# Abstract

# Introduction

Estuaries are undeniably powerhouses of productivity that contribute ecosystem services such as shoreline stabilization, vital habitat for waterfowl and fish, and environmental sponges soaking up excess pollutants and nutrients (Bertness, 1999; Megonigal & Neubauser, 2009). Along the lower salinity gradient within estuaries, tidal freshwater marshes (TFMs) provide similar ecosystem services and serve as nursery habitat for juvenile anadromous fishes during adaptation to higher salinities as they migrate to open ocean (Chalifour et al., 2019; Levy & Northcote, 1982). The Fraser River drains the largest catchment in British Columbia, and its estuary once covering XX km2 is now limited to approximately 2814 ha, one-third of which lies within the South Arm Marshes Wildlife Management Area (Schaefer, 2004). The loss of this habitat is suspected to be one of the driving causes of wild salmon population declines despite efforts to increase hatchery production and limit harvests (CITE). As sea levels rise TFMs will be further “squeezed” between unsuitable aquatic habitats and impervious cover or infrastructure.

Tidal marshes are transitory ecosystems (CITE), so consideration of resistance and resilience in TFMs from an ecosystem service perspective must be within the context of appropriate timescales. Resistance is thought to be a function of reciprocal positive feedback between vegetation trapping sediment loads from riverine transport (Corenblit et al., 2015; Peteet et al., 2018), while time to recovery is directly related to degree of disturbance in measuring system resilience (van Belzen et al., 2017). Management initiatives such as British Columbia’s Salmon Restoration and Innovation Fund or Sea Level Rise Adaptation programs target successes on 50-100 year horizons, so understanding what leads to resilient communities within this timescale is of great importance to agency managers wanting to maintain or create shoreline communities for immediate habitat conservation or floodwater protection initiatives. However, a general limitation of ecological studies is the ability to continue observations across time to generate meaningful long-term patterns of community stability. The opportunity to characterize plant community changes on decadal timescales is instructive to form inferences about drivers of community stability or change over time.

Ladner Marsh is part of the South Arm Marshes Wildlife Management Area in the Fraser River Estuary. While much of the marshland in the lower Fraser River Estuary was converted to log-sorting, fish cannery, agriculture, or dry docks, Ladner Marsh escaped these developments and is largely undisturbed. As far as records show it has never been diked, tilled, mown, or had flood control structures (CITE). To fill knowledge gaps in understanding marsh plant community composition, Ladner marsh was surveyed in 1979 and three dominant plant assemblages were identified as occupying habitat based on suspected drainage processes (Bradfield & Porter, 1982). In poorly drained areas furthest from tidal chan,nels the greatest floristic richness was found in assemblages dominated by bog bean (*Menyanthes trifoliata*). The ubiquitous Lyngby’s sedge (*Carex lyngbyei*) occupied habitats regularly flooded and drained, while natural levees formed at the banks of tidal channels were characterized by grassy fescue (*Festuca arundiancea*) assemblages. A subsequent survey in 1999 estimated impacts of invasive species purple loosestrife (*Lythrum salicaria*) on blue-listed Henderson’s checker mallow (*Sidalcea hendersonii*), collecting similar data as the 1979 study (Denoth & Myers, 2007). Throughout this time, Ladner Marsh has been protected as a Wildlife Management Area, and as a largely untouched habitat is an ideal ecological laboratory to monitor plant community stability over decadal timescales.

Despite escaping anthropogenic manipulations, natural disturbance events in Ladner Marsh that can lead to shifts in plant community succession have occurred. Major flooding events on the Fraser River occurred in 1894 and 1948 that breached dikes and flooded riverside communities. While damage surveys are not available for Ladner Marsh, it is reasonable to assume that these storm events inundated the marsh and likely deposited storm debris. While these natural disturbance events may not have altered the site’s topography or structure, the introduction of invasive plant species has been documented (Bradfield & Porter, 1982; Denoth & Myers, 2007).

* Describe history & invasion of purple loosestrife? “*Adams (1993) suggested that the colonization of tidal marshes by purple loosestrife (*Lythrum salicaria*) is facilitated by disturbance. Although wrack may be a significant agent of disturbance, the primary agent of disturbance within the Fraser River estuary appears to be wood debris, especially in tidal freshwater portions of the distributary channels*.” (Adams & Williams, 2004)
* Highlight importance of incremental sediment accumulation [rate per year] in contrast to documentation of delayed recovery following extreme disturbance (van Belzen et al., 2017).
  + Suggest that sedimentation over very long time may drive conversion to riparian habitat; reference riparian fringe at northern, eastern, and southern borders.

The main objective of this study was to determine whether the plant community assemblage types (hereafter, “assemblages”) identified forty years ago in Ladner Marsh (Bradfield & Porter, 1982) are still identifiable today. In the absence of known disturbance events and unchanged riverine processes since observations in 1979, I predict the same assemblage types should be identifiable. If sediment has been accruing over time, I would expect elevations overall to be higher, and *Carex lyngbyei* should be a more dominant assemblage, with some woody species encroachment. However, if marsh platform has been subsiding over time, I would expect elevations overall to be lower, and METR to be more spatially dominant. This study provides a unique opportunity to utilize long-term datasets to quantitatively assess shifts in community assemblage.

# Methods

## Transect delineation

No permanent markers were left in Ladner marsh, so precise transects assessed by Bradfield & Porter (1982) or Denoth & Myers (2007) were not identifiable in 2019. To approximate transect location the map from Figure 1 (1982) was overlaid onto 2019 Google Earth Imagery (Google Earth Pro 7.3.2.5776, Imagery Dates November 9, 2002 and June 12, 2019). Dominant channel features shown in Figure 1 (1982) were easily distinguished on Google Earth, and used as visual guides to place transect ends. GPS locations of transect beginnings and ends were georeferenced (NAD83) and transferred to Avenza 3.2 (72.23) for field wayfinding. Actual GPS locations of transect ends and assemblage area polygons were recorded in Avenza. Seven of the original eight transects were used - transect “Q” (1982) was omitted due to inaccessibility and conversion to thick riparian forest with an understory of Himalayan blackberry (*Rubus armeniacus*) since 1982. The last 30 m of transect “W” (1982) were truncated at its western edge due to inaccessibility into the often submerged low marsh. Quadrats in the original study that occurred in the tidal channels were not assessed, although lower benches submerged at higher tides were included. (COMPARISON FIG)

## Elevation

Elevation of plant assemblage types was assessed using a survey level (BRAND, MODEL) and standard surveying techniques recorded to the nearest cm, and estimating nearest mm when possible. Field site elevation profiles were related to Natural Resources Canada, Survey Canada station marker B737197 in the adjacent neighborhood (MAP?). Elevation was recorded for the beginning and ends of all transects, and at the boundaries and centers of plant assemblage types on the transect tape. All elevation measurements were taken on the same day as assemblage sampling before moving the transect tape to ensure precise elevation for the assemblage observed.

## Assemblage delineation & sampling

Assemblage types were considered if their boundary intersected the transect tape; assemblages tangential to the survey transect (but not intersecting it) were ignored. Assemblages were defined as being dominated >50% by one or two species. If no species was clearly dominant, the area was characterized as “undefined.” To keep survey methods consistent with the 1982 survey, 1 m2 quadrats were centered at the center of the assemblage region (FIG). No assemblage types were so small that the 1 m2 quadrat was less than 1 m from the boundary of the next assemblage. Along transects where the same assemblage reached > 20 m, quadrats were sampled every 10 m to reproduce a modal distance of 10 m (1982).

## Assemblage characterization

All vascular plant species observed within the quadrat were identified to lowest taxonomic level according to Hitchcock & Cronquist (1973). Individuals were defined as “in the plot” if their most basal stem originated >50% within the plot boundary; overhanging stems were not considered. Aerial coverage was considered as percent of the quadrat occluded by foliage; rambling lianas (*Lathyrus palustris*) were imagined as groundcover (even if climbing vertically). Percent cover of the quadrat was estimated to the nearest 1/64th m2, and later binned into quartile categories (< 25%, 25-50%, 50-75%, and > 75%).

## Data analysis

Data analysis followed the methods described in Bradfield and Porter (1982) to ensure comparison wherever possible. Hierarchical classification was generated in R using the vegan package, with Euclidean distance as the measure of interquadrat dissimilarity.

# Results

Want to show:

1. Change (or not) in clustering of assemblages across 3 time points (1979, 1999, 2019)
   1. Summary stats of total number of species, richness & evenness per assemblage type
   2. “Sp richness & density vary…: both are lowest in Carex-Poa type, and highest in Menyanthes type.” (pg 4).
      1. “May represent two extreme environmental conditions for establishment.” (B&P’82, pg 4)
2. Confirm assemblage not predicted by elevation; has elev changed since 1979 (\*can only be done if GB has orig elev data)?
   1. GB concluded assemblages more closely relate to channel proximity (rather than elevation) as a proxy of drainage. Can align 2019 assemblages with distance from major channels; minor “ankle-breaker” channels could be re-surveyed, but broad sense is that minor channels < 0.5 m deep did not significantly define assemblage boundaries.
3. Kridging of community dominance 1979, 1999, 2019? \*Amy had a thought on how to spatially estimate this?
   1. Using 2019 delineated assemblage boundaries can report proportional dominance of each assemblage type.

# Discussion

Surprising stability wrt 4-decade data; community more resistant than we thought (persistent) – changed less than imagined.

Propose mechanisms of community stability & invasion: why purple loosestrife; why not more RCG?

My observations of intermittent willow stands make me think riparian woody species could be advancing into higher/drier portions of the marsh. In conversation with Gary, he remembered the same thing/conclusion. There isn’t a discussion of this in his paper, but could reference personal comm.?

# Literature Cited

Adams, M. A., & Williams, G. L. (2004). Tidal marshes of the Fraser River estuary: Composition, structure, and a history of marsh creation efforts to 1997. In B. J. Groulx, D. C. Mosher, J. L. Luternauer, & D. E. Bilderback (Eds.), *Fraser River Delta, British Columbia: Issues of an Urban Estuary* (pp. 147–172). Geological Survey of Canada, Bulletin 547.

Bertness, M. D. (1999). *The ecology of Atlantic shorelines*. Sunderland, Mass: Sinauer Associates.

Bradfield, G. E., & Porter, G. L. (1982). Vegetation structure and diversity components of a Fraser estuary tidal marsh. *Canadian Journal of Botany*, *60*, 440–451.

Chalifour, L., Scott, D. C., MacDuffee, M., Iacarella, J. C., Martin, T. G., & Baum, J. K. (2019). Habitat use by juvenile salmon, other migratory fish, and resident fish species underscores the importance of estuarine habitat mosaics. *Marine Ecology Progress Series*, *625*, 145–162.

Corenblit, D., Baas, A., Balke, T., Bouma, T., Fromard, F., Garófano‐Gómez, V., … Walcker, R. (2015). Engineer pioneer plants respond to and affect geomorphic constraints similarly along water–terrestrial interfaces world-wide. *Global Ecology and Biogeography*, *24*, 1363–1376.

Denoth, M., & Myers, J. H. (2007). Competition between Lythrum salicaria and a rare species: Combining evidence from experiments and long-term monitoring. *Plant Ecology*, *191*, 153–161.

HItchcock, C. L., & Cronquist, A. (1973). *Flora of the Pacific Northwest, an illustrated manual*. Seattle and London: University of Washington Press.

Levy, D. A., & Northcote, T. G. (1982). Juvenile Salmon Residency in a Marsh Area of the Fraser River Estuary. *Canadian Journal of Fisheries and Aquatic Sciences*, *39*, 270–276.

Megonigal, J., & Neubauser, S. (2009). Biogeochemistry of tidal freshwater wetlands. In *Perillo GME, Wolanski E, Cahoon DR, Brinson MM (eds) Coastal wetlands: An integrated ecosystem approach* (pp. 535–562). Amsterdam: Elsevier.

Peteet, D. M., Nichols, J., Kenna, T., Chang, C., Browne, J., Reza, M., … Stern-Protz, S. (2018). Sediment starvation destroys New York City marshes’ resistance to sea level rise. *Proceedings of the National Academy of Sciences*, *115*, 10281–10286.

Schaefer, V. (2004). Ecological setting of the Fraser River delta and its urban estuary. In B. J. Groulx, D. C. Mosher, J. L. Luternauer, & D. E. Bilderback (Eds.), *Fraser River Delta, British Columbia: Issues of an Urban Estuary* (pp. 147–172). Geological Survey of Canada, Bulletin 547.

van Belzen, J., van de Koppel, J., Kirwan, M. L., van der Wal, D., Herman, P. M. J., Dakos, V., … Bouma, T. J. (2017). Vegetation recovery in tidal marshes reveals critical slowing down under increased inundation. *Nature Communications*, *8*, 1–7.