraging that the lessons learned and recommendations from this project could contribute to better success in future years of *N. luetkeana* restoration in Burrard Inlet.

While it is unlikely Burrard Inlet will return to pre-European contact conditions, the Tsleil-Waututh Nation is hopeful that through restoration actions, such as this project, a healthy Burrard Inlet can exist where wild foods are harvested, water is safe for cultural, spiritual, ceremonial, and recreational activities, important habitats are plentiful and connected, and high levels of biodiversity and healthy populations of key species can persist (Tsleil-Waututh Nation & Kerr Wood Leidal 2017).

References

Alsuwaiyan NA, Filbee-Dexter K, Vranken S, Burkholz C, Cambridge M, Coleman MA, Wernberg T (2022) Green gravel as a vector of dispersal for kelp restoration. Frontiers in Marine Science 9:910417

Amos CL, Martino S, Sutherland TF, Al Rashidi T (2015) Sea surface temperature trends in the coastal zone of British Columbia, Canada. Journal of Coastal Research 31:434-446

Bennett S, Wernberg T, Connell SD, Hobday AJ, Johnson CR, Poloczanska ES (2015) The ‘Great Southern Reef’: social, ecological and economic value of Australia’s neglected kelp forests. Marine and Freshwater Research 67:47-56

Davidson LW (1979) On the physical oceanography of Burrard Inlet and Indian Arm, British Columbia (T). PhD Dissertation, University of British Columbia, Vancouver

Dobkowski KA, Flanagan KD, Nordstrom JR (2019) Factors influencing recruitment and appearance of bull kelp, Nereocystis luetkeana (phylum Ochrophyta). Journal of Phycology 55:236-244

Eger A.M, Marzinelli, EM, Christie H, Fagerli CW, Fujita D, Gonzalez AP, Vergés A (2022) Global kelp forest restoration: past lessons, present status, and future directions. Biological Reviews 97:1449-1475

Filbee-Dexter K, Scheibling RE (2014) Sea urchin barrens as alternative stable states of collapsed kelp ecosystems. Marine ecology progress series 495:1-25

Filbee-Dexter K, Wernberg T (2018) Rise of turfs: a new battlefront for globally declining kelp forests. Bioscience 68:64-76

Flavin K, Flavin N, Flahive B (2013) Kelp farming manual: a guide to the processes, techniques, and equipment for farming kelp in New England waters. Ocean Approved LLC, Biddeford, Maine

Fredriksen S, Filbee-Dexter K, Norderhaug KM, Steen H, Bodvin T, Coleman MA, Wernberg T (2020) Green gravel: a novel restoration tool to combat kelp forest decline. Scientific reports 10:1-7

Helmuth B, Harley CD, Halpin PM, O'Donnell M, Hofmann GE, Blanchette CA (2002) Climate change and latitudinal patterns of intertidal thermal stress. Science 298:1015-1017

Khangaonkar T, Nugraha A, Xu W, Balaguru K (2019) Salish Sea response to global climate change, sea level rise, and future nutrient loads. Journal of Geophysical Research: Oceans 124:3876-3904

Krause-Jensen D, Duarte CM (2016) Substantial role of macroalgae in marine carbon sequestration. Nature Geoscience 9:737-742

Krumhansl KA, Okamoto DK, Rassweiler A, Novak M, Bolton JJ, Cavanaugh KC, Byrnes JE (2016) Global patterns of kelp forest change over the past half-century. Proceedings of the National Academy of Sciences 113:13785-13790

Lind AC, Konar B, Lind AC, Konar B (2017) Effects of abiotic stressors on kelp early life-history stages. Algae 32:223-233

Marushka L, Batal M, Tikhonov C, Sadik T, Schwartz H, Fediuk K, Chan HM (2021) Importance of fish for food and nutrition security among First Nations in Canada. Canadian Journal of Public Health 112:64-80

Morin J, Evans AB (2022) Historical Ecology in Burrard Inlet: Summary of Historic, Oral History, Ethnographic, and Traditional Use Information. University of British Columbia Faculty Research Publications, Vancouver, British Columbia

Muth AF, Graham MH, Lane CE, Harley CD (2019) Recruitment tolerance to increased temperature present across multiple kelp clades. Ecology 100:e02594

Pfister CA, Berry HD, Mumford T (2018) The dynamics of Kelp Forests in the Northeast Pacific Ocean and the relationship with environmental drivers. Journal of Ecology 106:1520-1533

R Core Team (2022) R: A language and environment for statistical computing. R Foundation for Statistical Computing, Vienna, Austria

Riche O, Johannessen SC, Macdonald RW (2014) Why timing matters in a coastal sea: Trends, variability and tipping points in the Strait of Georgia, Canada. Journal of Marine Systems 131:36-53

Schenk S, Supratya VP, Martone PT, Parfrey LW (2022) Long-term monitoring of macroalgal biodiversity in Stanley Park, Vancouver, British Columbia [Data Set]. Borealis

Schiltroth B (2021) Effects of climate change on two species of foundational brown algae, Nereocystis luetkeana and Fucus gardneri, within the Salish Sea. MSc. Thesis, Simon Fraser University, Burnaby

Shaffer S (2004). Preferential use of nearshore kelp habitats by juvenile salmon and forage fish. Georgia Basin/Puget Sound Research Conference, Olympia, 2003. Puget Sound Water Quality Authority, Olympia, Washington

ShoreZone. (2017). Interactive ShoreZone maps. https://www.shorezone.org/interactive-shorezone-maps/#BC_Map (accessed 20 November 2023)

Springer YP, Hays CG, Carr MH, Mackey MR (2010) Toward ecosystem-based management of marine macroalgae—The bull kelp, Nereocystis luetkeana. Oceanography and marine biology 48:1

Starko S, Bailey LA, Creviston E, James KA, Warren A, Brophy MK, Neufeld CJ (2019) Environmental heterogeneity mediates scale-dependent declines in kelp diversity on intertidal rocky shores. PLoS One 14:e0213191

Starko S, Neufeld CJ, Gendall L, Timmer B, Campbell L, Yakimishyn J, Baum JK (2022) Microclimate predicts kelp forest extinction in the face of direct and indirect marine heatwave effects. Ecological Applications e2673

Steneck RS, Graham MH, Bourque BJ, Corbett D, Erlandson JM, Estes JA, Tegner, MJ (2002) Kelp forest ecosystems: biodiversity, stability, resilience and future. Environmental conservation 29:436-459

Supratya VP, Coleman LJ, Martone PT (2020) Elevated temperature affects phenotypic plasticity in the bull kelp (Nereocystis luetkeana, Phaeophyceae). Journal of phycology 56:1534-1541

Supratya VP, Martone PT (2023) Kelps on demand: Closed-system protocols for culturing large bull kelp sporophytes for research and restoration. Journal of Phycology 60:73-82

Taft S, Oldford G, Lilley PL, Oetterich SB, Morin J, George M, Christensen V (2022) Reconstructing the pre-contact shoreline of Burrard Inlet (British Columbia, Canada) to quantify cumulative intertidal and subtidal area change from 1792 to 2020. University of British Columbia Faculty Research Publications, Vancouver, British Columbia

Tsleil-Waututh Nation (2022) Recent research on cumulative effects in Tsleil-Waututh Territory. Sacred Trust Initiative https://twnsacredtrust.ca/recent-research-on-cumulative-effects-in-tsleil-waututh-territory/ (accessed 1 March 2024)

Tsleil-Waututh Nation & Kerr Wood Leidal (2017) Burrard Inlet Action Plan. Tsleil-Waututh Nation, North Vancouver, British Columbia

Vadas RL (1972) Ecological implications of culture studies on Nereocystis Luetkeana. Journal of Phycology 8:196-203

Valentine PC (2019) Sediment classification and the characterization, identification, and mapping of geologic substrates for the glaciated Gulf of Maine seabed and other terrains, providing a physical framework for ecological research and seabed management. United States Geological Survey.

Vancouver Fraser Port Authority (2019) Viterra-Cascadia Terminal Capacity Expansion Project https://www.portvancouver.com/wp-content/uploads/2019/08/PER-19-006-Attachment-4.3.3-CEMP.pdf (accessed 1 March 2024)

Vancouver Fraser Port Authority (2023a) Canadian Pacific Kansas City: Cascadia Rail Expansion Phase 4. https://www.portvancouver.com/permitting-and-reviews/per/project-and-environment-review-applicant/status-of-permit-applications/canadian-pacific-railway

Vancouver Fraser Port Authority (2023b) Land Use Planning https://www.portvancouver.com/land/land-use-planning/ (accessed 1 March 2024)

Vancouver Fraser Port Authority (2024). The Port of Vancouver Homepage https://www.portvancouver.com/ (accessed 1 March 2024)

Wernberg T, Krumhansl K, Filbee-Dexter K, Pedersen MF (2019) Status and trends for the world's kelp forests. Pages 57-78. In: World seas: An environmental evaluation. Academic Press.

Appendix A Summary Statistics Tables

Table A.1 Summary statistics at four sites in Burrard Inlet from May 1st to August 31st, 2023 for average, maxiumum, and minimum temperature. Reference sites are italiczed.

Metric	Month	Site	n	Min	Median	Max	Mean	SE
Average Daily Temperature (°C)	May	*Second Narrows*	31	9.25	11.46	13.68	11.09	0.24
		Brockton Point N	31	9.51	11.57	14.12	11.38	0.23
		Nine O'clock Gun	31	9.48	11.51	13.98	11.24	0.22
		New Brighton	31	9.34	11.66	14.11	11.27	0.25
	June	*Second Narrows*	30	12.58	13.21	14.58	13.32	0.09
		Brockton Point N	30	12.30	13.00	14.98	13.27	0.13
		Nine O'clock Gun	30	12.33	12.97	14.84	13.19	0.12
		New Brighton	30	12.35	12.99	15.14	13.21	0.13
	July	*Second Narrows*	31	13.70	14.96	15.37	14.74	0.09
		Brockton Point N	31	12.71	14.94	15.52	14.61	0.15
		Nine O'clock Gun	31	12.75	14.67	15.34	14.43	0.13
		New Brighton	31	13.01	14.80	15.68	14.54	0.13
	August	*Second Narrows*	31	13.76	14.43	15.03	14.48	0.06
		Brockton Point N	31	13.12	13.97	15.23	14.12	0.11
		Nine O'clock Gun	31	13.25	14.01	15.11	14.09	0.09
		New Brighton	31	13.62	14.10	15.12	14.25	0.08
Maximum Daily Temperature (°C)	May	*Second Narrows*	31	9.67	12.52	14.92	12.12	0.27
		Brockton Point N	31	10.16	12.64	15.65	12.55	0.26
		Nine O'clock Gun	31	9.90	12.58	15.52	12.39	0.26
		New Brighton	31	9.68	12.47	15.74	12.37	0.31
	June	*Second Narrows*	30	13.18	14.46	16.66	14.55	0.16
		Brockton Point N	30	12.80	14.26	16.75	14.35	0.17
		Nine O'clock Gun	30	12.89	13.97	16.04	14.13	0.14
		New Brighton	30	12.63	13.73	16.74	14.15	0.20
	July	*Second Narrows*	31	15.38	16.17	16.81	16.13	0.06

		Brockton Point N	31	13.71	16.26	17.71	16.10	0.21
		Nine O'clock Gun	31	13.64	15.95	17.19	15.83	0.18
		New Brighton	31	13.79	16.04	16.71	15.69	0.17
	August	*Second Narrows*	31	14.39	15.66	16.72	15.64	0.11
		Brockton Point N	31	14.11	14.92	17.44	15.30	0.18
		Nine O'clock Gun	31	14.02	14.94	16.83	15.12	0.15
		New Brighton	31	14.07	14.79	16.74	15.06	0.15
Minimum Daily Temperature (°C)	May	*Second Narrows*	31	8.87	10.65	12.61	10.47	0.20
		Brockton Point N	31	8.73	10.49	13.05	10.49	0.21
		Nine O'clock Gun	31	8.74	10.03	13.11	10.23	0.21
		New Brighton	31	8.85	10.27	12.22	10.33	0.19
	June	*Second Narrows*	30	12.01	12.57	13.77	12.61	0.08
		Brockton Point N	30	11.24	12.22	13.62	12.31	0.10
		Nine O'clock Gun	30	11.40	12.13	14.14	12.29	0.12
		New Brighton	30	11.67	12.39	13.29	12.39	0.08
	July	*Second Narrows*	31	12.23	14.11	14.61	13.88	0.12
		Brockton Point N	31	11.24	13.52	14.42	13.25	0.15
		Nine O'clock Gun	31	11.40	13.49	14.29	13.22	0.15
		New Brighton	31	12.25	13.89	14.45	13.67	0.11
	August	*Second Narrows*	31	13.11	13.71	14.33	13.74	0.07
		Brockton Point N	31	11.85	12.86	14.08	12.97	0.13
		Nine O'clock Gun	31	11.69	13.02	14.11	12.93	0.12
		New Brighton	31	12.53	13.61	14.45	13.59	0.08

Table A.2 Salinity summary statisitics for the average daily salinity at four sites in Burrard Inlet separated by month. Salinity was measured in practical salinity units (PSU). Reference sites are italicized.

Metric	**Month**	**Site**	**n**	**Min**	**Median**	**Max**	**Mean**	**SE**
Average Daily Salinity (PSU)	May	*Second Narrows*	31	20.29	22.96	25.80	23.28	0.28
		Brockton Point N	31	19.29	22.35	25.65	22.54	0.31
		Nine O'clock Gun	31	18.82	22.50	25.57	22.73	0.31
		New Brighton	31	19.38	22.92	25.68	23.09	0.32
	June	*Second Narrows*	30	20.54	23.29	24.05	23.05	0.17

		Brockton Point N	30	19.75	22.61	23.57	22.23	0.21
		Nine O'clock Gun	30	19.38	23.57	25.22	23.32	0.25
		New Brighton	30	20.44	23.60	24.60	23.12	0.21
	July	*Second Narrows*	31	12.83	18.73	24.78	18.94	0.73
		Brockton Point N	31	20.71	23.17	24.24	23.12	0.15
		Nine O'clock Gun	31	22.46	25.16	26.15	24.98	0.15
		New Brighton	31	22.79	23.79	24.41	23.74	0.08
	August	*Second Narrows*	31	13.25	20.65	23.22	19.97	0.53
		Brockton Point N	31	23.47	24.96	26.11	24.89	0.14
		Nine O'clock Gun	31	20.36	26.14	27.14	25.84	0.25
		New Brighton	31	16.00	25.15	26.05	24.52	0.40
Maximum Daily Salinity (PSU)	May	*Second Narrows*	31	22.16	24.37	26.83	24.54	0.24
		Brockton Point N	31	21.37	24.61	27.70	24.70	0.28
		Nine O'clock Gun	31	20.71	24.97	27.33	24.88	0.30
		New Brighton	31	22.78	25.27	26.99	25.10	0.21
	June	*Second Narrows*	30	22.35	24.28	25.39	24.19	0.14
		Brockton Point N	30	21.72	24.04	25.29	23.86	0.17
		Nine O'clock Gun	30	22.01	24.86	26.16	24.68	0.20
		New Brighton	30	23.04	24.22	25.81	24.34	0.14
	July	*Second Narrows*	31	20.96	24.51	25.65	24.00	0.24
		Brockton Point N	31	23.00	24.48	25.73	24.54	0.11
		Nine O'clock Gun	31	24.96	26.26	27.09	26.19	0.10
		New Brighton	31	23.82	24.68	25.29	24.58	0.06
	August	*Second Narrows*	31	20.75	22.68	24.14	22.65	0.16
		Brockton Point N	31	24.85	26.12	26.68	25.91	0.10
		Nine O'clock Gun	31	25.08	26.95	27.77	26.86	0.11
		New Brighton	31	23.54	25.63	26.56	25.56	0.13
Minimum Daily Salinity (PSU)	May	Second Narrows	31	17.74	20.86	24.51	21.13	0.30
		Brockton Point N	31	15.49	19.51	24.12	19.90	0.37
		Nine O'clock Gun	31	15.12	20.35	24.32	20.53	0.38
		New Brighton	31	16.55	20.66	24.47	20.95	0.39
	June	*Second Narrows*	30	18.85	21.93	23.23	21.50	0.24
		Brockton Point N	30	16.95	21.00	22.61	20.31	0.29

		Nine O'clock Gun	30	17.87	21.79	24.05	21.70	0.29
		New Brighton	30	18.22	22.53	23.98	21.73	0.33
	July	*Second Narrows*	31	9.65	15.24	23.84	15.25	0.80
		Brockton Point N	31	18.20	21.37	23.43	21.35	0.23
		Nine O'clock Gun	31	11.27	23.94	25.59	22.44	0.66
		New Brighton	31	20.05	22.47	23.90	22.45	0.16
	August	*Second Narrows*	31	9.13	18.13	22.63	17.21	0.76
		Brockton Point N	31	19.92	23.84	25.62	23.48	0.28
		Nine O'clock Gun	31	14.22	25.77	26.76	24.45	0.57
		New Brighton	31	13.77	24.68	25.58	23.16	0.64

Table A.3 Monitoring Transect Substrate Composition. N is the number of plots sampled. The values were standardized so the cover of fine sediment, pebbles/gravels, and cobbles/boulders in a plot summed to 100%.

Metric	Dates	Site	n	Min	Median	Max	Mean	SE
Fine Sediment (%)	April 26-28	*Brockton Point N*	25	0	0	63	14	4
		Second Narrows	21	0	13	69	17	4
	June 5-8	*Brockton Point N*	27	0	12	32	9	2
		Brockton Point S	29	0	32	85	39	6
		Crab Park	31	12	63	100	52	6
		New Brighton	45	0	0	85	8	3
		Nine O'clock Gun	42	0	25	100	38	5
		Second Narrows	22	0	0	85	14	6
	Sept. 6-9	*Brockton Point N*	27	0	15	63	18	3
		Brockton Point S	29	14	48	85	48	4
		Crab Park	26	0	54	100	52	6
		New Brighton	36	0	15	67	22	3
		Nine O'clock Gun	39	0	35	100	41	4
		Second Narrows	27	0	17	100	24	5
Pebbles/ Gravels (%)	April 26-28	*Brockton Point N*	25	0	25	100	30	6
		Second Narrows	21	0	0	73	6	4

	June 5-8	*Brockton Point N*	27	0	28	87	36	5
		Brockton Point S	29	0	15	60	18	3
		Crab Park	31	0	0	76	21	5
		New Brighton	45	0	67	100	54	5
		Nine O'clock Gun	42	0	14	87	21	4
		Second Narrows	22	0	0	63	9	4
	Sept. 6-9	*Brockton Point N*	27	0	17	83	30	6
		Brockton Point S	29	13	27	83	29	3
		Crab Park	26	0	0	71	12	4
		New Brighton	36	0	48	100	45	5
		Nine O'clock Gun	39	0	15	71	18	3
		Second Narrows	27	0	0	71	13	3
Cobbles/ Boulders (%)	April 26-28	*Brockton Point N*	25	0	53	100	57	6
		Second Narrows	21	27	85	100	77	5
	June 5-8	*Brockton Point N*	27	0	54	100	54	5
		Brockton Point S	29	0	41	100	43	5
		Crab Park	31	0	15	85	27	4
		New Brighton	45	0	32	100	38	5
		Nine O'clock Gun	42	0	36	100	42	5
		Second Narrows	22	15	100	100	77	7
	Sept. 6-9	*Brockton Point N*	27	0	59	85	53	5
		Brockton Point S	29	0	17	67	24	4
		Crab Park	26	0	30	100	36	5
		New Brighton	36	0	23	100	33	5
		Nine O'clock Gun	39	0	33	100	40	5
		Second Narrows	27	0	68	100	63	6

Table A.4 Understory Seaweed percent cover in monitoring transects. The sample size (n) is the number of plots sampled. Reference sites are italicized.

Metric	Dates	Site	n	Min	Median	Max	Mean	SE
Understory Kelp (%)	April 26- 28	*Brockton Point N*	25	0	38	85	40	6
		Second Narrows	21	0	16	94	30	7

	June 5-8	*Brockton Point N*	27	0	31	101	36	5
		Brockton Point S	29	0	38	85	45	5
		Crab Park	31	0	63	100	56	6
		New Brighton	45	0	38	85	33	3
		Nine O'clock Gun	42	0	38	101	45	4
		Second Narrows	22	0	38	91	37	6
	Sept. 6-9	*Brockton Point N*	27	0	16	98	29	5
		Brockton Point S	29	0	63	98	47	7
		Crab Park	26	0	85	98	75	6
		New Brighton	36	0	38	98	42	5
		Nine O'clock Gun	39	0	16	98	34	6
		Second Narrows	27	0	16	78	21	5
Total Seaweed (%)	April 26-28	*Brockton Point N*	25	16	71	132	72	6
		Second Narrows	21	0	94	116	86	6
	June 5-8	*Brockton Point N*	27	16	69	122	72	6
		Brockton Point S	29	16	84	122	78	5
		Crab Park	31	0	91	131	80	6
		New Brighton	45	31	78	122	80	4
		Nine O'clock Gun	42	16	78	128	73	5
		Second Narrows	22	0	98	131	93	6
	Sept. 6-9	*Brockton Point N*	27	16	69	116	71	5
		Brockton Point S	29	31	78	116	76	4
		Crab Park	26	0	98	116	87	5
		New Brighton	36	47	85	132	84	4
		Nine O'clock Gun	39	0	69	156	66	6
		Second Narrows	27	31	69	131	75	4

Table A.5 Summary Statistics of Substrate and Understory Seaweed in Experimental Plots. The sample size (n) is the number of plots sampled.

Metric	Dates	Site	n	Min	Median	Max	Mean	SE
Fine Sediment (%)	April 26-28	Crab Park	8	38	85	98	72	8
		New Brighton	9	0	16	63	30	11

		Nine O'clock Gun	8	63	85	85	79	3
	Sept. 6-9	Crab Park	8	16	74	85	59	11
		New Brighton	8	0	27	85	34	9
		Nine O'clock Gun	6	16	63	85	54	8
Pebbles/ Gravels (%)	April 26-28	Crab Park	8	0	8	16	8	3
		New Brighton	9	16	53	101	48	11
		Nine O'clock Gun	8	0	0	38	7	5
	Sept. 6-9	Crab Park	8	0	0	16	6	3
		New Brighton	8	31	64	85	58	7
		Nine O'clock Gun	6	16	45	78	50	8
Cobbles/ Boulders (%)	April 26-28	Crab Park	8	16	23	75	32	7
		New Brighton	9	16	16	53	24	5
		Nine O'clock Gun	8	16	23	38	24	3
	Sept. 6-9	Crab Park	8	0	34	78	38	11
		New Brighton	8	0	16	31	17	3
		Nine O'clock Gun	6	0	8	31	10	4
Understory Kelp (%)	April 26-28	Crab Park	8	0	16	31	16	4
		New Brighton	9	5	38	85	41	9
		Nine O'clock Gun	8	0	16	31	14	3
	June 5-8	Crab Park	7	0	16	38	17	4
		New Brighton	0	NA	NA	NA	NA	NA
		Nine O'clock Gun	8	3	16	75	24	7
	Sept. 6-9	Crab Park	8	16	63	98	67	8
		New Brighton	8	16	70	98	61	11
		Nine O'clock Gun	6	0	38	85	40	10
Total Seaweed (%)	April 26-28	Crab Park	8	5	36	62	33	7
		New Brighton	9	26	74	109	74	10
		Nine O'clock Gun	8	21	50	71	49	6
	June 5-8	Crab Park	7	0	32	69	33	7
		New Brighton	0	NA	NA	NA	NA	NA
		Nine O'clock Gun	8	18	49	75	49	7
	Sept. 6-9	Crab Park	8	34	78	113	79	9
		New Brighton	8	31	94	116	82	9

		Nine O'clock Gun	6	31	58	101	60	8

Table A.6 Summary Statistics Bull Kelp Depth and Density. Reference sites are italicized. The sample size (n) is the number of plots surveyed.

Metric	Dates	Site	n	Min	Median	Max	Mean	SE
Bull Kelp Depth CD (m)	April 26-28	*Brockton Point N*	17	-2.8	0.5	1.1	-0.5	0.4
		Second Narrows	9	-1.0	0.0	1.0	0.0	0.2
	June 5-8	*Brockton Point N*	15	-2.9	-1.7	0.6	-1.4	0.3
		Brockton Point S	20	-2.2	-0.5	0.8	-0.6	0.2
		Nine O'clock Gun	25	-2.7	-0.7	0.7	-0.6	0.2
		Second Narrows	13	-3.1	-0.9	0.6	-0.9	0.3
	Sept. 6-9	*Brockton Point N*	5	-2.5	-1.4	0.3	-1.3	0.5
		Brockton Point S	5	-2.1	-0.8	0.2	-0.9	0.4
		Nine O’clock Gun	8	-2.3	-1.3	0.4	-1.2	0.3
		Second Narrows	6	-0.5	-0.4	0.9	-0.1	0.2
Bull Kelp Density (individuals per m^2)	April 26-28	*Brockton Point N*	17	1	5	10	5	1
		Second Narrows	9	1	7	16	7	2
	June 5-8	*Brockton Point N*	15	1	4	9	4	1
		Brockton Point S	20	1	3	10	4	1
		Nine O'clock Gun	25	1	2	11	3	1
		Second Narrows	13	1	2	5	2	0
	Sept. 6-9	*Brockton Point N*	5	1	2	7	3	1
		Brockton Point S	5	1	1	5	2	1
		Nine O'clock Gun	8	1	1	4	2	0
		Second Narrows	6	1	2	2	2	0

Table A.7 Stipe Length and Pneumatocyst Diameter Summary Statistics. Reference sites are italicized. The sample size (n) is the number of sporophytes measured.

Metric	Dates	Site	n	Min	Median	Max	Mean	SE
Stipe Length (cm)	April 26-28	*Brockton Point N*	45	5	15	56	18	2
		Second Narrows	35	10	50	145	52	5

	June 5-8	*Brockton Point N*	60	8	53	186	59	5
		Brockton Point S	0	NA	NA	NA	NA	NA
		Nine O'clock Gun	69	12	54	182	61	5
		Second Narrows	30	5	47	158	54	6
	Sept. 6-9	*Brockton Point N*	12	100	410	580	415	34
		Brockton Point S	11	80	380	600	367	48
		Nine O'clock Gun	14	60	285	520	308	41
		Second Narrows	9	80	330	450	282	40
Pneumat-ocyst Diameter (mm)	April 26-28	*Brockton Point N*	43	3	15	37	16	1
		Second Narrows	35	8	29	43	28	2
	June 5-8	*Brockton Point N*	60	9	32	57	32	2
		Brockton Point S	0	NA	NA	NA	NA	NA
		Nine O'clock Gun	69	3	37	59	35	2
		Second Narrows	30	10	34	55	34	2
	Sept.6-9	*Brockton Point N*	12	60	71	75	71	1
		Brockton Point S	11	37	60	68	59	2
		Nine O'clock Gun	14	38	63	90	65	4
		Second Narrows	9	30	57	75	56	6

Table A.8 Experimental Plots Summary Statisitics.

Metric	**Dates**	**Treatment**	**n**	**Min**	**Median**	**Max**	**Mean**	**SE**
Gravel Found (count)	April 26-28	Control	9	0	0	0	0	0
		Large	6	3	11	15	10	2
		Small	9	0	7	10	6	1
	June 5-8	Control	6	0	0	7	1	1
		Large	5	4	10	13	9	1
		Small	5	0	12	17	9	2
	Sept. 6-9	Control	6	0	0	0	0	0
		Large	5	0	1	4	2	1
		Small	3	0	0	1	0	0
Gravel with Kelp (count)	April 26-28	Control	9	0	0	0	0	0
		Large	6	0	0	5	1	1

		Small	9	0	0	1	0	0
	June 5-8	Control	6	0	0	0	0	0
		Large	5	0	0	0	0	0
		Small	5	0	0	0	0	0
	Sept. 6-9	Control	6	0	0	0	0	0
		Large	5	0	0	0	0	0
		Small	3	0	0	0	0	0

Table A.9 Sporophyte Treatment Summary Statistics. The sample size (n) is the number of sporophytes measured.

Metric	Date	Growth Medium	Site	n	Min	Median	Max	Mean	SE
Stipe length (cm)	April 26-28	Lab (Gravel)	Pacific Science Enterprise Centre	21	16	40	85	42	4
		Lab (Tile)	Pacific Science Enterprise Centre	15	7	32	71	34	4
		Large Gravel	New Brighton	6	20	41	70	43	7
			Nine O'clock Gun	4	4	10	12	9	2
		Tile	Crab Park	4	10	45	60	40	11
			Nine O'clock Gun	10	4	35	60	30	6
	June 5-8	Tile	Crab Park	2	50	98	146	98	48
			Nine O'clock Gun	6	18	62	125	68	19
Pneumat-ocyst Diameter (mm)	April 26-28	Lab (Gravel)	Pacific Science Enterprise Centre	21	4	15	24	15	1
		Lab (Tile)	Pacific Science Enterprise Centre	15	2	11	20	12	1
		Large Gravel	New Brighton	6	15	26	30	24	2
			Nine O'clock Gun	4	0	8	10	7	2
		Tile	Crab Park	4	2	25	30	20	6
			Nine O'clock Gun	10	0.2	22	34	18	4
	June 5-8	Tile	Crab Park	2	28	41	53	41	13
			Nine O'clock Gun	6	13	34	46	33	5

Holdfast radius (mm)	April 26-28	Lab (Gravel)	Pacific Science Enterprise Centre	21	12	20	30	21	1
		Lab (Tile)	Pacific Science Enterprise Centre	15	4	16	25	17	1
		Large Gravel	New Brighton	0	NA	NA	NA	NA	NA
			Nine O'clock Gun	0	NA	NA	NA	NA	NA
		Tile	Crab Park	4	2	10	24	12	5
			Nine O'clock Gun	10	0.2	11	30	13	3
	June 5-8	Tile	Crab Park	2	13	46	78	46	33
			Nine O'clock Gun	6	5	16	50	21	7

Appendix B Results of Statistical Tests

Table B.1 Results of Kruskal-Wallis tests. Reference sites are italicized.

Monitoring Period	Metric	Groups compared	Chi-squared value	Degrees of Freedom	p-value
April 26th-28th	Cobbles/Boulders (%)	*BP N, SN*	5.62	1	**0.02**
	Pebbles/Gravels (%)	*BP N, SN*	12.84	1	**0.0003**
	Fine Sediment (%)	*BP N, SN*	0.47	1	0.49
	Understory Kelp Cover (%)	*BP N, SN*	2.13	1	0.14
	Total Seaweed Cover (%)	*BP N, SN*	3.52	1	0.06
	Bull Kelp Depth (m)	*BP N, SN*	0.12	1	0.73
	Bull Kelp Density (individuals per m^2)	*BP N, SN*	1.12	1	0.29
	Stipe length (cm)	*BP N, SN*	33.23	1	**0.000000008**
	Stipe length (cm) – Experimental Treatments	Lab (Gravel), Lab (Tile), Large Gravel, *Reference: BP N, Reference: SN*, Tile	43.02	5	**0.00000004**
June 5th-8th	Cobbles/Boulders (%)	*BP N, BP S*, CR, NB, NOG, *SN*	30.86	5	**0.00001**
	Pebbles/Gravels (%)	*BP N, BP S,* CR, NB, NOG, *SN*	46.15	5	**0.000000008**
	Fine Sediment (%)	*BP N, BP S,* CR, NB, NOG, *SN*	63.33	5	**0.000000000002**

	Understory Kelp Cover (%)	*BP N, BP S,* CR, NB, NOG, *SN*	12.68	5	**0.03**
	Total Seaweed Cover (%)	*BP N, BP S,* CR, NB, NOG, *SN*	10.07	5	0.07
	Bull Kelp Depth (m)	*BP N, BP S*, NOG, *SN*	5.18	3	0.16
	Bull Kelp Density (individuals per m^2)	*BP N, BP S*, NOG, *SN*	6.40	3	0.09
	Stipe length (cm)	*BP N*, NOG, *SN*	0.53	2	0.77
	Stipe length (cm) – Experimental Treatments	*Reference: BP N*, *Reference: SN*, Tile	1.25	2	0.53
September 6th-9th	Cobbles/Boulders (%)	*BP N, BP S,* CR, NB, NOG, *SN*	33.06	5	**0.000004**
	Pebbles/Gravels (%)	*BP N, BP S,* CR, NB, NOG, *SN*	43.22	5	**0.00000003**
	Fine Sediment (%)	*BP N, BP S,* CR, NB, NOG, *SN*	41.21	5	**0.00000009**
	Understory Kelp Cover (%)	*BP N, BP S,* CR, NB, NOG, *SN*	39.02	5	**0.0000002**
	Total Seaweed Cover (%)	*BP N, BP S,* CR, NB, NOG, *SN*	14.233	5	**0.01**
	Bull Kelp Depth (m)	*BP N, BP S*, NOG, *SN*	7.07	3	0.07
	Bull Kelp Density (individuals per m^2)	*BP N, BP S*, NOG, *SN*	0.97	3	0.81
	Stipe length (cm)	*BP N, BP S*, NOG, *SN*	6.74	3	0.08

May 1st – Aug 31st	Average Daily Temperature (°C)	*BP N*, NOG, NB, *SN*	2.05	3	0.56
	Maximum Daily Temperature (°C)	*BP N*, NOG, NB, *SN*	4.14	3	0.25
	Minimum Daily Temperature (°C)	*BP N*, NOG, NB, *SN*	15.47	3	**0.001**
	Average Daily Salinity (PSU)	*BP N*, NOG, NB, *SN*	84.57	3	**0.0000000000000002**
	Maximum Daily Salinity (PSU)	*BP N*, NOG, NB, *SN*	106.8	3	**0.0000000000000002**
	Minimum Daily Salinity (PSU)	*BP N*, NOG, NB, *SN*	74.36	3	**0.0000000000000005**

Table B.2 Results of post-hoc pairwise comparisons using Wilcoxon Rank Sum Test. Ties in data were accounted for by using a continuity correction and a Bonferroni p-value adjustment was used to account for multiple comparisons. Reference sites are italicized.

Monitoring Period	**Metric**	**Comparison**	**p-value**
April 26th-April 28th	Stipe Length (cm) - Experimental Treatments	Lab (Gravel) – Lab (Tile)	1.00
		Lab (Gravel) – Large Gravel	1.00
		Lab (Gravel) – *Reference: BP N*	**0.00002**
		Lab (Gravel) – *Reference: SN*	1.00
		Lab (Gravel) – Tile	1.00
		Lab (Tile) – Large Gravel	1.00
		Lab (Tile) – *Reference: BP N*	**0.02**
		Lab (Tile) – *Reference: SN*	1.00
		Lab (Tile) – Tile	1.00
		Large Gravel – *Reference BP N*	1.00
		Large Gravel – *Reference: SN*	0.50
		Large Gravel – Tile	1.00
		Reference: BP N – Reference: SN	**0.0000001**
		Reference BP N – Tile	0.23

		Reference SN – Tile	1.00
June 5th-8th	Cobbles/Boulders (%)	*BP N* – *BP S*	1.00
		BP N – CR	**0.004**
		BP N – NB	0.40
		BP N – NOG	1.00
		BP N – *SN*	0.06
		BP S – CR	0.57
		BP S – NB	1.00
		BP S – NOG	1.00
		BP S – *SN*	**0.007**
		CR – NB	0.98
		CR – NOG	1.00
		CR – *SN*	**0.00007**
		NB – NOG	1.00
		NB – *SN*	**0.001**
		NOG – *SN*	**0.003**
	Pebbles/Gravels (%)	*BP N* – *BP S*	0.14
		BP N – CR	0.13
		BP N – NB	0.61
		BP N – NOG	0.14
		BP N – *SN*	**0.0005**
		BP S – CR	1.00
		BP S – NB	**0.0007**
		BP S – NOG	1.00
		BP S – *SN*	1.00
		CR – NB	**0.0007**
		CR – NOG	1.00
		CR – *SN*	1.00
		NB – NOG	**0.0003**
		NB – *SN*	**0.00002**
		NOG – *SN*	0.17
	Fine Sediment (%)	*BP N* – *BP S*	**0.002**
		BP N – CR	**0.00001**

		BP N – NB	0.77
		BP N – NOG	**0.03**
		BP N – *SN*	1.00
		BP S – CR	1.00
		BP S – NB	**0.000009**
		BP S – NOG	1.00
		BP S – *SN*	**0.02**
		CR – NB	**0.000000003**
		CR – NOG	0.69
		CR – *SN*	**0.0001**
		NB – NOG	**0.00005**
		NB – *SN*	1.00
		NOG – *SN*	0.06
	Understory Kelp Cover (%)	*BP N* – *BP S*	1.00
		BP N – CR	0.24
		BP N – NB	1.00
		BP N – NOG	1.00
		BP N – *SN*	1.00
		BP S – CR	1.00
		BP S – NB	1.00
		BP S – NOG	1.00
		BP S – *SN*	1.00
		CR – NB	**0.03**
		CR – NOG	1.00
		CR – *SN*	0.43
		NB – NOG	1.00
		NB – *SN*	1.00
		NOG – *SN*	1.00
September 6th-9th	Cobbles/Boulders (%)	*BP N* – *BP S*	**0.001**
		BP N – CR	0.33
		BP N – NB	**0.03**
		BP N – NOG	1.00
		BP N – *SN*	1.00

		BP S – CR	0.85
		BP S – NB	1.00
		BP S – NOG	0.57
		BP S – *SN*	**0.00006**
		CR – NB	1.00
		CR – NOG	1.00
		CR – *SN*	**0.01**
		NB – NOG	1.00
		NB – *SN*	**0.002**
		NOG – *SN*	0.10
	Pebbles/Gravels (%)	*BP N* – *BP S*	1.00
		BP N – CR	0.17
		BP N – NB	0.35
		BP N – NOG	1.00
		BP N – *SN*	0.41
		BP S – CR	**0.001**
		BP S – NB	0.24
		BP S – NOG	0.15
		BP S – *SN*	**0.01**
		CR – NB	**0.00002**
		CR – NOG	1.00
		CR – *SN*	1.00
		NB – NOG	**0.0002**
		NB – *SN*	**0.00006**
		NOG – *SN*	1.00
	Fine Sediment (%)	*BP N* – *BP S*	**0.00001**
		BP N – CR	**0.004**
		BP N – NB	1.00
		BP N – NOG	**0.005**
		BP N – *SN*	1.00
		BP S – CR	1.00
		BP S – NB	**0.0002**
		BP S – NOG	1.00

		BP S – SN	**0.003**
		CR – NB	**0.005**
		CR – NOG	1.00
		CR – *SN*	0.07
		NB – NOG	**0.04**
		NB – *SN*	1.00
		NOG – *SN*	0.19
	Understory Kelp Cover (%)	*BP N – BP S*	0.91
		BP N – CR	**0.00006**
		BP N – NB	0.81
		BP N – NOG	1.00
		BP N – SN	1.00
		BP S – CR	**0.04**
		BP S – NB	1.00
		BP S – NOG	1.00
		BP S – SN	0.12
		CR – NB	**0.0006**
		CR – NOG	**0.0004**
		CR – *SN*	**0.000003**
		NB – NOG	1.00
		NB – *SN*	**0.02**
		NOG – *SN*	1.00
	Total Seaweed Cover (%)	*BP N – BP S*	1.00
		BP N – CR	0.06
		BP N – NB	1.00
		BP N – NOG	1.00
		BP N – SN	1.00
		BP S – CR	0.56
		BP S – NB	1.00
		BP S – NOG	1.00
		BP S – SN	1.00
		CR – NB	1.00
		CR – NOG	0.20

		CR – *SN*	0.09
		NB – NOG	0.32
		NB – *SN*	1.00
		NOG – *SN*	1.00
May 1st – August 31st	Minimum Daily Temperature (°C)	*BP N* – NB	0.32
		BP N – NOG	1.00
		BP N – *SN*	**0.01**
		NB – NOG	0.17
		NB – *SN*	1.00
		NOG – *SN*	**0.004**
	Average Daily Salinity (PSU)	*BP N* – NB	**0.042**
		BP N – NOG	**0.00001**
		BP N – *SN*	**0.00002**
		NB – NOG	**0.013**
		NB – *SN*	**0.0000000001**
		NOG – *SN*	**0.000000000000006**
	Maximum Daily Salinity (PSU)	*BP N* – NB	1.00
		BP N – NOG	**0.00000008**
		BP N – *SN*	**0.000001**
		NB – NOG	**0.00000005**
		NB – *SN*	**0.000000001**
		NOG – *SN*	**0.0000000000000002**
	Minimum Daily Salinity (PSU)	*BP N* – NB	**0.004**
		BP N – NOG	**0.0008**
		BP N – *SN*	**0.00005**
		NB – NOG	1.00
		NB – *SN*	**0.00000000001**
		NOG – *SN*	**0.000000000003**

Appendix C Monitoring Transect Waypoints

Table C.1 GPS points of monitoring transects. Reference sites are italicized.

Site	Transect ID	Waypoint Position	Latitude (decimal)	Longitude (decimal)
Brockton Point N	BP_S1	offshore	49.30028	-123.11549
Brockton Point N	BP_S1	onshore	49.300227	-123.11627
Brockton Point N	BP_S2	offshore	49.30007	-123.11535
Brockton Point N	BP_S2	onshore	49.3	-123.11635
Brockton Point S	BP_S3	onshore	49.299333	-123.11633
Brockton Point S	BP_S3	offshore	49.299278	-123.11544
Brockton Point S	BP_S4	onshore	49.299056	-123.11636
Brockton Point S	BP_S4	offshore	49.298917	-123.11553
Nine O'clock Gun	NOG_N	onshore	49.298222	-123.11653
Nine O'clock Gun	NOG_N	offshore	49.298056	-123.11586
Nine O'clock Gun	NOG_T	offshore	49.29751	-123.11606
Nine O'clock Gun	NOG_T	onshore	49.29794	-123.11644
Nine O'clock Gun	NOG_S	onshore	49.297944	-123.11697
Nine O'clock Gun	NOG_S	offshore	49.297389	-123.11661
Crab Park	CR_W	onshore	49.286361	-123.10372
Crab Park	CR_W	offshore	49.286556	-123.104
Crab Park	CR_T	offshore	49.28658	-123.10338
New Brighton	NB_T	offshore	49.2912	-123.03664
New Brighton	NB_T	onshore	49.29083	-123.03694
New Brighton	NB_E1	onshore	49.290667	-123.03689
New Brighton	NB_E1	offshore	49.290917	-123.03664
New Brighton	NB_E2	onshore	49.290583	-123.03669
New Brighton	NB_E2	offshore	49.290889	-123.03642
Second Narrows	SN_W	offshore	49.29342	-123.0155
Second Narrows	SN_W	onshore	49.29327	-123.01544
Second Narrows	SN_E	offshore	49.29347	-123.01511
Second Narrows	SN_E	onshore	49.29323	-123.01507