Introduced Canada Geese in the Fraser River Estuary

A Conservation Challenge

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Disclaimer

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Canada Goose eating sedge, Fraser River Estuary

Executive Summary

The Fraser River Estuary (FRE) is Western Canada's largest estuary—it is a highly productive and biodiverse place, rich in wildlife where people have lived and gathered since time immemorial. Its vast complexity has increased significantly over the last two centuries as a result of its central role in the society and economy of Canada. Only 10-15% of the estuary's historic wetland habitats remain, and it is progressively becoming home to increasingly more invasive species and losing its biodiversity.

Canada Geese (CAGO) were introduced to the FRE around 1970. These introductions were intentional, resulting in a large hybrid population of non-migratory, resident CAGO in the FRE and the Lower Mainland of British Columbia (BC). There are now close to 5,000 resident CAGO in the FRE during the summer and more than 20,000 that winter throughout the Lower Mainland. Resident CAGO in the FRE are supported year-round by native marsh vegetation (i.e., sedges) where they graze on stems and leaves, and grub (excavate) for rhizomes and roots.

Although CAGO are native to much of North America, they have been extensively introduced across temperate North America over the last century, resulting in conflicts with human activities and environmental impacts in many areas. Historically, migratory CAGO populations would stop for only a few days each year in the FRE as they migrated north to breed or south to overwinter, and this had negligible impacts on the FRE ecosystem. Ecological impacts to wetland ecosystems by resident CAGO have been observed on the East and West Coasts of North America including Vancouver Island and the Gulf Islands in BC, inciting a number of successful and ongoing mitigation strategies.

This study on the ecological impacts of resident CAGO on sedge marshes in the FRE began in 2021. At 19 sites with sedge-dominant marshes, paired vegetation plots—one exclosed to CAGO herbivory paired with a control plot open to herbivory—at the marsh leading-edge were erected in July 2021 and monitored for one year. A total of 4,734 CAGO were counted over a 5-day period between 2-7 July 2022, in the FRE where CAGO were suspected to occur during the summer. Preliminary results from the first year of this study are presented herein.

Between July 2021 and July 2022, sedge height along marsh leading-edges at sites where CAGO herbivory was occurring increased on average by 43.6 cm ($p<0.001$, paired, two-sided t-test) within exclosures protected from CAGO herbivory. During the growing season from April to July 2022, sedge height increased at a rate of 0.76 cm/day when protected from CAGO foraging compared to 0.33 cm/day when exposed to CAGO foraging. In addition, stem density (per 0.25 m^2 sample area) increased on average by 20.4 stems in exclosed plots ($p<0.001$) but decreased by 19.9 stems in open plots ($p=0.005$). These preliminary findings are part of a larger study that will inform management activities to mitigate CAGO impacts on sedge marsh habitats in the FRE.

Glossary and Acronyms

BC: British Columbia

CAGO: Canada Geese

Estuary: Where freshwater meets saltwater (i.e., where the river meets the ocean).

Exclosure: A fenced area designed to prevent entry from wildlife, such as geese.

Fraser Valley & Lower Mainland: These regions are similar in area and are used interchangeably here. See map in Figure 1.

FRE: Fraser River Estuary

Grazing: Eating plant stems or leaves.

Grubbing: Eating belowground rhizomes and roots.

Herbivory: Consumption of plant material.

Resident/Introduced CAGO: Non-migratory CAGO that were introduced to an area and typically reside in a given area year-round.

Salish Sea: Also known as the Georgia Straight. See map in Figure 1.

Sedge: A type of grass-like plant that grows in wetlands (i.e., *Carex* spp.), most commonly the Lyngbye's sedge (*Carex lyngbyei*) that predominates in estuarine tidal marshes.

Tidal Marsh: Coastal ecosystem regularly flooded by tides.

Southern Coastal BC: The Lower Mainland, Southern-Central Vancouver Island, and the Gulf Islands.

Canada Geese at a heavily grazed sedge marsh, Fraser River Estuary

Introduction

For most people, the news that Canada Geese (*Branta canadensis;* CAGO) are a recent arrival to Southern British Columbia (BC), will come as a surprise. Systematic introductions to BC began only in the late 1960s and 1970s and, since then, Canada Geese have colonized much of Southern Coastal BC. Where they have established, they have negatively impacted native vegetation communities.

The Lower Fraser River and its estuary support the largest concentration of industrial activity in BC and a growing population of over 4 million residents. The Fraser River Estuary is an internationally recognized stopover site for hundreds of thousands of migratory birds (Butler et al., 2021) and forms the end of one of the greatest salmon rivers on the planet, the Fraser River (Groulx et al., 2004). People have lived on the Lower Fraser for millennia supported by its high productivity and abundance of wildlife. Draining over a quarter of the province, nutrient rich sediment from the Fraser along with the bodies of millions of salmon, fertilized the forests and floodplains of the Lower Fraser for thousands of years (Groulx & Mustard, 2004). Over the past century the estuary has been altered beyond recognition in many places, with less than 15% of the floodplain habitats remaining (Finn et al., 2021) and over 102 species now at risk of extinction (Kehoe et al., 2020).

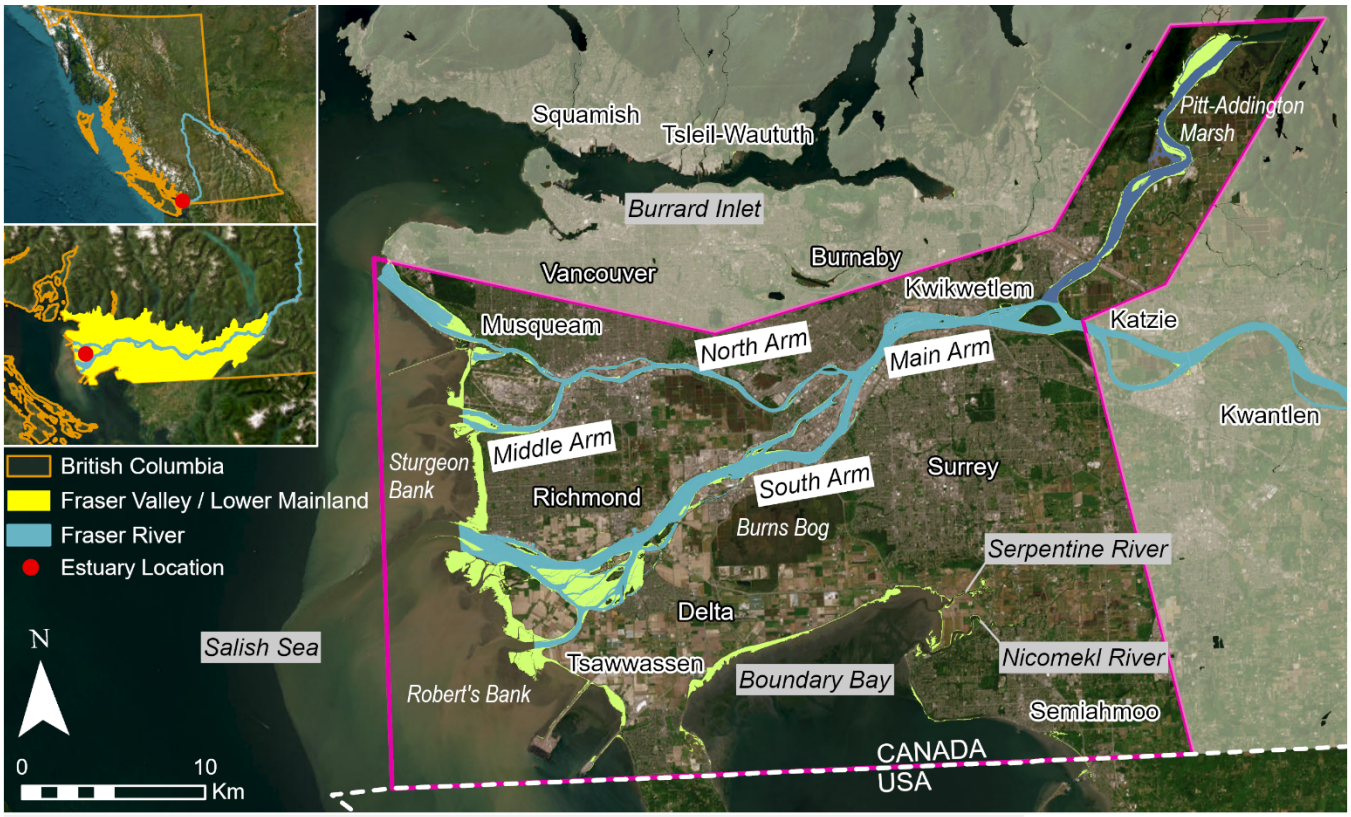
Marsh vegetation is at the interface between terrestrial and marine environments and plays a particularly important role in the Fraser River Estuary (FRE). The FRE's intertidal zones experience tidal fluctuations of up to 4 meters on a daily basis and are subject to strong currents and storms. Almost every stretch of coastline and riverbank in the FRE hosts marshes, with sedges (*Carex* spp.) being among the dominant plants. Sedge marshes are critical primary producers in the FRE's food web. They provide vital habitat for juvenile salmon (Chalifour et al., 2021) and attenuate wave and storm activity, protecting land from erosion.

The FRE provides favourable conditions for plant growth over extensive intertidal areas where salt-tolerant sedges can thrive. However, recent evidence suggests that herbivory by thousands of resident CAGO is causing significant marsh habitat loss, and likely broader negative ecological impacts. Evidence from census data suggests that the number of CAGO in the FRE has increased exponentially in recent decades (National Audubon Society, 2020), posing a conservation challenge.

This report provides a brief history of the FRE and its ecological significance. It reviews what is currently known about CAGO biology, ecology, and introductions to the FRE, and highlights research underway to fill key gaps in our understanding. It is hoped that through knowledge sharing and collaboration, we can find cost-effective CAGO management approaches to help protect and even restore important ecological processes in the FRE.

The Fraser River Estuary

An estuary forms where a river (freshwater) meets the sea (saltwater). The FRE[1] is an ecologically diverse area of approximately 1,000 km^2 formed at the meeting place of the Fraser River and the Salish Sea (Figure 1). This confluence of water is so rich in nutrients and fish that humans and animals have lived off its bounty for millennia (Appendix A).



Localities around the Fraser River Estuary

Delineation of the upriver (Eastern) extent of the estuary study area is shown here as the boundary line east of the Pitt River, however, the spatial boundary of the FRE can vary based on study context. First Nations' communities are represented by their approximate current localities, not precisely overlapping with the traditional unceded territories. Not all existing municipalities are labelled in the map.

Spatial data sources: Metro Vancouver Open Data Catalogue, BC Data Catalogue
Service layer credits: Earthstar Geographics, VFPA
Map projection: NAD 1983 BC Environment Albers
Date: August 4, 2022

Estuary Study Area
Fraser River
Pitt River
Tidal Marsh
Abc Waterbody
Abc Municipality
Abc Fraser River Arm
Abc First Nations Community
Abc Notable Landmark

Figure 1. *Fraser River Estuary; highlighting the Fraser River and Pitt River, tidal marsh habitats, municipalities, First Nations communities, and notable landmarks.*

[1] For the purpose of this report, the Fraser River Estuary (FRE) is the water and wetlands reaching from the foreshore (the western shore including Sturgeon Bank), past the point where the Fraser River and Pitt River converge to include the Pitt-Addington Marsh (see map in Figure 1).

As a globally significant stopover site for migratory birds, one of the world's most productive salmon rivers, and a highly efficient carbon sink, the FRE has immense value. The diverse Coast Salish Peoples of the Lower Fraser River maintained the health and well-being of the FRE through sustainable stewardship since time immemorial (LFFA-RELAW, 2021).

Many juvenile salmon depend on FRE marshes for food and habitat. Salmon fisheries in the Fraser River are foundational to communities and culture (Reid et al., 2022). Indigenous, commercial, and recreational salmon fisheries in BC are closely managed, and despite declines in recent decades they continue to have immense cultural and economic value (DFO, 2022).

Approximately 1.7 million birds of 263 different species use the tidal flats, floodplains, and marshes of the FRE annually (Butler et al., 2021). This makes the FRE and its delta the most important area in Canada for migratory and wintering waterfowl, shorebirds, songbirds, and raptors (Harrison et al., 2022).

As climate change increases the frequency and severity of potential floods, marshes in the FRE provide a natural line of defence that protects the communities from flooding (IPCC, 2014; Marin-Diaz et al., 2022).

Sandhill Cranes & Robert's Bank Deltaport

The FRE also supports one of the largest and most diversified ports in North America (VFPA, 2020a). Industrial activity and development in the FRE's sensitive waterways are integral to the local and national economy (Figure 2). Management of the FRE has a complicated past[2], and its future depends on better collaboration to ensure that ecosystem and community prosperity are not undermined by the push for incessant industrial growth. A co-governance structure with legislated framework has been identified as a means to achieve more effective conservation in the FRE (Kehoe et al., 2020, Suppl. S4).

Figure 2. *Log storage on the Fraser River (top-left), barge storage on the Fraser River (top-right), tidal marsh adjacent to agricultural land (bottom-left), industrial infrastructure on the shoreline of the Fraser River (bottom-right).*

[2] https://registrydocumentsprd.blob.core.windows.net/commentsblob/project-80496/comment-47754/FREMP%20Overview%20History%20of%20the%20FREMP%20OEL%20May2019FINAL.pdf

Introduced Canada Geese

Canada Geese Introductions and Population Growth

Canada Geese (*Branta canadensis*) are native to North America. They are a diverse group of waterfowl with broad adaptability to different habitats (Dickson, 2000). Consequently, historic breeding ranges remain unclear for some CAGO subspecies, especially the "giant" Canada Goose (*B. c. maxima*) that bred in milder, temperate zones (Hanson, 1965). CAGO were transient through Southern Coastal BC and the FRE prior to the mid-twentieth century as they stopped over for only a few days each year during spring and fall migrations. Indigenous and anthropological records and historical survey observations reviewed by Dawe & Stewart (2010) suggest that native CAGO did not breed in Southern Coastal BC and the FRE prior to European colonization.

In response to CAGO population declines in North America and in recognition of their recreational values (e.g., hunting), conservation measures and regulations were implemented to increase CAGO abundance and create new populations (Hanson, 1965; Smith et al., 2000). Captive breeding programs, relocations, introductions, and other measures to increase CAGO numbers occurred in urban, suburban, and protected areas across temperate North America around 1960-1990 (Dickson, 2000; Dennis et al., 2000; Smith et al., 2000). By 1990, CAGO management began shifting towards mitigation of emerging conflicts from new populations.

CAGO that currently breed and reside year-round in the Fraser Valley, FRE, and across Southern Coastal BC were introduced[3]. A systematic program around Vancouver and the Fraser Valley during the late 1960s and 1970s sourced CAGO primarily from Southern Ontario and Alberta, comprising 3 subspecies[4] (*B.c. maxima, B.c. interior,* and *B.c. moffitti*; Smith, 2000) and this resulted in a hybrid, resident CAGO population. The objectives of these introductions were to increase wildlife viewing and hunting opportunities (BC Ministry of Environment, 1979; Smith, 2000). However, hunting became increasingly limited due to urban expansion, while the abundance of water, greenspace, and farmland provided ideal habitat for CAGO to proliferate (Figure 11, Appendix A). The geese were effectively introduced into an environment where migration was unnecessary, habitat and resources were plentiful, and predation was minimal. Smith (2000) provides a detailed account of CAGO introductions in the Fraser Valley, as well as management recommendations.

Relocations of CAGO from certain areas (e.g. Stanley Park, Burnaby Lake, Deer Lake) that took place throughout 1970 to 1996 served to grow and disperse their population throughout the Fraser Valley (Smith, 2000; Appendix B, Figure 12). Today, there are more than 20,000 CAGO throughout the Fraser Valley (Figure 3; National Audubon Society, 2020).

Canada Geese at marsh edge, Fraser River Estuary

[3] The terms "resident" and "introduced" are used interchangeably to describe introduced CAGO populations.

[4] The Vancouver Canada Goose (*B.c. fulva*) is the closest breeding subspecies in proximity to the Fraser Valley, known to nest on Northern Vancouver Island (Dawe & Stewart, 2010), and it was not included in the introductions.

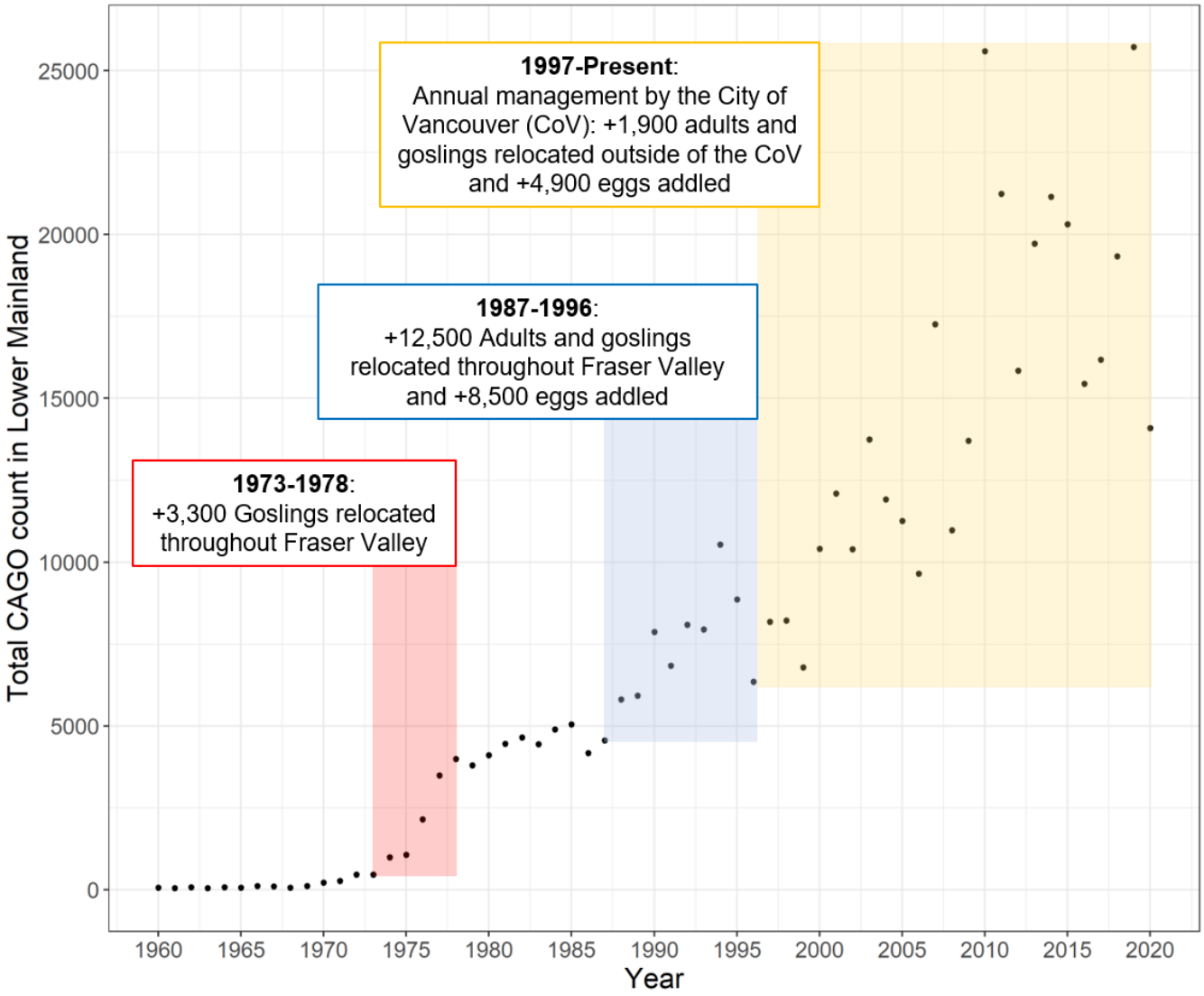


Figure 3. *Increasing abundance of wintering CAGO in the Lower Mainland based on Christmas Bird Counts (CBC; National Audubon Society, 2020), past management actions from 1960 to 1995 (Smith, 2000), and more recent management in the City of Vancouver (Pierce, 2016; K. Lauer, unpublished data, Sept 12, 2022). The Lower Mainland total count comprises data from the CBC count areas of Vancouver, Langley, Pitt Meadows, White Rock-Surrey-Langley, Abbotsford-Mission, Chilliwack, and Harrison River. For years where data were missing for CBC areas, the mean of the closest prior and later years with data were used.*

Biology and Ecology of Canada Geese

There are at least 11 recognized subspecies of CAGO in North America[5], variable in their breeding habitats, behaviour, and morphology (Dickson, 2000; Mowbray et al., 2020). CAGO are monogamous,

[5] https://www.allaboutbirds.org/guide/Canada_Goose/overview

forming life-long bonds between breeding pairs. Nesting begins in early spring, where a clutch of 2 to 8 eggs is typical (Mowbray et al., 2020; Figure 4). Females have high nest site fidelity, meaning that they return to the same locations to nest year after year. A young CAGO (gosling) will reach the size of an adult in about 30 days of age, becoming fully feathered and closely resembling an adult after 60 days (Yocom & Harris, 1965). Adult CAGO remain relatively close to their nest site when raising young through the spring. Beginning around mid-June in Southern Coastal BC, CAGO begin their annual wing and feather molt when they are flightless for at least 3 weeks (see Figure 5 for details on CAGO phenology and habitat preference in the Lower Mainland).

Figure 4. *Adult CAGO and 1-week old gosling (left), CAGO nest (right)*.

CAGO are highly adaptable to various natural and altered landscapes. During the breeding season and when CAGO are molting and incapable of flight (Figure 5), their increased vulnerability causes them to remain close to open water for safety. This makes the molting season an ideal time to survey CAGO since their habitat is predictable and they cannot fly between areas. Otherwise, they frequently occupy waterbodies (i.e., lakes, ponds, rivers, estuaries, bays, inlets), farmland, parks, greenspaces, and wetlands throughout the year.

CAGO are herbivores, meaning that they eat plant material exclusively (Mowbray el al., 2020). Resident CAGO rely primarily on graminoids (grasses, sedges, and rushes) and agricultural crops. Domesticated grasses found in parks and golf courses are a year-round favourite and Lyngbye's sedge (*Carex lyngbyei*),

the FRE's dominant sedge species, is consumed extensively (Stewart et al., 2022). Their large size (4-5 kg) and inefficient digestive system lead CAGO to feed regularly, consume a lot, and defecate frequently.

Another determinant of where and when CAGO use certain habitats in the FRE is sport hunting. CAGO are protected and managed under Canadian federal law; the *Migratory Birds Convention Act,* 1994, and its associated regulations. The hunting season for CAGO in the Lower Mainland spans a total of 108 days with a daily bag limit of 10 birds, and is split into four separate periods between 3 September and 10 March[6] (Figure 5).

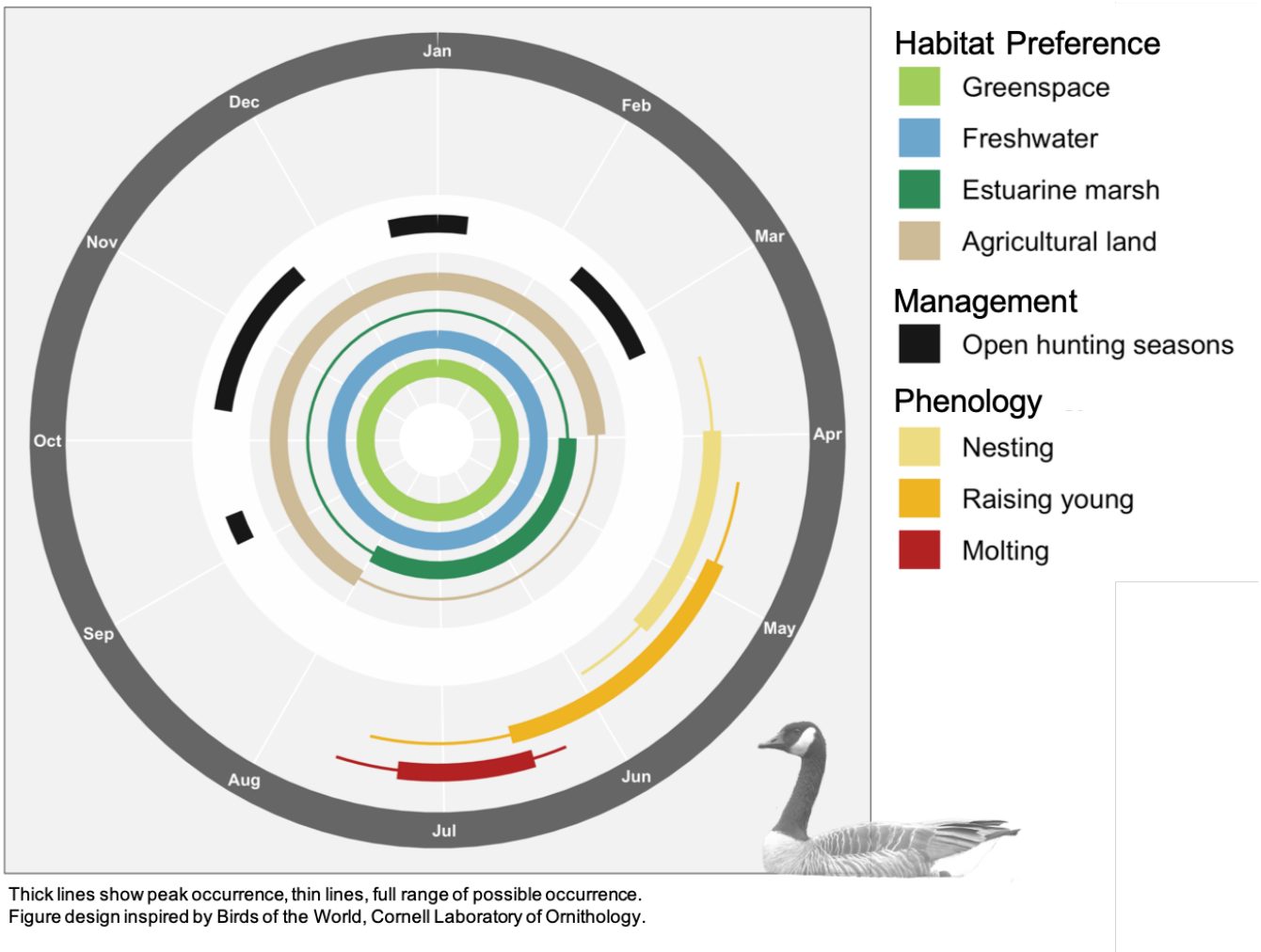


Figure 5. *Habitat preference, management (hunting), and phenology (annual life cycle events) of resident CAGO in the Lower Mainland of BC. Data sources include eBird (2022), Clermont (2015), and personal observations.*

[6] https://www2.gov.bc.ca/gov/content/sports-culture/recreation/fishing-hunting/hunting/regulations-synopsis#fraservalley

A Conservation Challenge

Impacts to ecosystems by introduced CAGO have been documented around the globe (e.g., Allan et al., 1995; Nichols, 2014), and locally in BC (e.g., Dawe et al., 2011, 2015). The tidal marshes of the FRE are a primary food source for thousands of resident CAGO each summer. Many also feed on the marshes during the spring breeding season, and year-round in some areas. Feeding takes place in the form of grazing aboveground stems and grubbing belowground components (rhizomes and roots), which inhibits plant growth and compromises substrate stability.

Management Issues

New resident CAGO populations in urban and suburban areas across North America have led to various conflicts with human activities and management challenges (Smith et al., 2000; USFWS, 2005). These include threats to air traffic near airports, fouling of public areas with feces, consumption of agricultural crops, and defensive behaviour towards people during the breeding season when CAGO are especially territorial (Breault & McKelvey, 1991; Mowbray et al., 2020). Introduced CAGO populations threaten wetlands in Eastern North America (Haramis & Kearns, 2007; Nichols, 2014), and create ecological and economic problems in areas where they have been introduced (Allan et al., 1995; Ankney, 1996; Reyns et al., 2018). In the Fraser Valley, CAGO are a nuisance on agricultural land and at many golf courses (Breault & McKelvey, 1991; Anonymous, personal communication, September 8, 2021).

Heavily grazed and eroding sedge marsh, Fraser River Estuary

Ecological Impacts in Southern Coastal BC

CAGO are now abundant breeders across Southern Coastal BC (Appendix B, Figure 13). Around the same time CAGO were brought to Metro Vancouver and the FRE, they were introduced to Vancouver Island (Dawe & Stewart, 2010). Resident CAGO are now common along the east coast of Vancouver Island, and their herbivory has degraded marshes in many small estuaries. Two of these estuaries lost an estimated 12-17 tonnes (dry mass) of plant material annually after becoming popular feeding grounds for introduced CAGO (Dawe et al., 2011, 2015). CAGO have also occupied the Gulf and San Juan Islands in the Salish Sea, where they are contributing to the loss of endangered plant communities and facilitating the spread of invasive plant species (Best & Arcese, 2008; Isaac-Renton et al., 2010). Where introduced CAGO impose a novel threat to native species or ecosystems, they are considered *invasive*.

In response to CAGO impacts on Vancouver Island, considerable restoration and mitigation work has occurred in recent years led by the Guardians of Mid Island Estuaries Society (GoMIES) and several First Nations Guardian Watchmen groups (Clermont, 2015). Five major estuaries on Vancouver Island's east coast have large eco-cultural restoration projects currently underway, all led by First Nations. An expansive, well-coordinated CAGO egg-addling program deployed from Campbell River to the Capital Region District facilitated by GoMIES and First Nations Guardian Watchmen groups is mitigating CAGO population growth and providing CAGO management training for Guardian groups on their traditional territories (G. Ashley, personal communication, July 29, 2022).

Ecological Significance and Threats in the Fraser River Estuary

The FRE's marshes are already severely threatened by factors such as industrial and agricultural development, dredging and dyking, invasion of non-native plants, and erosion from boat wake (Groulx et al., 2004; Boundary Bay Conservation Committee, 2016; Stewart, 2021). Up to 90% of wetlands in the FRE have already been lost since colonial settlement (Boyle et al., 1997). Sedge marshes are one of the most important primary producers of organic matter for the FRE ecosystem that includes insects, fish, shellfish, and birds (see Appendix C). Chinook salmon (*Oncorhynchus tshawytscha*) that rely on FRE marsh habitats make up >80% of the diet of endangered Southern Resident Killer Whales in the Salish Sea[7]. Impacts by CAGO in the FRE have been documented in recent decades (e.g. Adams & Williams, 2004); however, the issue persists and has not been mitigated. CAGO are being considered in some proposed marsh restoration projects due to the threat they pose to vegetation growth, including habitat offset plans for the proposed Robert's Bank Terminal 2 (VFPA, 2020b). Many sedge marshes being impacted by CAGO are only at a fraction of the biomass of a typical sedge marsh (Figure 6). Research from the Conservation Decisions Lab at UBC is currently investigating the impacts of CAGO in the FRE, the significance of these impacts to ecosystems and communities, and management recommendations.

[7] https://wwf.ca/species/southern-resident-killer-whales/

Figure 6. *Sedge marsh heavily grazed and grubbed by CAGO (left) and typical un-grazed sedge marsh (right) in the Fraser River Estuary, BC.*

Current Research

Background

Marsh restoration and creation in the FRE began in the 1980s, as mandated by new fisheries policies requiring 'no net loss' to fish habitat (DFO, 1986). Since then, various projects aimed to restore sedge marshes and other wetland habitats at sites across the FRE have occurred to varying levels of success (Lievesley et al., 2016). Selective herbivory by growing CAGO populations has been recognized as a threat to local marsh restoration efforts since the 1990s causing some projects to fail (Kistritz, 1996; Adams & Williams, 2004; Stewart et al., 2022). Restoring marsh habitats is an urgent priority in the FRE (Kehoe et al., 2020; LFFA-RELAW, 2021; Chalifour et al., 2022) and failure to address threats such as CAGO herbivory could contribute to the loss of biodiversity and impact many cultural, environmental, economic, and social values (Appendix C).

Sedge Marshes

Lyngbye's sedge[8] (*Carex lyngbyei*) is the dominant species at low to mid intertidal elevations in FRE marshes. It tolerates a brackish salinity regime and tides that inundate marshes on a daily basis. Tides, river currents, and brackish salt water make for a challenging environment where only a few native marsh species can thrive, and Lyngbye's sedge is one of them.

Reaching up to 1.5 meters in height, Lyngbye's sedge is a perennial herb that undergoes most of its growth from April to July (Kistritz et al., 1983). Following this period, most of the organic matter accumulated in stems and leaves is translocated to belowground rhizomes and roots. Rhizomes facilitate the lateral spread (expansion) of Lyngbye's sedge marshes through clonal reproduction where conditions are suitable (Lane, 2022). The biomass stored belowground is needed to initiate growth in spring. The rest of the organic matter left above ground slowly decomposes into the Fraser River, entering the estuary's detrital food web and the Salish Sea. Sedge biomass contributes to the FRE's role as a highly efficient carbon sink (Chmura et al., 2003).

Sedge marshes in the FRE provide critical rearing habitat for many populations of Pacific salmon, especially Chinook salmon. Juvenile salmon take refuge in marshes as they migrate oceanward through the estuary; these are ideal habitats for them to grow, feed, and become acclimatized to saltwater (Chalifour et al., 2019). This migration occurs from March-August, and the duration of marsh occupancy varies from days to months depending on the species and conservation unit (Chalifour et al., 2019, 2021).

Large areas of marsh in the FRE have been lost after intensive CAGO herbivory

[8] http://linnet.geog.ubc.ca/Atlas/Atlas.aspx?sciname=Carex%20lyngbyei

Methods and Study Design

Led by the Conservation Decisions Lab at UBC, 66 vegetation plots were constructed in July 2021 at the leading edge of sedge-dominant marshes across 19 sites in the FRE (North Arm: 5 sites, South Arm: 11 sites, Middle Arm: 3 sites). Sites were randomly selected from marshes with a sedge-dominant leading edge and accessibility from land. Plot locations and assignment of treatment type (exclosed versus open) at each site were randomly selected; exclosed plots were placed 50 m apart and each one was paired with an open plot at 5 m distance. All paired plots (n=33) were visually similar in their plant community, substrate, and topography. Sedge height and density did not differ between exclosed and open plots (respectively, $t(56)=0.348$, $p=0.73$, and $t(56)=0.98$, $p=0.33$; independent samples t-tests). Thus, the plots were balanced at the time of establishment (7-28 July 2021). Plots were located at the marsh leading-edge since this is where CAGO herbivory is highest, likely due to its immediate proximity to water (see Appendix D for details related to study design).

To estimate the population of resident CAGO in the FRE, surveys were conducted during 2-7 July 2022, aligned with the molting season when geese were flightless and concentrated along shorelines and on waterbodies. Surveying took place by boat and kayak, and on foot. CAGO were counted using binoculars or with the aid of aerial photography from a drone. Three areas were not surveyed but eBird data for these areas were incorporated into survey totals (eBird, 2022).

Values corresponding to sedge growth metrics are reported as mean ± standard deviation. Sedge height refers to the mean of the 10 tallest sedge plants per sample plot (0.25 m^2) and density is the number of sedge plants per sample plot (Appendix D). Vegetation data were analyzed using R Software version 4.2.1 and graphed with the ggplot2 package version 3.3.6 (R Core Team, 2022).

Results

Results presented in this report are preliminary in nature, based on only one year of data collection.

The purpose of the closed vegetation plots (exclosures) was to prevent herbivory by CAGO and, importantly, no herbivory occurred inside exclosures during the first 2 to 3 weeks of growth when sedge stems are especially vulnerable. However, some grazing did occur when sedges grew taller than the exclosure's cable fencing during June and July or when goslings were able to bypass the fence due to their smaller size. These incursions resulted in the final height of sedges in exclosed plots being lower than they would have been if grazing had been excluded. To account for this, growth rates from the first half of the growing season (April to May) and a correction factor to account for slightly slower growth rates during June and July (Kistritz et al., 1983) were used (see Appendix D for additional details).

Marsh Vegetation

Evidence of herbivory in the form of clipped (eaten) sedge stems and leaves was observed at 17 of 19 sites. At sites where herbivory occurred, sedge height and density within each plot were not correlated (Appendix D). This independence of the experimental measures allowed for the unbiased analysis of both height and density. See Figure 7 for a detailed example of one-year change in sedge height and density in a single vegetation plot pair at a heavily grazed site.

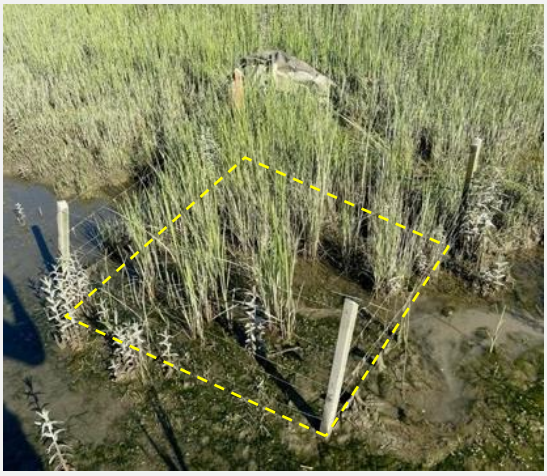
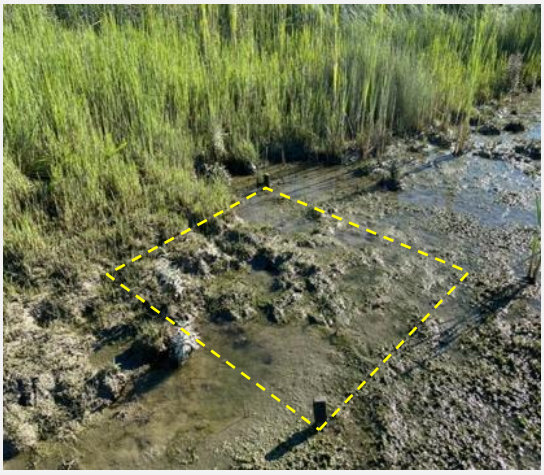
Site 21.1		
	Exclosed plot	**Open plot**
July 2021	Sedge height: **14** cm Sedge stem density: **54**/0.25 m^2	Sedge height: **16** cm Sedge stem density: **132**/0.25 m^2
July 2022	Sedge height: **61** cm Sedge stem density: **110**/0.25 m^2 	Sedge height: **6** cm Sedge stem density: **47**/0.25 m^2 
1-Year change	Sedge height: **+47 cm** Sedge stem density: **+56/0.25 m^2**	Sedge height: **-10 cm** Sedge stem density: **-85/0.25 m^2**

Figure 7. *Sedge height and stem density change from paired vegetation plots at site 21.1 between July 2021 and July 2022. Plots are situated at the leading edge of a sedge-dominant marsh in the FRE, and the approximate plot area is outlined in yellow.*

Sedge height increased significantly between 2021 and 2022 at sites where CAGO herbivory occurred in exclosed plots ($t(28)=-10.3$, $p<0.001$, paired, two-sided t-test) but not in open plots ($t(28)=0.69$, $p=0.50$). Sedge height between 7-28 July 2021 and 11-15 July 2022, after being protected from CAGO, increased by 43.6 cm ± 22.8 cm (Figure 8). Although a change in mean sedge height in open plots with herbivory was not observed, decreases were observed at some heavily grazed sites (Figure 7).

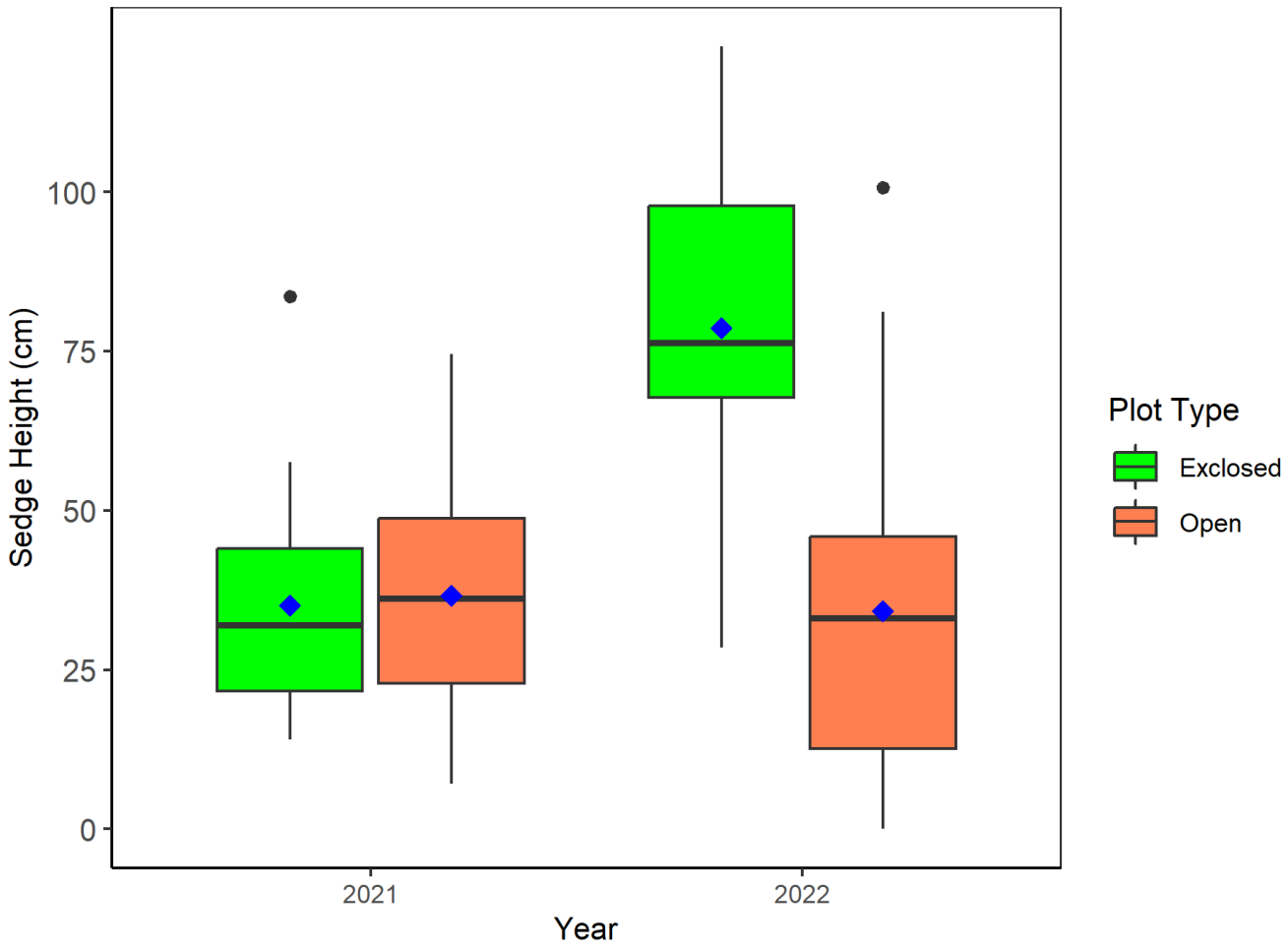


Figure 8. *Box plot showing sedge height (cm) in exclosed (n=28) and open plots (n=28) immediately after plot establishment (July 2021; left) and after one year of establishment (July 2022; right) at sites where CAGO herbivory occurred. A significant increase occurred in exclosed plots from 2021-2022 (p<0.001). Adjusted July 2022 heights were used for certain plots (Appendix D). Blue points show mean values.*

Between 1 April and mid-July 2022 (101 to 104 days) at sites where CAGO herbivory occurred, sedge increased by 0.76 ± 0.24 cm/day when protected from CAGO (n=29) versus 0.33 ± 0.24 cm/day when unprotected (n=29) (Figure 9). At sites where CAGO herbivory did not occur sedge increased by 0.50 ± 0.07 cm/day (n=8).

The fact that sedge height at sites without herbivory was lower than in exclosed plots at sites with herbivory (Figure 9) was likely due to environmental differences at the marsh leading-edge between these sites. The mean elevation above sea level of plots at sites with herbivory was 0.15 ± 0.57 m (n=58) but -0.69 ± 0.07 m at sites without herbivory (n=8). Sedge that is able to grow at lower elevations in the absence CAGO herbivory may experience reduced growth if located near the limit of its suitable

environmental conditions. However, with CAGO herbivory being highest at lower elevation marsh edges (Dawe et al. 2011), the leading edge of sedge marshes with herbivory may be restricted to higher elevations where conditions are favourable for higher growth.

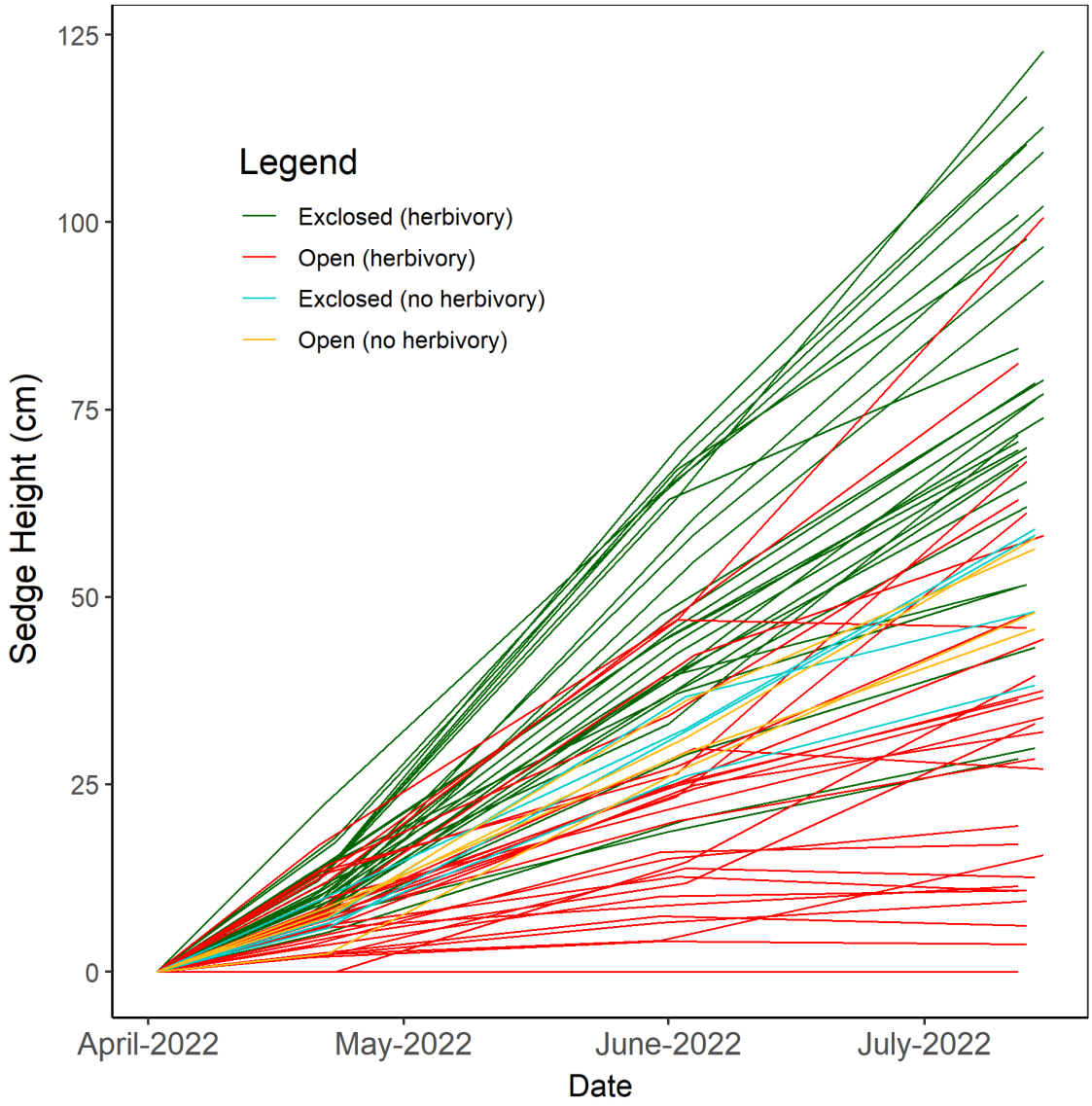


Figure 9. *Sedge height (cm) from 1 April to mid-July 2022 for all plots (n=66), coloured based on plot type (exclosed or open) and presence of CAGO herbivory.*

A significant increase in sedge density occurred in exclosed plots ($t(28)=-4.4$, $p<0.001$, paired, two-sided t-test) compared to a significant decrease in open plots ($t(27)=3.1$, $p=0.005$) from 2021 to 2022 at sites where CAGO herbivory occurred (Figure 10). Sedge density between 7-28 July 2021 and 11-15 July 2022,

after being protected from CAGO, increased on average by 20.4 ± 36.5 stems/0.25 m^2 and decreased on average by 19.9 ± 46.5 stems/0.25 m^2 when unprotected (n=29).

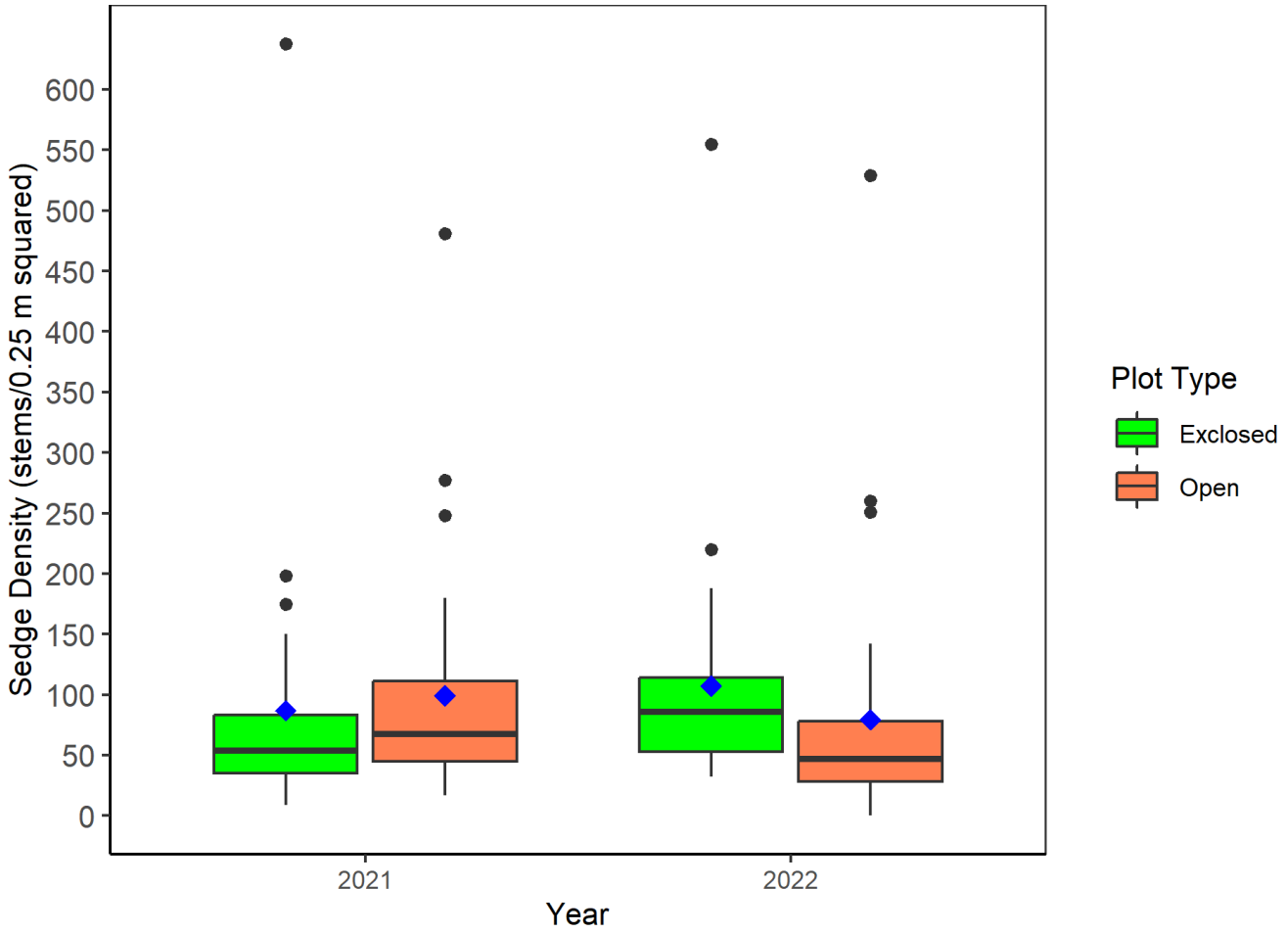


Figure 10. *Box plot showing sedge stem density (stems/0.25 m^2) in exclosed (n=28) and open plots (n=28) immediately after plot establishment (July 2021; left) and after one year of establishment (July 2022; right) at sites where CAGO herbivory occurred. Density increased significantly in exclosed plots (p<0.001) and decreased in open plots (p=0.005) across years. Black dots (outliers) represent certain sites with extremely high sedge density. Blue points show mean values.*

Canada Geese Surveys

A total of 4,734 CAGO were counted across all coastal and riverine waterbodies in the FRE and Pitt River area during 2-7 July 2022. For a map of survey results, see Figure 15, Appendix E.

Discussion

Sedge marshes in the FRE grew taller and had higher stem densities when protected from CAGO herbivory. These results suggest that CAGO are reducing the habitat quality and overall biomass of these marshes, and possibly limiting their outward expansion into tidal flats where conditions for growth are suitable. Note that some confounding environmental factors influencing sedge growth or CAGO behavior are not accounted for in these preliminary analyses.

CAGO herbivory is most intense at the marsh leading-edge, which is especially problematic for Lyngbye's sedge marshes that spread clonally with rhizomes into lower elevations (Lane, 2022). Interactions between CAGO and sedge marsh edges therefore do not only highlight a direct loss of biomass from grazing, but also reveal possible long-term trends in marsh recession and apparent inability to spread laterally where grazing is intense. It may be possible to restore low-elevation areas that have been denuded of vegetation due to CAGO herbivory through active stewardship[9].

Herbivory due to the large, resident CAGO population in the FRE must be having extensive ecological impacts. FRE subregions where CAGO were most abundant align closely with the highest grazing impacts (unpublished data). Conversely, the subregion on the South Arm of the Fraser River where CAGO were not observed during summer surveys (Figure 15, Appendix D) experienced little or no herbivory. The fact that the leading edge of sedge marshes at sites without herbivory is lower in elevation compared to sites with herbivory suggests that CAGO herbivory is limiting the expansion of sedge marshes to lower elevations and therefore resulting in wide-scale marsh recession.

Juvenile salmonids occupy FRE sedge marshes where intensive CAGO herbivory has been documented (D. Scott, personal communication, July 4, 2022), suggesting that mitigating CAGO herbivory and restoring heavily grazed marshes would be highly beneficial. Hence, addressing the CAGO invasion issue could play an important role in restoring salmon populations, especially Chinook salmon (Chalifour et al., 2022).

Previous research in the FRE has identified habitat loss at natural marshes along the western foreshore and at restored marshes along the Fraser River, and implicated resident CAGO as one of the drivers of marsh recession (Balke, 2017; Gan, 2021; Stewart et al., 2022). The preliminary findings herein provide additional evidence that sedge marshes in the FRE are being negatively affected by resident CAGO, consistent with their impacts in small estuaries on Vancouver Island (Clermont, 2015).

[9] https://watershedsentinel.ca/articles/protecting-and-restoring-estuaries-from-geese/

Conclusion and Future Research Considerations

These preliminary findings provide new and updated insights into a proximate causal factor contributing to sedge marsh habitat loss in the FRE. There is great potential for marsh habitat restoration if CAGO herbivory can be eliminated or substantially reduced. Lyngbye's sedge marshes are capable of re-establishing through natural expansion and assisted planting but only if they are subjected to low herbivory levels.

Fundamentally, what to do about marsh-loss caused by CAGO presents a conservation science decision problem that requires an understanding of the ecological impacts of CAGO in the estuary, the expected benefits of alternative management actions to combat these impacts, the cost of actions, and their socio-political feasibilities. By framing this environmental problem as a decision problem on how to mitigate the ecological impacts of resident CAGO in the FRE, the relevant objectives can be clearly defined and alternative actions can be evaluated together with their associated trade-offs and uncertainties (Gregory et al., 2012). Such a process would need to involve all key groups including First Nations, various levels of government and non-government organizations, industry, university scientists, and the public.

While it is clear that resident CAGO present a direct threat to sedge marshes, a more in-depth understanding of biotic and abiotic factors involved and their interactions is required to inform successful long-term management approaches designed to restore and conserve marsh habitats within the FRE. Inclusive and integrated stewardship efforts could help restore myriad values offered by the Fraser River Estuary and support the coexistence of all living beings around the estuary for generations to come.

Tidal flat, marsh, and riparian forest, Fraser River Estuary

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Appendix A: The Fraser River Estuary

History of the Estuary

The Fraser River emerged approximately 10,000 years ago from under the ice, as a warmer climate caused glaciers to retreat[10]. Around a similar time in history are the earliest records of Indigenous Peoples (i.e., First Nations) in the Pacific Northwest. The Lower Mainland and Fraser River Estuary (FRE) were unknown to European explorers until about 1790. Simon Fraser paddled down the Fraser River in 1808, introducing the mighty river to the 'western' world. For millennia prior to colonization by European settlers and still to this day, the Fraser Valley region and FRE has been inhabited and cared for by First Nations, namely the Coast Salish Peoples. The Coast Salish are a diverse group of Peoples whose traditional, ancestral, and unceded territories are situated in around the Salish Sea. The FRE falls within the traditional territories of Musqueam, Tsawwassen, Semiahmoo, Kwikwetlem, Kwantlen, Qayqayt, Katzie, Stó:lō, and other Nations. Indigenous Peoples living near the Fraser River and across the Salish Sea historically depended and still depend on the estuary's abundance of resources (Reid et al., 2022).

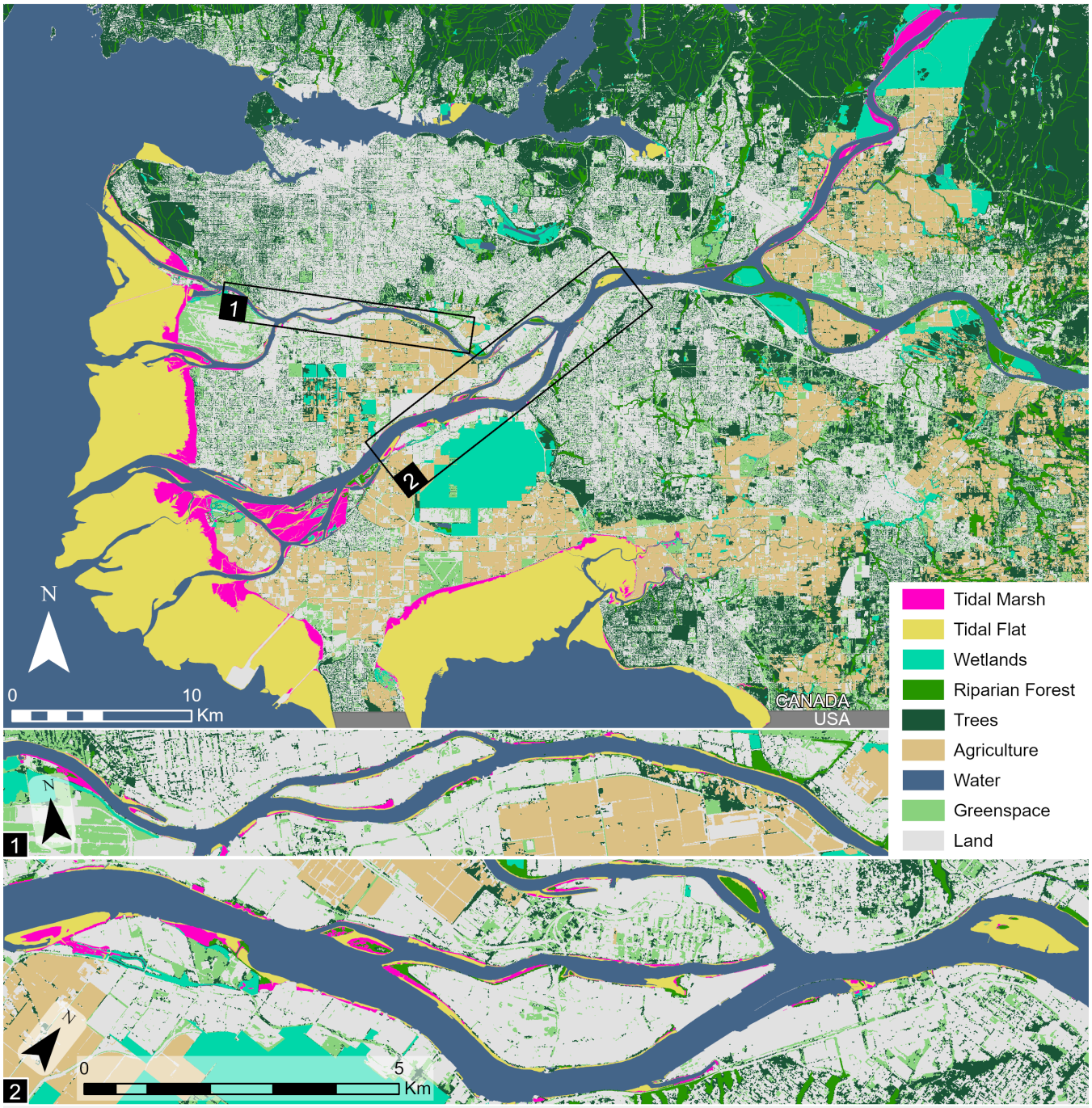
Historically, the FRE was largely dominated by forest and floodplain habitats such as marshes, bogs, grasslands, and swamps (North & Teversham, 1984). It was home to salmon, elk, wolves, and a variety of other wildlife in abundances that we could only imagine today (Boyle et al., 1997). "Discovery" of the Fraser River and the FRE by Europeans occurred between 1790 and 1830, and settler colonization ensued (Kew, 2004).

The Estuary Today

The region surrounding the FRE—Metro Vancouver—supports over 2.6 million inhabitants, including many Indigenous peoples that have lived here since time immemorial (Statistics Canada, 2021). In less than 200 years the FRE has been fundamentally altered, much of it being developed/built-up or converted to agriculture (Figure 11). Approximately 38% of the FRE is protected under legislation, with the majority of this area designated as provincial Wildlife Management Areas established for the conservation of fish and birds (Butler et al., 2021). Figure 11 shows mapped estuarine habitat and landcover classification in the FRE.

The land at the mouth of the FRE (i.e., all of Delta, Richmond, and nearby islands) is the Fraser River Delta, created by sediments deposited by the Fraser River. The delta incudes eelgrass beds, and unvegetated mud and sand flats used by approximately 1.6 million birds on an annual basis (Butler et al., 2021). Approximately 17 million tonnes of sediment per year are delivered to the FRE from the Fraser River (McLean & Tassone, 1991) and deposited in the river, on the delta, or into the Salish Sea.

[10] http://www2.moa.ubc.ca/musqueamteachingkit/delta.php



Habitats and Landcover of Metro Vancouver and the Fraser River Estuary

Map scale is consistent between inset maps 1 & 2.
Spatial data source: Metro Vancouver Open Data Catalogue, Community Mapping Network
Map projection: NAD 1983 UTM Zone 10N
Date: August 4, 2022

Figure 11. *Map of habitats and landcover in the Fraser River Estuary with an emphasis on wetland habitats. Inset maps 1 & 2 show stretches of the Fraser River where tidal marsh is relatively scarce and fragmented. See p.32 for descriptions and sources of habitat and landcover classes.*

Habitat and landcover classes in Figure 11

Tidal Marsh: Marsh habitat (e.g., sedges) growing in an intertidal zone. Source: Metro Vancouver Sensitive Ecosystem Inventory (SEI) 2014, Community Mapping Network.

Tidal Flat: Mudflat, sandflat, or eelgrass beds growing in an intertidal zone. Source: Metro Vancouver SEI 2014, Community Mapping Network.

Wetland: All wetland habitats aside from tidal marsh and tidal flats (e.g., freshwater marsh, bog, swamp, fen). Certain areas classified as wetlands adjacent to the Fraser River may include some tidal marsh. Source: Metro Vancouver SEI 2014.

Riparian Forest: Forest growing adjacent to a body of water (i.e., stream, river, lake). Source: Metro Vancouver SEI 2014.

Trees: Coniferous and deciduous trees and forests. Source: Metro Vancouver Land Cover Classification (LCC) 2014.

Agriculture: Agricultural crops and grass/herbs within areas zoned as agricultural land. Source: Metro Vancouver LCC 2014, Vancouver Generalized Land Use Classification 2016.

Water: All open water (i.e., rivers, streams, ocean, lakes, ponds, reservoirs). Source: Metro Vancouver Generalized Land Use Classification 2016.

Greenspace: Natural or modified grass/herbs (e.g., city park grass, golf course greens, airport grass). Source: Metro Vancouver LCC 2014.

Land: Primarily representative of developed, urban land, but also includes landcovers that are not identified on the map (e.g., beach, rocky intertidal). Source: Metro Vancouver Generalized Land Use Classification 2016.

Appendix B: Canada Geese Introductions and Regional Abundance

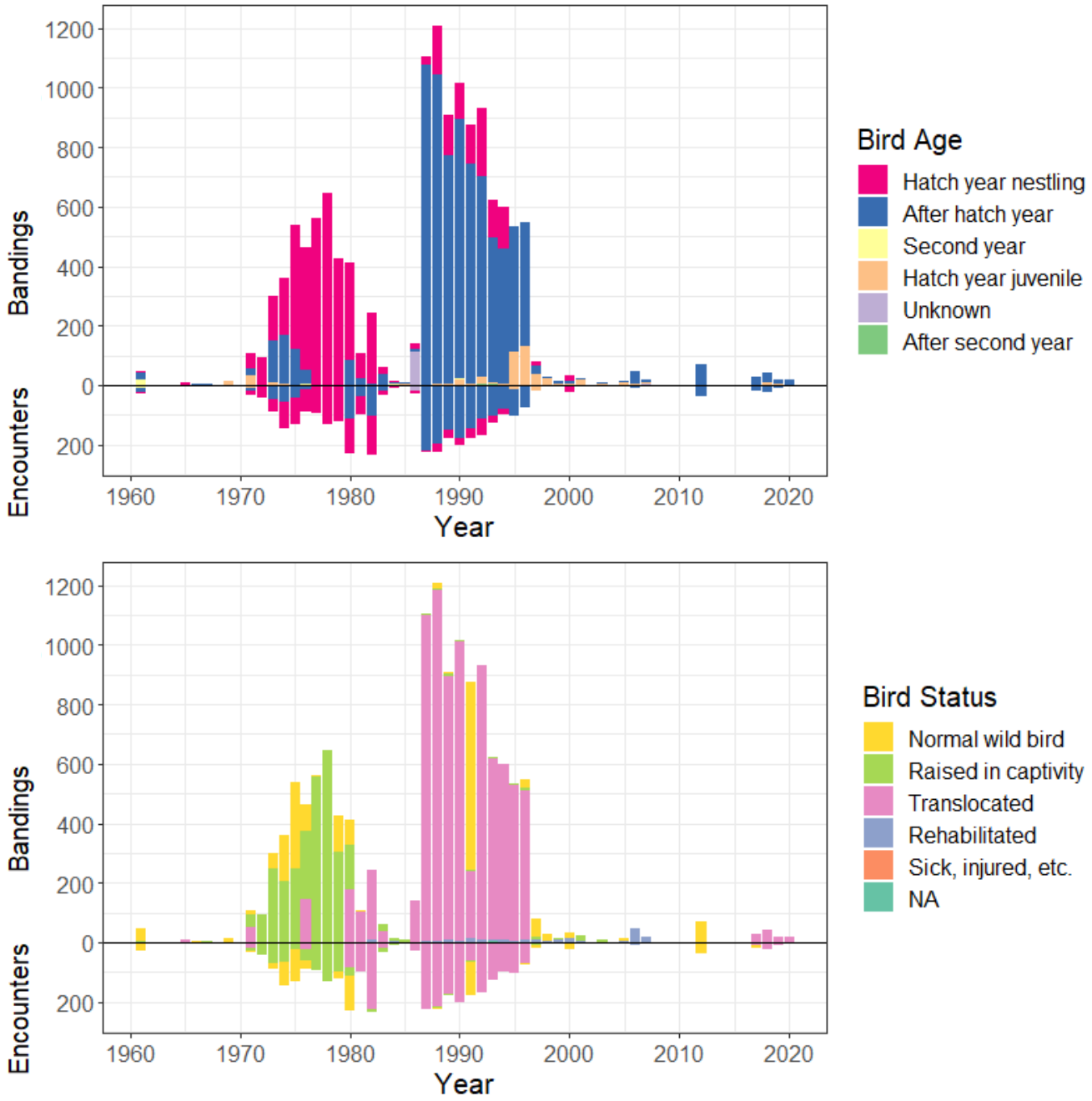


Figure 12. *CAGO banding and encounter records (1960-2021) showing the number of geese banded (upper y-axis) and encountered (lower y-axis) per year in the Lower Mainland, BC (North American Bird Banding Program, 2021). Figure bars are filled by bird age (top panel) and bird status (bottom panel) at time of banding or encounter.*

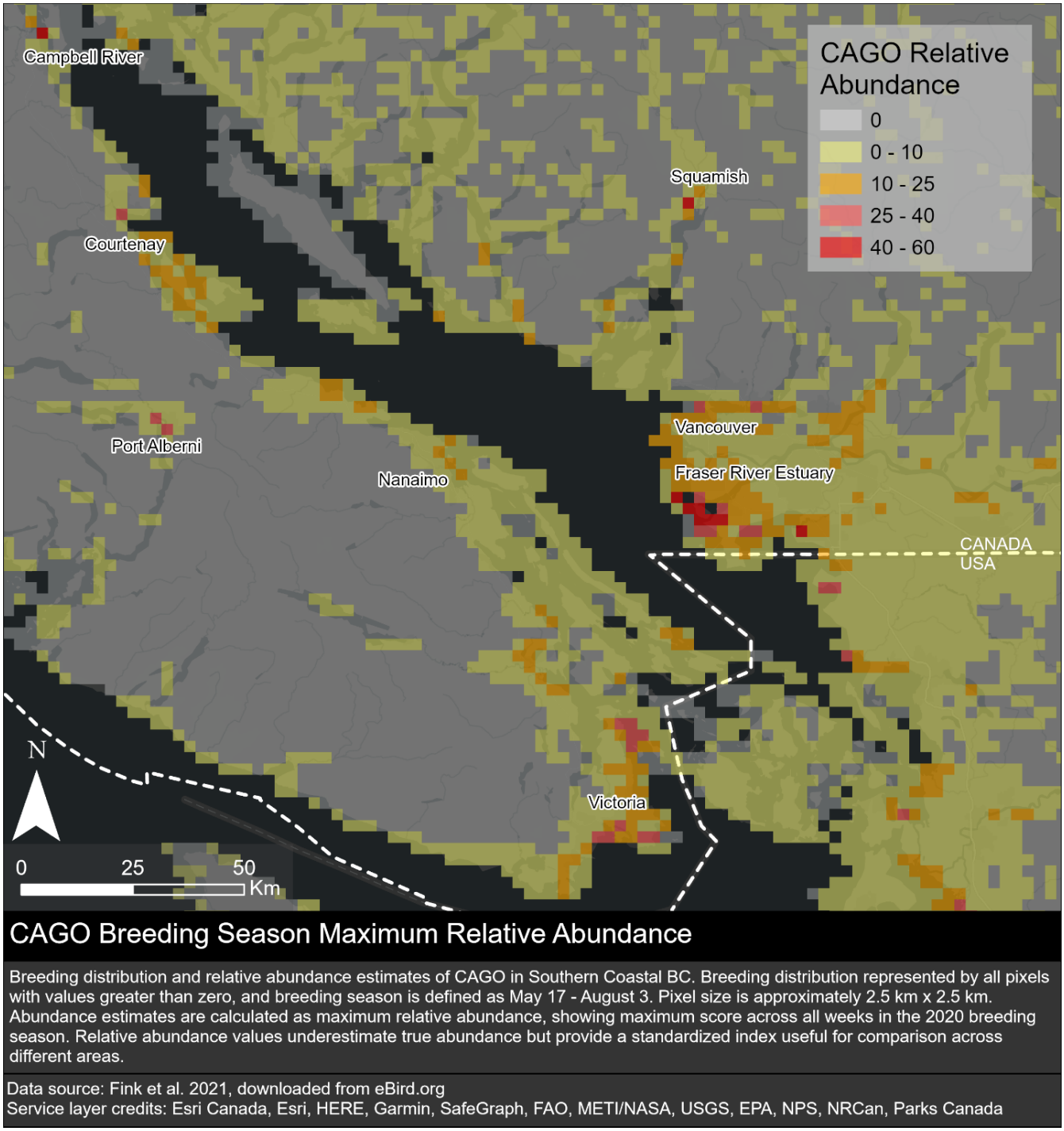


Figure 13. *Maximum relative abundance of breeding CAGO in Southern Coastal BC (Fink et al., 2021). Pixels represent survey effort by an experienced eBirder over 1 hour of time and 1 km distance[11]. Data downloaded from eBird Status and Trends[12].*

[11] https://science.ebird.org/en/status-and-trends/faq#mean-relative-abundance

[12] https://science.ebird.org/en/status-and-trends/species/cangoo/abundance-map

Appendix C: Summary of Issue and Influence Diagram

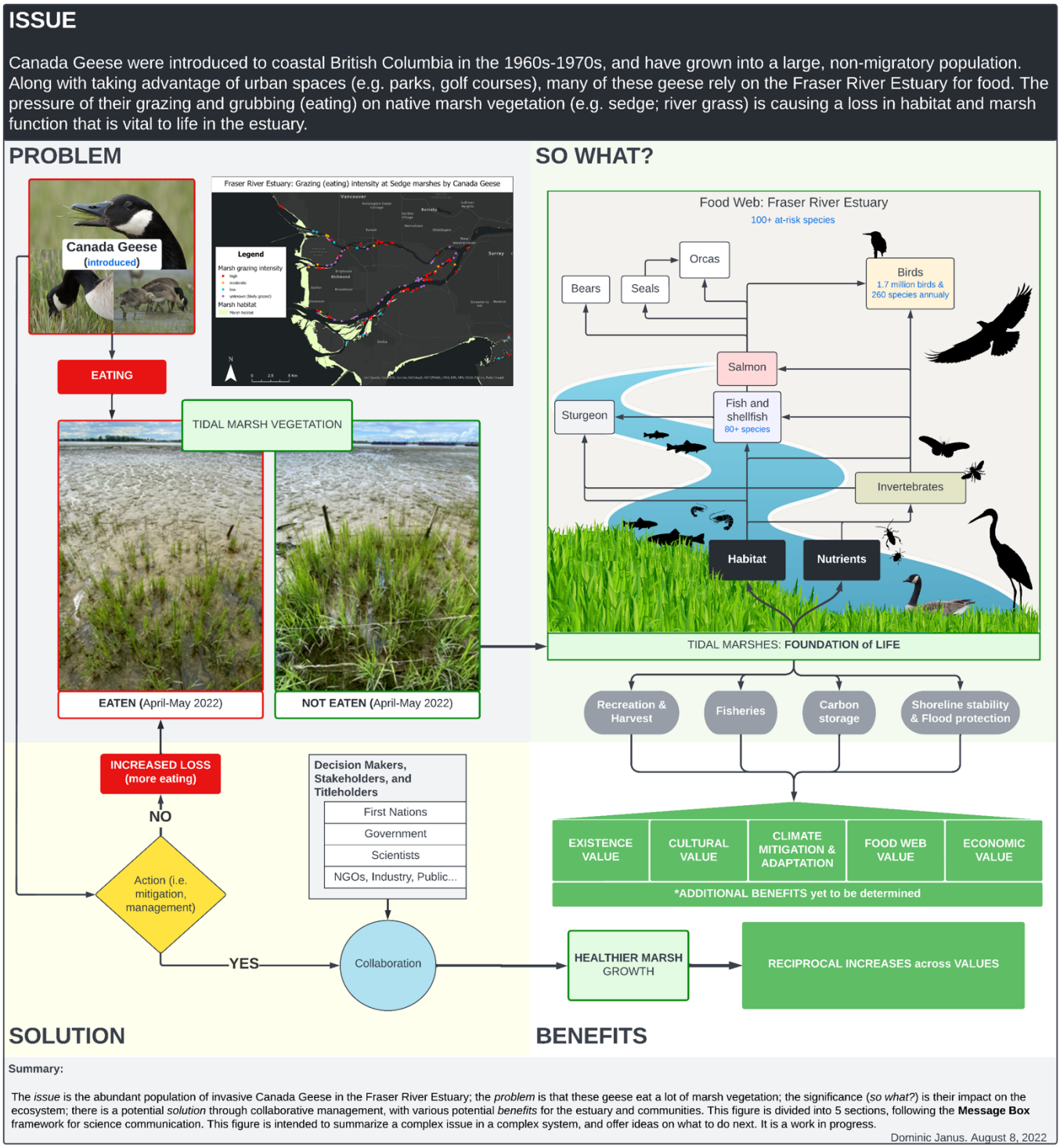


Figure 14. *Influence diagram summarizing the issue of the impacts of introduced Canada Geese in the Fraser River Estuary. Diagram sections follow the Message Box framework for science communication.*

Appendix D: Methods and Data Analyses

Study design

Fenced vegetation plots (n=33) preventing access by CAGO each paired with an open plot (n=33), allow for monitoring seasonal and annual differences in sedge growth between different treatments of CAGO herbivory. Plots measure 1.5 m by 1.5 m with an inner sampling area of 50 cm by 50 cm (0.25 m^2) where data are collected on sedge height, density, and vigour. Height was recorded as the mean height of the 10 tallest sedge plants in the 0.25 m^2 sampling area. Baseline sedge height and density data were collected immediately after the establishment of each plot between July 7-28, 2021. Data collection was repeated in 2022 on 3 occasions; 19-22 April, 30 May-3 June, and 11-15 July 2022.

Data analyses

The sedge height data met the assumptions of parametric statistics (Wilks-Shapiro tests and evaluation of Q-Q plots, data not shown). Since sedge density data were positively skewed and did not meet the assumption of normality, a logarithmic transformation was used to normalize the distribution. Density data for one open plot with 0 stems in 2022 was removed from analyses. An alpha level of 0.05 was used in all analyses. To compare related data (between years) a paired, two-tailed, Student t-test was used, while the comparison of independent groups (treatments) was carried out by an independent samples, two-tailed Student t-test (Howell, 2010). The analysis of data collected at the time of the establishment of the study sites where herbivory occurred revealed that density of sedge and its height within each plot type were not significantly correlated both in 2021 ($r = -0.26$, $p = 0.18$, and $r = -0.23$, $p = 0.23$, $n = 29$ for open and enclosed plots, respectively). Similar analysis applied to data collected in July 2022 revealed concordant results ($r = -0.26$, $p = 0.18$, and $r = -0.23$, $p = 0.23$, $n = 29$ for open and enclosed plots, respectively).

Sedge height estimates

Twelve of 33 exclosures were grazed by CAGO in June-July 2022. Since there were no sedges left uneaten in each of these 12 exclosures, an actual measurement for un-grazed sedge height could not be determined. The un-grazed sedge height for these plots was estimated using the rate of aboveground accumulation of organic matter from mid-April to June, which slows into July as translocation of nutrients to belowground components occurs (from Kistritz et al., 1983). Estimates were achieved using growth rates calculated from un-grazed exclosures (n=19).

Growing season start date

In mid-April 2022 during the first round of data collection, sedge had already begun growing at most plots. Moreover, plots were also visited in mid-March, and no sedge growth was observed. For the sake of having a reliable start date for aboveground sedge growth, 1 April, in 2022, was chosen based on informed on-site judgement and previous research in the same study area (Kistritz et al., 1983).

Appendix E: Canada Geese Survey Results

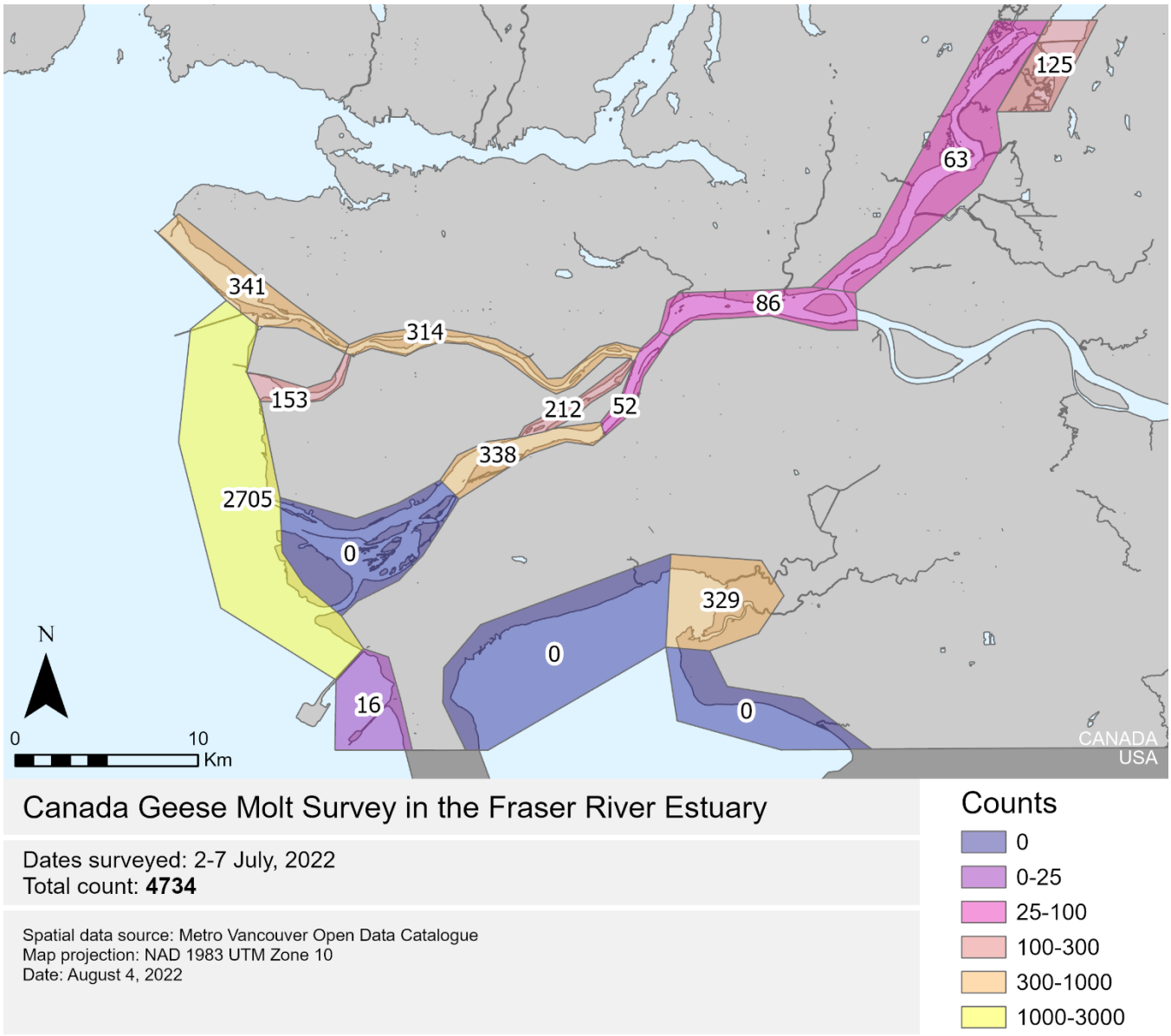


Figure 15. *Summary of Canada Geese observations during the 2022 molting season survey in the Fraser River Estuary.*