Marsh and Riparian Habitat Compensation in the Fraser River Estuary:

A Guide for Managers and Practitioners

Image Credit: Megan Lievesley

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1 Purpose of Report

This guide is designed to help improve the state of habitat compensation in the Fraser River Estuary by making sound, evidence-based recommendations guided by the findings of Lievesley and Stewart (2016), *Assessing Habitat Compensation and Examining Limitation to Native Plant Establishment in the Lower Fraser River Estuary*. The findings from this study indicate that only one-third of sampled marsh habitat compensation projects created between 1983 and 2010 are acceptably compensating for habitat losses; and that several riparian habitat compensation projects from this same time period had significant deficiencies.[1] These findings indicate that there is still much room for improvement in the field of habitat compensation in the Fraser River Estuary.

The primary limiting factor to marsh compensation success was found to be high invasive and exotic plant cover, and low native plant cover. This can be attributed to site location, hydrologic conditions, waterfowl grazing, and log debris among other factors. Riparian compensation projects were most limited by poor site design, as many projects failed to resemble natural riparian environments in their structure, function, and connectivity to the aquatic environment. This guide is designed to assist and improve the work of land managers, policy makers, and habitat creation practitioners by using the findings from this study as the guiding principles for sound recommendations.

2 Background

2.1 Ecology of the Fraser River Basin and Estuary

The Fraser River is the largest river in British Columbia (BC) and has the fifth largest drainage basin in Canada. The river passes through 11 biogeoclimatic zones including alpine, interior forest, grasslands, and coastal forests before reaching the Pacific Ocean. The Fraser River basin (Figure 1) hosts many species, including 40 species of native freshwater fish, 5 species of salmon, and is considered the most productive salmon river system in the world. Over 300 species of birds inhabit the basin and at least 21 waterfowl species use it as their breeding grounds. The basin also contains 1446 species of vascular plants.[2]

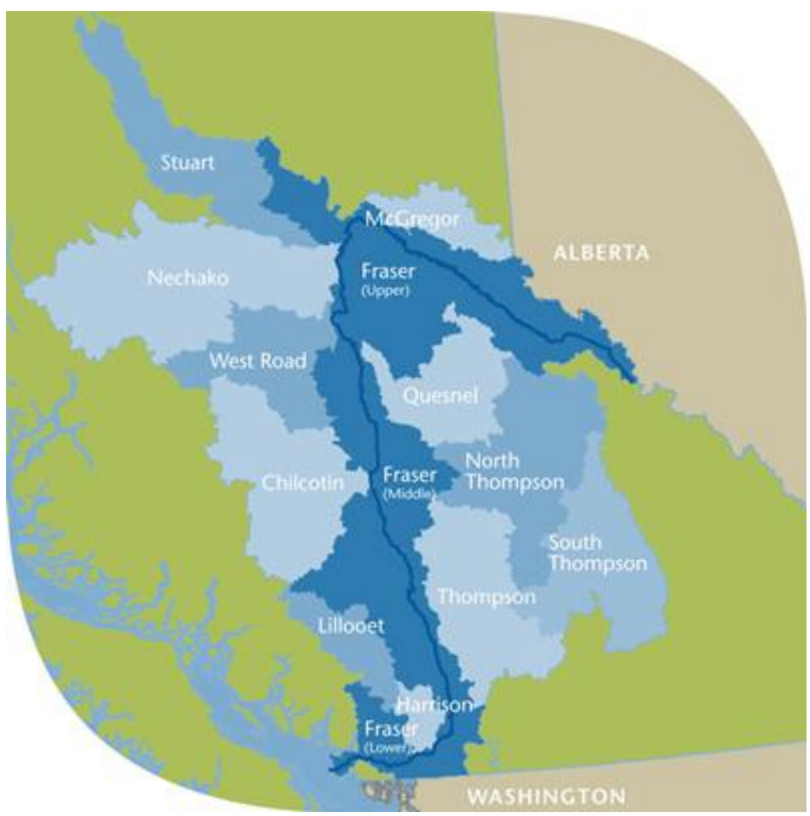

Figure 1: Fraser River Basin. Scale: 1:50,000. Image credit: Fraser Basin Council.

The estuary portion of the river has been recognized as a globally important centre of biodiversity with intertidal wetlands alone covering approximately 17,000 hectares. Wetlands are an essential part of the estuary environment and are of particular importance to the early life stages of many animals. The Fraser Estuary provides essential rearing grounds for over 80 species of fish and shellfish, and over 300 species of invertebrates. Annually, an average of more than 2 billion juvenile salmon spend weeks to months in the estuary before beginning their ocean migration. The estuary is also very important to migratory birds, supporting the highest concentration of migratory birds in Canada from at least 3 different continents.[2,3] Up to 1.4 million birds can be seen utilizing the Fraser Estuary during peak migration times.[3]

Riparian habitats are the narrow ecotone between the aquatic and terrestrial environment that are subject to frequent flooding, and are a vital component in estuary ecosystems.[4] Riparian habitats provide many ecological functions including stream bank stabilization, filtering of sediments and nutrients, storing and delaying the release of terrestrial runoff, and moderating stream temperature through shading and evapotranspiration.[5–8] For wildlife, riparian ecotones can serve as corridors between habitats, provide important nesting and security cover, and produce food for birds, mammals and insects in both the terrestrial and aquatic environment.[8,9] Riparian vegetation is particularly important for birds, providing habitat for more species of breeding birds than any other habitat in the western United States, despite accounting for less than 1% of the landscape.[10]

2.2 Threats to the Fraser River Basin and Estuary

The Fraser Basin is heavily populated, with two-thirds of BC's population living within it, 54% of which is concentrated in the lower Fraser River area.[2] Many land use operations occur throughout the basin including 50% of BC's sustainable timber yield, 60% of BC's metal mines, 90% of BC's gravel extraction, 25 major dams on Fraser River tributaries, and 20% of BC's farmland is irrigated using water from the Fraser or its tributaries.[2] Additionally, 70% of the Fraser River Estuary's wetlands have been diked, drained, and filled to reclaim land for development.[3]

Land use and urbanization have significantly impacted the biota of the Fraser River. Of the 1446 species of vascular plants that grow in the Fraser basin, only 60% of them are native and approximately 25% of those are rare or endangered.[2] Historically, the Fraser River has one of the largest salmon runs the in the world, but annual returns have been declining on average for decades.[11,12] Land use habits and the state of local biota punctuate the need to preserve important habitat in the Fraser River, not just for ecologically and economically significant species, but for the entire ecosystem.

2.3 Management of the Fraser River Estuary: 1985-2013

The Fraser River Estuary Management Program (FREMP) was established in 1985 in response to a growing need for collaboration among resource agencies in the Fraser River Estuary. The program was largely operated by 5 authorities (Environment Canada, Fisheries and Oceans Canada, BC Ministry of Environment, Metro Vancouver, Vancouver Fraser Port Authority), but also had participation by more than 30 local agencies representing governments, port authorities, and First Nations over its 28-year existence. This partnership was mandated to protect and improve environmental quality, provide economic development opportunities, and sustain the quality of life in and around the Fraser River Estuary.[13]

Guided by this mandate, a major responsibility of the FREMP partnership was to provide a coordinated project review for development proposals in and around fish habitat in the estuary. Project reviews and approval protocols were guided by the *No-Net-Loss* (NNL) *Principle*, which emerged in the 1980s as an attempt to maintain or increase the productive capacity of aquatic habitats, while still allowing for development.[14] This principle, which was introduced in the Department of Fisheries and Oceans Canada (DFO) *Policy for the Management of Fish Habitat* was primarily achieved through habitat compensation; defined as:

> "The replacement of natural habitat, increase in the productivity of existing habitat, or maintenance of fish production by artificial means in circumstances dictated by social and economic conditions, where mitigation techniques and other measures are not adequate to maintain habitats for Canada's fisheries resources." [14]

In total, 151 compensation projects were completed from 1985-2013, representing a variety of fish habitats including mudflats, intertidal marshes, riparian areas, stream channels, and offshore reefs.

2.4 Management of the Fraser River Estuary: 2013-Present

In March 2013, federal government funding was cut from the FREMP budget and the program ended. Following the closure, the responsibility of project reviews for development proposals in and around fish habitat fell to the Vancouver Fraser Port Authority (VFPA). However, as of January 2015 permitting in the provincial region of the Fraser River became the responsibility of the BC Ministry of Forests, Lands, and Natural Resource Operations (FLNRO), and project reviews are now handled by the BC Environmental Assessment Office. As a result, proposals located in the federally-controlled region of the Fraser River are managed by VFPA and proposals located in the provincially-controlled region are managed by FLNRO (Figure 2).[15]

Figure 2: Modern project reviews in the Fraser River Estuary are primarily handled by the BC Ministry of Forests, Lands, and Natural Resource Operations (green) and the Vancouver Fraser Port Authority (red), depending on the location of the proposed project. Imagery credit: Port of Vancouver.

In 2013 the DFO *Policy for the Management of Fish Habitat*[14] was replaced by the *Fisheries Productivity Investment Policy.*[16] The new policy shares similar goals to its predecessor, aiming to "maintain or enhance the ongoing productivity and sustainability of commercial, recreational and Aboriginal fisheries". However, some terminology was revised, including "compensation" and "no-net-loss" being replaced by "offsetting". Similar to "compensation", habitat "offsetting" primarily includes habitat restoration, enhancement, and creation projects.

2.5 Challenges of Compensation and Offsetting

Several challenges threaten the effectiveness of the compensation and offsetting principle. First, the guiding policies primarily value habitat for economically-important fish (e.g. salmonids), even though the estuary is host to many species with differing habitat requirements. As a result, lost habitat is at risk of being undervalued, while habitat gained may be overvalued. This was most evident in DFO compensation formulas adopted by FREMP, where intertidal mudflats were considered to be 10-50% the value of intertidal marsh, placing a greater ecological value on marsh habitat.[17] Using this formula as a guide, mudflats were often filled-in or raised to create "higher-value" compensation marsh habitat.[18] Such losses and gains may have favoured salmonids, while reducing suitable habitat of other important species, such as migrating shorebirds and shellfish.

Second, the principle of habitat compensation assumes that the structure and function of lost habitat can be recreated, which is yet to be accepted in the scientific community.[19–21] This uncertainty was considered in the FREMP framework, as marsh habitat was frequently replaced at a greater than 1:1 ratio to account for unforeseen stressors, time lags in vegetative establishment, and to potentially achieve a net gain of habitat in the estuary.[22] Despite these precautions, uncertainty remains as to whether the current compensation framework is effective at recreating all elements of habitat lost, largely due to a lack of supporting data.

Third, pre- and post-construction monitoring has not been standardized, making compensation success difficult to assess. For several years compensation projects were approved without a commitment to quantitative monitoring. This resulted in a reliance on the more cost effective qualitative monitoring method, which limits the ability to compare between pre- and post-construction.[23] In recent years quantitative monitoring has been adopted, typically for only five years on intertidal marsh projects and only three years on riparian projects.[22] There are concerns as to whether compensation can be adequately assessed within these short monitoring periods, considering it has been recommended that salmon rearing habitat be monitored for three years prior to compensation and both marsh and salmon rearing habitat be monitored for ten years post construction.[17,24]

3 Lievesley and Stewart, 2016: Study Summary

Assessing habitat compensation and examining limitations to native plant establishment in the Lower Fraser River Estuary

3.1 Study Rationale

In light of the above challenges, this study investigated the success of FREMP habitat compensation projects and evaluated the effectiveness of compensation in maintaining habitat productivity in the Fraser River Estuary. The project objectives were:

1. To consolidate all compensation site monitoring information available to date, building upon the existing database accessible via the FREMP-BIEAP (Burrard Inlet Environmental Action Program) Habitat Atlas.[i]
2. Survey intertidal marsh[ii] and riparian compensation sites and update the database using standardized methods to show the current features and ecological functions of the sites.
3. Complete and publish comprehensive reports of the results from this study as well as evidence-based recommendations for past, present and future compensation projects.
4. Upload monitoring and mapping data, and published reports to the FREMP-BIEAP Habitat Atlas to allow for continued research and reference.[i]

3.2 Key Findings

This study focussed on marsh and riparian compensation sites in the Fraser River Estuary. Due to the broad definition of no-net-loss (the guiding principle for most of these sites), the success criteria for marsh habitat compensation projects were based on (1) similar studies conducted throughout North America and (2) feedback provided by local managers and practitioners.[19,25–30] The resulting compensation success criteria were classified as poor (0 – 64%), fair (65 – 84%), and good (>85%). For a complete definition of these success criteria please see *Appendix I - Methods*.

Due to time constraints and the more variable nature of riparian habitats (e.g. longer establishment times, varying successional stages) riparian compensation sites were not rated for success in this study. In lieu of defined success criteria, recommendations for improving riparian compensation projects are based on the definition of a natural riparian habitat (see *Appendix II – Natural Riparian Habitats*), as well as visual comparisons with intact riparian habitats in the region.

3.2.1 Marsh Compensation

The study assessed compensation success based on two criteria: (1) the area of habitat established and (2) the proportion of native species. For each site, the proportion of native species was compared to the two nearest reference sites; providing a realistic standard of success. It was found that 65% of compensation sites were rated as “good” for achieving their intended area, while only 50% of sites were rated “good” for achieving the proportion of native species.

The primary reasons compensation sites were below the area goal included erosion, lack of established vegetation, and incompletion of project objectives (e.g. only two of three compensation marshes were constructed).

The proportion of native plant species relative to non-native species was more likely to limit compensation site success. Contrary to the theory that habitat compensation will progress along predictable trajectories, this study found that the age of a compensation site did not influence the proportion of native species. Instead, the proportion of native species was found to be influenced by several factors including:

- Distance from the mouth of the river
- Poor Lyngbye’s sedge *(Carex lyngbyei)* establishment

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[i] http://www.cmnbc.ca/atlas_gallery/fremp-bieap-habitat-atlas

[ii] The term “marsh” is exclusively used in this study opposed to “wetland” because only the vegetated marsh zone was assessed. The term “wetland” encompasses the mudflat environment as well as the vegetated marsh zone.

- Waterfowl grazing
- Potentially drier conditions on compensation sites than reference sites
- Log debris accumulation

Age of a compensation site does not influence success

Time since construction did not have a significant influence on the proportion of native species. The marsh compensation sites surveyed ranged in age from 5 – 32 years at the time of sampling (2015) and no relationship was observed between the age of a compensation site and the proportion of native species. This suggests that compensation sites do not improve nor deteriorate along a predictable trajectory.

Proportion of native species decreased with distance from river mouth

The proportion of native species in a site was found to have a significant negative correlation with its distance from the mouth of the river[iii]; in other words, the further upriver a site is located, the fewer native species and more non-native species there are. Literature suggests that this is likely due to the effect of salinity, indicating that marsh plant communities are significantly influenced by their location in the estuary.[31] However, tidal inundation, river hydrology, elevation, slope, soil properties, and urbanization are just a few other factors that may also play a role in this relationship.

Lyngbye's sedge was half as dominant on compensation sites vs. reference sites

Lyngbye's sedge (*Carex lyngbyei*) is the most common estuarine sedge in the Pacific Northwest and has historically been the primary species planted in local compensation marshes.[32] This study found that Lyngbye's sedge was the most dominant native species in both compensation and reference sites; however, it was approximately half as dominant on compensation sites than reference sites[iv]. Disturbance is linked to the spread of exotic and invasive species; therefore, it is possible that the suppression of Lyngbye's sedge in compensation sites may begin at the time of site creation, when disturbed soil is most available for colonization by these competitor species.[33,34]

Lyngbye's sedge stem height was significantly shorter in the presence of waterfowl grazing

Waterfowl grazing may also be influencing Lyngbye's sedge fitness. The maximum stem height of Lyngbye's sedge (*Carex lyngbyei*) was significantly shorter[v] at sites where waterfowl grazing was observed. Since many invasive marsh species are not favoured by waterfowl for grazing (e.g. yellow iris [*Iris pseudacorus*], purple loosestrife [*Lythrum salicaria*]), it is possible that waterfowl may not only impact Lyngbye's sedge directly through grazing, but indirectly by giving non-palatable invasive species a competitive advantage.

Compensation sites may be drier than reference sites

The Wetland Indicator Status (WIS) rating system was used in this analysis.[35] This system assigns a numeric value to each individual marsh species that reflects its likelihood of occurring in a wetland. A WIS of 1 reflects a plant species that only occurs in wetlands, while a WIS of 5 reflects a species that only occurs in dry uplands.[36] By multiplying each species' WIS rating by its dominance (to account for the site abundance of the species) and applying it to an entire site, one can infer whether a site is more

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[iii] Compensation sites: $P < 0.001$, $R^2 = 0.38$, $N = 54$; Reference sites $P = 0.002$, $R^2 = 0.88$, $N = 7$

[iv] $P = 0.021$, CI = 95%; Compensation sites $N = 45$, Reference sites $N = 7$

[v] $P = 0.039$, CI = 95%; Waterfowl grazing $N = 18$, No waterfowl grazing $N = 27$

hydrologically representative of a wetland or an upland environment. For the purpose of this study, this metric is called Site WIS (SWIS).

This study found that the average SWIS was significantly higher[vi] (indicating drier) on compensation sites than reference sites. SWIS also had a positive correlation with exotic species on both compensation and reference sites[vii], indicating that drier site conditions favour the establishment of exotic species and inhibit the establishment of native hydrophytes. Higher SWIS may indicate inadequate site submergence time, which may be the result of (1) incorrect site elevation due to improper construction, (2) incorrect site elevation due to natural aggradation or (3) poor water retention due to unsuitable site substrate. However, further research is required to substantiate the cause of higher SWIS on compensation sites.

Log debris protection lowers amount of log debris accumulation

Log debris was observed in most compensation marshes, with varying degrees of impact. This study found that sites containing a form of log debris protection, such as a log boom, adjacent marina, or lattice fence, had significantly less log debris accumulation compared with sites that had no log debris protection.[viii]

3.2.2 Riparian Compensation

The primary issues affecting the success of riparian compensation projects included:

- Inconsistent methods in reporting compensation area
- Presence of non-native species and invasion by Himalayan blackberry (*Rubus armeniacus)*
- Low tree densities
- Lack of connectivity with the aquatic environment
- Designs do not mimic structure and function of natural riparian environments

Inconsistent methods in reporting compensation area

Many FREMP riparian compensation projects were measured in linear meters during project implementation. Plants were frequently planted in a straight line, and the length of that line was included in the site record. However, these linear meter measurements were later inputted to the 1980 – 2013 FREMP records as *square meters,* without any unit conversion. To add to confusion, in recent years FREMP riparian projects were actually planted and measured in square meters. To date, the 1980 – 2013 FREMP records contain no information regarding the unit used to measure each site; as a result, FREMP riparian compensation records in their current form are inadequate for assessing habitat gains, losses, and the spatial success of compensation.

Presence of non-native species and invasion by Himalayan blackberry

Riparian habitats were observed to be threatened by a relatively low diversity of non-native species in their over- and understory strata. Eighty-one percent of sites containing trees had a high proportion of native species (81-100%) in their overstory stratum and 58% of sites had a high proportion of native species in their understory stratum. Non-native species in the overstory included European mountain-ash (*Sorbus aucuparia*), European birch (*Betula pendula*), and purple leaf plum (*Prunus cerasifera*). The most common non-native understory shrub species were invasive Himalayan blackberry and exotic rugosa *rose* (*Rosa rugosa*). Rugosa rose was likely planted as a substitute to native roses, as it has higher

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[vi] $P = 0.049$, CI = 95%; Compensation sites N = 45, Reference sites N = 7
[vii] Compensation sites $P < 0.001$, $R^2 = 0.30$, N = 54; Reference sites $P < 0.001$, $R^2 = 0.52$, N = 7
[viii] Log boom vs no protection $P = 0.017$, marina vs no protection $P = 0.007$

ornamental value, and does not exhibit the rapid expansive growth of native roses, which can prove problematic near public trails. Himalayan blackberry typically establishes through natural seed dispersal and is an aggressive invasive species that can dominate entire habitats.

Low tree densities

The number of tree stems per hectare observed at riparian compensation sites varied greatly, from 0 to 16,840, and the median stems per hectare was 157. The number of stems per hectare in the reference site was 733. Seventy-four percent of the compensation sites surveyed had fewer stems per hectare than the reference site. However, only one reference site was surveyed due to time constraints, and therefore, comparisons to reference site conditions are not statistically significant. Overall, it was observed that overstory density was low, which limits the resemblance of compensation habitats to that of a natural riparian habitat (see *Appendix II – Natural Riparian Habitats*).

Lack of connectivity with aquatic environment

Riparian compensation sites often occurred at the top of riprap slopes, where they have limited connectivity with the aquatic environment and will rarely, if ever, get inundated by flooding. Some compensation projects attempted to mitigate this by incorporating pots or pockets into the riprap slope and planting them with shrubs and trees. Although this method increases the connectivity between the terrestrial and aquatic environments, it has limitations. Planting mortality was high in these pockets and trees and shrubs are not recommended on dike slopes, as root penetration may cause cracking, loosening, wind throw holes, and seepage.[37]

Designs do not mimic structure and function of natural riparian habitats

Riparian compensation sites varied greatly in design. The most common design observed consisted of a thin strip of vegetation, often only 1 m wide, placed between a public walking trail and the top of the riprap dike. Some riparian compensation projects had large spaces of manicured lawn between vegetation patches. In some cases, it was observed that shrubs and sometimes trees were being trimmed and hedged in public parks and near residential developments to maintain sightlines and preserve aesthetic value. Hedging understory vegetation causes dense growth, limiting the ability of birds and other animals to utilize it as habitat. It also prevents the vegetation from overhanging the watercourse, diminishing its ability to provide shade and nutrients to the aquatic environment. Very few sites had wide areas of vegetation resembling a natural riparian habitat (*Appendix II – Natural Riparian Habitats*).

4 Recommendations

This outline lists the habitat compensation recommendations based on the findings of Lievesley and Stewart (2016). The recommendations have been divided by (1) habitat type (marsh or riparian) and (2) project phase (site design for future projects, monitoring for future projects, and remedial follow-up activities for completed projects).

Outline

4.1 Marsh Compensation

4.1.1 Site Design – Future Projects

a. ***Consider river hydrology in site selection to limit potential impacts of log debris, erosion, and sediment deposition***

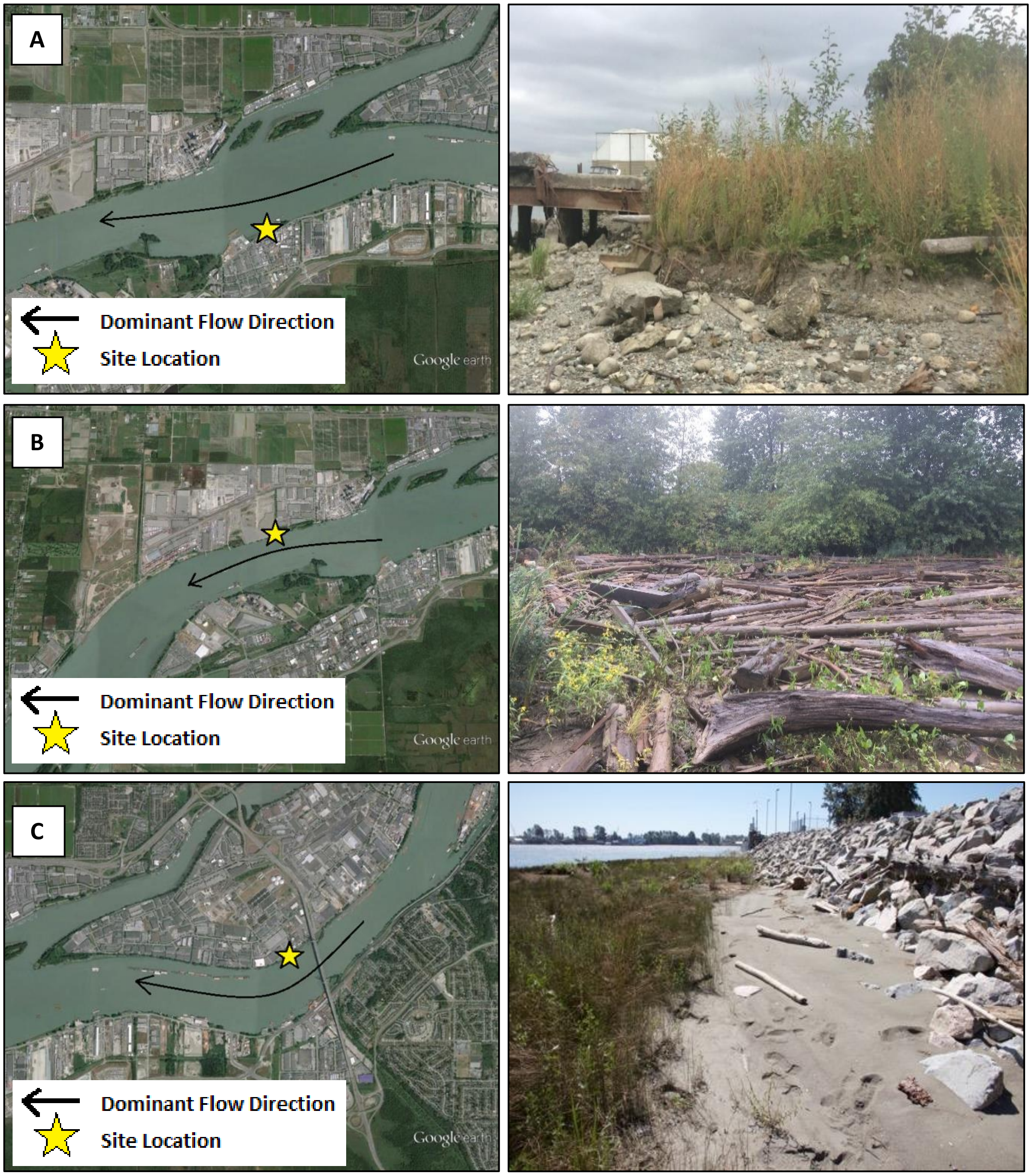


Figure 3: The location of a compensation site can greatly determine its longevity and likelihood of degradation: (A) scouring and erosion at site 10-003, (B) log debris accumulation at site 10-002-B, and (C) sediment deposition at site 12-007. Image credits: Google Earth (imagery) and Megan Lievesley (photos), July 2015.

The location of a compensation site along the river channel can greatly determine its longevity as viable habitat; influencing factors that can degrade a site over time, such as log debris accumulation, erosion, and sediment aggradation (Figure 3).

High-velocity river currents were responsible for several degraded compensation sites, particularly in outer bends of the river where currents scoured the marsh (Figure 3A) or deposited high amounts of log debris (Figure 3B). Compensation sites along inner bends of the river (Figure 3C), were more likely to be impacted by sediment deposition, which can potentially limit the establishment of plantings.

By evaluating flow rates and river morphology, compensation practitioners can predict where susceptible areas will occur, and avoid or adapt their plans accordingly. Bank erosion typically occurs on the outer bends of the river, where high-velocity currents flow into the river bank. Fluvially-transported log debris, though variable depending on size of individual pieces, is also likely to accumulate on outer channel bends.[38] Sediment accumulation is most likely to occur where river currents decrease, for example in reaches upstream of channel constrictions, or on the inside of sharp river bends.[39]

b. *Install log debris protection when possible or utilize existing structures, especially if constructing an embayed marsh*

Log debris from both natural and anthropogenic sources is extremely common in the Fraser River; however, urban infrastructure such as sea-walls and riprap banks have greatly diminished the ecological and structural role of this debris.[40] Excessive log debris build-up can severely impact plant growth and site productivity; however, log debris removal is expensive, temporary, and vegetative regrowth can have limited success.[40] Therefore, prevention of log debris accumulation is preferable. This study found that the presence of log debris protection, such as lattice fences, log booms, and marinas significantly decreased the amount of log debris accumulation (Figure 4).

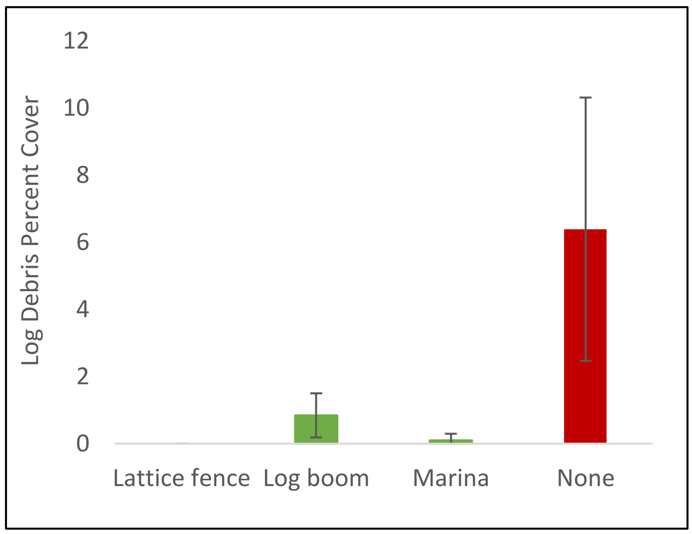


Figure 4: Mean percent cover (± 95% CI) of log debris with the presence of log debris protection. Lattice fence N = 2, log boom N = 16, marina N = 7, other N = 4, none N = 32.

Although this study did not find a significant difference[ix] in log debris accumulation between marsh design types (e.g. embayed marshes vs. marshes protruding into the river), observations indicated that embayed marshes were more prone to log debris build-up than other marsh designs. Log debris protection should be considered when building an embayed marsh, particularly for sites that are in high-risk locations along the river (4.1.1 a).

[ix] No significant difference was found between marsh design types, likely due to small sample sizes between design types and/or because the sampling method was designed for vegetation, not log debris.

c. *Ensure appropriate elevation is established and appropriate substrate is used to support marsh vegetation*

The metric, Site Wetland Indicator Status (SWIS), was used to infer the hydrologic condition of each site. This was calculated using the numeric Wetland Indicator Status (WIS) value of each species present with their dominance (see *Appendix I - Methods* for more details).[35] This study found that compensation sites had a significantly higher (indicating drier) mean SWIS than reference sites (Figure 5). Site WIS was found to have a positive correlation with exotic species, indicating that drier conditions favour the establishment of exotic species and inhibit the establishment of native hydrophytes.

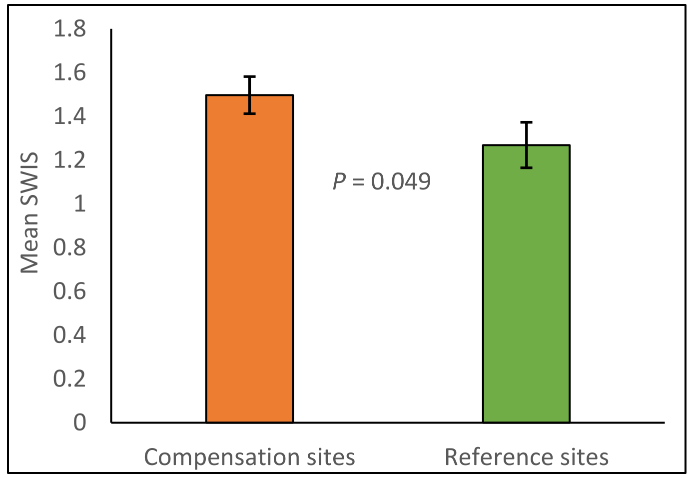


Figure 5: Mean Site wetland indicator status (± 95% CI) for compensation sites (N = 45) and reference sites (N = 7).

Although several factors are likely responsible for these results, high SWIS can be an indicator of inadequate site submergence time due to high elevation. High elevation may be the result of errors in the site design, errors in design implementation, or natural accretion, which can occur on a site over time.[41] Regardless of cause, practitioners must ensure elevational targets are correct during (1) pre-construction, acquiring target site elevation from nearby reference sites; (2) construction, via quality monitoring and (3) post-construction, through long-term monitoring and adaptive management. By doing so, practitioners and managers will help to ensure that conditions are most suitable for the desired plant community, thus increasing the likelihood of long-term project success.

d. *Consider influence of salt wedge in selection of native species*

Marsh compensation projects have typically been planted with plugs acquired from nearby donor marshes and are therefore suited to the environmental conditions.[23] In recent years, practitioners have become increasingly dependent on nursery-grown plugs for their planting prescriptions. As a result there is a greater risk that plants with poorer adaptation to variations in tidal inundation, salinity, and other environmental factors may be selected.

This study found that the dominance of some native and non-native species was related to their proximity to the river mouth, likely reflecting changes in salinity. The dominance of relatively salt-tolerant species such as Lyngbye's sedge (*Carex lyngbyei*) and Baltic rush (*Junus balticus*), significantly decreased with distance from the mouth of the river, while slough sedge (*Carex obnupta*), a less salt-tolerant species, significantly increased (Figure 6). Although Lyngbye's sedge and Baltic rush are relatively salt-tolerant, they are also capable of germinating and growing in non-saline conditions. Therefore, their decline upriver is likely the result of increased competition in the freshwater environment from less salt-tolerant species.[31]

In light of this, practitioners should exercise care when selecting native species for compensation site planting. If transplanted plugs are being used, donor sites should be selected based on their proximity and their similarity to the site, considering factors such as salinity, tidal inundation, and elevation. If nursery stock is used, practitioners should favour salt-tolerant species such as Lyngbye's sedge and seacoast bulrush (*Bolboschoenus maritimus*) in sites near the estuary mouth, as they are best suited to establish under these conditions. Upriver, plantings should be representative of nearby reference habitats, likely including a greater diversity of salt-sensitive species such as slough sedge (*Carex obnupta*), beaked sedge (*Carex utriculata*), and Sitka sedge (*Carex sitchensis*). By carefully considering the environmental factors that influence community composition, practitioners are more likely to select species that are capable of establishing long-term.

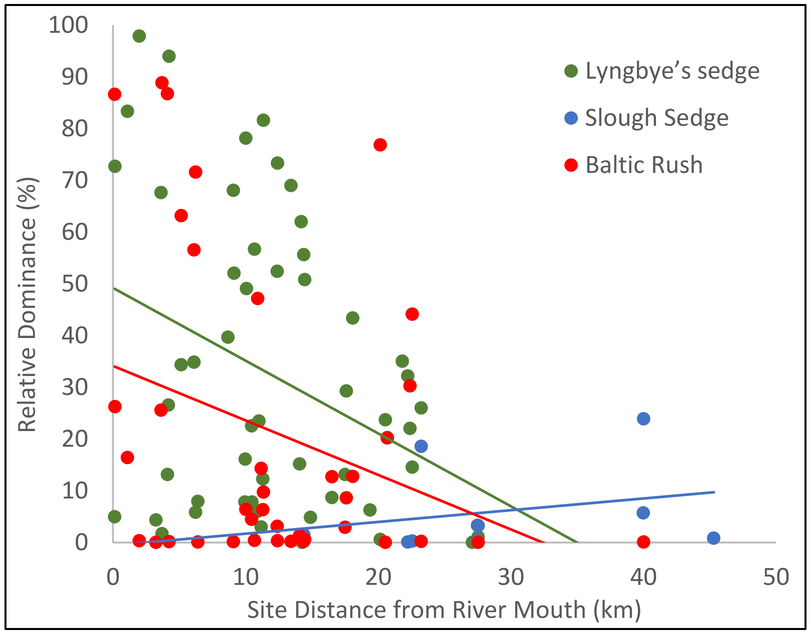


Figure 6: Relative dominance (%) of Lyngbye's sedge, slough sedge, and Baltic rush in relation to site distance from the river mouth (km) (N = 54).

e. *Select marsh design appropriate for target vegetation*

The design of marsh compensation sites can influence the establishment and composition of plant communities.[42,43] Most compensation marshes in the estuary are built as elevated marsh benches with a protective riprap berm bordering the foreshore (Figure 7A). Although design specifics vary, these marshes are typically capable of supporting target sedge communities.

A less-frequent design used in the Fraser River Estuary are excavated basins built into the existing shoreline. These typically function as tidal lagoons that are connected to the river via one or two tidal drainage channels (Figure 7B). Several of these lagoons were surveyed during this study, and it was noted that excavated marsh basins were more likely to be dominated by cattails (*Typha* spp.) than sedges (*Carex* spp.). In one example, a site that had been designed as "an intertidal sedge basin" was instead dominated by non-native lesser cattail (*Typha angustifolia;* 93% relative dominance), despite having been planted with Lyngbye's sedge (*Carex lyngbyei*) at the time of site creation in 1994. The findings were consistent with many studies, which indicate that poorly-drained, and/or hydrologically-stable wetlands are often more susceptible to cattail establishment, and less-suitable for sedge communities**.** It has also been found that cattails are highly productive in eutrophic conditions, which is typically the result of nutrient loading and/or waterlogged soils; whereas the productivity of native graminoids (e.g. sedges, grasses, rushes) remain unchanged.[42,43]

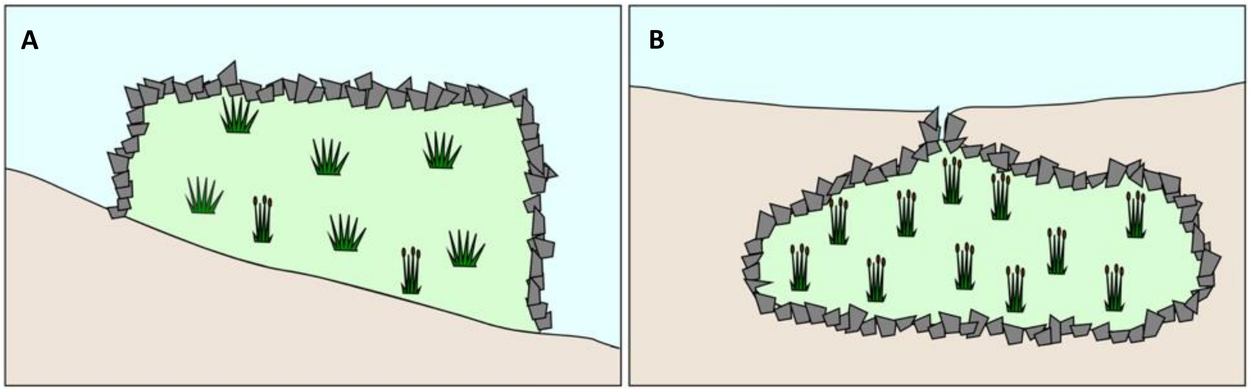


Figure 7: Illustrations of (A) elevated marsh bench and (B) excavated marsh basin compensation designs used in the Fraser River Estuary. Illustration credit: Daniel Stewart.

Considering this, and factors raised in previous sections (4.1.1 a – d), practitioners should consider the influence of abiotic processes on vegetation when designing a project. If the project goal is to produce a sedge meadow, then only sites that mimic and facilitate the natural conditions of sedge meadows are likely to have long-term success.

f. *Integrate marsh and riparian compensation habitats*

Riparian buffers have been associated with increased aquatic ecosystem health, improving habitat complexity (large woody debris, vegetation), temperature moderation (vegetative cover), primary productivity (detrital inputs), and water quality (pollutant buffering)[44]. Therefore, combining marsh compensation projects with existing riparian habitats, or incorporating a riparian buffer into marsh compensation designs may improve the quality and functioning of marsh habitat compensation.

Several existing compensation projects contain both riparian and marsh compensation; however, the two habitats are isolated from each other by a steep riprap slope (Figure 8A). Future projects should consider new designs that better integrate riparian vegetation into marsh interface (Figure 8B).

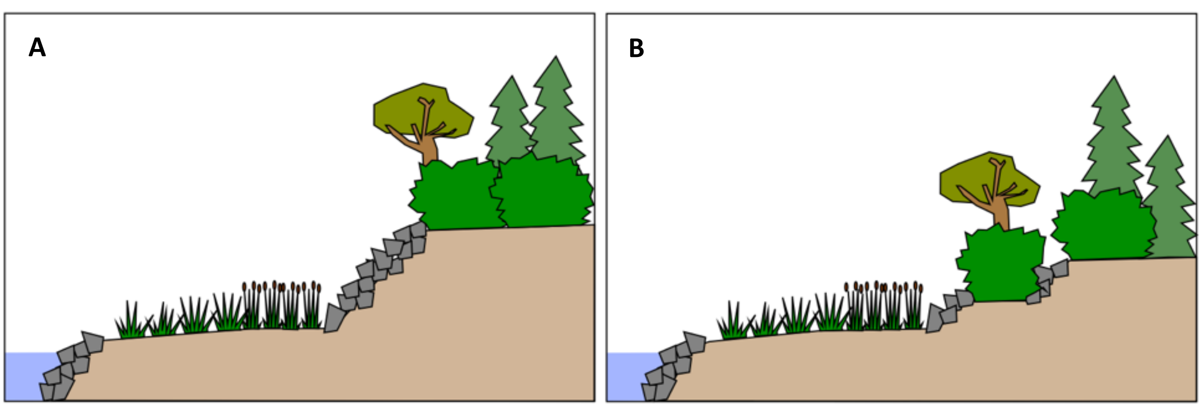


Figure 8: Marsh and riparian habitats are often separated by a riprap slope in compensation designs, limiting the influence of the riparian habitat on the aquatic environment (A). An alternative to this design is a terraced slope, which would improve the integration of habitats (B). Illustration credit: Daniel Stewart.

g. Consider mitigating the effects of waterfowl grazing to protect Lyngbye's sedge during early establishment

Waterfowl grazing, particularly by Canada Geese, may influence Lyngbye's sedge *(Carex lyngbyei)* fitness. This study found that the maximum stem height of Lyngbye's sedge was significantly shorter at sites where evidence of waterfowl grazing was observed (Figure 9). Canada geese grazing has been known to reduce Lyngbye's sedge revegetation efforts to 0% survival following the initial year of establishment.[23,45] However, grazing may also indirectly affect Lyngbye's sedge fitness by giving invasive plant species a competitive advantage as many invasive marsh species are not palatable to waterfowl (e.g. yellow iris [*Iris pseudacorus*], purple loosestrife [*Lythrum salicaria*]). Implementing mitigation measures such as exclusion fencing, sightline obstructions, or scare devices may reduce the impact of waterfowl grazing.

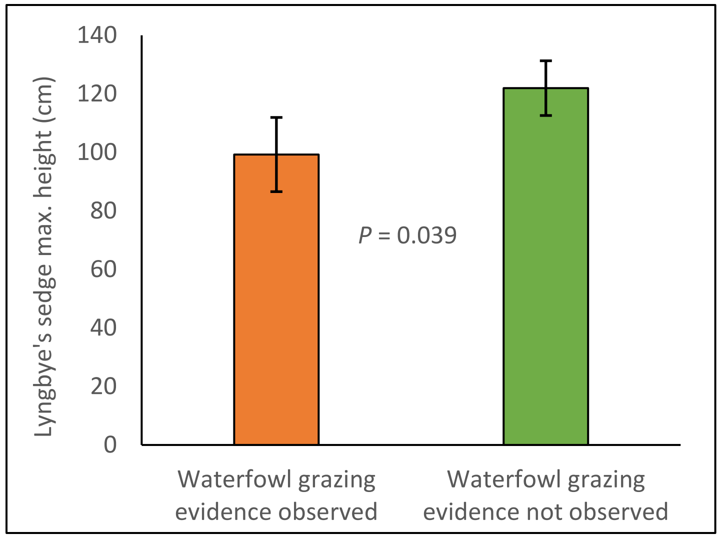


Figure 9: Mean maximum stem height of Lyngbye's sedge (± 95% CI) in sites with evidence of waterfowl grazing observed (N=18) and not observed (N=27).

4.1.2 Monitoring – Future Projects

a. *Establish baseline data prior to compensation actions*

The *Practitioners Guide to Habitat Restoration* states:

> "where existing habitat is enhanced, practitioners must recognise that the existing habitat has intrinsic value to be considered when determining the amount of habitat gain through compensation. Only the difference in productive capacity between the before and after scenarios can be considered as compensatory gains."[46]

Although this statement acknowledges the importance of pre-impact data, the guide does not state what type of data should be used (quantitative or qualitative) nor how the data should be collected. Quantitative data collection, not qualitative, is generally required to compare pre- and post-construction conditions; however, it is more time consuming and costly. As a result, quantitative baseline data has often been avoided by habitat compensation practitioners.[23] This lack of baseline data limits the ability to evaluate the success or failure of a project, and to conclude if no-net-loss/offsetting has been effectively achieved.[19,30,47–49] It is recommended that quantitative, pre-impact assessment surveys be conducted prior to any habitat disturbance, and that inventory methods be repeatable during post-construction monitoring to enable comparability of data.

For quantitative habitat assessment methods please refer to *Appendix I - Methods* or to the methods section of Lievesley and Stewart (2016).[1]

b. *Apply adaptive management and mitigate stressors*

The Canadian Environmental Assessment Agency defines adaptive management as:

> "[…]a planned and systematic process for continuously improving environmental management practices by learning about their outcomes. Adaptive management provides flexibility to identify and implement new mitigation measures or to modify existing ones during the life of a project."[50]

Adaptive management relies on sound planning and methods to allow for the identification of inadequate or undesirable outcomes. Using consistent methods to measure habitat area, community composition, and proportion of native and non-native species (outlined in *Appendix I - Methods*) allows practitioners the ability to detect inadequate or undesirable outcomes and adapt the monitoring and/or mitigation strategy.

c. *Accurately map projects to facilitate future monitoring and research*

Compensation site areas in GIS shapefile format were provided by the 1980 – 2013 FREMP records for this project. Although these records were useful in physically locating most compensation sites, they lacked precision and were often incomplete. This proved problematic for discerning between created and natural habitats for vegetation sampling.

Of the 54 compensation sites visited in 2015 during this study, only 32% had precise enough shapefiles to confidently determine the area of the site. The remaining 68% required some degree of investigation and assumption to estimate the boundaries of the compensation area. Estimating project boundaries threatens the quality of data and increases field work duration.

For example, compensation site 10-004 contained both a marsh and riparian habitat compensation component; however, upon retrieval of the existing GIS shapefiles only a single red line existed (Figure 10). Upon investigation, the site boundaries of the marsh and riparian compensation were estimated and are shown as blue polygons (Figure 10). The large discrepancy between the existing shapefiles and the ground-truthed data emphasizes the need for accurate mapping at the time of site creation.

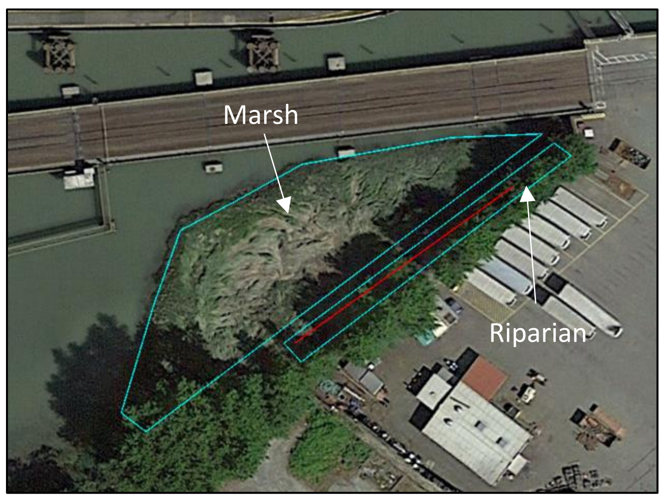


Figure 10: Mapping data included in 1980 - 2013 FREMP records were often inadequate for precise sampling. In this example, historic site boundaries (red) differed greatly from ground-truthed site boundaries (blue). Image credit: Bing Maps, Community Mapping Network website.

Future habitat compensation practitioners should accurately map compensation sites using the most robust GPS technologies and protocols available, as well as adhering to the Sensitive Habitat Inventory and Mapping (SHIM) GPS standards.[51] To improve the quality of future research and monitoring data should be shared. Sharing will increase the opportunities for practitioners and managers to enhance and/or mitigate habitats in the future and provide a platform for research. The Community Mapping Network is a valuable source to facilitating such data sharing opportunities (Section 5).

d. *Monitor establishment of plant communities*

Monitoring methods should be standardized between compensation sites and reference sites, as well as between pre-construction and post-construction phases. They should allow for plant communities to be (1) assessed over time, (2) compared to pre-construction and/or reference site conditions, and (3) assessed to compare the proportion of native and non-native species. This study found that compensation sites had notably-less native species than reference sites and that Lyngbye's sedge (*Carex lyngbyei*) had significantly lower dominance on compensation sites than reference sites. Standardized monitoring methods (*Appendix I - Methods*) allow practitioners to identify issues such as those mentioned above and apply adaptive management.

e. *Actively control invasive species that tend towards monotype stands*

In a review of marsh habitat compensation Matthews and Endress (2008) found that sites that failed to meet legal standards of native species dominance were frequently dominated by reed canarygrass (*Phalaris arundinacea*) and lesser cattail *(Typha angustifolia*).[19] Lievesley and Stewart (2016) found similar results in the Fraser River; of the twelve sites that ranked poor for proportion of native species, eight were dominated by reed canarygrass and two were dominated by lesser cattail and the hybrid version, blue cattail *(Typha x glauca*) (Figure 11). Controlling these species in compensation sites is recommended, as they can tend towards monotype dominance and degrade habitat quality and functioning.[34] Sites completely dominated by these species may only benefit from a complete reconstruction.

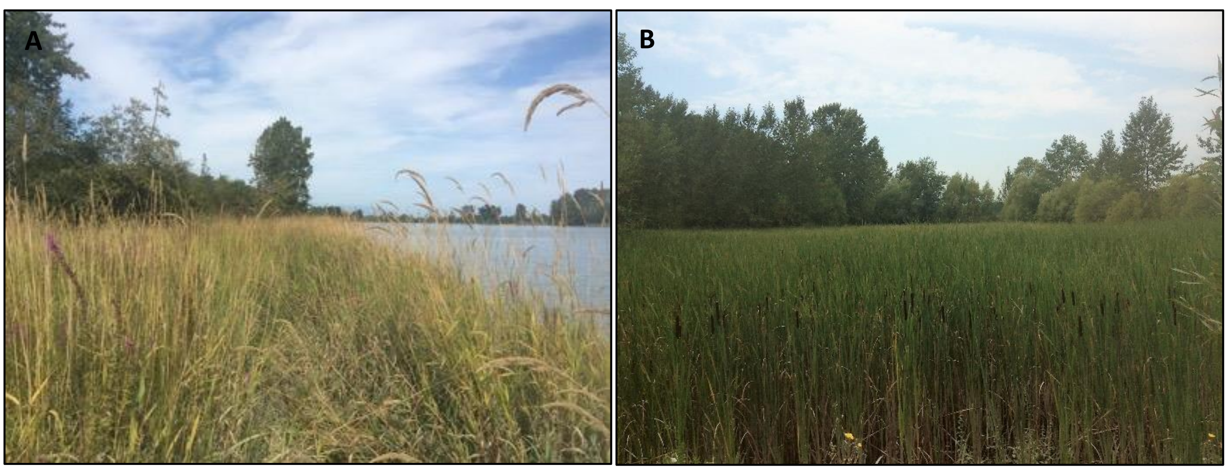


Figure 11: Compensation sites dominated by invasive reed canarygrass (A) and lesser or blue cattail (B). Image credits: Megan Lievesley, July-August 2015.

f. *Increase monitoring of Lyngbye's sedge and actively control invasive and exotic species during initial years of compensation*

Lyngbye's sedge (*Carex lyngbyei*) is the most common estuarine sedge in the Pacific Northwest and has been the primary species used in habitat compensation in the Fraser River Estuary.[32] However, this study found that Lyngbye's sedge was approximately half as dominant on compensation sites compared with reference sites (Figure 12). Disturbed habitats are more susceptible to the colonization of exotic and invasive species than intact habitats.[33,34] Suppression of Lyngbye's sedge in compensation sites may begin at the time of site creation, when disturbed soil is most available for colonization by invasive species. If unmanaged, several exotic and invasive species may compete with and displace native plant communities over time.

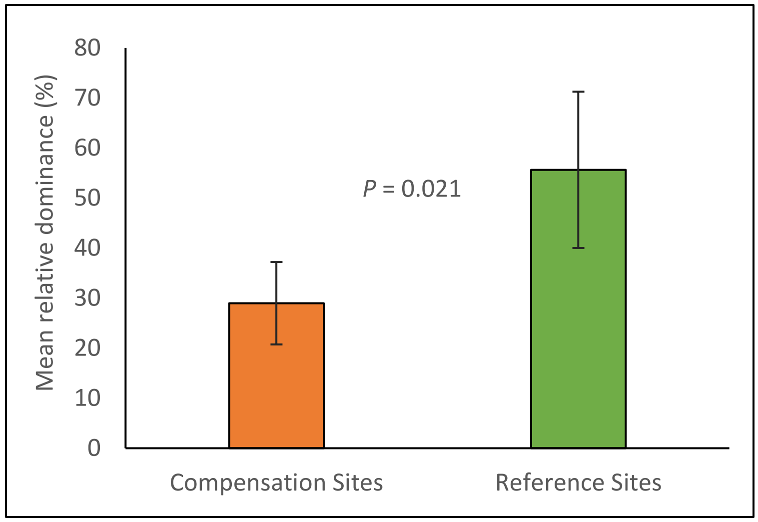


Figure 12: Mean relative dominance (± 95% CI) of Lyngbye's sedge in compensation sites (N = 54) and in reference sites (N = 7).

Diminished Lyngbye's sedge dominance on compensation sites is not fully understood; however, invasive and exotic species competition likely plays a significant role. Lyngbye's sedge survival and fitness should be monitored during the initial years of establishment, and problematic invasive and exotic species be controlled.

g. *Adapt site monitoring frequency and invasive species management to conditions of surrounding habitats*

This study found that the proportion of native species decreased significantly with distance from the mouth of the river (Figure 13) and the proportion of non-native species increased. This strongly suggests that compensation projects farther east in the Fraser River will require more monitoring and non-native species mitigation to achieve desirable results. Other environmental factors, such as proximity to invasive species or hydrological forces, may also influence the success of a compensation project. Consideration of a compensation site's distance from the river mouth and surrounding conditions can help predict budget considerations during the planning stage; however, mitigation measures should be addressed through adaptive management strategies.

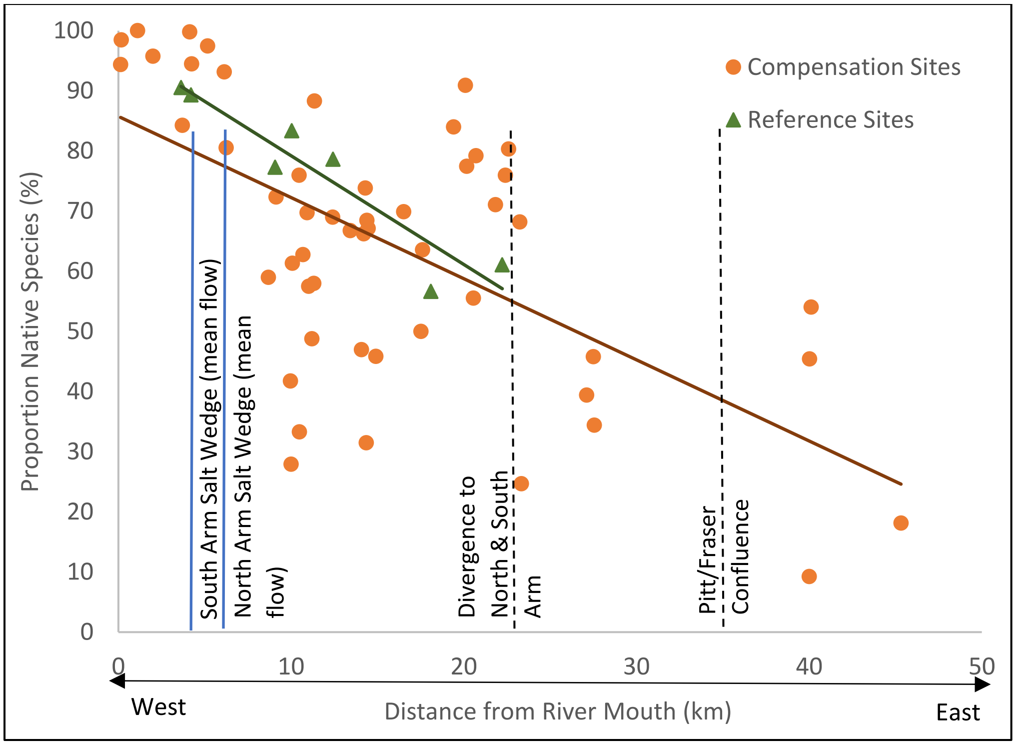


Figure 13: Regression of proportion of native species (%) with distance from the mouth of the river in both marsh compensation sites (orange, N = 55) and marsh reference sites (green, N = 7).

h. *Increase monitoring period*

Upon investigation of 54 marsh compensation sites ranging in age from 5 to 32 years at the time of sampling (2015), this study found that neither the proportion of compensation site area nor the proportion of native species correlated with time (Figure 14). Additionally, a number of other studies criticize the assumption that restored and compensated marshes progress along predictable trajectories.[20,52–54] The lack of age-related trends suggests that other factors may have a greater influence on site success. This indicates that adaptive management and longer-term monitoring is required to mitigate on-going influences.

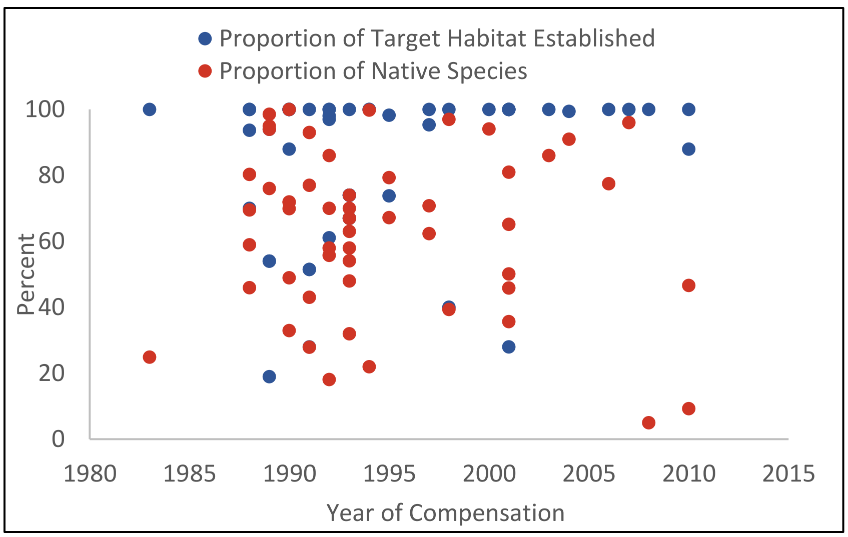


Figure 14: Regression of compensation assessment criteria used in this project (proportion of target habitat established [N = 54] and proportion of native species [N = 54]) over time.

The need for longer monitoring periods was affirmed in a 2016 poll of practitioners and government agencies, where 78% of respondents stated that marsh compensation monitoring periods should be greater than the current five-year standard.[x] The current five-year monitoring period should be

[x] N = 9

revisited, and where necessary, increased. Increased monitoring is more likely to identify (1) novel stressors that emerge several years after site creation (e.g. introduction of invasive species), and (2) chronic stressors that can gradually degrade a site over several years (e.g. erosion or sediment deposition).

4.1.3 Completed Projects That Did Not Achieve Objectives

a. *Control invasive species*

This study found that 83% of the marsh compensation projects that ranked poor for proportion of native species were dominated by either reed canarygrass (*Phalaris arundinacea*), lesser cattail *(Typha angustifolia*), or blue cattail *(Typha x glauca*). Controlling invasive species that tend towards monotype stands as soon as they are identified is recommended. Unchecked, these species will dominate sites and degrade habitat quality and functioning.[34] These species can be difficult to control once established, and as a result heavily dominated sites may require extensive restoration, or creation of replacement compensation habitat elsewhere. Invasive species in surrounding areas should also be controlled to minimize invasion of susceptible compensation sites.

b. *Remove log debris from impacted sites*

Log debris accumulation is a very common occurrence in the Fraser River. Even though the wood originates from both natural and anthropogenic sources, urban infrastructure such as sea walls and riprap banks greatly diminish the ecological and structural role of natural log debris accumulation (Figure 15).[55] Log debris removal is common practice to address concerns regarding boat safety and marsh health; however, revegetation post-removal has yielded mixed results. One study found that removal of log debris from the Fraser River Park marsh resulted in poor regrowth in the high marsh.[40]

Figure 15: Accumulation of wood debris can greatly impact the productivity of compensation marshes. Due to a failed log boom, 16% of this marsh was covered by log debris. Image credit: Daniel Stewart, August 2016.

The highest percent cover of log debris observed in this study was 53%; however, most sites were not considered to have excessive log debris accumulation. Where removal efforts are required, it is recommended that well-embedded logs in the high marsh zone be left, because bare ground encourages the colonization of non-native species. Removal efforts should be focused in the low- to mid-marsh zone where Lyngbye's sedge (*Carex lyngbyei*) dominates and is more likely to re-establish quickly.

4.2 Riparian Compensation

4.2.1 Site Design – Future Projects

a. Create wide riparian strips and limit edge habitat

This study found that the most common riparian compensation design, a 1 m strip of vegetation placed between a public walking trail and the riprap dike, failed to accurately resemble natural riparian habitats (see *Appendix II – Natural Riparian Habitats*)(Figure 16). Though narrow, linear plantings possess some ecological value, these habitats contain a high edge-to-interior habitat ratio, and subsequently lack habitat for species that are sensitive to edge habitat microclimates (e.g salamanders), human disturbance (e.g. nesting songbirds), and space constraints (e.g. trees). These narrow, linear plantings instead support edge-adapted species that are often non-native (e.g. European Starling [*Sturnus vulgaris*], noxious weeds).

Figure 16: By design, many riparian compensation projects are unable to replicate natural riparian habitats due to space limitations, species selections, and human interference. Image credits: Daniel Stewart, August 2016.

To replicate natural riparian processes, Environment Canada recommends a 30 m vegetated riparian area on both sides of streams to provide for and protect aquatic habitat.[56] Agriculture and Agri-Food Canada recommends a 5 m buffer width for bank stability, 10 – 30 m buffer for sediment removal, and 10 - 300 m for wildlife habitat.[57] *Establishing Fisheries Management and Reserve Zones in Settlement Areas of Coastal British Columbia* recommends a 50 m riparian management on both sides of fish bearing channels, and 30 m on land next to wetlands in order to protect habitat features, functions and processes.[58] Though recommended buffer widths vary from source to source, it is widely accepted that wider buffers offer greater ecological benefit.[57]

It is recommended that future riparian compensation projects be designed wider to limit the amount of edge habitat and better replicate the ecological functions of a natural riparian habitat.

b. Improve integration between aquatic and terrestrial environment

Riparian buffers surrounding wetlands have been associated with increased wetland health.[59] Therefore, combining riparian compensation with existing marsh habitat or incorporating riparian and marsh compensation projects together may improve the quality and functioning of both habitats.

Although several compensation projects observed in this study contained both riparian and marsh habitat compensation, these habitats were often located in separate locations or were isolated from each other by a riprap dike; thus, reducing the interactions and benefits associated with habitat connectivity.

One common designs observed in this study included the installation of pots or “pockets” into the riprap slope which were then planted with trees or shrubs. Although this method better integrates riparian vegetation with the aquatic environment, planting survival was low (Figure 17A). Additionally, trees and shrubs are generally discouraged on dike slopes, as root penetration may cause cracking, loosening, wind throw holes, and seepage.[37]

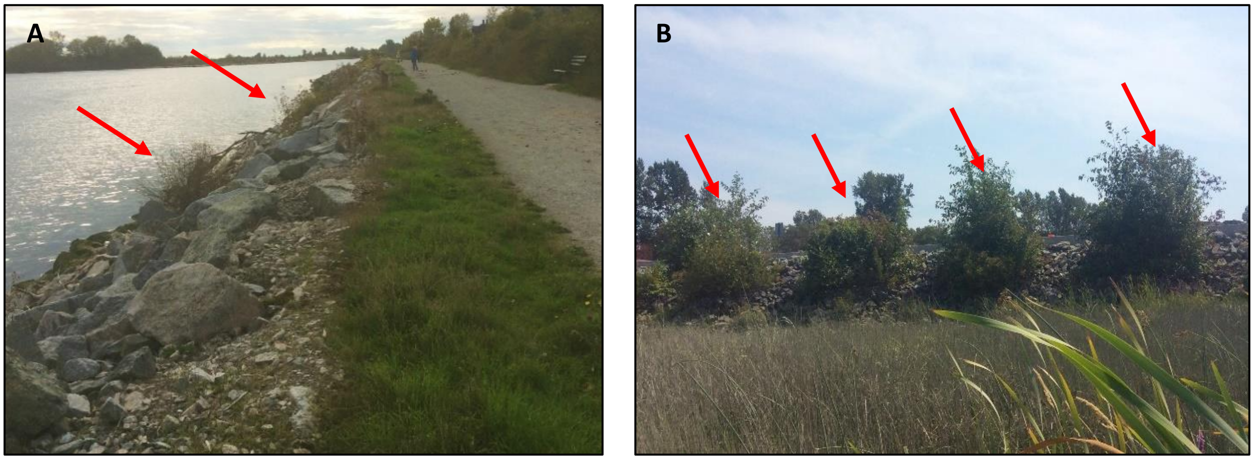


Figure 17: Habitat pockets showed varied success, such as Site 04-005 (A), where plants were stunted and desiccated by mid-summer, and Site 09-013 (B) where vegetation remained vigorous throughout the growing season. Image credits: Megan Lievesley, July 2015.

To increase the integration of terrestrial and aquatic habitats, it is recommended that novel or improved designs be tested and implemented in future compensation projects. Novel designs, such as a terraced dike (Figure 18) may increase the integration of habitats, while maintaining dike integrity. Additionally, learning from successful riprap dike plantings may provide useful information that can be incorporated into future designs (Figure 17B).

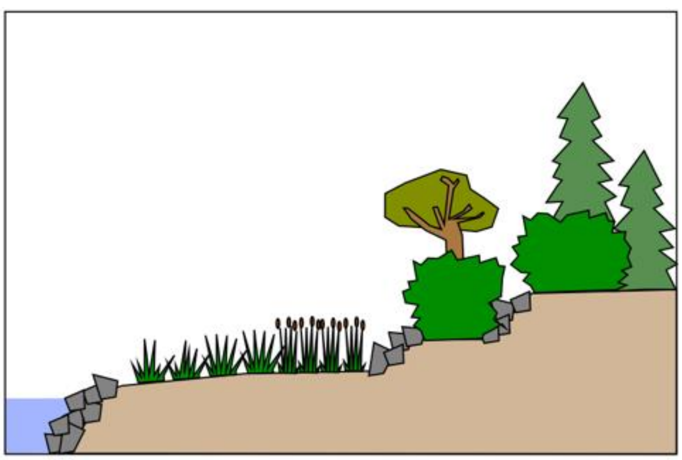


Figure 18: Example of a terraced riparian compensation design, in which a terrace is incorporated into the riprap slope and planted with riparian vegetation to improve integration between the aquatic and terrestrial environment. Illustration credit: Daniel Stewart.

c. Design compensation with a balance of anthropogenic and habitat values

This study observed that shrubs and even sometimes trees in compensation sites were being trimmed and hedged. This generally occurred in public parks and near residential developments to maintain sightlines and preserve aesthetic values. There are several reasons why hedging should be avoided. First, hedging causes shrubs to grow dense, limiting the ability of birds and other animals to utilize them as habitat. Second, hedging does not allow vegetation to overhang the watercourse, diminishing its ability to provide shade and nutrients to the aquatic environment. Third, hedging causes the trajectory of the habitat to remain static, limiting the ability of plants to form the structural diversity of mature riparian environments.[1]

It is recommended that habitat and anthropogenic values be better integrated. This can be achieved through measures such as alternating hedging and non-hedging of the vegetation to provide pockets of views and strategically planting trees to limit sightline loses. It may also require that riparian habitats be compensated at a >1:1 ratio, accounting for human values that may inhibit the natural processes within compensation sites.

d. *Plant riparian compensation with native plants only, incorporating a high diversity of species including fruit-bearing plants*

It was observed in this study that riparian compensation plantings included, on average, a low diversity of species and often non-native ornamental species were favoured in place of native species (Figure 19). Although non-native species can provide structure, shelter and food for native fauna, it is recommended that practitioners favour native species, regardless of the hardiness or aesthetic value of non-native species.

Figure 19: In place of native species, many riparian plantings included ornamental exotic species, such as European mountain-ash (Sorbus aucuparia) (A) and rugosa rose (Rosa rugosa) (B). Image credits: Daniel Stewart, August 2016.

Several reasons support this recommendation. First, native plant communities are known to benefit a greater diversity of native fauna, as native fruit-bearing plants are a high-value food source for many animal species.[60,61] Second, planting native species is in-line with the underlying principle of habitat compensation, which aims to replicate the assemblage of lost habitats. Third, low native species diversity inhibits a site's resilience to ecological threats and changes over time.[62,63] Therefore, it is recommended that riparian compensation sites be planted with a <u>high diversity</u> of <u>native</u> riparian species that include <u>fruit-bearing</u> plants.

e. *Initial understory plantings should be dense*

Himalayan blackberry *(Rubus armeniacus*) was the most prolific invasive species encountered in riparian compensation sites in the Fraser River Estuary, with one site containing 75% total cover. Blackberry is known to aggressively invade disturbed sites as well as riparian habitats making early successional riparian compensation sites highly susceptible to invasion.[64] It has been suggested that dense plantings of native species at the outset of habitat compensation may limit the establishment of Himalayan blackberry.[60]

f. *Plant trees*

Over 70% of the riparian compensation sites surveyed during this study had a lower stem density of trees than in the reference site, and 16% of riparian compensation sites contained no trees at all. Other studies have found that aquatic systems in forested watersheds are the healthiest with 45 – 65% forest cover in the overstory.[65] It is recommended that riparian compensation projects be planted with a high enough density of trees to aim for 45 – 65% cover in the mature overstory.

g. *Include and/or preserve existing wildlife trees where possible*

During this study, it was observed that very few snags and/or wildlife trees were present in riparian compensation sites. Snags and wildlife trees provide habitat for cavity nesting species (Figure 20) and forage for many different species of wildlife. Existing snags and/or wildlife trees should be salvaged and maintained in compensation projects as long as they do not pose a safety hazard to the public or compensation practitioners. In the absence of safe existing snags and/or wildlife trees, nest boxes should be constructed, or artificial wildlife trees be imported to increase the biological productivity of the site.

Figure 20: Tree swallow feeding young in wildlife tree. Image credit: Craig Wallace, 2009.

4.2.2 Monitoring – Future Projects

a. *Establish baseline data prior to compensation actions*

The *Practitioners Guide to Habitat Restoration* states that,

> "where existing habitat is enhanced, practitioners must recognise that the existing habitat has intrinsic value to be considered when determining the amount of habitat gain through compensation. Only the difference in productive capacity between the before and after scenarios can be considered as compensatory gains."[46]

Similar to marsh habitat compensation (4.1.2 a) riparian compensation projects should collect quantitative baseline date prior to compensation actions. Quantitative baseline data improves the ability to assess the success or failure of a project, and to conclude if no-net-loss/offsetting has been effectively achieved.[19,30,47–49]

For quantitative riparian habitat assessment methods please refer to *Appendix I - Methods* or to the methods section of Lievesley and Stewart (2016).[1]

b. *Apply adaptive management and mitigate stressors*

The Canadian Environmental Assessment Agency defines adaptive management as:

> "a planned and systematic process for continuously improving environmental management practices by learning about their outcomes. Adaptive management provides flexibility to identify and implement new mitigation measures or to modify existing ones during the life of a project."[50]

Adaptive management is reliant on sound planning and methods to allow for the identification of inadequate or undesirable outcomes. Using consistent quantitative methods to assess the habitat increases practitioners' ability to detect inadequate or undesirable outcomes and adapt the monitoring and/or mitigation strategy.

c. *Accurately map projects to facilitate future monitoring and research*

Compensation site areas in GIS shapefile format were provided by the 1980 – 2013 FREMP records for this project; which remain publicly available on the Community Mapping Network (CMN) website.[xi] The records were useful in physically locating most compensation sites; however, similar to the marsh compensation, the actual precision of these digital areas was often insufficient. Unlike marsh compensation sites, the available riparian data was almost entirely comprised of digital lines rather than polygon areas, resulting in the inability to determine intended site area.

Future habitat compensation practitioners should accurately map compensation sites using the most robust GPS technologies and protocols available, creating GIS shapefiles wherever possible. They should also adhere to the Sensitive Habitat Inventory and Mapping (SHIM) GPS standards.[51] To improve the quality of future research and monitoring data should be shared. Sharing will increase the opportunities for practitioners and managers to enhance and/or mitigate habitats in the future and provide a platform for research. The Community Mapping Network is a valuable resource that facilitates long-term data sharing opportunities (Section 5).

d. *Ensure all areas are reported in Square Meters*

This study observed that the unit of measure used to describe habitat area was inconsistent. While all sites were reported in square meters in the 1980 – 2013 FREMP records, further investigation found that many sites were originally measured in linear meters at the time of compensation and not accurately converted to square meters. For example, a site may be reported as 100 square meters; however, upon field inspection it is found to be 100 linear meters by 4 linear meters resulting is 400 m^2. It is recommended that all riparian compensation projects measure and report in square meters.

e. *Actively control invasive species*

Himalayan *blackberry (Rubus armeniacus*) was the most prolific invasive species encountered in riparian compensation sites in the Fraser River Estuary. Blackberry is known to aggressively invade disturbed habitats as well as riparian habitats making early successional riparian compensation sites highly susceptible to invasion.[64] If Himalayan blackberry remains un-checked it can create dense thickets that can prevent the establishment of native trees and shrubs, and inhibit natural colonization by other native species (Figure 21). Although Himalayan blackberry can provide some habitat value, it is a less-preferred riparian species, as it creates a monotype stand with lower species diversity, does not contribute large woody debris, and does not provide sufficient shade to the aquatic environment.[66] Himalayan blackberry should be actively controlled if discovered in riparian compensation projects.

Figure 21:Example of a riparian compensation site dominated by invasive Himalayan blackberry. The site was planted in 2003 and blackberry now occupies 90% of the habitat (sampled August 2015). Image credit: Megan Lievesley, July 2016.

[xi] http://cmnbc.ca/atlas_gallery/fremp-bieap-habitat-atlas

f. *Increase duration of monitoring protocol*

Riparian habitats have a long establishment time and progress through various successional stages before reaching maturity (Figure 22). Riparian compensation projects should be monitored, utilizing adaptive management, for upwards of 20 years or more. Effective monitoring plans will reduce monitoring frequency over time if the habitat is establishing well and invasive species are under control.

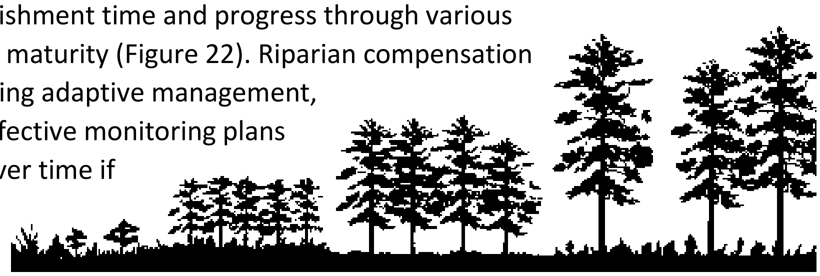


Figure 22: Forest successional stages. Image credit: North Carolina Forestry Library.

4.2.3 Completed Projects That Did Not Achieve Objectives

a. *Plant trees*

Over 70% of the riparian compensation sites surveyed during this study had a lower stem density of trees than the reference riparian site and 16% of compensation sites contained no trees at all. Forty-five to 65% forest cover in the overstory has been found to be the optimal forest cover to benefit both the terrestrial and aquatic ecosystem.[65] It is recommended that riparian compensation projects that have failed to achieve a sufficient density of trees should receive additional plantings, keeping in mind the above cover recommendation.

b. *Control invasive species*

Himalayan *blackberry (Rubus* armeniacus) was the most prolific invasive species encountered in riparian compensation sites. Sites that were found to be significantly degraded by this species or other invasive species should receive treatments to control the spread.

c. *Alter landscaping methods*

It was observed in this study that some shrubs and trees in compensation sites were being trimmed and hedged. This generally occurred in public parks and near residential developments to maintain sightlines and preserve aesthetic value. Hedging understory vegetation causes the plants to grow dense, limiting the ability of birds and other animals to utilize them as habitat. It also prevents the vegetation from overhanging the watercourse, diminishing its ability to provide shade and nutrients to the aquatic environment.[1]

It is recommended that riparian compensation projects currently receiving this treatment be revisited and new vegetation maintenance plans, aiming to better integrate habitat and anthropogenic values, be designed and conveyed to all relevant landscaping authorities. Prior maintenance methods may be improved through measures such as alternating hedging and non-hedging of the vegetation to provide pockets of views and strategically planting trees to limit sightline losses.

5 The Community Mapping Network: A Data Repository

The Community Mapping Network (CMN) has been and continues to be an invaluable resource for managers, policy makers and businesses operating in the Fraser River Estuary. For several years, the CMN has hosted BIEAP-FREMP program data on a Habitat Atlas; which most notably includes a 2006-2007 habitat inventory, shoreline colour coding, FREMP compensation project records (1980-2013), and revised project records (2015) (Figure 23); which were authored as part of this study. The importance of these data makes the Habitat Atlas a vital information resource for many parties; and we recommend that the Atlas be increasingly utilized in the future. To access these data, visit the CMN Habitat Atlas website: http://www.cmnbc.ca/atlas_gallery/fremp-bieap-habitat-atlas.

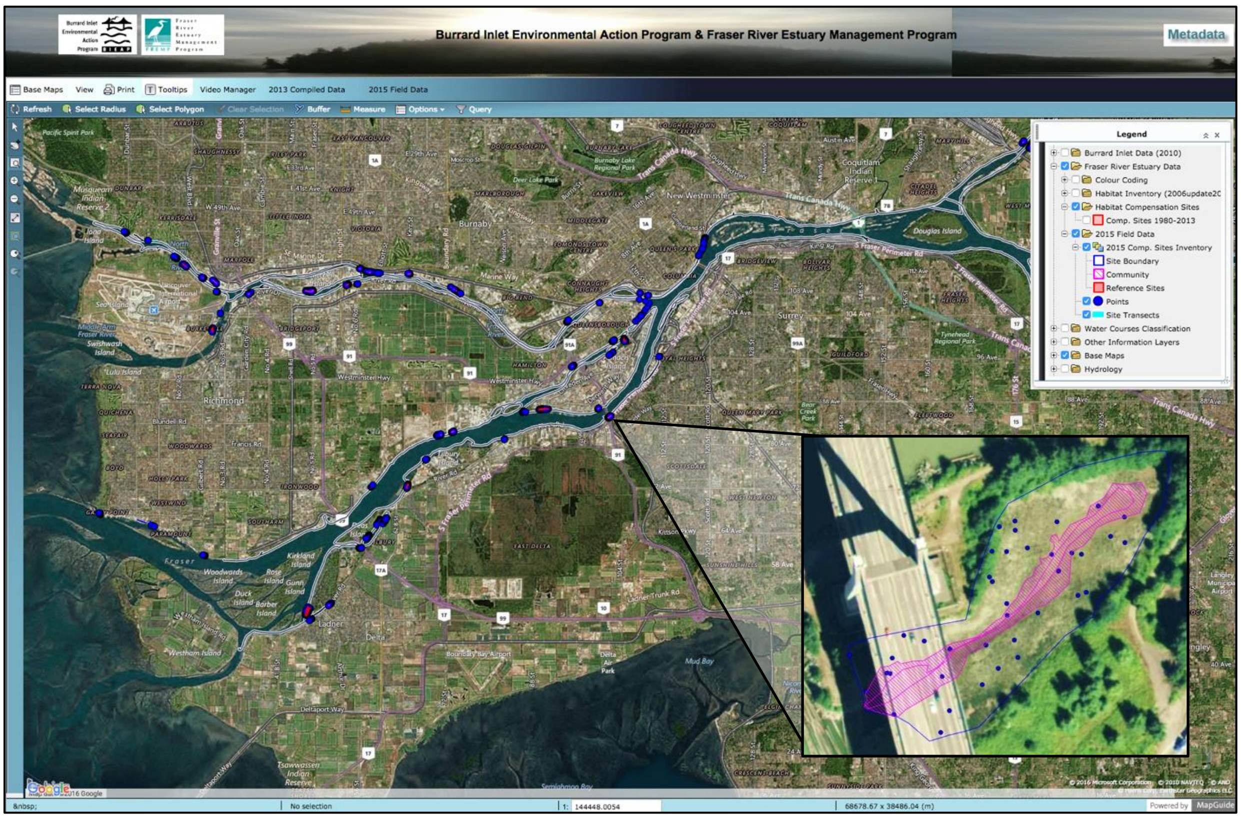


Figure 23: All revised FREMP compensation project records completed for this study are publicly *available on the FREMP-BIEAP Habitat Atlas; including detailed mapping (inset photo), site reports, and raw field data.*

In the absence of BIEAP-FREMP, no agency has formally adopted the role of data collator. As a result, (1) researchers are now at greater risk of committing redundancies in their studies, as they may be unaware of similar research being conducted and (2) compensation site monitoring has become increasingly difficult, as many compensation site records, personal comments, and original site designs have disappeared. Agencies, students, and practitioners should use the CMN as a resource for sharing future compensation project information, as well as other relevant estuary monitoring data.

To inquire about CMN, and how project data can be integrated into the Atlas, contact the Program Directors listed below:

Brad Mason, CMN Director masonb12@telus.net
Rob Knight, CMN Director rknight@telus.net

6 Closing Statement

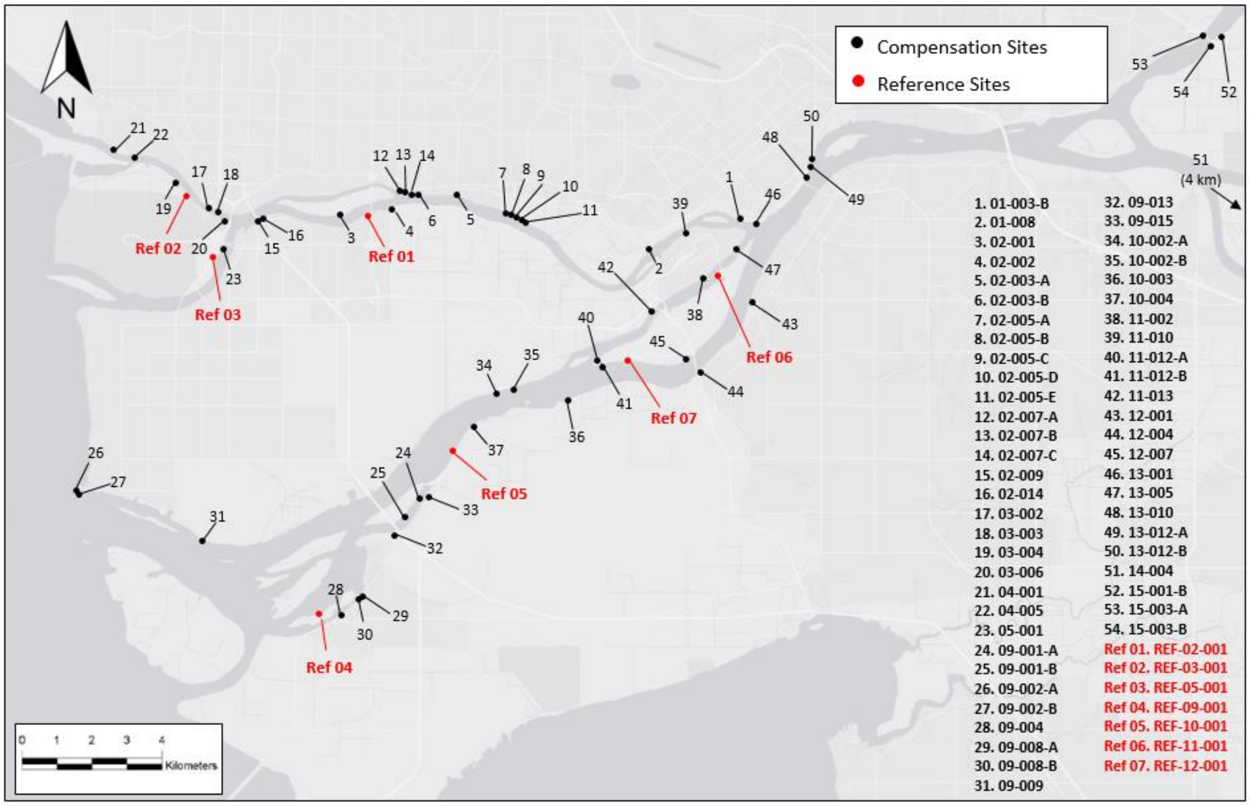
This guide, drawing upon the findings of Lievesley and Stewart (2016), outlines evidence-based recommendations for improving marsh and riparian habitat compensation in the Fraser River Estuary. The marsh compensation recommendations provided aim to mitigate the impacts of site location, invasive species, hydrologic conditions, waterfowl grazing, and log debris on the diminished proportion of native species on compensation sites. Though riparian compensation sites did not have defined success criteria like marsh compensation, many deficiencies were observed. The recommendations in this report aim to improve riparian habitat compensation by using the definition of a natural riparian habitat as well as legislative regulations as guiding principles. By utilizing these recommendations, it is expected that the work of land managers, policy makers, and restoration practitioners in the region will be improved.

This study did not survey all compensation sites in the region and cannot address concerns such as sea-level rise and climate change, but the recommendations in this report should serve as a starting point for continued research and improvement. It is paramount that the ecological condition of the estuary as well that the effectiveness of compensation efforts be well understood to mitigate existing and emerging threats. This will ensure that the governments, managers, and practitioners are equipped to preserve the health and integrity of the estuary for future generations.

Appendix I - Methods

Study Area

Between July and October, 2015 fifty-four marsh compensation sites and 7 reference marshes were sampled in the Fraser River Estuary from the mouth of the estuary to the Pitt River and Golden Ears Bridges (Appendix I - Figure 1). Additionally, 21 riparian compensation sites and 1 reference riparian site were sampled throughout the same region.



Appendix I - Figure 1: Marsh compensation and reference sites surveyed, July-October 2015.

The sites were selected for surveying using a semi-random process. The Fraser River Estuary is separated in 15 habitat management zones by Fisheries and Oceans Canada. By randomly selecting a different zone to survey each day, equal representation across the estuary was ensured throughout the sampling season. Once a zone was selected the potential sites within each zone were scrutinized using satellite imagery. Due to time constraints, sites that appeared easy to locate and access were favoured.

Site Boundary Delineation

The compensation site boundaries included in the 1980 – 2013 FREMP records vary in precision; therefore, establishing accurate site boundaries was necessary to collect relevant data. Where possible, project proponents were contacted to confirm compensation boundaries. In lieu of this, site boundaries were defined by considering a number of factors, such as the age and composition of vegetation in relation to that of neighbouring habitat, anthropogenic barriers (e.g. piers, riprap, trails), and any relevant information provided in the 1980 – 2013 FREMP site record (e.g. size of habitat created).

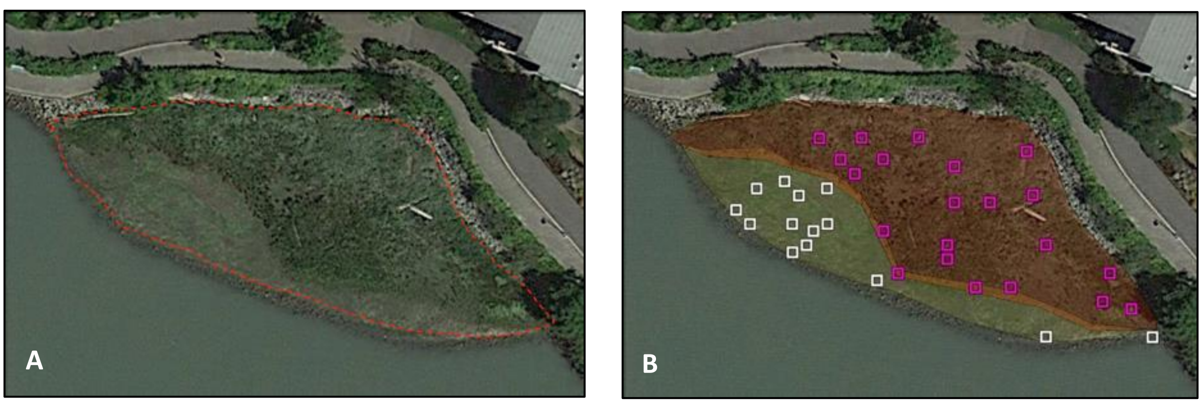
Reference Site Selection

Reference sites are ideally selected for their ability to represent the state of an environment undisturbed by human activity.[67] Such undisturbed environments are absent in much of the Fraser River Estuary. Thus, within the framework of this project the term "reference site" refers to least-disturbed environments that represent reasonable target conditions for successfully-established habitat creation projects in the region.[68] Though replicating reference site conditions is not mandated by law, local reference sites provide comparable targets for evaluating the success of established habitat creation projects, as they share similar environmental conditions and external stressors. Using these criteria, seven marsh reference sites and one riparian reference site were identified and sampled.

Marsh Compensation Study Methods

Field Sampling

Prior to sampling compensation site boundaries were mapped using a Trimble Geo 7x. If distinct vegetation communities, marked by distinct changes in environmental factors [69], were observed then these would also be mapped. In most marsh habitats, the distinct communities would be representative of either an estuarine marsh or mudflat habitat. The transition from marsh to mudflat communities was often abrupt, allowing for easy delineation for sampling and mapping. Where communities transitioned along a gradual gradient, boundaries between communities were established by walking through the middle of the transition zone. By delineating distinct communities, the compensation site was sampled using a stratified-random sampling method. Sample plot points were generated using a random point generating tool (Appendix I - Figure 2).[70]



Appendix I - Figure 2: Example of stratified random sampling methods used in marsh sampling, July - October 2015. Methods included (A) identification of site and community boundaries and (B) randomly generated sample points within the communities. Imagery credit: Google Earth.

Given enough space, a minimum of 20 sample plots, spaced $\geq$ 2 m apart, was the target sample size for each vegetation community. A 1 m X 1 m quadrat was used to sample the vegetation at each sample plot. All vascular plant species within the plot were identified; assigned an origin class of native, exotic, invasive, threatened, or unknown; and percent cover was estimated. The same two field personnel were used for the entire study to minimize observer bias. Bare ground was also estimated as seen from above and any wood debris captured within sample plots were estimated for percent cover.

Stressors such as waterfowl grazing and wood debris were not well represented by the sampling methods; in such cases, stressors were recorded qualitatively. Evidence of waterfowl grazing included (1) the 'mowing' or uniform height reduction of sedge meadows; (2) the widespread absence of leaf tips, specifically in palatable species; and (3) direct waterfowl observations (specifically Canada Geese [*Branta canadensis*]) that were seen grazing and/or using the site.

Wood debris was documented in sample plots in the form of percent cover; however, in some cases large areas would be completely covered in wood debris, preventing any vegetation growth. When this was encountered the entire area of wood accumulation would be mapped.

Data Processing and Analysis

Basic habitat analysis started with determining the mean percent cover, frequency, and relative dominance of each species as well as determining the relative percent cover (e.g. proportion) of each species origin category (native, non-native, invasive). Mean percent cover was determined by obtaining the average across all sample plots in each vegetation community.

Absolute dominance for each species was calculated by multiplying the species' mean percent cover by its frequency. Frequency was determined by counting the number of times each species occurs in the sample plots. For each species, the relative dominance was then calculated by dividing its absolute dominance by the sum of all absolute dominances, excluding any unvegetated cover such as bare ground, log debris, or rock:

$$relative\ dominance\ (species\ x) = \frac{absolute\ dominance\ (species\ x)}{\sum\ absolute\ dominance\ of\ all\ species}$$

Species origin was analysed similarly. For each plot the sum of the percent cover for each origin class was determined and the mean percent cover was calculated based on those sums. The relative mean percent cover for each origin class was calculated by dividing the mean percent cover by the sum of all mean percent covers.

Each species has a numerical Wetland Indicator Status (WIS) assigned by the US Army Corps of Engineers, under the *National List of Wetland Plants*[35] which reflects its likelihood of occurring in a wetland. A WIS of 1 reflects a species that almost always occurs in wetlands, while 5 reflects a species that almost never occurs in wetlands.[36] By using each species dominance and its WIS and applying it to an entire site the hydrologic qualities of a site can be inferred. For the purpose of this study this was called Site WIS (SWIS) and it was calculated as follows:

$$SWIS = \sum_{i-1}^{n} \left(\frac{species\ relative\ dominance}{100} \times species\ WIS \right)$$

By using the above basic analysis, a number of questions can be addressed using statistical analysis. To compare means one-way ANOVA analysis was used when variances were homogenous. If a significant difference was detected between one or more groups, then a post-hoc test was used to determine between which groups the difference occurred. When variances were not homogenous a non-parametric Kruskal-Wallis test was used. If a significant difference was detected between one or more groups using the Kruskal-Wallis test then a Mann-U-Whitney test was used to determine between which groups the difference occurred. To detect a correlation, regression analysis was used. If two regressions were to be compared; for example, if a correlation was detected for both compensation and reference sites, and you wanted to determine if the regression of the compensation and the reference sites differed significantly; an ANCOVA test was used to detect a difference.

Determining Marsh Compensation Success

Compensation site success was determined based on two criteria: (1) the area of habitat area established and (2) the proportion of native plant species. Success was broken up into three categories:

poor (0-64%), fair (65 – 84%), and good (85% and higher). Criterion 1 (the area of habitat established) was determined by delineating marsh habitat from other non-target habitats, (e.g. unvegetated mudflat), and comparing the area of marsh habitat to the area required in the conditions for project approval. Criterion 2 (the proportion of native species) success categories had to be flexible due to varying conditions throughout the Fraser River. Therefore, the percent categories were normalized to the two nearest reference sites. For example, if the proportion of native plant species at the two nearest reference sites average out to 80% then the target (100%) for the compensation site becomes 80%, and the success categories are shifted accordingly (see Appendix I - Table 1).

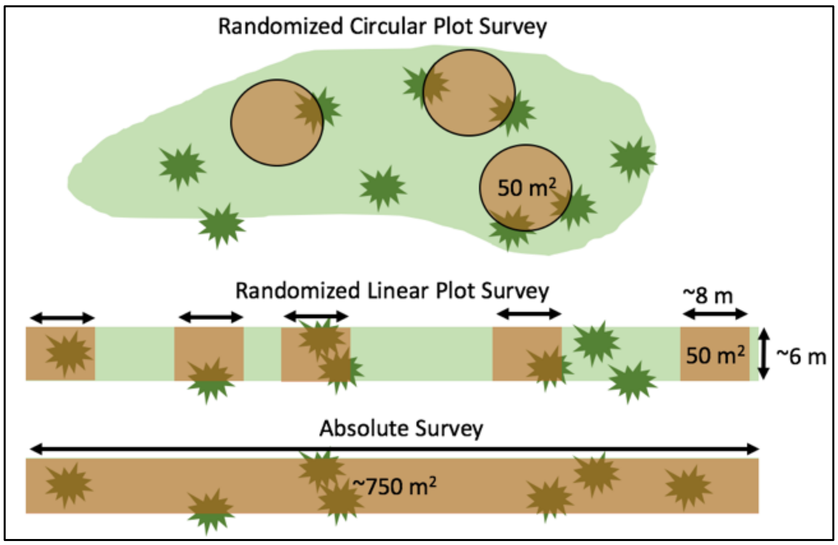
Appendix I - Table 1: Example of success categories and their percent parameters used to evaluate the success of marsh compensation projects in this study. The normalized target for Criterion 2: Porportion of Native Species is 68-80% in this example site.

	Success Ranking Categories		
	Poor	**Fair**	**Good**
Standard Success Percent Range: *Criterion 1: Proportion of Target Habitat Established*	0 - 64	65 - 84	85 - 100
Normalized Success Percent Range: *Criterion 2: Proportion of Native Species*	0 - 51	52 - 67	68 - 80+

Riparian Compensation Methods

Field Sampling

Riparian habitat assessment methods were adapted from *Provincial Riparian Assessment and Prescription Procedures.*[71] Where possible, 50 m^2 circular plots were used to sample overstory (i.e. tree) and understory (i.e. shrub) species. Similar to marsh surveys, sample plot locations were randomly generated. These methods were flexible however, as many riparian sites were too narrow to allow for circular plots or too small to achieve a minimum sample size. When riparian habitats were linear strips, 50 m^2 sample plots were created by dividing 50 m^2 by the average width of the strip to obtain a sample block length (see example in Appendix I - Figure 3). The location of the beginning of the sample length was determined using a random number generator. In cases where the riparian habitat was too small to be randomly sampled (e.g. less than ~150 m^2), absolute surveys were conducted.



Appendix I - Figure 3: Sampling design methods used for riparian habitat assessments, July - October 2015. Illustration credit: Daniel Stewart

Vegetation that originated outside of the sample plot was not included in data, regardless of whether a portion of the plant was overhanging the sample plot. Overstory vegetation was assessed based on diameter at breast height (DBH) classes, where the number of trees of each species and an estimate of height for the tallest tree in each DBH class were recorded. All understory shrub species were recorded along with their % cover, which was estimated using the same methods as marsh species (see page 31).

As with marsh habitats, some stressors were identified, but not well represented by the sampling design. Stressors such as illegal dumping, hedging, and site design were qualitatively described for each compensation site.

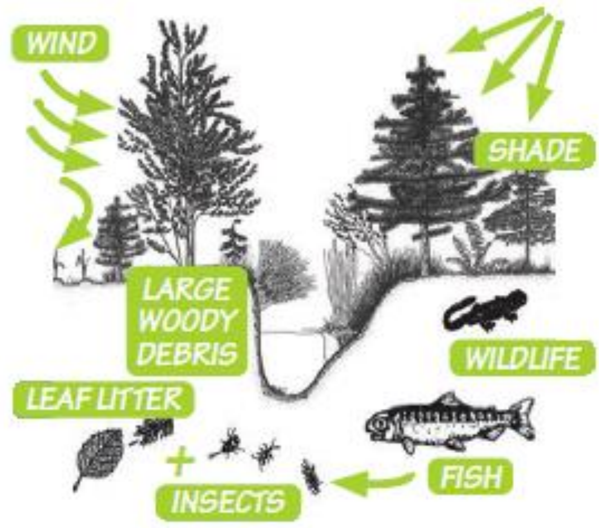
Data Processing and Analysis

The most important indicator of species abundance in the overstory is the number of stems per hectare. This is calculated by multiplying the stem count for each 50 m^2 plot by 200. If an absolute measure of riparian habitat was taken, 1 ha was divided by the area sampled, then the number of trees for each species was multiplied by this number.

The mean percent cover and confidence interval (95%) for the understory vegetation were calculated using the same method as for the marsh habitat if plots were used. If an absolute measure of riparian habitat was taken, then the estimated percent cover for each species is reported and there is no confidence interval.

Species origin for understory riparian vegetation was analyzed the same way as for marsh habitat. For each plot the sum of the percent cover for each origin class was determined and the absolute mean percent cover was calculated based on those sums. The proportion of each origin class was calculated by dividing the mean absolute percent cover by the sum of all mean absolute percent covers.

Appendix II – Natural Riparian Habitats



Appendix II - Figure 1: Riparian area processes. Image credit: Ministry of Forests, Lands and Natural Resource Operations

Riparian habitats are the narrow ecotone between the aquatic and terrestrial environment that are subject to frequent flooding, and are a vital component in estuary ecosystems. Riparian habitats provide many ecological functions including stabilization of stream banks, filtering of sediments and nutrients, stream flow rates and ground water levels through evapotranspiration, and the moderation of stream temperature through shading and evapotranspiration.[4–8] Riparian habitats also provide movement corridors for various animals, nesting and cover habitat, and food for birds, mammals and insects in both the terrestrial and aquatic environment.[8,9] Riparian vegetation is particularly important for birds, providing habitat for more species of breeding birds than any other habitat in the western United States, despite accounting for less than 1% of the landscape.[10]

In the Lower Fraser River region, healthy riparian habitats typically have a mixture of shrubs, deciduous trees, and coniferous trees, decreasing in moisture tolerance with distance from the watercourse. The reference site surveyed as part of this study had a mean 52% cover of mature shrub vegetation in the understory and a stem density of 733 stems/ha in the overstory. Other studies have found that 45 to 65% forest cover in the overstory of riparian habitats provides the most benefit both the terrestrial and aquatic ecosystem.[65]

The Ministry of Forests, Lands and Natural Resource Operations provides many documents regarding BC's Riparian Area Regulations at:

http://www2.gov.bc.ca/gov/content/environment/plants-animals-ecosystems/fish/riparian-areas-regulation

including a detailed revegetation guide for riparian habitats:

http://www2.gov.bc.ca/assets/gov/environment/plants-animals-and-ecosystems/fish-fish-habitat/riparian-areas-regulations/rar_reveg_guidebk_sept6_2012_final.pdf

Literature Cited

1. Lievesley M, Stewart D. *Assessing Habitat Compensation and Examining Limitations to Native Plant Establishment in the Lower Fraser River Estuary*. Vancouver, BC; 2016. http://cmnbc.ca/sites/default/files/Assessing Habitat Compensation_2016+Appendix I-IV.pdf.

2. Gray C, Tuominen T. *Health of the Fraser River Aquatic Ecosystem*. Vol I. Vancouver, BC; 1998. http://www.dfo-mpo.gc.ca/Library/246310.pdf.

3. BC Ministry of Environment. *Estuaries in British Columbia*. Victoria, BC; 2006. http://www.env.gov.bc.ca/wld/documents/Estuaries06_20.pdf.

4. Goodwin CN, Hawkins CP, Kershner JL. Riparian restoration in the Western United States: overview and perspective. *Restor Ecol*. 1997;5(4S):4-14. doi:10.1111/j.1526-100X.1997.00004.x.

5. Barling RD, Moore ID. Role of buffer strips in management of waterway pollution: a review. *Environ Manage*. 1994;18:543-558. doi:10.1007/BF02400858.

6. Donat M. *Bioengineering Techniques for Streambank Restoration: A Review of Central European Practices*. Vancouver, BC; 1995. http://www.env.gov.bc.ca/wld/documents/wrp/wrpr_2.pdf.

7. Hood WG, Naiman RJ. Vulnerability of riparian zones to invasion by exotic vascular plants. *Plant Ecol*. 2000;148:105-114. doi:10.1023/A:1009800327334.

8. Richardson DM, Holmes PM, Esler KJ, et al. Riparian vegetation: degradation, alien plant invasions, and restoration prospects. *Divers Distrib*. 2007;13(1):126-139. doi:10.1111/j.1366-9516.2006.00314.x.

9. Naiman RJ, Decamps H. The ecology of interfaces: riparian zones. *Annu Rev Ecol Syst*. 1997;28:621-658. doi:10.1146/annurev.ecolsys.28.1.621.

10. Knopf KL, Samson FB. Scale perspectives on avian diversity in western riparian ecosystems. *Conserv Biol*. 1994;8:669-676. doi:10.1046/j.1523-1739.1994.08030669.x.

11. The Canadian Press. Lowest sockeye run prompts fishery closures on Lower Fraser River. *Global News*. http://globalnews.ca/news/2880569/lowest-sockeye-run-prompts-fishery-closures-on-lower-fraser-river/. Published August 12, 2016.

12. Hoekstra G. “Grim” Fraser River salmon runs even worse than forcast. *Vancouver Sun*. http://vancouversun.com/business/local-business/grim-fraser-river-salmon-runs-even-worse-than-forecast. Published August 8, 2016.

13. BIEAP/FREMP. Fraser River Estuary Management Program: Overview. http://www.bieapfremp.org/main_fremp.html. Accessed July 14, 2016.

14. Department of Fisheries and Oceans Canada (DFO). *Policy for the Management of Fish Habitat*. Vol 1. Ottawa, ON: Fish Habitat Mangagement Branch; 1986. doi:10.1017/CBO9781107415324.004.

15. O'Neil P. B.C. minister attacks closure of office that helps protect Fraser River Estuary and Burrard Inlet. *Vancouver Sun*. http://www.vancouversun.com/business/minister+attacks+closure+office+that+helps+protect+Fraser+River+estuary+Burrard+Inlet/8048051/story.html. Published March 4, 2013.

16. Port Metro Vancouver. *Fisheries Productivity Investment Policy: A Proponent's Guide to Offsetting*. Vancouver, BC; 2015. http://www.portvancouver.com/wp-content/uploads/2015/05/PER-Application-Guide-Final-2015-07-29.pdf.

17. Langer O. Welcome and introduction: evolution of policy and review of DFO's attempts to achieve a no net loss of habitat. In: *No Net Loss of Habitat: Assessing Achievement*. Richmond, BC; 1997:1-5. http://www.dfo-mpo.gc.ca/Library/224524.pdf.

18. Kistritz R. Habitat compensation, restoration and creation in the Fraser River Estuary: are we achieving a no-net-loss of fish habitat? *Can Tech Reports Fish Aquat Sci*. 1996;(2349):70 + Appendices (113). http://www.dfo-mpo.gc.ca/Library/196076.pdf.

19. Matthews JW, Endress AG. Performance criteria, compliance success, and vegetation development in compensatory mitigation wetlands. *Environ Manage*. 2008;41(1):130-141. doi:10.1007/s00267-007-9002-5.

20. Race MG. Critique of wetlands mitigation policies in the United States based on an analysis of past restoration projects in San Francisco Bay. *Environ Manage*. 1985;9(1):71-82. doi:10.1007/BF01871446.

21. Kihslinger RL. Success of wetland mitigation projects. *Natl Wetl Newsl*. 2008;30(2):14-16. http://www.tetonwyo.org/compplan/LDRUpdate/RuralAreas/Additional Resources/Kihslinger 2008.pdf.

22. Naito B. Personal communication with Brian Naito (DFO), July 27, 2016.

23. Adams MA, Williams GL. Tidal marshes of the Fraser River Estuary: composition, structure, and a history of marsh creation efforts to 1997. In: Groulx BJ, Mosher DC, Luternauer JL, Bilderback DE, eds. *Fraser River Delta, British Columbia : Issues of an Urban Estuary*. ; 2004:147-172. doi:10.4095/215772.

24. Smokorowski KE, Bradford MJ, Clarke KD, Clement M, Gregory RS, Randall RG. *Assessing the Effectiveness of Habitat Offset Activities in Canada: Monitoring Design and Metrics*. Vol 3132.; 2015. http://www.dfo-mpo.gc.ca/Library/357725.pdf.

25. Lopez RD, Fennessy MS. Testing the floristic quality assessment index as an indicator of wetland condition. *Ecol Appl*. 2002;12(2):487-497. doi:10.2307/3060957.

26. Ambrose RF, Lee SF. *An Evaluation of Compensatory Mitigation Projects Permitted Under Clean Water Act Section 401 by the California State Water Resources Control Board , 1991-2002 . An Evaluation of Compensatory Mitigation Projects Permitted Under Clean Water Act Section 401*.; 2007.

27. Fernandez M, Burchell M, Jennings G. *Field Evaluation of Restored Wetlands in North Carolina*

Using Floristic Indices, Rapid Assessments, and Environmental Parameters. Raleigh, NC; 2012. http://www.aswm.org/pdf_lib/restoration_webinar/ncsu_eli_final_report_sept2013.pdf. Accessed April 25, 2016.

28. Moreno-Mateos D, Power ME, Comín FA, Yockteng R, Comin FA, Yockteng R. Structural and functional loss in restored wetland ecosystems. *PLoS Biol*. 2012;10(1):1-8. doi:10.1371/journal.pbio.1001247.

29. Turner RE, Redmond A m, Zedler J. Count it by acre of function - mitigation adds up to net loss of wetlands. *Natl Wetl Newsl*. 2001;23(6). http://files.ali-cle.org/files/coursebooks/pdf/Ck081-ch18.pdf.

30. Quigley JT, Harper DT. Effectiveness of fish habitat compensation in canada in achieving no net loss. *Environ Manage*. 2006;37(3):351-366. doi:10.1007/s00267-004-0263-y.

31. Hutchinson I. Salinity tolerance of plants of estuarine wetlands and associated uplands. In: *Washington State Shorelands and Coastal Zone Management Program: Wetlands Section*. Burnaby, BC: Department of Geography, Simon Fraser University; 1988:1-81.

32. Pojar J, MacKinnon A. *Plants of the Pacific Northwest Coast: Washington, Oregon, British Columbia and Alaska*. Vancouver, BC: Lone Pine Publishing; 2004.

33. Galatowitsch SM, Anderson NO, Ascher PD. Invasiveness in wetland plants in temperate North America. *Wetlands*. 1999;19(4):733-755. doi:10.1007/BF03161781.

34. Zedler JB, Kercher S. Causes and consequences of invasive plants in wetlands: opportunities, opportunists, and outcomes. *CRC Crit Rev Plant Sci*. 2004;23(5):431-452. doi:10.1080/07352680490514673.

35. Lichvar RW, Butterwick M, Melvin NC, Kirchner WN. *Western Mountains, Valleys, and Coast: 2014 Regional Wetland Plant List*. Waashington, DC; 2014. https://www.codot.gov/programs/environmental/wetlands/documents/nwpl-western-mountains-2014.

36. Lichvar RW, Melvin NC, Butterwick ML, Kirchner WN. *National Wetland Plant List Indicator Rating Definitions*. Washington, DC; 2012. https://www.fws.gov/wetlands/documents/national-wetland-plant-list-indicator-rating-definitions.pdf.

37. BC Water Land and Air Protection. *Dike Design and Construction Guide: Best Management Practices for British Columbia*. Vancouver, BC; 2003. http://www.env.gov.bc.ca/wsd/public_safety/flood/pdfs_word/dike_des_cons_guide_july-2011.pdf.

38. Abbe TB, Montgomery DR. Patterns and rocesses of wood debris accumulation in the Queets River Basin, Washington. 2003;51:81-107. doi:10.1016/S0169-555X(02)00326-4.

39. Church M. *Sediment Management in the Lower Fraser River: Criteria for a Sustainable Long-Term Plan for the Gravel-Bed Reach*. Vancouver, BC: Ministry of Public Safety and Solicitor General; 2010. http://ibis.geog.ubc.ca/fraserriver/reports/Sed_manage_Fraser.pdf.

40. Thomas P. *Wood Debris Removal from British Columbia's Lower Fraser River Marshes: An Analysis of a Comples Restotation Issue*. Vancouver, BC; 2002. http://urbanecology.ca/documents/Student Technical Series/Thomas, Patty.pdf.

41. Williams GL. Telephone conversation with D. Stewart. August 02, 2016.

42. Boers AM, Zedler JB. Stabilized water levels and Typha invasiveness. *Wetlands*. 2008;28(3):676-685. doi:10.1672/07-223.1.

43. Woo I, Zedler JB. Can nutrients alone shift a sedge meadow towards dominance by the invasive Typha × glauca. *Wetlands*. 2002;22(3):509-521. doi:10.1672/0277-5212(2002)022[0509:CNASAS]2.0.CO;2.

44. BC Ministry of Forests Lands and Natural Resource Opetations. *Riparian Areas Regulation*.; 2004. doi:10.1017/CBO9781107415324.004.

45. Crandell CJ. Effect of grazing by Branta Canadensis (Canada Geese) on the fitness of Carex lyngbyei (Lyngby's sedge) at a restored wetland in the Duwamish River Estuary. 2001. http://depts.washington.edu/uwbg/research/theses/Caren_Crandell_2001.pdf.

46. Fisheries and Oceans Canada. *Practitioners Guide to Habitat Compensation*. Ottawa; 2002. http://www.dfo-mpo.gc.ca/Library/270280.pdf.

47. Kentula ME, Sifneos JC, Good JW, Rylko M, Kunz K. Trends and patterns in Section 404 permitting requiring compensatory mitigation in Oregon and Washington, USA. *Environ Manage*. 1992;16:109-119. doi:10.1007/BF02393913.

48. Cole CA, Shafer D. Section 404 wetland mitigation and permit success criteria Pennsylvania, USA, 1986-1999. *Environ Manage*. 2002;30:508-515. doi:10.1007/s00267-002-2717-4.

49. Harper DJ, Quigley JT. No net loss of fish habitat: a review and analysis of habitat compensation in Canada. *Environ Manage*. 2005;35:1-13. doi:10.1007/s00267-004-0114-x.

50. Canadian Environmental Assessment Agency. Adaptive Management Measures under the Canadian Environmental Assessment Act. Policy and Guidance. https://www.ceaa-acee.gc.ca/default.asp?lang=En&n=50139251-1. Published 2016.

51. Mason B, Knight R. Sensitive Habitat Inventory and Mapping (SHIM). Community Mapping Network. http://www.cmnbc.ca/atlas_gallery/shim-sensitive-habitat-inventory-and-mapping. Published 2015.

52. Zedler J. The challenge of protecting endangered species habitat along the Southern California coast. *Coast Manag*. 1996;19:35-53. doi:10.1080/08920759109362130.

53. Zedler JB, Callaway JC. Evaluating the progress of engineered tidal wetlands. *Ecol Eng*. 2000;15:211-225. doi:10.1016/S0925-8574(00)00077-X.

54. Zedler JB, Callaway JC. Tracking wetland restoration: do mitigation sites follow desired trajectories? *Restor Ecol*. 1999;7:69-73. doi:10.1046/j.1526-100X.1999.07108.x.

55. Thonon I. *The Fraser River Debris Trap: A Cost Benefit Analysis*. Vancouver, BC; 2006. http://www.fraserbasin.bc.ca/_Library/Water/report_debris_trap_2006.pdf.

56. Environment Canada. *How Much Habitat Is Enough?* Third Edit. (Bryan G, Henshaw B, eds.). Toronto, ON: Environment Canada; 2013.

57. Agriculture and Agri-Food Canada. Riparian Buffers. Shelterbelt Planning and Establishment. http://www.agr.gc.ca/eng/science-and-innovation/agricultural-practices/agroforestry/shelterbelt-planning-and-establishment/design/riparian-buffers/?id=1344888191892. Published 2015.

58. Millar J, Page N, Farrell M, Chilibeck B, Child M. Establishing fisheries management and reserve zones in settlement areas of coastal British Columbia. *Can Manuscr Rep Fish Aquat Sci*. 1997;0(2351):1-62 + i-x.

59. Wray HE, Bayley SE. *A Review of Indicators of Wetland Health and Function in Alberta's Prarie, Aspen Parkland and Boreal Dry Mixed Wood Regions*. Edmonton, AB; 2006. http://aep.alberta.ca/water/programs-and-services/surface-water-quality-program/documents/IndicatorsWetlandHealthFunction-Mar2006.pdf.

60. Astley C. How does Himilayan blackberry (Rubus armeniacus) impact breeding bird diversity? A case study of the Lower Mainland of British Columbia. 2010. doi:10.1017/CBO9781107415324.004.

61. Burghardt KT, Tallamy DW, Gregory Shriver W. Impact of native plants on bird and butterfly biodiversity in suburban landscapes. *Conserv Biol*. 2009;23(1):219-224. doi:10.1111/j.1523-1739.2008.01076.x.

62. Green RN, Klinka K. *A Field Guide for Site Identification and Interpretation for the Vancouver Forest Region*. Victoria, BC: British Columbia Ministry of Forests; 1994.

63. Dreesen D, Harrington J, Subirge T, Stewart P, Fenchel G. Riparian restoration in the Southwest: species selection, propogation, planting methods, and case studies. In: Dumroese RK, Riley LE, Landis TD, eds. *National Proceedings: Forest and Conservation Nursery Associations-1 999,2000, and 2001*. Ogden, UT: USDA Forest Service, Rocky Mountain Research Station; 2002:253-272.

64. Invasive Species Council of British Columbia. Himalayan Blackberry. Invasive Species. http://bcinvasives.ca/invasive-species/identify/invasive-species/invasive-plants/himalayan-blackberry. Published 2014. Accessed March 11, 2016.

65. Cappiella K, Fraley-McNeal L. The importance of protecting vulnerable streams and wetlands at the local level. In: *Wetlands and Watersheds Article Series*. Washington, DC: Prepared for the Office of Wetlands, Oceans and Watersheds, U.S. Environmental Protection Agency; 2005:48.

66. Bennett M. *Managing Himalayan Blackberry in Western Oregon Riparian Areas*. Corvallis, OR; 2007. http://smallfarms.oregonstate.edu/sites/default/files/em8894-1.pdf.

67. Roegner GC, Diefenderfer LH, Borde AB, et al. *Protocols for Monitoring Habitat Restoration Projects in the Lower Columbia River and Estuary*. Portland, OR; 2008.

http://www.pnl.gov/main/publications/external/technical_reports/PNNL-15793.pdf.

68. Brophy L. *Effectiveness Monitoring at Tidal Wetland Restoration and Reference Sites in the Siuslaw River Estuary: A Tidal Swamp Focus*. Corvallis, OR; 2009. http://ir.library.oregonstate.edu/xmlui/handle/1957/35621.

69. Collins JN, Goodman-Collins D. *Data Collection Protocol: Plant Community Structure of Intertidal-Upland Ecotone*. Vol 19. San Francisco, CA; 2010. http://www.tidalmarshmonitoring.org/pdf/Collins2010_PlantCommunityStructureIntertidalUplandTransitionZone.pdf.

70. University of New Hampshire. KML Tools Project. UNH Cooperative Extension. http://extension.unh.edu/kmlTools/index.cfm. Published 2015. Accessed November 23, 2015.

71. Koning CW. *Riparian Assessment and Prescription Procedures*. Vancouver, BC; 1999. http://www.env.gov.bc.ca/wld/documents/wrp/wrtc_6.pdf.