A contrast of two novel deterrents of goose herbivory at Westham Island foreshore tidal marsh

by
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Declaration of Committee

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Title:	**A contrast of two novel deterrents of goose herbivory at Westham Island foreshore tidal marsh**
Examining Committee:	**Chair:**
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Abstract

Since the 1980s, at least 160 ha of marsh vegetation has died off in Sturgeon Bank and Westham Island, located within the Fraser River Estuary. Proposed causes for this marsh recession include sediment deficit, relative sea-level rise, increased salinity, and goose herbivory. At Westham Island, the loss of tidal marsh vegetation is locally distinct in that it occurs in a closed polygon shape versus along the leading edge of the marsh, suggesting that goose herbivory is a principal cause. Goose herbivory on tidal marsh vegetation has become a global problem as many geese populations are becoming hyperabundant. In the Fraser River Estuary, Canada goose (*Branta canadensis*) and snow goose (*Anser caerulescens*) numbers have been increasing exponentially. I conducted a field experiment, testing two novel goose herbivory deterrents at Westham Island's foreshore tidal marsh: metal and snow fencing placed flat against the substrate. I used a randomized complete block design with six replicates and three treatments: metal fencing, snow fencing and control (no fencing). Each treatment's effectiveness was assessed by monitoring changes in common three-square bulrush (*Schoenoplectus pungens*) every two weeks throughout the summer season (June-September 2022) in terms of stem density, percent cover, and percent of stems grazed. Results indicated that there was no difference in stem density, percent cover, and percent of stems grazed between the two fencing types. However, compared to bulrush in the controls, both snow and metal fencing treatments yielded a higher stem density and percent cover ($\bar{x}$% difference = 82.9%, 53.1%, respectively) as well as a lower percent of stems grazed. These results suggest that both fencing materials are equally effective at deterring goose herbivory in a tidal marsh. Additional assessments are needed to clarify whether this technique can be scaled up to promote marsh recovery throughout the entire area of recession.

Keywords: Tidal marsh recession, Goose herbivory deterrents, Goose management, Canada geese, Common three-square bulrush, Snow fencing, Chain-link fencing

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List of Acronyms

ECCC --------------- Environment and Climate Change Canada

ESRI ---------------- Environmental Systems Research Institute

SCCLMP ----------- South Coast Conservation Land Management Program

1.0 Introduction

Tidal marshes are among the most productive ecosystems globally, and they provide many essential ecosystem services (Torio & Chmura 2013; Rob 2014). They serve as a critical nursery ground for fish and invertebrates and are essential habitat for migratory birds. Some of the most valuable ecosystem services include carbon sequestration and storage, erosion control, and filtering pollutants (Mo et al. 2017).

Almost half of the world's tidal wetlands have been lost since the 1980s (Torio & Chmura 2013). Urbanization and sea level rise due to anthropogenic climate change have resulted in a 'coastal squeeze' that leads to loss of tidal marshes (Dooby 2004; Torio & Chmura 2013). Although measures are in place to protect tidal marshes from urbanization, one of the biggest stressors is climate change and its associated direct impacts (e.g., sea-level rise) and indirect impacts (e.g., goose herbivory). To restore tidal wetlands and support ecological resilience we need to better understand the effects of climate change on tidal wetlands.

1.1 Marsh Recession at the Fraser Delta Front

The Fraser River Estuary in BC is designated as a wetland of international importance and is one of three RAMSAR sites located in the province. Many of the tidal marshes in the estuary are part of the Pacific Flyway and are important to migrating waterfowl. Although much of the estuary is protected, recent studies have shown a steady loss of vegetation along the leading edge of tidal marshes located in Sturgeon Bank and Roberts Bank. (Balke 2017; Marijnissen & Aarninkhof 2017). From 1989 to 2011 about 160 ha of marsh vegetation from the northern part of Sturgeon Bank has been loss (W.S Boyd et al., ECCC, unpubl. data).

Sediment deficit, relative sea-level rise, increased salinity, and goose herbivory are hypothesized causes of marsh recession along Sturgeon Bank and Roberts Bank (Balke 2017). An increasing number of studies have identified sea-level rise and increased salinity levels as leading causes of tidal marsh recession globally (Mckee et al. 2004; Craft et al. 2009; Kinney et al. 2014; Smith et al. 2017). However, it is becoming increasingly evident that herbivory by Canada geese (*Branta canadensis*) and snow geese (*Anser caerulescens*) is a major contributor to loss of tidal marsh vegetation in North America (Boyd 1995; Jefferies et al. 2005; Lefebvre et al. 2017; Gan 2021; Appendix 1).

Westham Island on Roberts Banks has been losing marsh vegetation since the late 1980s. It is estimated that about 50 ha of tidal marsh vegetation has been loss from the Island's foreshore tidal marsh (W.S Boyd et al., unpubl. data). The loss of tidal marsh vegetation at Westham Island is locally distinct in that it is not occurring along the leading edge of the marsh. Instead, it occurs in the middle of the low marsh within a closed polygon (Fig. 1). This distinct pattern of marsh recession at Westham Island suggests that goose herbivory is the principal cause (Eric Balke, SCCLMP, pers. comm.).

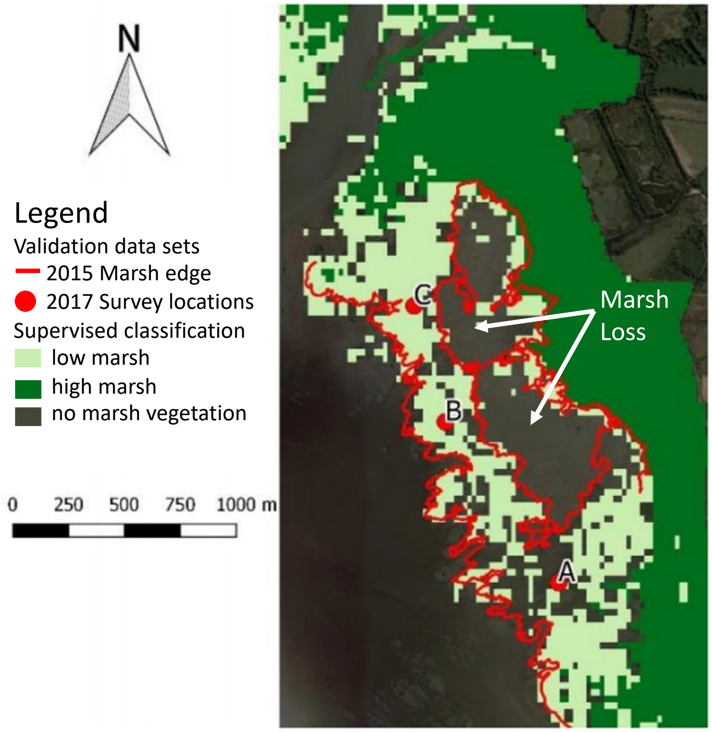

Figure 1: Map of marsh extent in 2015 at Westham Island measured using GPS by Mason (2016). The 2017 field survey locations were used to validate estimates of plant cover at the site based on spectral unmixing and supervised classification. Map adapted from Marijnissen & Aarninkhof (2017).

1.2 Effects of Hyperabundant Goose Populations on Tidal Marshes

In the early 20th century, both Canada goose and lesser snow goose populations declined in North America (Jefferies et al. 2005; Lefebvre et al. 2017). Because of this decline, both species were legally protected, and sanctuaries were established to help assist their recovery (Lefebvre et al. 2017). Subsequent increases in abundance of both species, resulted from a combination of factors including the protective measures taken, increasing use of agricultural crops that geese graze on, and increasingly favorable environmental conditions on their breeding grounds caused by climate change. Hyperabundant goose populations are now degrading the integrity and biodiversity of their natural habitats (Jefferies et al. 2006; Lefebvre et al. 2017). Goose herbivory has led to significant tidal marsh losses along the Patuxent River, USA, (Haramis & Kearns 2007) and in Hudson Bay, Canada (Jefferies et al. 2006). Snow goose herbivory contributed to bulrush losses in the Fraser River Estuary (Boyd 1995; W.S Boyd et al., unpubl. data). Resident Canada geese have caused significant declines in *Carex lyngbyei* in the Campbell River Estuary and Little Qualicum River Estuary in British Columbia, Canada (Dawe et al. 2011; Dawe et al. 2015).

1.3 Current Goose Management Practices

Commonly used methods for deterring goose herbivory are not practical in large and exposed areas such as foreshore tidal marshes. The most common and effective method of deterring goose herbivory is erecting barriers or fences to exclude geese from walking into the site (Canadian Wildlife Service 2010; Link 2005; Smith 1999; Doncaster & Keller n.d.). The biggest challenge of this method is the enclosed area needs to be relatively small to exclude geese (they require about 6 m to take off and land) (Doncaster & Keller n.d.). Thus, larger exclosures require wiring along the top to divide the exclosed area into smaller cells. Hazing devices including flags and streamers, scarecrows, noise-making devices, and dogs, are other standard methods of managing goose herbivory (Doncaster and Keller n.d.). In high-energy tidal marsh environments, many of these hazing devices do not last very long. Scarecrows and noise-making devices are not long-term solutions as geese can quickly become habituated to these methods (Smith et al. 1999; Link 2005; Simonsen et al. 2016; Simonsen et al. 2017). The use of dog or predator birds needs to be done indefinitely as studies have shown that geese population quickly reestablish in an area after the harassment has ended (Smith et al. 1999). There has been success in reducing geese populations using lethal methods like hunting, culling, egg addling, and oiling. However, legal, and societal implications need to be considered before attempting these methods (Canada and Wildlife 2010; Link 2005).

In tidal marsh restoration, preventative actions to reduce goose herbivory on newly planted marsh vegetation have become common. Restoration efforts at Little Qualicum River Estuary and Nanaimo River Estuary included using a novel eco-cultural goose exclosure to deal with goose herbivory on newly planted *Carex lyngbyei* (Cummings 2020, Adrienne & Lawrence 2020). My research project aims to fill in this knowledge gap to come up with a large-scale deterrent to mitigate goose herbivory in tidal marshes.

1.4 Research Focus

Identifying low-cost, low-maintenance methods of deterring goose herbivory over large areas will likely be an essential component to restoring tidal marsh vegetation. To mitigate goose damage to the Westham Island foreshore marsh, suitable deterrents must be able to withstand the high-energy tidal marsh environment.

My research will focus on addressing the following questions:

1. What is the relative effectiveness of snow versus metal fence (when laid flat on the substrate) to reduce goose herbivory and thus aid the recovery of marsh vegetation?
2. What is the relative effectiveness of snow versus metal fencing (when laid flat on the substrate) to reducing goose herbivory in adjacent unfenced areas?

To address this question, my research goal will be to test the following hypotheses:

1. When laid flat and affixed to the substrate, snow fence will be more effective at reducing goose herbivory than metal fencing due to the larger surface area of the snow fencing compared to the metal fencing.
2. When laid flat and affixed to the substrate snow fencing and metal fencing will be equally effective at reducing goose herbivory in adjacent unfenced areas.

To assess the effectiveness of each fence type (and of controls with no fencing) as goose herbivory deterrents, I recorded percent bulrush coverage, stem count density and percent of grazed stems. I also assessed the ability of the fencing to deter goose herbivory in adjacent unfenced areas by recording stem count density and percent of grazed stems in unfenced areas. This will be year one of a multiyear study.

2.0 Methods

2.1 Study Site

My study site is about 50 ha and occurs within the tidal marsh along the west side of Westham Island in Delta, BC (Fig 2). The study site is partially within the George C. Reifel Migratory Bird Sanctuary and is surrounded by highly productive agricultural lands.

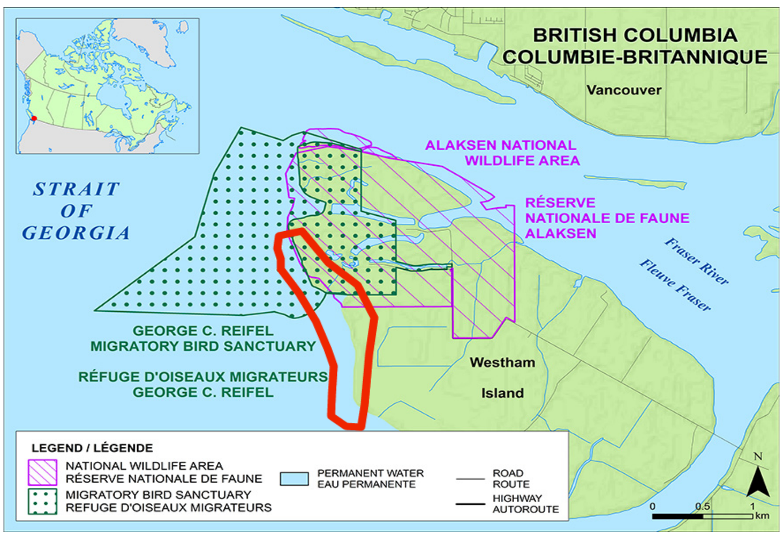

Figure 2: Map of the study site (outlined in red) in foreshore tidal marsh along the west side of Westham Island. Boundaries of Alaksen National Wildlife Area and George C. Reifel Bird Sanctuary are also indicated. (Map source from ECCC).

This study site has shifted over the past 30 years from being dominated by bulrush marsh to unvegetated mudflats (E. Balke, pers. comm.). The study site is surrounded by vegetated marsh that is composed of mostly monotypic stands of common three-square bulrush (*Schoenoplectus pungens*). As noted above, this site was selected for study and restoration as it is believed that goose herbivory is the main cause of the marsh being converted to mudflat.

2.2 Experimental Design

I divided the study site into three quadrants from north to south, and then established two study blocks within each quadrant (Fig. 3). I then randomly located two study blocks in each quadrant with stipulations that each pair of study blocks were 100 m apart and ≥80 m from existing experiments and infrastructure.

One of these quadrants was located within the George C. Reifel Bird Sanctuary. Each study block contained three treatments placed 30 m apart from one another: a control (no fencing), steel metal fencing, and snow fencing (Fig. 4). Snow and metal fencing were laid flat and affixed to the substrate in the snow and metal fencing treatment plots, respectively. Each fence treatment plot consisted of four strips of fencing (1.2 × 15 m) that were separated by three unfenced strips (1 m × 15 m), yielding a total size of 7.8 m × 15 m for each treatment. Control treatments had similar dimensions to the fenced treatments, but no fencing was added. The middle unfenced stripped was use as a walking path to facilitate stem density counts. The two remaining unfenced strips were used to assess the ability of fencing to deter goose herbivory in adjacent unfenced strips. The fenced strips in each treatment had no existing vegetation while about half of the unfenced strips had existing common-square bulrush. In each of the treatments I planted 28 plugs of common three-square bulrush in two rows of 14 each placed 1 m apart. Each plug consisted of five to eleven bulrush stems and a root mass of about 20 cm depth. The addition of the plugs provided a similar baseline of common three-square bulrush stems across all the treatments.

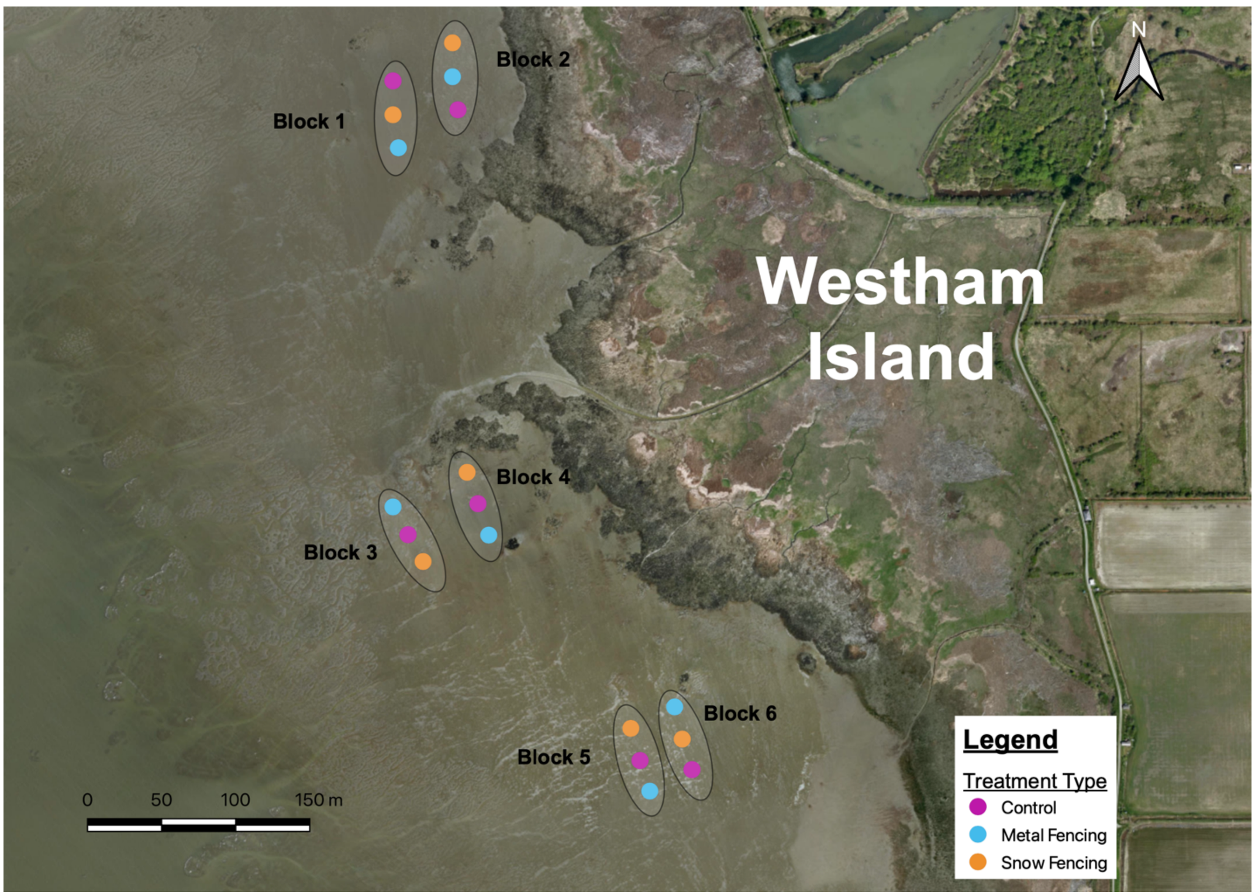

Figure 3: Location of the three experimental treatments within each of the six study blocks at the Westham Island study site (Map source: ERSI).

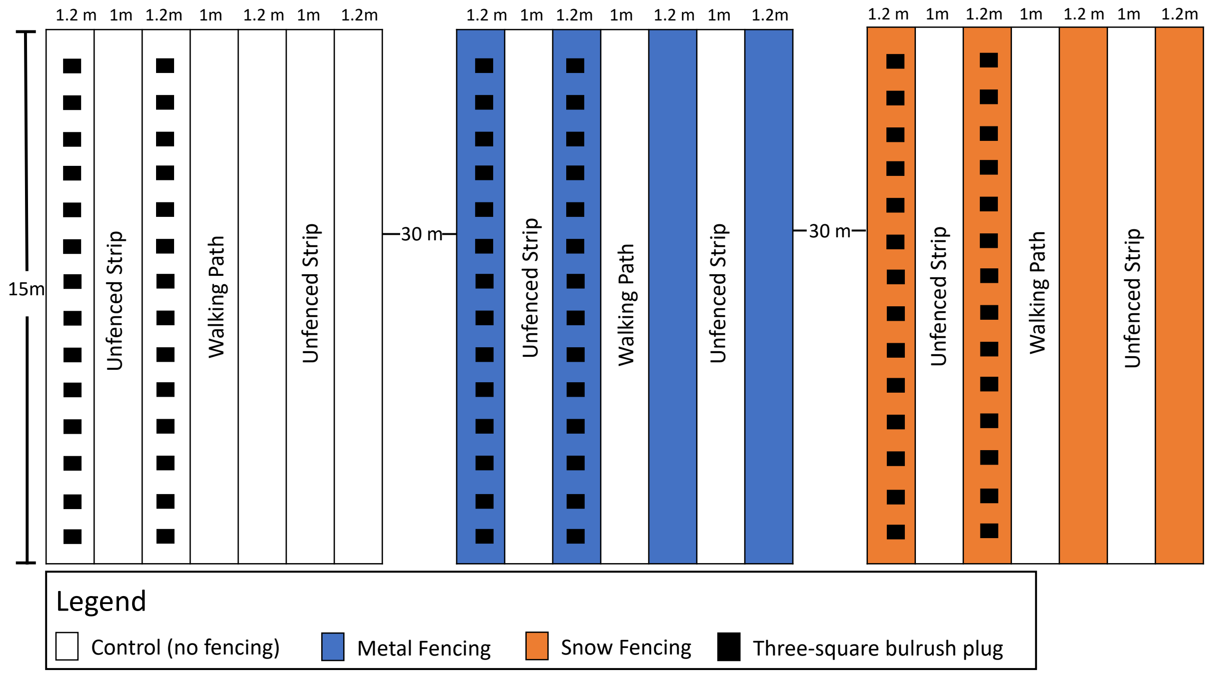

Figure 4: Schematic of the experimental design used for each of the six blocks in the study of goose herbivory deterrents in tidal marshes along Westham Island, BC. The locations of the three treatment types (control, metal fence, snow fence) were randomly assigned within each study block. Two strips in each treatment were each planted with 14 common three-square bulrush plugs, where bulrush was placed under fencing for the two fenced treatments. The walking path was used to facilitate stem density counts in the adjacent columns. The unfenced strips were used to assess the ability of the fencing to deter goose herbivory in adjacent unfenced areas

2.3 Field Methods

I visually estimated bulrush stem density and percent cover every two weeks from June to September 2021. To better understand the role of goose herbivory in altering bulrush density and cover, I also visually estimated the percent of stems that were grazed within each treatment. I also visually estimated stem density and percent of stems that were grazed in the two unfenced strips in each treatment to assess the ability of fencing to deter goose herbivory in adjacent unfenced areas.

2.4 Statistical Analyses

To assess the effectiveness of each treatment in deterring goose herbivory, I used ANOVA to contrast the difference in bulrush stem density, percent cover, and percent of bulrush stems grazed among treatments. In each of the ANOVA tests I included the date as an additional factor. I then used the Tukey Honestly Significant Difference (T.HSD) test to help identify differences among treatments. I explored transforming the percent cover and percent of bulrush stems grazed using two different transformations (log, arcsine square root). However, the statistical results using these transformations did not differ appreciably from the untransformed data, and thus I report results using untransformed data to enhance their interpretability. I used identical statistical analyses to contrast the difference in bulrush stem density and percent of bulrush stems grazed in the adjacent unfenced strips (avoiding the middle-unfenced strip that was used as a walkway). The unfenced striped stem count density was converted into percent of initial to standardize for pre-experiment differences among treatments. After initial analysis, the unfenced strips data indicated non-normal distribution. I explored using a log transformation to meet the ANOVA assumption of normal data. However, given that ANOVA is relatively robust to this violation given equal and modestly large sample size, the statistical results did not differ appreciably from the untransformed data. All statistical analysis was done in RStudio using an α level of 0.05.

3.0 Results

3.1 Bulrush in fenced areas

There was a difference in bulrush stem density among treatments ($F_{2,5} = 14.60$, $p < 0.001$) with lower density in the controls compared to both the snow fencing ($p = 0.002$) and the metal fencing ($p = 0.001$) (Fig. 5A). There was no difference in stem density between the two types of fencing ($p = 0.939$). There was a difference in percent cover of bulrush among treatments ($F_{2,5} = 7.87$, $p = 0.001$) with lower percent cover at the controls compared to both the snow fencing ($p = 0.011$) and the metal fencing ($p = 0.029$) (Fig 5B). There was no difference in percent cover between the two types of fencing ($p = 0.929$). There was a decline over time in both stem density ($F_{5,10} = 23.90$, $p < 0.001$) and percent cover ($F_{5,10} = 9.98$, $p < 0.001$) in all treatments.

In study block 1, the metal fence treatment was consistently an outlier throughout the summer period of data collection. Removing this block from the analyses again yielded a difference between the treatments in stem density ($F_{2,4} = 10.32$, $p < 0.001$), but in this case there was a higher stem density in the snow fencing versus the metal fencing treatment ($p = 0.005$). Similarly, removal of block 1 yielded a difference among treatments in percent cover ($F_{2,4} = 7.34$, $p = 0.001$), with a higher percent cover in the snow fencing versus the metal fencing treatment ($p = 0.022$). After removal of block 1 there was no difference between the control and metal treatments for both stem density ($p = 0.090$) and percent cover ($p = 0.454$).

Throughout the progression of the summer season, bulrush stem density and percent cover in the control treatment declined at a much faster rate than in fenced treatments (Fig. 5). The onset of declines in stem density and percent cover in all three treatments coincided with the arrival of many Canada geese in late July.

Grazing on bulrush was not observed until 22 July 2021. For observations after 22 July, there was a difference in the percent of bulrush grazed among treatments ($F_{2,5} = 11.54$ $p < 0.001$), with higher percent of stems grazed in the control compared to the snow fencing ($p = 0.002$) and the metal fencing ($p = 0.026$) (Fig 5C). There was no difference in percent of grazed stems between the two types of fencing ($p = 0.706$). There was an increase over time in percent of stems grazed ($F_{5,10} = 10.902$, $p < 0.001$) in all treatments.

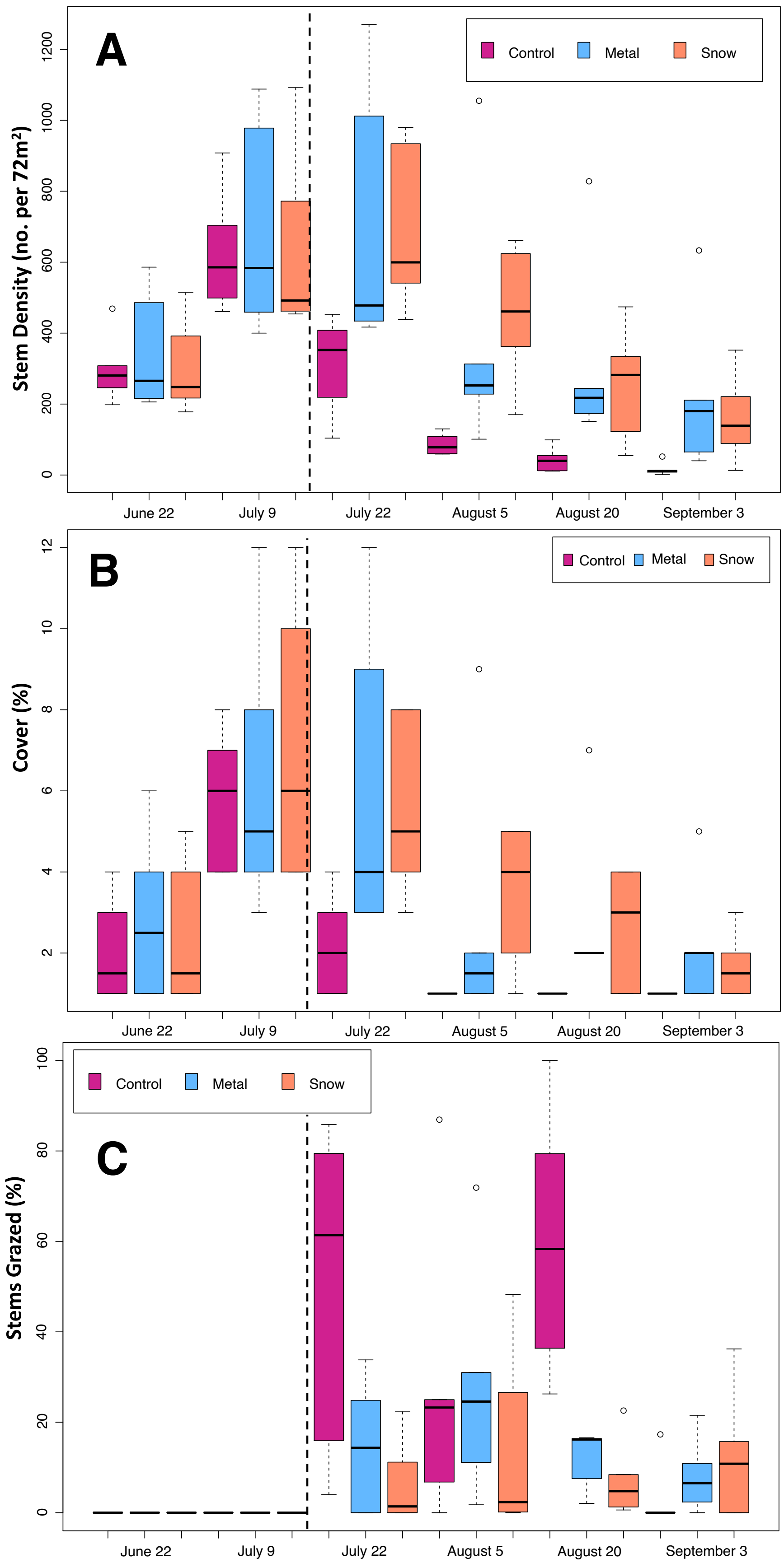

Figure 5: Change in bulrush stem density (A), percent cover (B), and percent of bulrush stems that were grazed (C) for the three herbivory deterrent treatments during the summer season (June-September 2021) at Westham Island, BC. Lower and upper box boundaries are the 25th and 75th percentiles, respectively, horizontal lines inside boxes are medians, lower and upper error bar lines are the 10th and 90th percentiles, respectively, and circles indicate outliers. The dashed vertical line indicates the timing of arrival of by the main influx of Canada geese to the study site.

3.2 Bulrush in adjacent unfenced areas

There was no difference in bulrush stem density in adjacent unfenced areas among treatments ($F_{2,5}$ = 1.27, p = 0.287) (Fig. 6A). There was no difference in percent of bulrush grazed in adjacent unfenced areas among treatments ($F_{2,5}$ = 1.77, p= 0.179) (Fig. 6B). There was also no change over time in stem density ($F_{5,10}$ = 2.46, p= 0.105) or percent of stems grazed ($F_{5,10}$ = 2.97, p= 0.067) in the unfenced areas in all three treatments. Although no statistical difference was noted between the treatments, areas adjacent to the fencing treatments maintained a higher stem density count and lower grazing pressure later into the summer compared to the control. In the control treatment the maximum grazing rate was nearly double that of the fenced treatments.

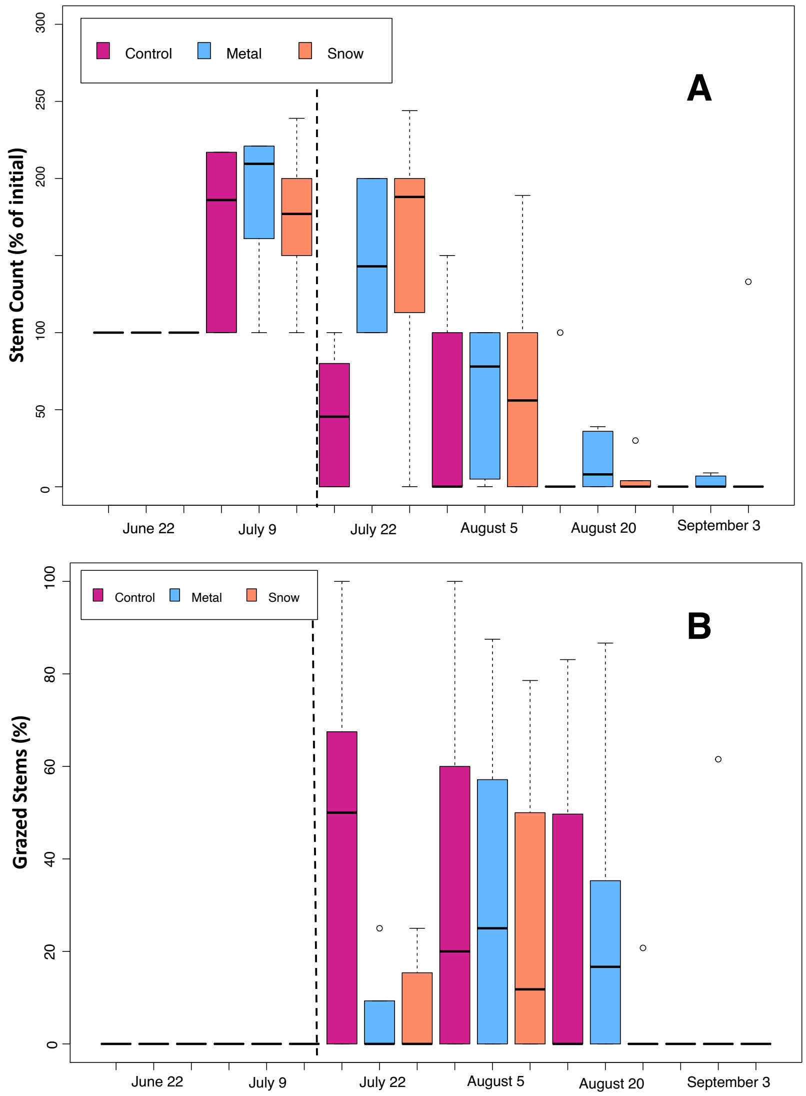

Figure 6: Changes in bulrush stem density (A) and percent of bulrush stems grazed (B) for the unfenced strips of all three herbivory deterrent treatments during the summer season (June-September 2021) at Westham Island, BC. Lower and upper box boundaries are the 25th and 75th percentiles, respectively, horizontal lines inside boxes are medians, lower and upper error bar lines are the 10th and 90th percentiles, respectively, and circles indicate outliers. The dashed vertical line indicates the timing of arrival of by the main influx of Canada geese to the study site.

4.0 Discussion:

Both snow fencing and metal fencing effectively deterred goose herbivory through mid-summer at Westham Island tidal marsh. All three treatments (snow fencing, metal fencing, control) saw a similar peak in bulrush stem density and percent cover in early July before the arrival of Canada geese. After the arrival of Canada geese in late July, there was a marked decline in bulrush stem density and percent cover in all treatments. However, the decrease in bulrush stem density and percent cover occurred faster in the control treatment compared to the metal and snow fencing treatments, suggesting that fencing provided some protection. The decline in stem density and percent cover in the fencing treatments can also be attributed to seasonal senescence of marsh vegetation.

One of the metal fencing treatments was consistently an outlier throughout the summer. When I removed the block with this outlier from analyses snow fencing had a higher percent cover and stem density of bulrush compared to metal fencing. This result could suggest that snow fencing might provide a higher level of protection against goose herbivory than metal fencing.

The initial results of the unfenced area showed that although not significant, the fenced treatments did provide some protection against herbivory in the unfenced adjacent regions. Shortly after the arrival of Canada geese in late July, the control treatment had higher grazing activity in the unfenced areas compared to the snow fencing and metal fencing treatments. In the fenced areas there was a sharp decline in bulrush stem density in the control treatment once the geese arrived (between 9 and 22 July 2021) while the metal and snow fencing treatments did not display this decline until later in the season (between 22 and 5 August 2021). This could suggest that the geese preferred to graze in areas with no adjacent fencing material but quickly moved on to the fencing treatments once the control treatments had little to no bulrush left to graze.

Given that both fence types performed similarly in terms of temporarily deterring geese herbivory, I contrasted them in terms of the following important criteria: cost, durability, maintenance, labour, and byproducts released (Table 1). The cost of metal fencing is nearly double of the snow fencing treatment. However, the metal fencing seems more durable than the snow fencing in the high-energy tidal zone (Appendix 2). Snow fencing will not biodegrade from the environment in a reasonable time unlike the metal fencing meaning that it will eventually have to be removed from the environment. Snow fencing will require yearly maintenance that entails manually lifting it before the growing season, replacing it on top of the substrate, and re-securing it with stakes. This action will prevent rhizomes from intertwining with the snow fencing. This yearly maintenance is not required of the metal fencing as it will ultimately biodegrade in brackish water. However, metal fencing may need to be re-secured to the stakes every year as parts of the fence biodegrade and become unattached to the stakes (Appendix 2). Snow fencing is lighter and easier to transport and manipulate, resulting in reduced installation labour than metal fencing. Although snow fencing degrades more slowly than metal fencing the longer the snow fencing is in the mudflat, the more it will fragment and degrade into the environment and settle into the sediment as microplastics (Huang et al. 2021). Microplastics can impact animals by impairing growth, development, reproduction, and, in some cases, causing death (Li et al. 2020; Huang et al. 2021). Plant roots can absorb microplastics and nanoplastics from the sediment, inhibiting their growth (Li et al. 2020). The galvanized metal fencing has a layer of zinc that can leech into the soil as the fence starts to biodegrade. Zinc can have both beneficial and toxic effects on vegetation growth. Zinc is essential in the development and function of plant chloroplasts (Sharma et al. 2013). Zinc is often strongly bound to manganese (Mn) oxide and iron (Fe) which limits its uptake by plants, and this deficiency can lead to reduced plant growth and a lower tolerance to stressors (Sharma et al. 2013; Tuiwong et al. 2021). However, Arreghini et al. (2001) showed that excess zinc can severely limit the growth of California bulrush (*schoenoplectus californicus*) rhizomes. Baseline levels of zinc in the soil must be identified to determine the effects of the leached zinc on vegetation growth.

In a zinc-limited environment, the leeching zinc may be beneficial to plant growth; however, in a zinc-rich environment, the added zinc may cause plant dieback.

Table 1: Comparison of snow and metal fencing treatments for reducing goose herbivory in terms cost, durability, maintenance, labour,and byproducts released. These comparisons are relative and are explained more thoroughly in the text.

Fencing Type	*Cost (per ha)* *	*Durability*	*Maintenance*	*Labour*	*Byproducts released*
Galvanized Metal	$49,500	Medium	Medium	High	Zinc
Snow	$26,500	Low	High	Medium	Microplastics

* Cost is based only on materials and does not include other costs such as transportation and installation.

In most cases, metal fencing may be the better long-term option to deterring goose herbivory. Although the initial cost of using metal fencing is higher, this type of fencing is more durable, requires less yearly maintenance, and releases a less harmful byproduct. However, given that Canada geese seem to be a more significant threat to marsh vegetation than snow geese, it may not be necessary to maintain deterrents throughout the entire year (Gan 2021; Appendix 1). Canada geese graze at the Westham Island marsh from late July until late October. If the aim is to reduce mainly Canada goose herbivory, snow fencing may be the better option as it is lighter and thus easier to install. Further, removing snow fence after every growing season would eliminate the need for yearly maintenance. The durability of snow fencing will no longer be a big concern as it will be removed yearly allowing fencing to last longer as it will only be exposed to the environment 4 months instead of 12 months.

Although my initial results suggest this novel deterrent effectively mitigates goose herbivory, further experimentation is needed to assess its viability as a management tool. The senescence of marsh vegetation coincides with the arrival of snow geese to the site, and this limits our ability to assess the effects the deterrents have on snow geese grazing. Snow geese are more likely to grub the substrate to access the bulrush rhizomes (Boyd 1995). A multi-year study is needed to assess the ability of the fencing treatments to aid in the recovery of marsh vegetation. The durability of both metal and snow fencing is not as high as is necessary to last an entire year in the foreshore tidal marsh. I recommend testing different materials such as nylon or stainless-steel fencing to see if a more durable material can be used. It is also crucial to experiment with other anchoring methods, such as using longer stakes. There were many missing stakes by mid-February, leading me to believe that longer stakes may be needed to secure the fencing. Lastly, I recommend further experimentation on the fencing's ability to deter goose herbivory in adjacent unfenced areas. Although not significant, my results indicated that fencing could potentially protect marsh vegetation in areas immediately adjacent to the fence. It would be beneficial to understand how far apart fencing strips can be placed and still provide protection to the unfenced adjacent regions. Understanding this maximum spacing of fencing will help to reduce considerably the cost of the deterrent.

Managing goose herbivory is an effective step in restoring marsh vegetation. However, for marsh vegetation to recover, I believe herbivory deterrents must be complemented by methods designed to reduce goose numbers. Goose populations will continue to rise as climate change enhances conditions on their breeding grounds and as agriculture continues to increase feeding opportunities. I recommend using a combination of physical deterrents to mitigate goose herbivory and lethal methods to control geese populations (culling, hunting, egg addling, and oiling). This combination has proven effective on Vancouver Island, where a private organization, Guardians of the Mid-Island Estuaries, has successfully worked with First Nations and the provincial government to harvest Canada geese and use eco-cultural goose herbivory deterrents to restore tidal marsh vegetation (Auger 2021). Lethal methods of controlling goose populations are often not socially acceptable and may cause controversy. Therefore, I recommend educating the public about hyperabundant goose populations and their effects on marsh ecosystem services. Educational material should include information on methods used to control goose populations. The more educated the public is about the detrimental impacts of hyperabundant goose populations, the less likely one will face controversy when looking at lethal means of controlling goose populations.

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Appendix 1

A1.1 Effects of Canada Goose (*Branta canadensis*) and Snow Goose (*Chen caerulescens*) Herbivory on Tidal Marsh Recession at the Westham Island Marsh (Year 2)

Gan (2021) was the first year of a multiyear study focused on determining the relative effects of Canada geese versus snow geese on the abundance of common three-square bulrush on Westham Island foreshore tidal marsh. The study consists of two field-based experiments, a marsh edge exclosure experiment and a mudflat exclosure experiment. The marsh edge exclosure experiment was conducted to assess how common three-square bulrush will respond in the absence of goose herbivory, while the mudflat exclosure experiment was conducted to assess the ability of the mudflats to revegetate in the absence of goose herbivory. Each experiment consists of four blocks, each with four treatments (no grazing, excludes snow geese grazing, excludes Canada geese grazing, excludes both species grazing). The marsh edge exclosure experiment straddled the vegetated edge of the tidal marsh while the mudflat exclosure experiment was conducted in the mudflat (Fig A1-1).   I collected data following methods outlined in Gan (2021) for both experiments.

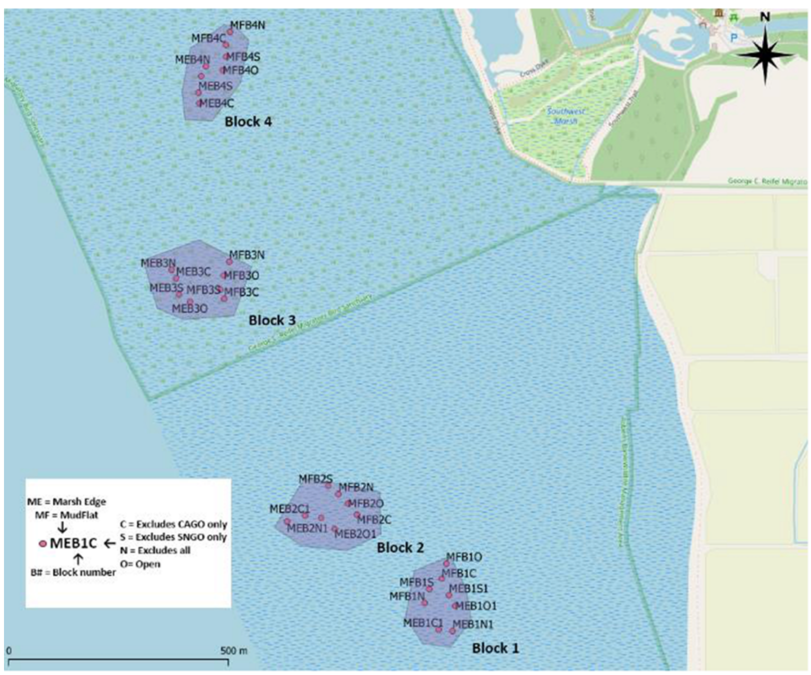

Figure A1- 1: Locations of study blocks and treatments for the two experimental studies (marsh edge and mudflat) at Westham Island, BC. Map Source Gan (2021).

A1.2 Year 2 Results of Gan (2021) Marsh Edge Exclosure Experiment

The year 2 results for this study followed a similar trajectory as the year 1 results. There was a difference in bulrush percent cover among treatments ($F_{3,2}$ = 11.43, $p < 0.001$), where cover was lower in plots that exclude snow geese compared to the no grazing exclosures (p < 0.001) and to plots that exclude only

Canada geese ($p < 0.001$) (Fig A1-1). There was no difference among the open grazing treatment compared to both the Canada goose exclosure ($p = 0.100$) and the snow goose exclosure ($p = 0.196$).

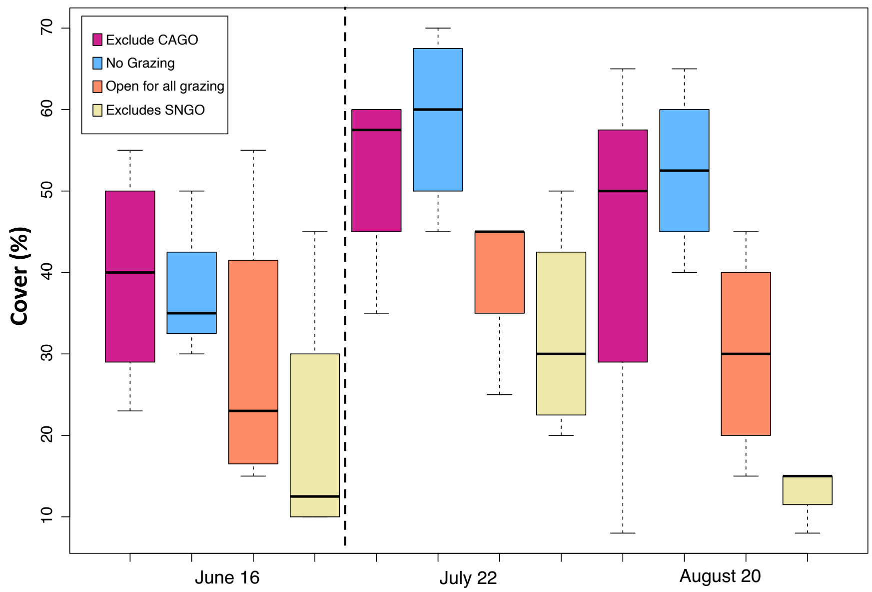

Figure A1- 2: Change in percent cover for the four treatments aimed to assess Canada and snow goose herbivory located in the marsh edge during the summer season (June-August 2021) at Westham Island, BC. Lower and upper box boundaries are the 25th and 75th percentiles, respectively, horizontal lines inside boxes are medians, lower and upper error bar lines are the 10th and 90th percentiles, respectively, and circles indicate outliers. The dashed vertical line indicates the timing of arrival of by the main influx of Canada geese to the study site.

A1.2 Year 2 results of Gan (2021) Mudflat Exclosure Experiment

The year 2 results for this study followed a similar trajectory as the year 1 results. There was a difference in bulrush percent cover among treatments ($F_{3,2} = 49.32$, $p < 0.001$), where cover was lower in the snow goose exclosure compared to the no grazing exclosure ($p < 0.001$) and the Canada goose exclosure ($p < 0.001$) (Fig A1-3). There was no difference among the snow goose exclosure and the open grazing treatment ($p = 0.929$). Unlike like the year one there was a difference between the Canada goose exclosure and the permanently closed exclosure ($p = 0.018$) (Fig A1-2).

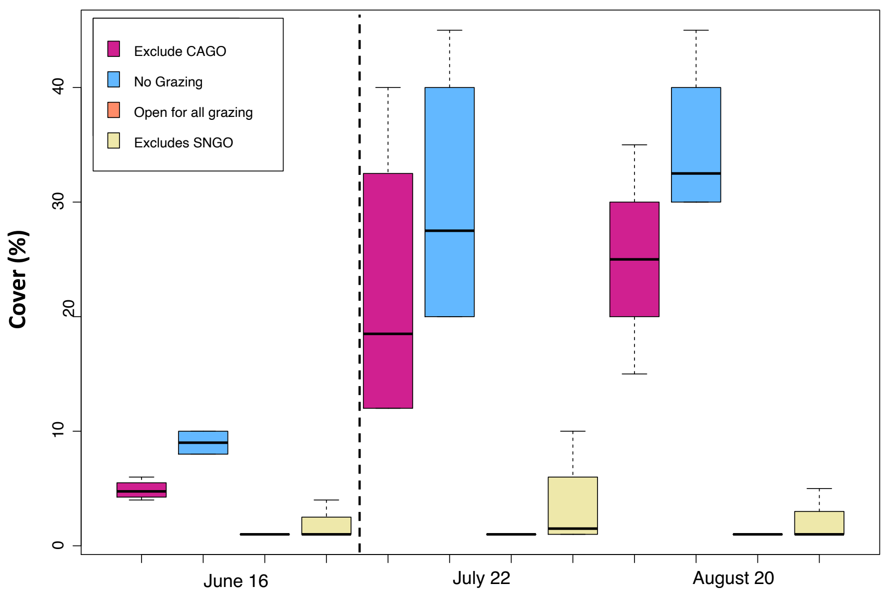

Figure A1- 3: Changes in percent cover for the four treatments aimed to assess Canada and snow goose herbivory located in the unvegetated mudflat during the summer season (June-August 2021) at Westham Island, BC. Lower and upper box boundaries are the 25th and 75th percentiles, respectively, horizontal lines inside boxes are medians, lower and upper error bar lines are the 10th and 90th percentiles, respectively, and circles indicate outliers. The dashed vertical line indicates the timing of arrival of by the main influx of Canada geese to the study site.

Appendix 2

Photo Monitoring Examples

I set up four photo monitoring stations at each treatment using 60 cm wooden stakes, placed 5 meters from the edge in each of the four cardinal directions. I assessed changes in bulrush abundance and structure over time by contrasting photos taken during the peak and end of the bullrush growing season (i.e., mid-July vs. late September). I also took photos of the conditions of the plots in late February 2022.

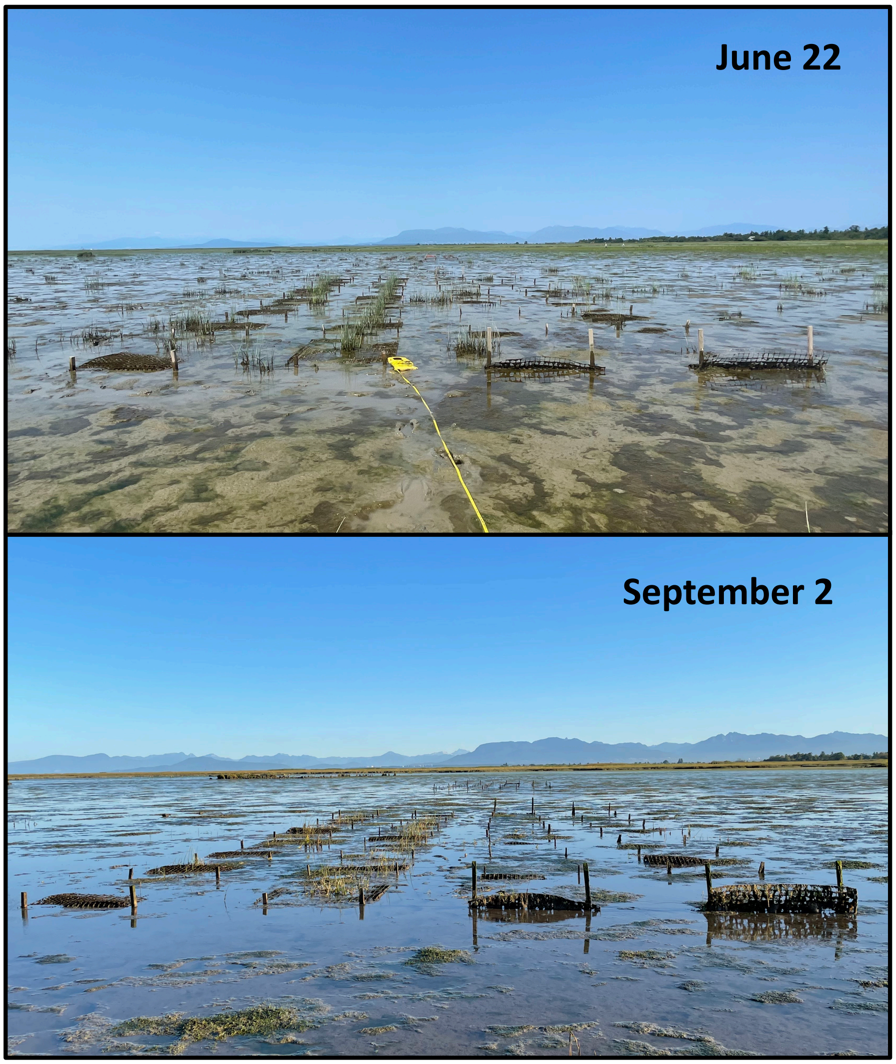

Figure A2- 1: Photos showing change in vegetation in experimental block six at Westham Island, BC tidal marsh from June to September 2020.

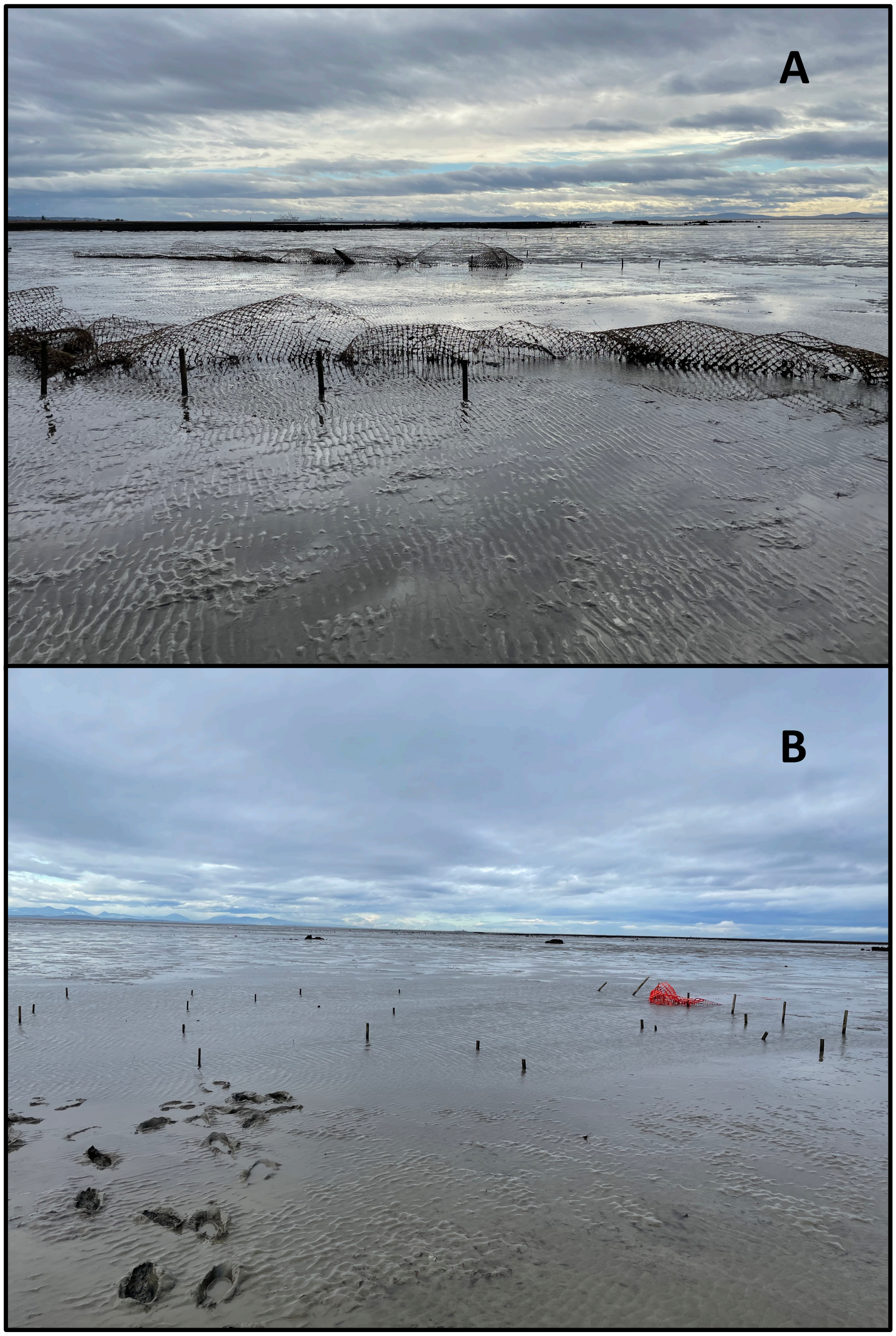

Figure A2- 2: Condition of A) metal fencing and B) snow fencing goose deterrents in mid-February 2022 at Westham Island, BC.