Assessing Habitat Compensation and Examining Limitations to Native Plant Establishment in the Lower Fraser River Estuary

Megan Lievesley, Daniel Stewart, Rob Knight, & Brad Mason

BC Conservation Foundation & Community Mapping Network

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Megan A. Lievesley, MSc, B.I.T.
BC Conservation Foundation
(+1) 778-895-0133
mlievesley@gmail.com
2246 Vanness Ave., Vancouver, BC, V5N 2M2

Daniel Stewart, BSc, Dipl.Tech
BC Conservation Foundation
(+1) 778-873-0867
danjstew@gmail.com
207-6750 Balmoral St., Burnaby, BC, V5E 1J3

Rob Knight
Community Mapping Network
(+1) 604-947-2446
rknight@telus.net

Brad Mason
Community Mapping Network
(+1) 604-888-6120
masonb12@telus.net

Abstract

This study assessed the status of marsh and riparian habitat compensation projects constructed within the Fraser River Estuary Management Plan (FREMP) framework from 1983-2011. In addition to monitoring compensation effectiveness, this study also investigated the limiting agents to successful native plant establishment in these habitats. From July-October 2015, 54 marsh and 19 riparian habitat compensation projects were surveyed. Marsh compensation success/compliance was assessed based on (1) the proportion of compliance area established, and (2) the proportion of native plant species, to determine whether no-net-loss (NNL) of habitat was achieved in the Fraser Estuary. It was found that only 1/3 of compensation sites were compliant in both measures, and the greater limiting factor to site success was the successful establishment of native species. Compensation sites were found to have notably less native species coverage than reference sites, significantly lower dominance of *Carex lyngbyei* (the most dominant species in Lower Fraser River wetlands) than reference sites, and a species composition that was significantly more representative of high-marsh and upland environments than reference sites. It was also found that the proportion of native species decreased significantly, and the dominance of some species shifted with distance up river. Other factors found to influence the floristic integrity of native species and compensation site condition include log debris accumulation, waterfowl grazing, and invasive species. Riparian compensation habitat was found to be considerably more variable in design and accountability. Proportion of compliance area established, proportion native trees and shrubs, and density were examined and discussed in this study. Major limitations to riparian compensation success included low density of tree plantings, low diversity of shrub species, poor control measures for invasive species, and the labelling of manicured landscapes as riparian compensation habitat. This project determined that, while some sites are achieving NNL, as a whole NNL has not been achieved through compensation projects in the Fraser River Estuary. Recommendations were made based on the findings of this study to improve mitigation and monitoring of current and future projects and to move towards the accomplishment of NNL.

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1 Project Background

1.1 Mandate of the Fraser River Estuary Management Program

The Fraser River Estuary Management Program (FREMP) was established in 1985 in response to a growing need for collaboration and resource collation among agencies in the Fraser River Estuary. More than 30 agencies representing federal, provincial, and local governments, port authorities, and First Nations participated in the FREMP partnership, as well as several decision-making authorities (Environment Canada, Fisheries and Oceans Canada, BC Ministry of Environment, Metro Vancouver, Port Metro Vancouver) all participated in the management of the program until its closure in 2013. Fundamentally, FREMP was formed to combine partner resources in order to:

(1) conserve and enhance the environmental quality of the river and estuary to sustain healthy fish, wildlife, plants and people;
(2) respect and further the estuary's role as the social, cultural, recreational, and economic heart of the region; and,
(3) encourage human activities and economic development that protect and enhance the environmental quality of the estuary (Mason & Knight 2013).

1.2 Compensation and the No-Net-Loss Principle

One responsibility of the FREMP partnership was to provide a coordinated project review for proposed works within the Estuary. Until its closure in March 2013, 2521 applications were submitted to FREMP for project review, representing a variety of impacts such as dredging, bridge works, demolition, and dike maintenance.

Project reviews and conditions for approval were guided by the *No-Net-Loss* (NNL) principle, which emerged in the 1980s in an attempt to conserve the productive capacity of aquatic habitats in Canada, while still allowing for development in and around fish habitat (DFO 1986). This principle was included in the *Policy for the Management of Fish Habitat* (1986), which was created to achieve a *Net Gain* of habitat through conservation (via compensation and the NNL principle), restoration, and creation activities (Kistritz 1996). Upon the implementation of this policy, the Minister of Fisheries stated, "It is, I believe, an ambitious but realistic policy designed to achieve a Net Gain of Habitat for Canada's fisheries resources in a manner that will be of benefit to all users. It does this by providing a comprehensive framework for the conservation, restoration, and development of fish habitats and strategies for the implementation of its various components" (Langer 1997). By applying the NNL principle, the FREMP partnership aimed to balance unavoidable habitat losses in the Fraser River Estuary through *habitat compensation* on a project-by-project basis (Kistritz 1996). *Compensation* in the framework of the NNL principle required the creation and/or replacement of habitat lost, which was determined based on the size and type of impacted habitat.

1.3 Challenges of the No-Net Loss Principle

Several major challenges threaten the effectiveness of this compensation-dependent approach. First, the NNL principle was difficult to apply in the Fraser Estuary compared with other fish habitats, as (1) 5 species of Pacific Salmon are present in the River, with varying habitat needs in differing regions of the estuary (Levy & Northcote 1982, Levy & Slaney 1993) and (2) the Fraser Estuary provides vital habitat for several non-salmonid species, including avian species migrating along the Pacific Flyway. As a result, defining adequate compensation for habitat lost can be problematic; particularly when habitat is valued in the context of only a few species (i.e. salmonids), as opposed to an ecosystem. This was most evident in DFO compensation formulas adopted by FREMP, where marsh was given a 0.1:1 - 0.5:1 value relative to mudflat (Langer 1997). Using this formula as a guide, mud/sandflats were lost at a greater rate than marsh habitats, as they were often filled-in and raised to create higher-value compensation marsh habitats (Kistritz 1996). Such losses and gains may have favoured salmonids, while reducing suitable habitat for non-salmonid species.

Second, the principle of habitat compensation assumes that the structure and function of destroyed habitat can be recreated, which is yet to be accepted in the scientific community and is poorly studied in the Fraser Estuary (Race 1985, Kihslinger 2008, Matthews & Endress 2008). Because of this, the effectiveness of the habitat compensation approach, including habitat replacement formulas applied by DFO, is questionable. Further research is required to ensure true compensation is achievable on a multi-species level, and to determine under what conditions (e.g. size of site, design type, location in river) projects are most likely to succeed.

Third, for several years FREMP projects were created without a concurrent commitment to pre or post-construction monitoring (Adams & Williams 2004). In more recent projects, monitoring remained non-standardized but quantitative monitoring was adopted, typically for ≤ 5 years. In both cases, there are concerns as to whether such monitoring was adequate for assessing the long-term compensation success of created habitats (Smokorowski et al. 2015). Langer (1997) noted that 10 years is adequate to determine project success. Smokorowski et al. (2015) recommend monitoring salmonid rearing habitat three years before compensation to establish a baseline, three years after compensation to identify immediate change, three years of later sampling (between 4-9 years after), and 10 years later to capture long-term changes to the site. Although these recommendations may have been unrealistic within the FREMP framework, they point out the need for pre- and post- impact monitoring at compensation sites, which unfortunately appears to have been overlooked in several FREMP projects. Without these data, NNL calculations are ultimately limited, as the before-after changes in habitat value are poorly understood and not quantified.

1.4 Project Rationale

This report investigates the long-term success of FREMP compensation habitats, and in so doing evaluates the effectiveness of the NNL principle in maintaining estuary health. To date, Kistritz (1996) is the only other known report of this kind. The Kistritz report is now limited in its modern application as (1) it was published in 1996, and results are likely to have changed and (2) the report only evaluated sites created from 1983-1992. Using a combination of research and field sampling, this project aimed to:

1. Consolidate all compensation site monitoring information available to date, building upon the existing database that is accessible via the FREMP-BIEAP Habitat Atlas.
2. Visit and re-inventory (monitor) selected compensation sites and update the database using standardized methods to show current features and ecological functions of those sites.
3. Complete and publish comprehensive reports of monitoring data and findings on the success and failures for the surveyed compensation sites.
4. Update the public access FREMP-BIEAP database and provide publicly available raw data for future research and reference.

2 Methods

2.1 Study Area

Between July 9th and October 16th, 2015 a total of 71 compensation sites, representing 56 projects were visited in the Lower Fraser River from the mouth of the Estuary (west) to the Pitt River and Golden Ears Bridges (east) (Figure 1). Of the 71 sites compensation sites visited, 54 sites representing 39 FREMP project IDs were sampled. Due to time constraints, only marsh and riparian habitat projects were assessed and the area of study was limited to compensation sites directly within and alongside the Fraser River. Compensation sites located in marine habitats at the estuary mouth and in the Boundary Bay watershed were excluded.

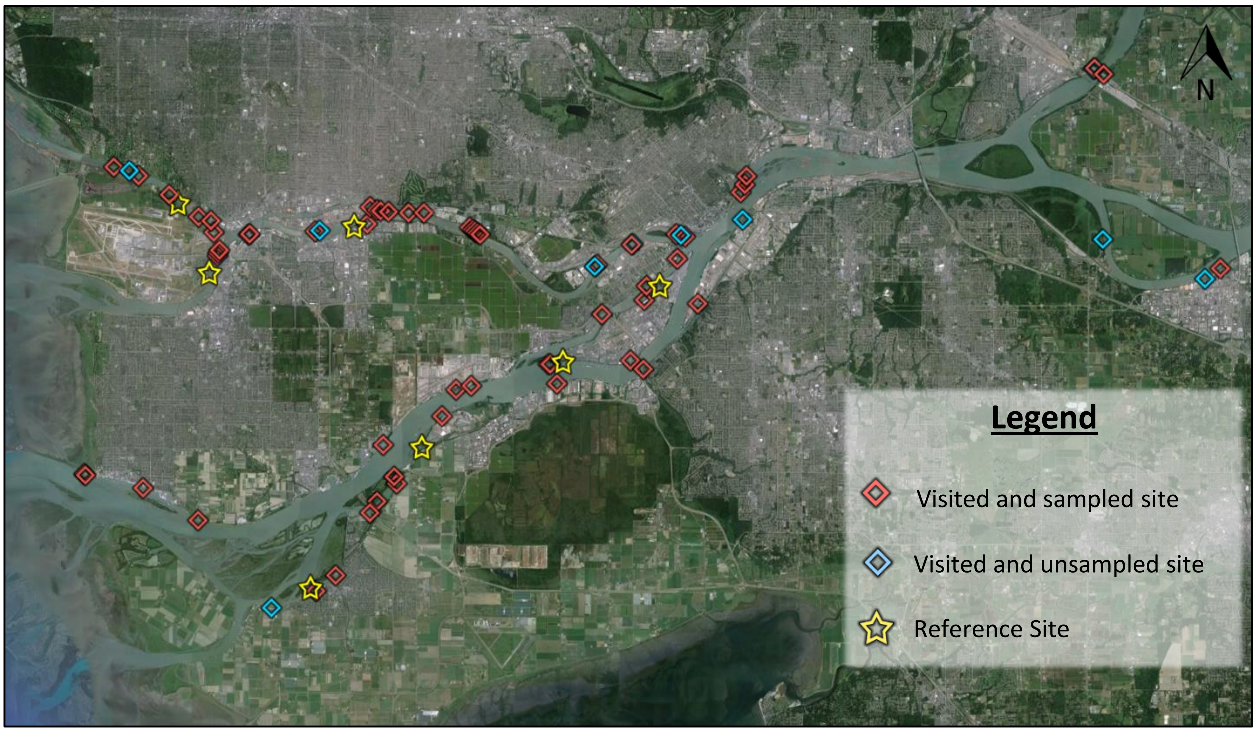


Figure 1: Compensation sites visited during surveys, July-October 2015. Sites along the marine boundary and in the Boundary Bay watershed were excluded.

2.2 Site Boundary Delineation

The compensation site boundaries included in legacy FREMP - BIEAP Habitat Atlas records vary in precision (see Limitations 4.3.2); therefore, establishing accurate site boundaries was important to legitimize sampling results. Where possible, project proponents were contacted to confirm compensation boundaries; however, in the absence of this resource site boundaries were defined by considering a number of factors. These factors included the age/composition of vegetation in relation to that of neighbouring habitat, anthropogenic barriers (piers, riprap, trails, etc.), and any relevant information provided in the legacy FREMP site record (e.g. m^2 of habitat created).

2.3 Reference Site Selection

Reference sites are ideally selected for their ability to represent the state of an environment undisturbed by human activity (Roegner et al. 2008). Such undisturbed environments are not present in much of the Lower Fraser River Estuary; so within the framework of this project the term "reference site" refers to least-disturbed environments that illustrate desired target conditions or pre-disturbance conditions for habitat creation in the region (Brophy 2009).

In total, fifteen potential reference marshes were identified using aerial imagery. The reference suitability of sites was then confirmed via field visits, which looked at (1) site accessibility and (2) the degree impact of human-associated stressors. Sites that required boat access, and sites that were heavily influenced by stressors (e.g. invasive species) were not sampled. Invasive species and other stressors were permitted in reference sites, but the site had to represent a reasonable target for habitat creation/restoration projects in the region (e.g. sites dominated by *Phalaris arundinacea* or *Typha angustifolia* were not considered reasonable targets) (Brophy 2009). Using these criteria, seven of the fifteen potential marsh reference sites were considered adequate and were sampled (Figure 1).

Only a single riparian reference site was selected and sampled over the course of this project. Although more sites are required for valid statistical analyses, sampling of other riparian reference sites was limited by time constraints and a greater project emphasis on marsh habitats. As a result, data from the sampled riparian reference site could not be statistically compared to those of riparian compensation sites; these data are only referenced in the discussion.

2.4 Marsh Habitat Sampling Methods

This study assessed 39 of a possible 96 marsh compensation projects. Projects were selected for sampling based on accessibility and availability of historical information, while ensuring equal sampling throughout the region. Compensation marshes were sampled using a stratified random sampling method. Sites were stratified into vegetation communities based on distinct changes in environmental factors (Collins & Goodman-Collins 2010). In most cases the communities either represented estuarine marsh or mudflat habitats. Marsh habitats generally have high vegetative cover and are dominated by species that reach a minimum 30 cm in height. Marsh plant species are typically either obligate wetland or facultative wetland species as defined by Lichvar et al. (2014), and are typically less salt-tolerant. Mudflat habitats have greater inundation times, and are sparsely vegetated by obligate hydrophytes, typically $\leq$ 10 cm in height (Reed Jr. 1988). Depending on the habitat's proximity to marine environment, estuary mudflat species are typically halophytic or at least moderately salt-tolerant (Akins & Jefferson 1973).

Prior to visiting a site, compensation site and vegetation community boundaries were estimated using Google Earth software (Figure 2). Polygons were intentionally drawn approximately 5 m wider than estimated site boundaries to account for errors in imagery interpretation. These polygons were then uploaded to the University of New Hampshire KML Tool project; a website designed to produce random GPS locations within uploaded polygons (Figure 2) (University of New Hampshire 2015). Before sampling the site, community boundaries were ground-truthed, adjusted if necessary, and mapped using a Trimble Geo 7x GPS. 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.

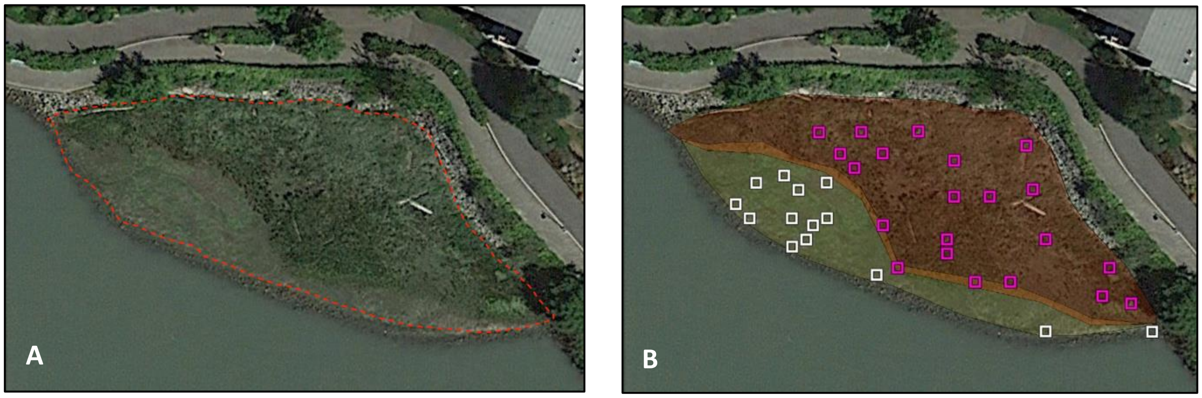


Figure 2: Example of stratified random sampling methods used in marsh sampling, July - October 2015. Methods included aerial imagery interpretation to identify site boundaries (A) and manual drawing of vegetation communities, followed by generation of random points within the communities (B).

A minimum of 20 plots was the target sample size for each vegetation community; however, in reality this varied based on site and community size. Minimum distance between generated plots was 2 m, and all plots were named numerically. An excess number of sample plot points were intentionally generated for each vegetation community to compensate for points that fell outside of the ground-truthed site or community boundaries. For example, if 40 points were generated but only 20 are required to adequately sample the site, points 1 through 20 would be sampled. If point 14 fell outside of the actual site boundary or within a different community, then points 1 through 21 were sampled, and point 14 would be excluded. All sample plot locations were uploaded to a Garmin GPSMAP 64s, which was used to locate sample plots in the field.

A 1 m X 1 m quadrat was used to sample the vegetation at each sample plot. The quadrat was placed directly over the center of the randomly generated point with one edge parallel to the River. All plant species within the plot were identified and percent cover estimated. Each field personnel estimated percent cover for each species and the average of those estimates was recorded. The same two field personnel were used for the entire study to minimize observer bias. Bare ground was also estimated as seen from above. Species that could not be identified in the field were recorded, photographed, and pressed for identification in the office. Due to stratification of vegetation, total percent cover was capable of exceeding 100% (Oregon Department of State Lands 2009).

2.4.1 Observance of Impacts

In many sites, impacts and stressors such as excessive waterfowl grazing or wood debris were evident but not captured in our sampling methods. In such cases, impacts were identified and recorded at each compensation site. Evidence of waterfowl grazing was observed by looking at the tips of *Carex lyngbyei* and noting whether the tops had been grazed to a uniform height. Such uniformity was likely the result of waterfowl, which typically enter a site at high tide and graze emergent *C. lyngbyei* stems. Grazing was also directly noted if waterfowl, specifically Canada Geese (*Branta canadensis*) were observed utilizing and/or grazing in the site.

Wood debris was generally well documented in sample plots in the form of percent cover; however, the impact of log debris accumulation was also qualitatively assessed, and recorded as low, medium, or high. The presence of any log debris protection structures (log boom, marina, fencing, etc.) were also noted at the time of survey.

2.5 Riparian Habitat Sampling Methods

Riparian habitat assessment methods were adapted from *Provincial Riparian Assessment and Prescription Procedures* (Koning 1999). Plot sizes of 3.99 m radius (50 m^2) were used to sample overstory (tree) as well as understory (shrub) species. Where possible, sample plot locations were determined using the University of New Hampshire KML Tool Project (University of New Hampshire 2015) as with marsh surveys (see 2.4); however, many riparian sites were too narrow to allow for circular plots, or too small to achieve a minimum sample size. When riparian habitats existed in narrow, linear strips, 50 m^2 sample plots were identified by dividing 50 m^2 by the average width of the strip to obtain a sample block length (see example in Figure 3). The location of the beginning of the sample length was determined using a random number generator. In cases where riparian habitat was too small to be sampled (~ less than 150 m^2), absolute surveys were conducted (Figure 3).

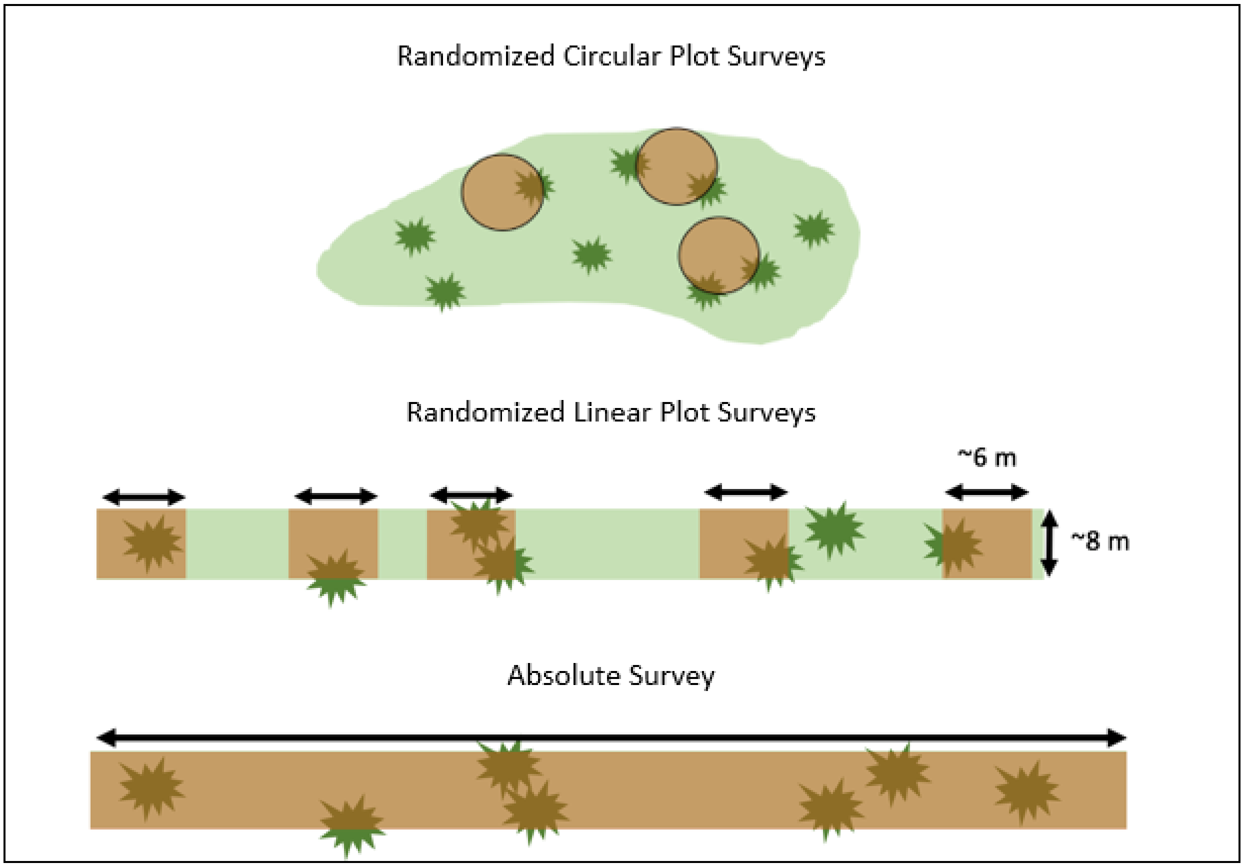


Figure 3: Sampling design methods used for riparian habitat monitoring, July - October 2015.

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 (>22 cm, 12.6 – 21.9 cm, 7.5 – 12.5 cm, 0.1 – 7.4 cm, and <1.3 m tall). The number of trees of each species and an estimate of height for the tallest tree in each DBH class were recorded (adapted from Koning (1999)). All understory shrub species were recorded along with their % cover, which was estimated using the same methods as marsh species (see 2.4).

2.5.1 Observance of Impacts

As with marsh habitats, some impacts and stressors were identified in riparian habitats that were not captured in our sampling design. Such impacts (e.g. illegal dumping, hedging) were recorded and described at each compensation site.

2.6 Data Processing and Analysis

2.6.1 Species Origin Classification

All recorded plant species were placed into one of 5 origin categories for analysis: Invasive, Exotic, Native, Threatened, or Unknown. The line between invasive and exotic species is not well-defined, as exotic species are often only labelled as invasive after significant ecological or economic impacts have been incurred (Jogesh, Carpenter, & Cappuccino, 2008; Klinkenberg, 2013). In British Columbia, several invasive species lists are available as guiding documents, but many fail to identify species that possess localized invasive qualities (e.g. *Typha angustifolia*). For this reason, a list of invasive species was created specifically for this project based on location and national guiding publications, as well as personal field observations (see Appendix II – Species Classified as Invasive).

Non-threatened (native) and threatened (native) species were separated in the raw data. Any plant species that was provincially blue- or red-listed, and/or federally SARA or COSEWIC-listed was considered threatened. All remaining native species were considered non-threatened. They were separated for potential future analysis of threatened species; however, for the purpose of this study they were later combined to analyze the proportion of native species as a whole.

A number of genera have native and non-native species that occupy similar habitats within the Lower Fraser River region and have differentiating characteristics that are poorly described or only observable under certain conditions. Due to these limitations these species were only recorded to genus and received an origin status of "unknown". These genera include *Lycopus* [regional species: *americanus* (native) and *europaeus* (exotic)], *Alisma* [regional species: *triviale* (native) and *plantago-aquatica* (exotic)], and *Persicaria* [regional species: *hydropiperoides* (native) and *hydropiper* (exotic)].

2.6.2 Marsh Habitat 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 (proportion) of each species origin category. Mean percent cover was determined by obtaining the average across all sample plots in each community and a 95% confidence interval was calculated using the following equation:

$$C.I. = \overline{X} \pm t_{\frac{\alpha}{2}} \frac{S}{\sqrt{n}}$$

where $\overline{X}$ = the sample mean
S = the sample standard deviation
$t_{\frac{\alpha}{2}}$ = the t distribution value for the desired confidence level α

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 in a similar way. 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, or proportion, for each origin class was calculated by dividing the mean percent cover by the sum of all mean percent covers.

Prior to analyzing any data, the data sets for the North Arm and the South Arm of the Fraser River were separated and analyzed to determine if a significant difference occurred between the arms. This was usually completed using ANCOVA and one-way ANOVA analysis. If the North and South Arms were found to differ significantly ($P < 0.05$) then data of compensation sites and references sites would be analyzed for each arm separately. If the North and South Arms were not found to differ significantly ($P > 0.05$) then data of compensation sites and references sites could be analyzed together.

One-way ANOVA, Kruskal-Wallis, and Mann-Whitney U tests used to look at differences between compensation and reference sites excluded compensation sites with project ID's 13-000 and higher from analysis because no reference sites were identified or sampled in the zones containing these project ID's.

2.6.2.1 Compensation Assessment

Compensation assessment is based on two criteria: (1) proportion of target habitat established and (2) proportion of native species. These percentages were then placed into one of three success categories: Poor (0-64%), Fair (65 - 84%), and Good (> 85%). The success categories were chosen based on similar studies and expert opinion. Other studies have used between 65 – 75% as the lowest threshold for highest level of success (Lopez & Fennessy 2002, Ambrose & Lee 2007, Fernandez et al. 2012); however, these studies used more criteria to determine success than this study. Matthews and Endress (2008) found that projects with fewer assessment criteria are more likely to yield successful results than those with more criteria. Therefore, to balance the fewer assessment criteria this study employed stricter percentile categories.

Target habitat is defined as habitat characterized by a typical marsh environment with high percent cover of vegetation and species that grow to a minimum of 30 cm in height. Proportion of target habitat established is the amount of target marsh habitat created and established as a percent of what is reported in the legacy FREMP database. The legacy FREMP database did not separate compensation sites under the same project ID; therefore, when multiple sites within the same ID were surveyed, the area of all sites was summed and the sum was taken as a proportion of what was reported in the legacy database. These multi-site projects were marked with an asterisk in the appendix and online database.

The second success criterion is the proportion of native species relative to exotic, invasive and unknown. This is calculated by summing the proportion of threatened and non-threatened native species, described in section 2.6.1. Due to varying conditions throughout the Lower Fraser River the success standards for this criterion varied from site-to-site. The success categories stated above (poor, fair, and good) for the proportion of native species were normalized to the two nearest reference sites. For example, if the average proportion of native species at the reference sites was 80%, then the target for a "Good" score becomes 80% with a 15% buffer. Where possible, one reference site was selected upstream and one downstream of the compensation site. Reference sites from the same arm were selected if possible. For a detailed example of success ranking, see Appendix IV – Marsh Compensation Assessment Methods.

2.6.2.2 Compensation Age and Distance to River Mouth

A regression analysis was used to assess whether the compensation assessment criteria correlate with time, using the date of compensation completion.

To investigate the effects of marsh location on site qualities, distance to river mouth was measured for all compensation and reference marshes. The river mouth was defined as the terminal boundary of terrestrial habitat at the mouth of the Fraser River, which varied in longitude depending on river arm. Distances were based on channel distance, and were measured manually through the Google Earth measuring tool. When the river diverged and multiple routes existed, the shortest distance to the river mouth was always used.

Regression analysis was used to assess whether the second compensation assessment criterion, proportion of native species, correlates with distance from the river mouth in compensation and reference sites. For this analysis compensation site 03-004 was excluded as an outlier. This site contains a nearly completely homogenous stand of invasive *Typha angustifolia* and only 22% proportion of native species, while the next nearest sites contain 84% and 96% proportion of native species respectively. ANCOVA analysis was used to determine if there was a significant difference between the regressions of the compensation sites and the reference sites.

2.6.2.3 Species Composition and Dominance

All species with relative dominance over 10% were reported for each site description report; however, only the 5 most dominant native and non-native species were considered for regional analysis.

Typha x glauca and *Typha angustifolia* were combined for analysis, as they often occur in similar habitats and are adapted to tolerate similar hydrological conditions. *Typha x glauca* is the hybrid of the native *T. latifolia* and the invasive *T. angustifolia*, but acts aggressively, similar to *T. angustifolia*. *Agrostis stolonifera* and *Agrostis capillaris* were also combined for regional analysis as they occupy a similar range and role in the marsh community as exotic species.

The mean relative dominance for each species was compared using one-way ANOVA analysis to determine if there was a significant difference between compensation sites and reference sites. Regression analysis was conducted on each species to determine if its relative dominance correlated with distance from the mouth of the river.

2.6.2.4 Wetland Indicator Status

The presence and abundance of plant species has long been used by ecologists to better understand site qualities (Klinka et al. 1989). Using knowledge of the ecology of wetland plant species, and in this case their dependency/tolerance of wetted conditions, makes it possible to infer the hydrologic qualities of a site (Lichvar et al. 2012)(Lichvar et al. 2012). Wetland plants have been well-studied by the US Army Corps of Engineers, who produced a *National List of Wetland Plants* (1988), which has undergone several revisions. This list places plant species into five qualitative wetland indicator categories, which was adopted for this study (Table 1).

Table 1: Wetland Indicator Status adopted from US Army Corps of Engineers (Lichvar et al., 2012, Reed Jr. 1988)

Wetland Indicator Status	Definition	Numeric Rating
Obligate wetland	Almost always occur in wetlands.	1
Facultative wetland	Usually occur in wetlands, but may occur in non-wetlands.	2
Facultative	Occur in wetlands and non-wetlands.	3
Facultative upland	Usually occur in non-wetlands, but may occur in wetlands.	4
Upland	Almost never occur in wetlands.	5

The wetland indicator status (WIS) of each species encountered in this study was determined using the most recent US Army Corps plant list (Lichvar et al. 2014); however, this list is not exhaustive and some species are not documented. The WIS of the missing species was determined based on a combination of (1) the indicator class of the closest relatives, (2) species ecology information found in other resources, and (3) personal observations (see Appendix III – Prescribed Wetland Indicator Status for Species absent from Lichvar et al. (2014)).

A *site* WIS was calculated using each species WIS and the species' influence on the overall site by weighting that influence based on its relative dominance. This produced a site WIS that was based on the relative influence of each species present.

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

Site WIS was analysed to determine if its mean is significantly different between compensation sites and reference sties. Levene's test determined that the variances were not homogeneous; therefore, a Mann-Whitney-U test was used to determine if the mean site WIS differed significantly between compensation sites and reference sites.

A regression analysis was conducted to determine if site WIS correlates with distance from the mouth of the river for compensation sites and reference sites. An ANCOVA analysis was used to determine if there was a significant difference in the regression between compensation and reference sites.

A regression analysis was used to determine if the proportion of native, exotic, and invasive species correlates with site WIS in compensation sites and reference sites. ANCOVA analysis was then used to determine if there was a significant difference in the regression between compensation and reference sites for each criterion.

2.6.2.5 Log Debris

The presence of the different types of log debris protection structures were analyzed to determine if their presence significantly reduces the amount of log debris on a site. Levene's test for homogeneity determined that the variances between groups were not homogenous; therefore, the Kruskal Wallis non-parametric test was used to determine if there is a significant difference between one or more log debris protection structures. Significant results detected by the Kruskal Wallis test were subject to the Mann-Whitney-U test to determine between which groups the differences occur.

2.6.2.6 Waterfowl Grazing

The mean maximum stem height of *Carex lyngbyei* was analyzed using a one-way ANOVA to determine if it was significantly shorter in the presence of waterfowl grazing evidence. A one-way ANOVA was alsused to determine if the observance of waterfowl grazing was significantly different between compensation sites and reference sites or between sites containing a mudflat community and those not containing a mudflat community.

2.6.3 Riparian habitat

Riparian compensation habitat was historically measured in linear meters and occasionally square meters; however the legacy FREMP database reports all riparian compensation habitat in square meters. This unit uncertainty can create a large discrepancy between the actual vs. reported habitat created. Whether riparian habitat was created using linear meters or square meters was determined where possible, based on original project notes; however, when not possible it had to be assumed that square meters were used. To compare the amount of habitat found during 2015 surveys to the FREMP legacy records, sites confirmed to have been measured in linear meters were compared against 2015 findings in linear meters, while all others were compared in square meters.

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.

3 Results

From July 9th to October 16th, 2015 a total of 71 compensation sites, representing 56 projects were visited. Of the 71 compensation sites visited, 54 sites representing 39 projects were surveyed, as well as 7 reference sites. Thirty-eight sites contained only marsh habitat, 16 sites contained marsh and riparian habitat, and 5 sites contained only riparian habitat. The compensation sites not surveyed were not surveyed for a variety of reasons including; the site was washed away, the site could not be located, or the site was not accessible due to near-by construction. All details are outlined in Appendix VII and Appendix VIII.

3.1 Marsh Compensation Habitat

3.1.1 Compensation Assessment

Marsh compensation sites were assessed using two criteria; the proportion of target (marsh) habitat established, expressed as a percent of the project goal indicated in the legacy FREMP database (criterion 1), and the proportion of native species, normalized to reference site standards (criterion 2). The lowest proportion of criterion 1 found in the 54 marsh compensation sites was 19%, while twenty-six compensation sites (47%) either met or exceeded the area goal and an additional nine sites (16%) were within 15% of the area goal. The mean of criterion 1 was 84% ± 6 and the median was 99%. The lowest normalized proportion of criterion 2 was found to be 26% and the highest was over 100%. The mean was 79% ± 8 and the median was 83%. The lowest actual proportion of native species recorded on a compensation site was 5% and the highest was 100%. The mean actual proportion of native species on compensation sites was 63% ± 7 and the median is 67% (Figure 4).

Though the proportion of native species was not found to be significantly different on compensation sites than on reference sites (P = 0.26), there is a marked difference between the mean and medians. The mean actual proportion of native species on reference sites was 77% ± 10 and the median was 80% compared with 63% ± 7 and 67% respectively.

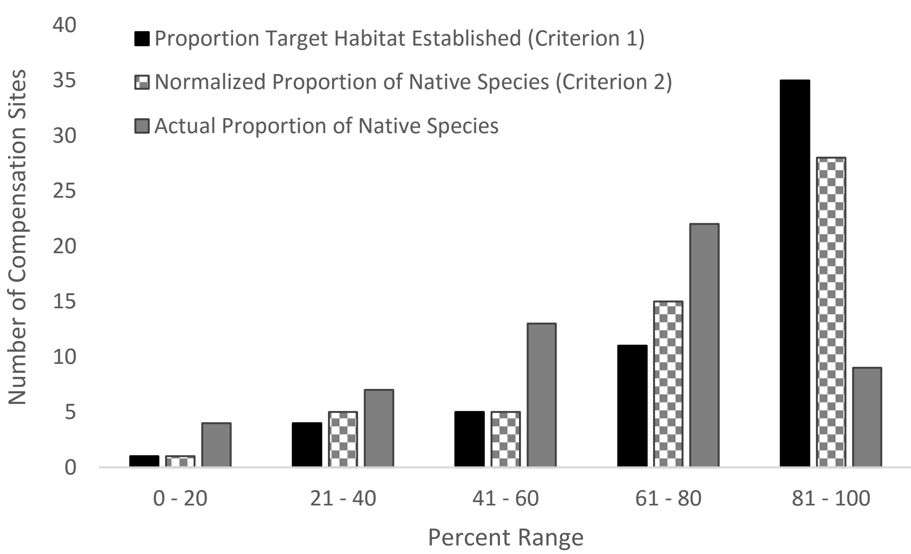


Figure 4: Number of compensation sites in 20% intervals for (1) proportion of target habitat established,(2) proportion of native species normalized to reference site standards, (3) and actual relative mean percent cover of native species.

Each criterion was given a success ranking of poor, fair, or good at every compensation site. For criterion one 18% of sites scored poor, 18% scored fair, and 65% scored good. For criterion two 22% of sites scored poor, 28% scored fair, and 50% scored good (Table 2).

Table 2: Number of compensation sites and proportion of compensation sites in each of the three success rankings for (1) the proportion of target habitat established and (2) proportion of native species normalized to reference site standards.

	Criterion 1: Proportion Target Habitat Established		**Criterion 2: Proportion of Native Species**	
	Number of Sites	Proportion of Sites (%)	Number of Sites	Proportion of Sites (%)
Poor	10	18.5	12	22.2
Fair	10	18.5	15	27.8
Good	35	64.8	27	50.0

Four percent of compensation sites scored poor for both criteria and 33% scored good for both criteria. The remainder scored fair or a combination or poor, fair, and good (Table 3).

Table 3: Number and proportion of compensation sites for each success rank combination after criteria are combined.

	Number of Sites	Proportion of Sites (%)
Poor/Poor	2	3.7
Poor/Fair	2	3.7
Poor/Good	15	27.8
Fair/Fair	6	11.1
Fair/Good	11	20.4
Good/Good	18	33.3

3.1.2 Compensation Age and Compliance

The oldest compensation site sampled was 32 years old at the time of sampling, completed in 1983; the youngest site sampled was 5 years old, completed in 2010; and the mean age of compensation sites was 20 years old, with 1995 as the mean year of creation. A regression analysis determined that neither the proportion of target habitat established ($P = 0.09$), nor the proportion of native species ($P = 0.39$) correlate with the age of the compensation site (Figure 5).

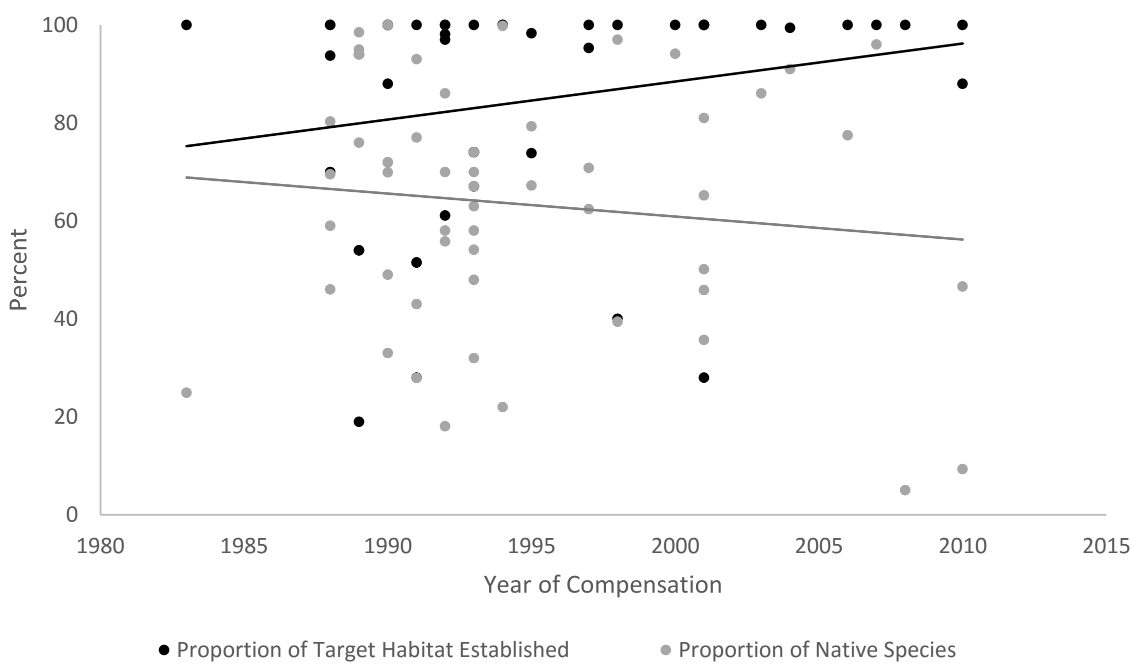


Figure 5: Regression of compensation assessment criteria; proportion of target habitat established (N = 54) and proportion of native species (N = 54); over time.

3.1.3 Proportion of Native Species Across the Lower Fraser River

The proportion of native species was found to negatively correlate with increased distance from the mouth of the river for both compensation sites ($P < 0.001$) and reference sites ($P = 0.004$) (Figure 6). The regression produced R^2 values of 0.38 and 0.88 for compensation sites and reference sites respectively, suggesting that the best fit line explains 38% and 88% of the variation in the proportion of native species.

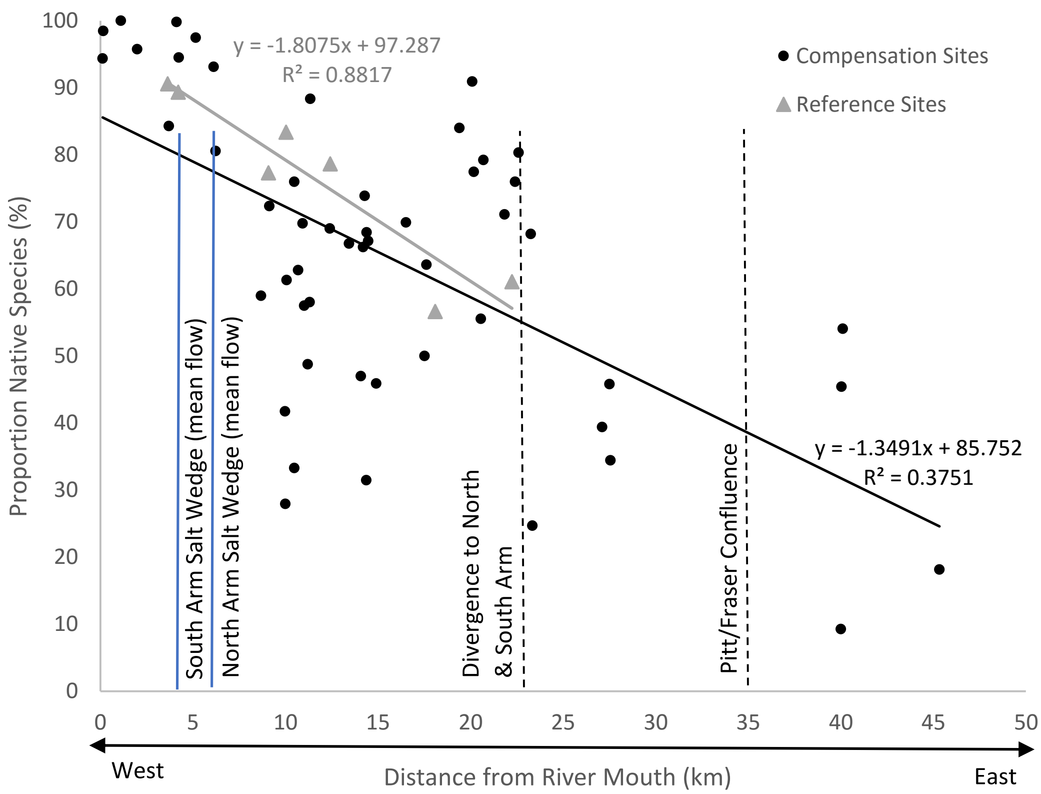


Figure 6: Regression of proportion of native species with distance from the mouth of the river for compensation sites (N = 54) and reference sites (N = 7).

Inversely, the proportion of non-native species (exotic and invasive species combined) on compensation sites were found to positively correlate with increasing distance from the mouth of the river for both compensation sites ($P < 0.001$) and reference sites ($P = 0.002$). The regression produced R^2 values of 0.23 and 0.88 for compensation sites and reference sites respectively, suggesting that the best fit line explains 23% and 88% of the variation in the proportion of native species.

3.1.4 Species Composition and *Carex lyngbyei* Dominance

The native species with the greatest mean relative dominance throughout the whole sample area of the Fraser River in compensation sites was *Carex lyngbyei* with a mean relative dominance of 25%. *Juncus balticus* was the next most abundant with 14.5% and *Carex obnupta*, *Juncus articulatus*, and *Typha latifolia* had a mean relative dominance less than 4%. *Carex lyngbyei* was also the most dominant native species in reference sites, but was significantly more dominant in reference sites than in compensation sites ($P = 0.021$) with a mean relative dominance of 55% (Figure 7). *Typha latifolia* was the next most dominant species with 8.9% mean relative dominance, followed by *J. balticus* with 6.5%. *Carex obnupta* and *J. articulatus* were both less than 1%.

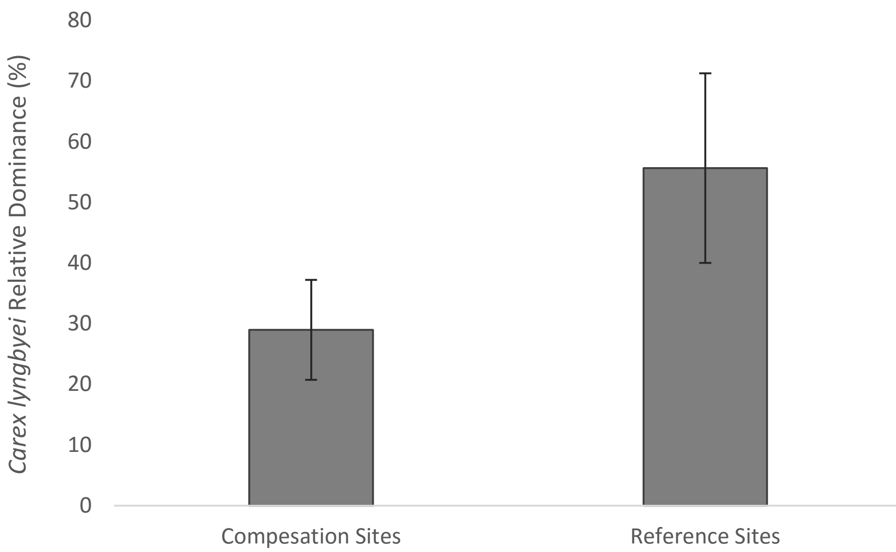


Figure 7: Mean relative dominance (± 95% CI) of Carex lyngbyei in compensation sites (N = 45) and in reference sites (N = 7).

The non-native species with the greatest mean relative dominance throughout the whole sample area of the Fraser River in compensation sites was *Phalaris arundinacea* with a mean relative dominance of 11.4%. *Phalaris arundinacea* was the most dominant species in 20% of compensation sites and its highest relative dominance in a single site was 90%. Exotic bentgrasses were the next most dominant with 6.9% followed by *Myosotis scorpioides* with 5.6%. *Lythrum salicaria* as well as *Typha angustifolia* and *Typha x glauca* combined were both less than 4%. The highest dominance of *Lythrum salicaria* in a single site was 30% and the highest dominance of *Typha angustifolia* or *Typha x glauca* was 93%.

Phalaris arundinacea was also the most dominant non-native species in the reference sites with a mean relative dominance of 6.0%, followed by exotic bentgrasses with 4.4%. *Lythrum salicaria, M. scorpioides*, as well as *T. angustifolia* and *Typha x glauca* combined were less than 3%. There were no significant differences detected for the mean relative dominance the of the non-native species between compensation and reference sites.

Of the 5 most dominant native species, 3 had a significant relationship with distance from the mouth of the river. Relative dominance of *C. lyngbyei* had the strongest negative correlation ($P < 0.001$) with distance from the mouth of the river and the R^2 value suggests that the best fit line explains 20% of the variation in the data. *Juncus balticus* also had a negative correlation ($P = 0.01$) with distance from the mouth of the river and the R^2 value suggests that the best fit line explains 12% of the variation in the data. *Carex obnupta* had a positive correlation ($P = 0.001$) with distance from the mouth of the river and the R^2 value suggests that the best fit line represents 18% of the variation in the data (Figure 8). This suggests that *C. obnupta* replaces *C. lyngbyei* as the dominant *Carex* species farther away from the mouth of the river. Despite being the most dominant *Carex* species to the east, *C. obnupta* displays relatively low dominance in the east compared with *C. lyngbyei* in the west. This is likely due to increasing competition from non-native species farther east.

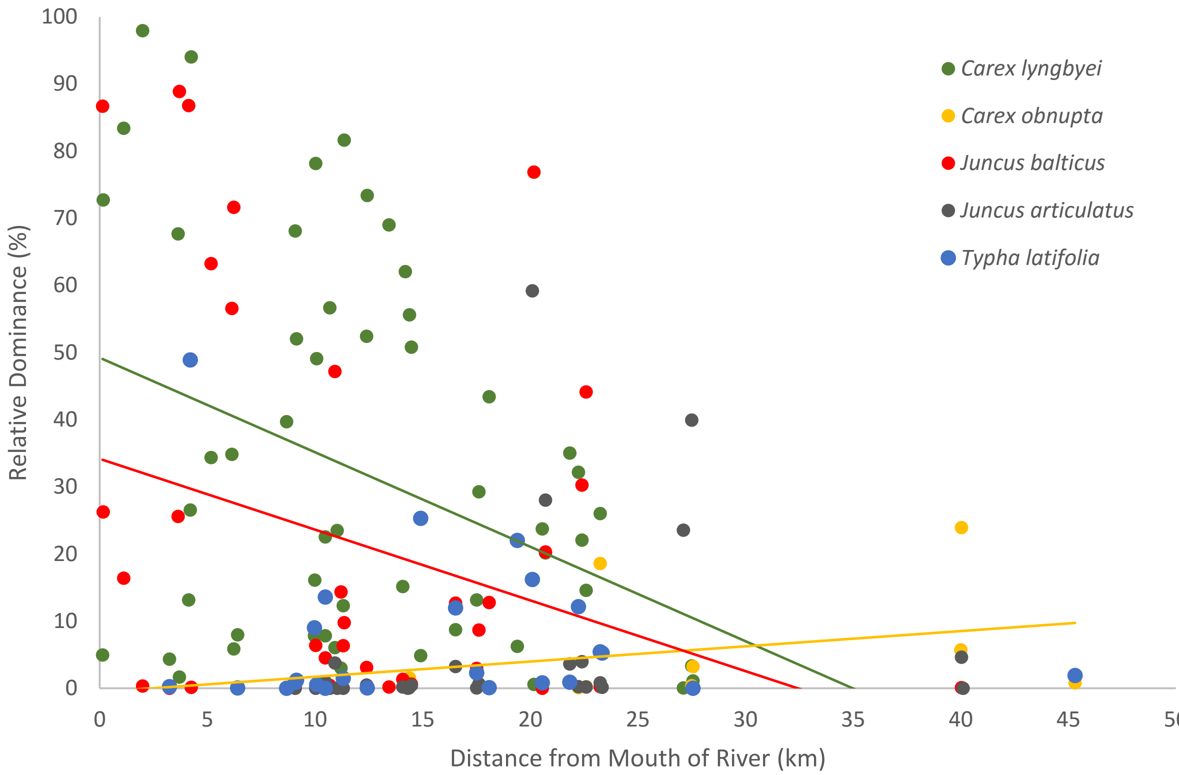


Figure 8: Regression of relative dominance with distance to the mouth of the river (km) for the five most dominant native species sampled; Carex lyngbyei, Carex obnupta, Juncus balticus,, Juncus articulatus, and Typha latifolia (N = 54).

3.1.5 Site Wetland Indicator Status

The wetland indicator status (WIS) of a species reflects the likelihood that that species occurs in a wetland or upland (U.S. Army Corps of Engineers 2012). By calculating the site WIS based on each species relative dominance and WIS we can infer whether an entire site is more representative of a wetland or upland environment.

Four compensation sites had the lowest possible site WIS of 1 – obligate wetland. The highest site WIS observed was 2.4, recorded at two sites, indicating that the majority of the plants at these sites were between 2 – facultative wetland (usually occurs in wetlands, but may occur in non-wetlands) and 3 – facultative (occurs in wetlands and non-wetlands equally). The mean site WIS in compensation sites was 1.5, between 1 – obligate wetland and 2 – facultative wetland. The lowest site WIS observed in reference sites was 1.1, the highest was 1.5, and the mean site WIS for reference sites was 1.27. Compensation sites were found to have a significantly higher ($P = 0.049$) mean site WIS than reference sites (Figure 9).

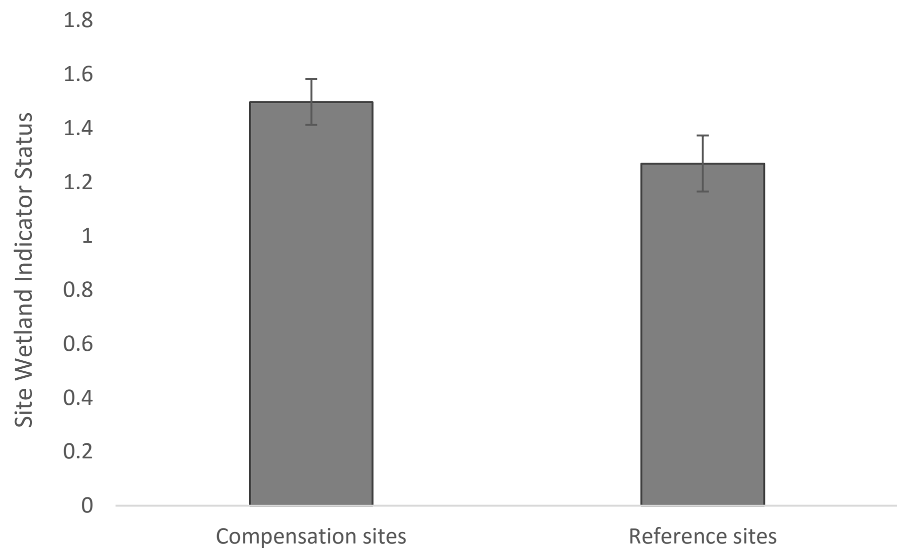


Figure 9: Mean site wetland indicator status (± 95% CI) for compensation sites (N = 45) and reference sites (N = 7). Wetland Indicator Status Across the Lower Fraser River

Site WIS correlates positively with distance from the mouth of the river in compensation sites (P = 0.002) and in reference sites (P = 0.03). ANCOVA analysis determined that the regression for the compensation sites and the reference sites differ significantly. Though both compensation site WIS and reference site WIS increase with distance from the mouth of the river, reference sites have significantly lower mean site WIS (Figure 10).

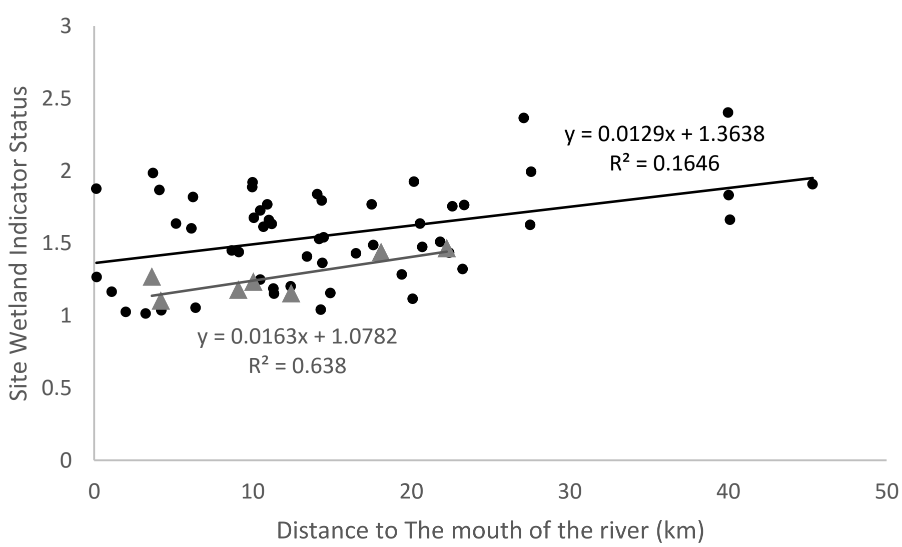


Figure 10: Regression of site wetland indicator status with distance to the mouth of the river on compensation sites (N = 54) and on reference sites (N = 7).

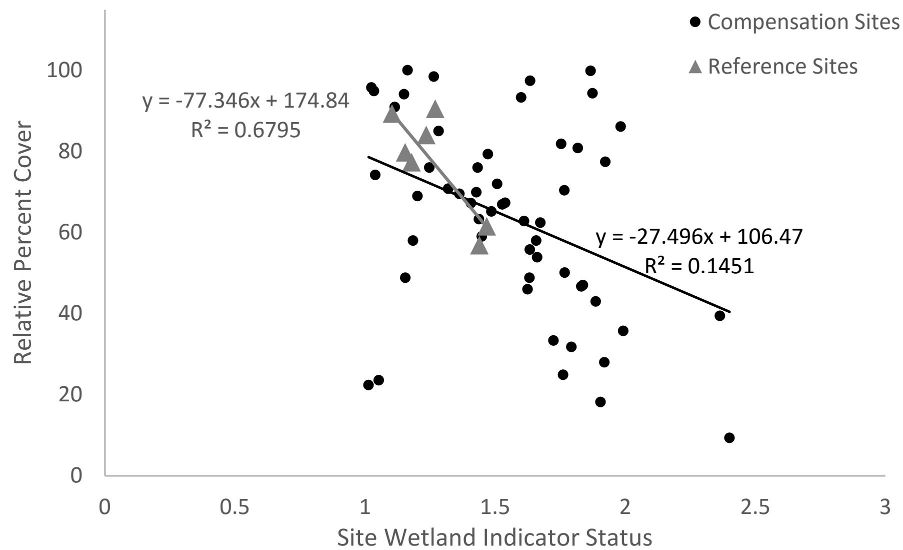
3.1.5.1 Site Wetland Indicator Status and Species Origin

Proportion of native species in compensation sites had a negative correlation with site WIS (P = 0.004) and the R^2 value indicates that 15% of the variation in the data is explained by the best fit line. Proportion of native species in reference sites also had a negative correlation with site WIS (P = 0.02) and the R^2 value indicates that 67% of the variation in the data is explained by the best fit line (Figure 11a). ANCOVA analysis determine that the compensation site regression did not differ significantly from the reference site regression.

Proportion of exotic species in compensation sites had a positive correlation with site WIS ($P < 0.001$) and the R^2 value indicates that 30% of the variation in the data is explained by the best fit line (Figure 11b). Proportion of exotic species in reference sites was found to almost have a significant positive correlation with site WIS ($P = 0.07$) and the R^2 value suggests that 52% of the variation in the data is explained by the best fit line (Figure 11b). ANCOVA analysis determine that the compensation site regression did not differ significantly from the reference site regression.

Proportion of invasive species did not have a significant correlation with site WIS.

a) Native Species



b) Exotic Species

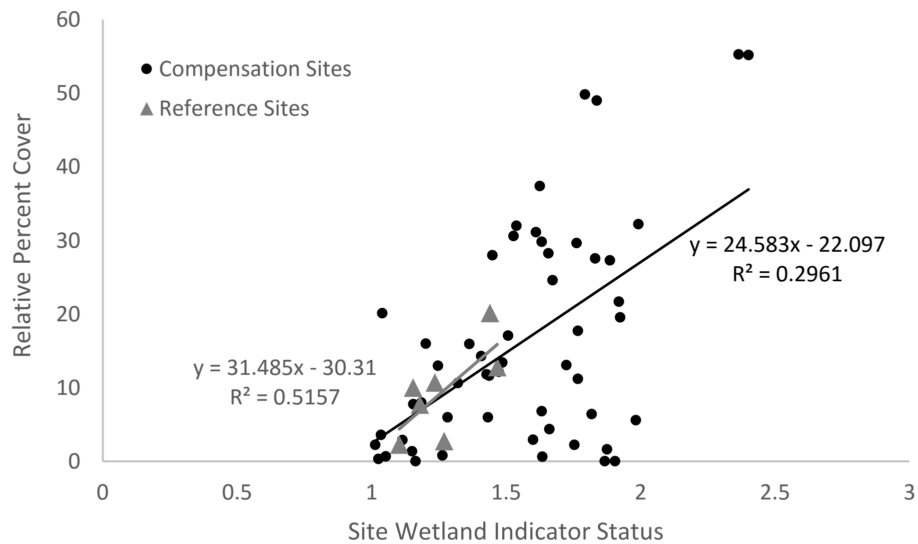


Figure 11: Regression of relative percent cover (proportion) with site wetland indicator status for a) native species on compensation sites (N = 54) and reference sites (N = 7) and b) exotic species on compensation sites (N = 54) and reference sites (N = 7).

3.1.6 Log Debris

The highest percent cover of log debris observed on a compensation site was 53%, while 29 sites (54%) reported 0% cover of log debris in the sampling data. The mean % cover of log debris for all compensation sites is 4.3%. Despite 54% of sites reporting no log debris during vegetation sampling, log debris was present on many of these sites. Due to the patchiness of log debris accumulation it is often not observed in vegetation samples; therefore, comments on log debris accumulation was reported separately in individual site descriptions (Appendix VII – Marsh Compensation Site Descriptions).

Percent cover of log debris was not found to differ significantly between marsh design type. However, during field observations it was anecdotally observed that embayment-designed marshes often had an accumulation of log debris at the back of the site.

The percent cover of log debris on compensation sites where a log boom was present was found to be significantly lower compared with sites with no log debris protection (P = 0.017). The percent cover of log debris on compensation sites where a marina was present directly adjacent to the site was found to be significantly lower compared with sites with no log debris protection (P = 0.007) and sites containing other forms of log debris protection (0.029). Though sites where a lattice fence was present had 0% cover of log debris, lattice fence protection did not differ significantly from no protection or other forms of protection. This is likely due to the small sample size (N = 2) (Figure 12).

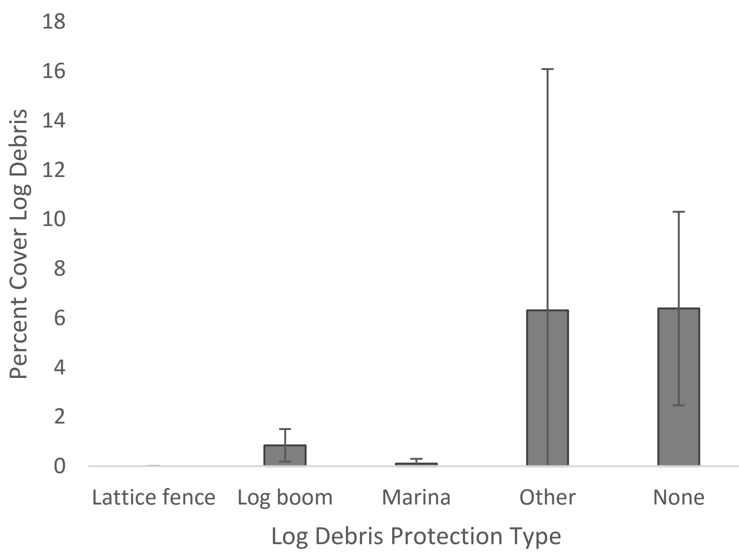


Figure 12: Mean percent cover (± 95% CI) of log debris with varying levels of log debris protection: lattice fence (N = 2), log boom (N = 1)6, marina (N = 7), other (N = 4), and none (N = 32).

3.1.7 Waterfowl Grazing

The shortest mean maximum stem height for *Carex lyngbyei* on compensation sites was 49 cm, the tallest was 161 cm, and the mean for all compensation sites was 110 cm.

The mean maximum stem height of *C. lyngbyei* was found to be significantly lower (P = 0.006) in sites where clear evidence of waterfowl grazing was observed (99 cm ± 13 compared with 122 cm ± 9) (Figure 13).

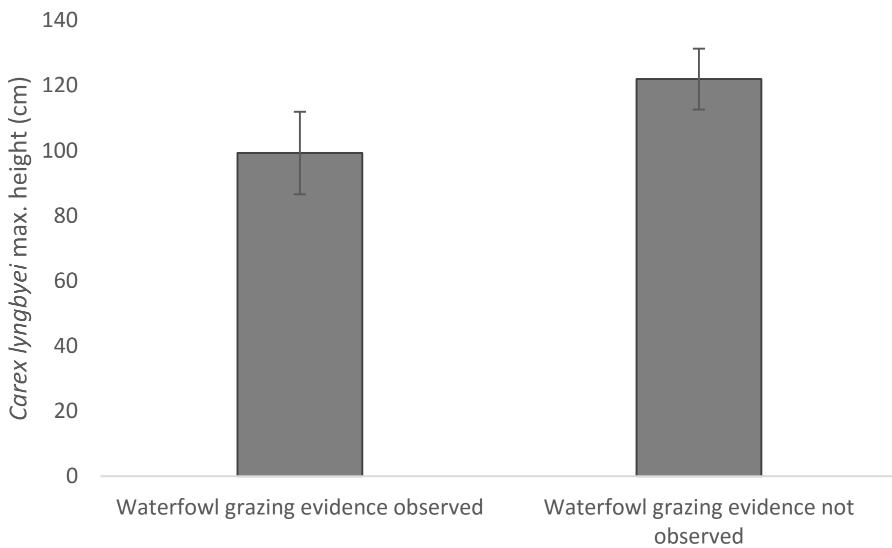


Figure 13: Mean maximum stem height of Carex lyngbyei (± 95% CI) with the observation of waterfowl grazing evidence. Waterfowl grazing evidence observed, N = 18. Waterfowl grazing evidence not observed, N = 27. Error bars: 95% confidence interval.

The observance of waterfowl grazing evidence was significantly more common on reference sites, than compensation sites (P = 0.039), but not significantly more common on sites with a mudflat vegetation community than those without.

3.1.8 *Typha angustifolia* and *Typha x glauca*

Typha angustifolia and *Typha x glauca* were observed at twelve different locations throughout the survey region through site surveys or incidental observations. The relative dominance of these species ranged from 0.4 to 93% and the mean percent cover ranged from 2.3% to 51% on compensation sites (Table 4). Four incidental observations of *T. angustifolia* or *T. x glauca* stands were observed outside of compensation or reference sites and one incidental observation was observed on a compensation site where the vegetation survey did not sample the stand. The stands observed incidentally ranged from very expansive (e.g. Site 01, estimated to be thousands of m^2) to moderate (e.g. Site 03, estimated to be tens of m^2) (Figure 14).

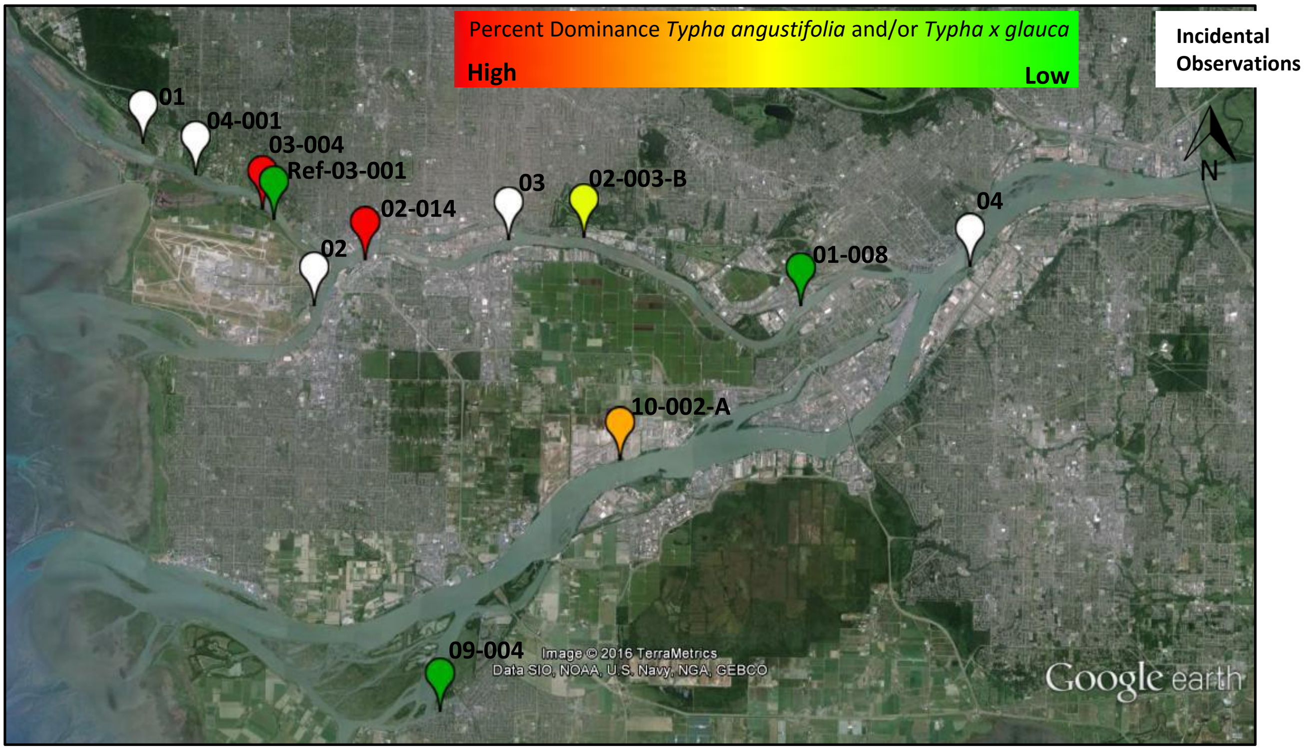


Figure 14: Locations of surveyed and incidental observations of Typha angustifolia and Typha x glouca.

Table 4: Percent Cover and relative dominance of surveyed Typha angustifolia and Typha x glouca and location and comments of incidentally observed Typha angustifolia and Typha x glouca.

Site	Location	Observation Type	*Typha angustifolia*		*Typha x glauca*		Comments
			Percent Cover	Relative Dominance	Percent Cover	Relative Dominance	
03-004		Surveyed	51.3	92.71082	0	0	-
02-014		Surveyed	36.7	79.14645	0	0	-
10-002-A		Surveyed	4.75	2.637607	16.1	22.35025	-
02-003-B		Surveyed	6.4	5.430566	0	0	-
09-004		Surveyed	4.5	1.215149	0	0	-
01-008		Surveyed	2.3	0.418277	0	0	-
REF-03-001		Surveyed	0.24	0.05261	0	0	-
04-001		Surveyed/ Incidental	-	-	-	-	Small patch present, but not encountered during survey
01	10U 484969E 5452616N	Incidental	-	-	-	-	Very extensive stand
02	10U 489651E 5448339N	Incidental	-	-	-	-	Extensive stand
03	10U 494849E 5450174N	Incidental	-	-	-	-	Moderate stand
04	10U 507272E 5449670N	Incidental	-	-	-	-	Moderate stand

3.2 Riparian Compensation Habitat

From July 9th to October 16th, 2016 a total of 19 compensation sites and 1 reference site were surveyed for riparian habitat. Fourteen compensation sites contained marsh and riparian habitat, and 5 sites contained only riparian habitat.

3.2.1 Area

Riparian habitat was not assessed based on the proportion of target habitat established because establishing reliable boundaries was too variable. Riparian compensation habitat was historically measured in linear meters and occasionally square meters; however, the legacy FREMP database reports all riparian compensation habitat in square meters. This confusion leads to large discrepancies when evaluating the actual habitat created versus the reported habitat gained. Five sites (26%) were not found to meet the area gain reported in the legacy FREMP database; 2 sites (11%) had an area discrepancy greater than 1001 m², while 3 sites (16%) had a discrepancy of less than 50 m, assuming these sites were measured in linear meters. Twelve sites (63%) met and/or exceed the area goal; however, the discrepancies were still great for a number of sites. Four sites (21%) had discrepancies between 101 – 1000 m², three sites (16%) had discrepancies between 51 and 100 m², three sites (16%) had discrepancies between 0 – 50 m², and three sites (16%) had discrepancies between 0 – 51 m (Figure 15).

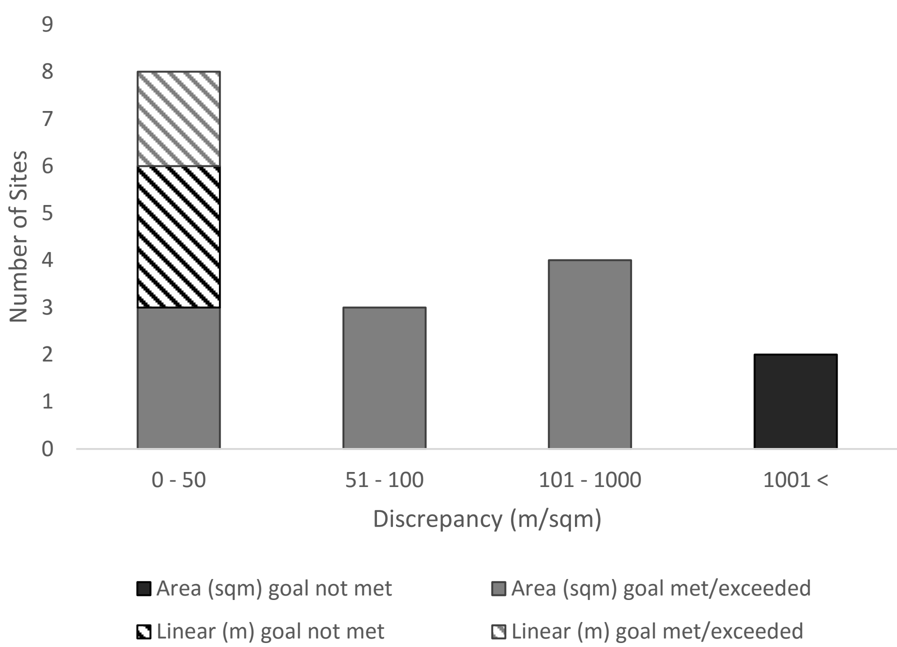


Figure 15: Number of sites per level of discrepancy between 2015 surveys and legacy FREMP habitat records. Depending on whether habitat is considered linear, or area, units are expressed in metres or square meters.

3.2.2 Vegetation

3.2.2.1 Proportion Native Species

Most riparian compensation sites contained between 81 – 100% native species. Thirteen sites (68%) contained between 81 – 100% native species in their overstory, two sites (11%) contained 61 – 80% native trees in their overstory, and one site (5%) contained only 25%. Eleven sites (58%) contained between 81 – 100% native shrubs in their understory, two sites (11%) contained 61 – 80%, two sites (11%) contained 41 – 60%, two sites (11%) contained 21 – 40%, and two sites (11%) contained 0 – 20%. Sixty-eight percent of the trees in the reference site were native species and 100% of the shrubs surveyed in the understory were native (Figure 16).

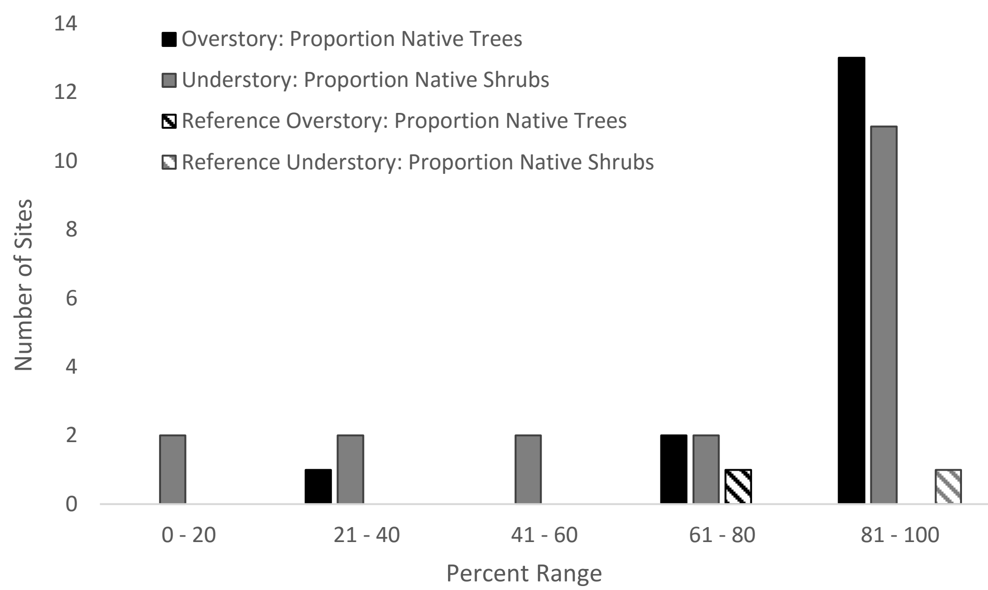


Figure 16: Percent native trees in the overstory and relative % cover of native shrubs in the understory of riparian compensation sites and reference site.

3.2.2.2 Density

Three sites (16%) contained no trees and an additional three had less than 100 stems per hectare. Seven sites (37%) contained 101 – 500 stems per hectare, two sites (11%) contained 501 – 1000 stems per hectare, three sites (16%) contained 1001 – 5000 stems per hectare, and one site (5%) contained greater than 5000 stems per hectare with 16,840 stems per hectare. The reference site contained 733 stems per hectare (Figure 17).

The mean number of stems per hectare was 1410 (± 1722); however, the few sites with very high densities heavily skew the mean; therefore, the median is a more appropriate measure of the typical riparian compensation habitat observed, which was 157.2 stems/ha.

Regression analysis determined that stems per hectare in compensation sites does not correlate with time since compensation (data not shown).

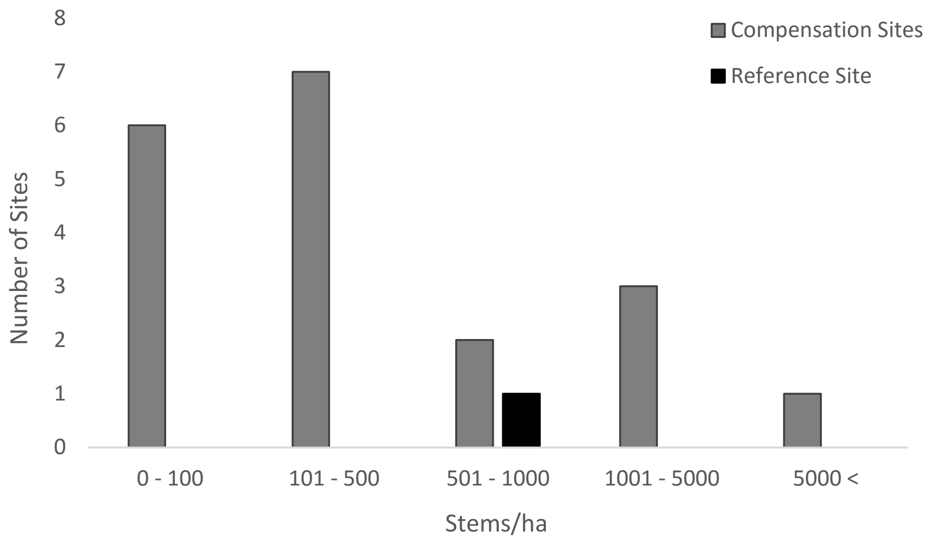


Figure 17: Density (stems/ha) of trees in the overstory of riparian compensation sites.

Two sites (11%) contained 0 – 20% cover vegetation in the understory with the lowest recorded percent cover at just 10%. Two sites (11%) contained 21 – 40%, five sites (26%) contained 61 – 80%, and ten sites (53%) contained 81 – 100% cover vegetation in the understory layer with seven sites (37%) at 100%. The reference site contained a mean vegetation cover of 52% (Figure 18).

Regression analysis determine that percent cover vegetation does not correlate with time (data not shown).

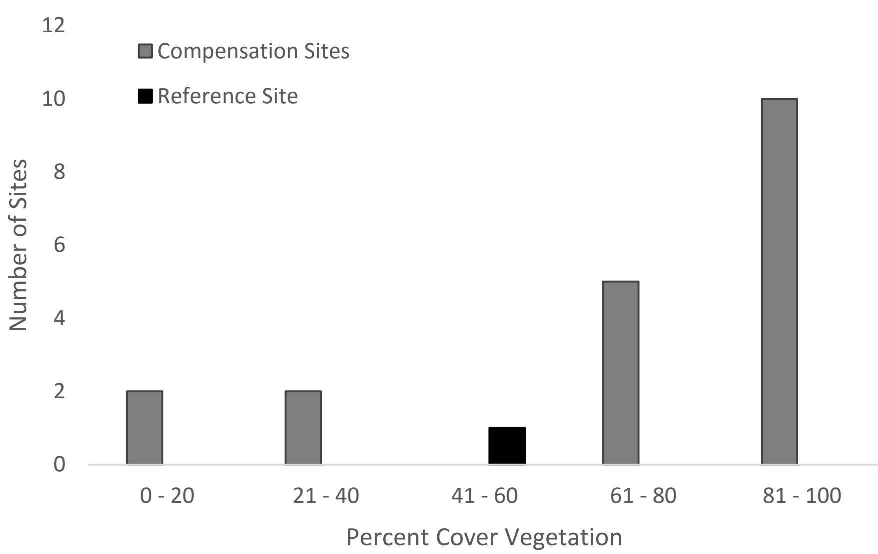


Figure 18: Absolute percent cover of shrub vegetation in the understory of riparian compensation sites.

3.2.3 Manicured Vegetation

Some riparian compensation sites were observed to resemble more of a manicured landscape than a natural habitat. This included planting of a single species, planting of ornamental exotic trees and shrubs, large spaces of lawn between vegetation (Image 1), and trimming vegetation for aesthetics and views (Image 2).

Image 1: Compensation site 09-016

Image 2: Compensation site 13-005

3.3 Public Access Database

A detailed site description record has been created for each site surveyed in this study (Appendix VII – Marsh Compensation Site Descriptions and Appendix VIII – Riparian Compensation Site Descriptions). Each record includes background information about the site, a general site description, area sampled, morphological features, impacts and stressors, wildlife evidence and sightings, adjacent land use, threatened plant species, invasive plant species, plant community descriptions, dominant species, breakdown of native vs. non-native species, an assessment of compensation success, mitigation, monitoring, and photos. These records, along with raw field data, have been uploaded to the existing FREMP-BIEAP Habitat Atlas and are easily assessable to the public at http://www.cmnbc.ca/atlas_gallery/fremp-bieap-habitat-atlas. All site records can be found under the '2015 Field Data' heading.

4 Discussion

4.1 Marsh Compensation Habitat

4.1.1 Compensation Assessment

Sixty-five percent of the 54 marsh compensation sites surveyed were considered to have adequately met the area requirements (good ranking) and 50% were considered to have adequately achieved a desirable proportion of native species cover (good ranking); however, only 33% of all compensation sites met both the area requirement and the desirable amount of native species cover with a ranking of "good" (Table 3).

The area requirements achieved in this study are higher than those found in literature from other regions. Ambrose and Lee (2004) found that only 46% of compensatory wetlands in California met their area requirements, compared with 65% in this study; and a review of Illinois compensatory wetlands found that the mean area established was 70% of the legislated requirement (Matthews & Endress 2008), compared to 84% in this study. Matthews and Endress (2008) also note that the deficit was not necessarily due to the failure to build sites, but a failure to achieve the desired habitat on those sites. This is similar to a number of sites in this study that contain mudflat habitat where marsh habitat was intended.

Fifty percent of surveyed compensation sites achieved a good proportion of native species. Matthews and Endress (2008) found that, despite richness of native species in compensation sites often achieving levels greater than those in reference sites, the proportion of native species remained low compared to reference sites. Similarly, Moreno-Mateos et al. (2012) found in a meta-analysis study of 621 restored wetlands across the world that biological structure (primarily plant assemblages) was on average 26% lower than in reference sites. This study found the mean proportion of native species in compensation sites was 63% and 77% in reference sites; resulting in compensation sites having 18% less coverage of native species on average than reference sites.

Thirty-three percent of all surveyed compensation sites met both the area requirement and the desirable amount of native species cover (Good ranking), while only 4% of sites were poor in both assessment criteria; the remaining 63% ranked as fair or a combination of poor, fair, or good. Assessing compensation compliance has been studied elsewhere and the results vary considerably. Turner et al. (2001) conducted a meta-analysis of studies reviewing compensatory wetland compliance and success. They found that half of the studies reported that most compensatory wetland projects were compliant most of the time while the other half of the studies reported that projects were only compliant 4 to 49% of the time. Matthews and Endress (2008) found that 30% of the projects achieved all of the mitigation goals and Quigley and Harper (2006) found that 37% of compensatory wetland projects achieved a net gain or no-net-loss of habitat productivity.

Wetland compensation projects with fewer assessment criteria have been found to be more likely to yield successful results and the proportion of native species has been found to be a good indicator of a relatively successful site verses a relatively less successful site (Matthews & Endress 2008). The assessment system used in this study only used two criteria to assess compensation success, but used a narrow success margin of 85% and greater. It also uses proportional percent cover of native species as one of the key indicators of success. In addition, reference sites were used as the benchmark for the target proportion of native species, creating an attainable and realistic goal.

4.1.2 Compensation Age and Compliance

Matthews and Endress (2008) found that the proportion of native species increased slightly over the first four years of compensation and many studies have found that species richness and diversity are the highest in the first few years after compensation activities (Noon 1996, Atkinson et al. 2005, Anderson 2007, Matthews & Endress 2008), supported by the fact that diversity often increases in response to disturbance, including compensation activities (Odum 1985, Sheil & Burslem 2003).

This study assessed wetland compensation projects that ranged from 5 to 32 years in age, with the mean age being 20 years at the time of sampling. It was found that neither the proportion of target habitat established, nor the proportion of native species correlated with the age of the compensation site (Figure 5). However, there are more sites with poor establishment of target habitat amounts prior to 2000, suggesting that compliance may be improving over time or that marsh habitat is being lost in some cases. The spread of the native species data strongly suggests that the age of the site has little influence on the proportion of native species. Matthews and Endress (2008) also found no trends in compliance over time; however, other studies have observed an increase in the abundance of invasive species over time (Reinartz & Warne 1993, Noon 1996, Moore et al. 1999, Garde et al. 2004), while others report an increase in floristic quality and native species over time (Reinartz & Warne 1993, Noon 1996, Mushet et al. 2002, Balcombe et al. 2005). The literature reports conflicting results for long term trends and a number of studies criticize the assumption that restored wetlands progress along predictable trajectories (Race 1985, Zedler 1996, Zedler & Callaway 1999, 2000). The lack of trends in compliance based on age suggests that other factors may have a greater influence on site success; indicating that adaptive management and long term monitoring may be required to mitigate on-going influences.

4.1.3 Proportion of Native Species and Species Diversity Across the Lower Fraser River

The proportion of native species in both compensation and reference sites decreased significantly as distance from the mouth of the river increased (Figure 6). Decreasing salinity is likely the driving force behind this trend, among other, less-influential factors. The distance reached by the salt wedge in the North Arm of the Lower Fraser River is 6.2 km from the mouth of the river during average flows and is 4.8 km in the South Arm; however, during low flows it can penetrate as far as 11 km in the North Arm and 20.4 in the South Arm (Ages & Wollard 1976). Studies on tidal marshes have shown that as salinity decreases, species diversity increases (Anderson et al. 1968, Wass & Wright 1969, Atkinson et al. 1990, Perry & Atkinson 1997). Preliminary analysis suggests that species diversity in this study increases with distance from the mouth of the river (data not shown). This is represented by the high dominance of *Carex lyngbyei* and *Juncus balticus* (often over 80% relative dominance) in the first 15 km from the mouth of the river, followed by the decline in relative dominance by any single species farther east (Figure 8). Salt tolerant species, such as *C. lyngbyei* and *J. balticus*, are capable of germinating and growing in non-saline conditions, but are often suppressed by the greater diversity of non-salt tolerant species (Hutchinson 1988a). Despite being habitat generalists, many of the exotic species identified in this project, (e.g. *Agrostis* sp., *Myosotis* sp.) are not considered salt-tolerant (Hutchinson 1988a), explaining their increase with distance from the mouth of the river.

The decrease in the proportion of native species along a west to east gradient suggests that future compensation projects should consider this in site design and monitoring planning. Compensation projects farther away from the mouth of the river should consider an increased monitoring schedule and higher budget for invasive and exotic species management.

4.1.4 Wetland Indicator Status (WIS)

The proportion of native species was also found to decrease with increasing site wetland indicator status (WIS) in both compensation and reference sites (Figure 11a), and inversely, the proportion of exotic species was found to increase with increasing site WIS (Figure 11b) in both compensation and reference sites. Invasive species were not found to have a relationship with site WIS. Higher site WIS is associated with plant communities that tend towards drier conditions. Many non-invasive exotic species observed in this study were generalists associated with drier, upland conditions, and often ranked 3 (facultative) to 5 (obligate upland) on the WIS scale. Invasive species, however, typically were hydrophytes. One of the most problematic species found in this study, *Phalaris arundinacea,* scores a 2 (facultative wetland) while most other species including *Lythrum salicaria, Iris pseudacorus,* and *Typha* sp. score a 1 (obligate wetland) on the WIS scale.

Site WIS in both compensation sites and reference sites was found to increase with distance from the mouth of the river (Figure 10). However, the proportion of native species was found to decrease with distance from the mouth of the river, likely due to salinity. Site WIS has a negative correlation with native species (Figure 11a) and a strong positive correlation with exotic species (Figure 11b). It is questionable whether the trend of increasing site WIS with distance from the mouth of the river is a product of a physical force due to its location or if it is simply due to its association with native and exotic species and their subsequent relationship with distance.

Though the relationship between site WIS and distance from the mouth of the river is questionable, compensation marshes in this study were found to have a significantly higher site WIS than natural reference marshes (Figure 10). Matthews and Endress (2008) found that unsuccessful compensation sites often had vegetation communities more characteristic of upland ecology based on their mean WIS, leading them to conclude that inappropriate wetland hydrology was the culprit. A number of factors could contribute to the higher site WIS in compensation sites including shorter submergence time caused by too high of elevation or lack of water retention caused by poor retention by the soils. Levings and Nishimura (1997) found the submergence time of reference marshes in the Fraser River Estuary to range from 33.2% to 50.7%, while transplanted/compensation sites submergence time ranged from 26.4% to 60.1%. This indicates that artificially created marshes have a wider variance in submergence time than natural marshes, supporting the possibility that the higher site WIS of some compensation sites may be the result of shorter submergence time and higher elevation.

It has been suggested that the elevation of some compensation marshes may be raising over time due to sediment aggradation (G. Williams, pers. comm., 24 February 2016). This is not supported by the data in this study, which indicates that there is no change in the proportion of native species over time (Figure 5). However, it is possible that site aggradation may be occurring on a site-by-site basis, and dependent on site design, location and other factors that are not isolated in this study.

Therefore, high elevation, likely due to poor site design or poor water retention due to substrate selection, are likely causes of higher mean site WIS in compensation sites. More research is required to confidently determine the cause; however, this can serve as a reminder to compensatory wetland contractors to be diligent in site design in terms of elevation and substrate choice. Additionally, baseline site elevation profiles, if not already recorded, need to be recorded and made available to facilitate future monitoring actions.

4.1.5 *Carex lyngbyei* Dominance

Carex lyngbyei is the most common shoreline sedge in the Pacific Northwest and is often the dominant species in tidal marshes, creating dense, often monotype stands (Pojar & MacKinnon 2004). It provides habitat and food for mammals, birds, and invertebrates and is the foundation of the detrital food web (Ewing 1982, 1983, 1986, Seliskar & Gallagher 1983, Simenstad 1983, Hutchinson 1988b). Because of its ecological importance and transplant-ability, *C. lyngbyei* is often the primary species transplanted or planted for revegetation of tidal marsh restoration in the Lower Fraser River (Adams & Whyte 1990, Levings & Nishimura 1997, Adams & Williams 2004). *Carex lyngbyei* was found to be the most dominant species among compensation sites with a mean relative dominance of 25% followed by *Juncus balticus* at 14.5%; however, at 25%, *C. lyngbyei* is less than half as dominant in compensation sites as in reference sites, which boast a mean relative dominance of 55% (Figure 7). This is comparable to the findings by Levings and Nishimura (1997), who found that the percent cover of *C. lyngbyei* was less than 50% of that observed in reference sites in the Lower Fraser River.

The lower dominance of *C. lyngbyei* in compensation sites may be attributed to the initial disturbance of creating a compensation wetland. Disturbance is linked to both the spread of invasive and exotic species (Galatowitsch et al. 1999, Zedler & Kercher 2004) as well high diversity during the initial years after disturbance (Odum 1985, Noon 1996, Sheil & Burslem 2003, Atkinson et al. 2005, Anderson 2007, Matthews & Endress 2008). The lower percent cover of native species in compensation sites (63% ± 6.5) compared to reference sites (77% ± 10) suggests that invasive and exotic species are likely playing a role is suppressing *C. lyngbyei* dominance. Additionally, the literature suggests that higher diversity of native weedy species may also contribute to suppressing *C. lyngbyei* dominance.

The diminished success of *C. lyngbyei* in compensation sites compared with reference sites suggests that future wetland compensation projects should increase monitoring and management in the first few years post construction to ensure *C. lyngbyei* establishment.

4.1.6 Species Composition

Though *Carex lyngbyei* was the most dominant species in both compensation sites and reference sites, secondary dominant species differed. *Juncus balticus* was the secondary dominant species in compensation sites with 14.5% relative dominance, but the third most dominant species in reference sites with only 6.5%. *Typha latifolia* was the secondary dominant species in reference sites with a relative dominance (8.9%), more than four times that in compensation sites (2.2%). The differences in secondary dominant species may reflect site hydrology and design (see section 4.1.5), as *J. balticus* is typically a mid-elevation marsh species (above *C. lyngbyei)*, while *T. latifolia* favours wetter, low-marsh conditions (Seliskar & Gallagher 1983). Low-marsh habitat was typically more abundant in reference sites than compensation sites (personal observation), as reference sites occurred on gradual gradients extending from high marsh to the intertidal, whereas compensation marshes were typically mid-to-high marsh benches elevated and isolated above the intertidal with a rip-rap berm. Although the absence of transition marsh in many compensation sites favours some species over others, it is uncertain whether one species composition is preferable, as the ecological value of *T. latifolia* vs. *J. balticus* is uncertain.

This study found that the dominance of *C. lyngbyei* and *J. balticus* decrease with distance from the mouth of the river, while *Carex obnupta,* a salt-sensitive sedge, increases (Hutchinson 1988a). *Juncus articulatus* and *T. latifolia* were not found to have a relationship with distance from the mouth of the river. These findings support the compensation actions already taking place by most consultants; replacing *C. lyngbyei* and *J.*

balticus with freshwater-adapted species like *C. obnupta* as they move east. However, future compensation projects could consider increasing the use of other dominant native species that are not found to vary significantly depending on their location in the transition zone between *C. lyngbyei* dominance to *C. obnupta* dominance, such as *Juncus articulatus* and *T. latifolia*.

4.1.7 Invasive Species

Wetlands are highly susceptible to invasive species; according to the Global Invasive Species Database, although only approximately 6% of the global land mass is wetland habitat, 24% of the most invasive plants invade wetlands. Wetlands make good habitat for invasives because there is constant through-flowing water, anoxic soils, nutrient fluxes, and frequent disturbance (Zedler & Kercher 2004). Susceptibility to invasive species is exacerbated in urban landscapes (Galatowitsch et al. 1999, Zedler & Kercher 2004) and compensatory wetlands are even more susceptible due to the initial disturbance of creating the habitat.

Phalaris arundinacea was the most abundant invasive species recorded in this study, dominating 20% of compensation sites as the most dominant species, and averaging a relative dominance of 11.4%. Until recently, the origin of *P. arundinacea* remained uncertain and was assumed native. As a result, the species was not well-managed and was even included in the planting plan of several older FREMP compensation sites (e.g. site 13-001). However, recent research indicates that *P. arundinacea* was brought to North America shortly after 1850, where it has benefitted from habitat alteration, dispersal by humans, and high genotypic diversity due to the frequent introduction of new genetic material to North America (Galatowitsch et al. 1999, Lavergne & Molofsky 2004). Since its introduction, *P. arundinacea* has rapidly invaded riparian and wetland habitats across its whole region of North America (Galatowitsch et al. 1999). In Wisconsin it dominates, with greater than 80% cover, more than 40,000 ha of wetlands (Bernthal & Willis 2004) and was found to be the dominant species in 19% of compensation sites in Illinois (Matthews & Endress 2008). Matthews et al. (2009) found in a review of compensatory wetlands that sites that failed to meet legal standards of native species dominance were frequently dominated by *P. arundinacea* and *Typha angustifolia*. We found similar results in this study; of the twelve sites that ranked poor for proportion of native species, eight were dominated by *P. arundinacea* and two were dominated by *T. angustifolia* or *Typha x glauca*. Controlling *P. arundinacea* on compensation sites is recommended as it can tend towards monotype dominance and degrade habitat quality and functioning (Zedler & Kercher 2004). It is recognized that this species can be difficult to control and heavily dominated sites may only benefit from a complete restoration. For this reason, site description forms include information about sites that contain small, easily controlled patches of *P. arundinacea* in their mitigation section.

The next highest invasive species found in this study was *T. angustifolia* and *Typha x glauca* (*Typha angustifolia* x *Typha latifolia* hybrid) with a combined mean dominance of 3.7%, but the highest dominance observed in a single site was 93%. The third most abundant invasive species was *Lythrum salicaria* with a mean dominance of 3.2% and the highest dominance observed for this species in a single site was 30%. *Lythrum salicaria* and *T. angustifolia* with *T. x glauca* have very similar mean overall dominances, but very different maximum dominances. This indicates that *T. angustifolia* with *T. x glauca* are not very widespread, but where they are present they tend towards monotype dominance (Zedler & Kercher 2004), while *L. salicaria* is much more widespread, but does not tend towards monotype dominance. Even though *L. salicaria* does not tend towards monotype dominance it is still a highly invasive species along riverbanks and in wetlands across temperate North America (Galatowitsch et al. 1999) and saw a 13-fold increase in Manitoba over a ten-year period (Zedler & Kercher 2004).

Unlike *L. salicaria, T. angustifolia* and *T. x glauca* are not recognized as invasive species in this region, despite their designation as invasive in other regions of North America and their ability to aggressively colonize and dominate habitats (Galatowitsch et al. 1999, Selbo & Snow 2004, Zedler & Kercher 2004). In nearby Washington State, the Washington State Noxious Weed Control Board proposed *T. angustifolia* be listed as a Class B invasive species (contain established populations and prevent expansion), but was instead listed as Class C (optional control enforcement, optional education) (Washington State Noxious Weed Control Board 2013). These *Typha* spp. are competitive invaders as they can withstand hydrological disturbance, extended inundation and fluctuating salinity (Hutchinson 1988a, Grace & Wetzel 1998, Wilcox et al. 2008). They also displace native species through shading, dense underground rhizome mats, and allelopathy (biochemically inhibits growth of other species) (Zedler & Kercher 2004, Jarchow & Cook 2009).

Typha angustifolia and *T. x glauca* were observed at twelve different locations throughout the Lower Fraser River in dominances ranging from 0.4 to 93% (Figure 14). These *Typha* spp. appeared to be concentrated in the western section of the North Arm with the highest dominance observed at Macdonald Park, Richmond (compensation site 03-004). Site 03-004 was originally created as a "sedge basin" in 1994; however, is now a monotype stand of *T. angustifolia* and *T. x glauca*. We suspect that *T. angustifolia* may have spread from location 01 in Figure 14 where we observed potentially thousands of square meters of *T. angustifolia* monotype culture.

Little evidence can be found of *T. angustifolia* management or research in the Fraser River region. Although the genetic and ecological threat of *T. angustifolia* is well-studied, the species is still available in local garden centres as a decorative ornamental, and was observed in ponds of private condo developments near the Fraser River as an ornamental. As proactive measure, we recommend the removal of all exotic *Typha* spp. from garden centres, as hybridization appears to occur with several other exotic *Typha* sp., not just *angustifolia* (Washington State Noxious Weed Control Board 2013). Where *T. angustifolia* and *glauca* are already established, removal actions should be pursued while populations are small and manageable (exception of location 01, Figure 14).

4.1.8 Log Debris

The wood debris trap located between Agassiz and Hope on the Fraser River captures between 25,000 to 100,000 m^3 of wood debris annually during spring freshet (Thonon 2006); however, much wood debris enters the Lower Fraser River annually from other sources or by passing the debris trap. Despite the fact that 90-95% of the log debris caught in the Fraser River debris trap is of natural origin (Thonon 2006) urban infrastructure such as sea-walls and riprap banks have greatly diminished the ecological and structural role of this debris in the Lower Fraser River (Thomas 2002). Therefore, removal of log debris is a common practice to address concerns regarding boat safety and marsh health. Thomas (2002) found that removal of log debris from the Fraser River Park marsh yielded mixed results. While some plant regrowth was observed, *Leymus mollis* (dune grass) grew or bare ground persisted in the high marsh habitat. Therefore, prevention of log debris accumulation is preferable over expensive removal activities followed by potentially poor regrowth. This study found that lattice fences, off shore log booms, and marinas adjacent to marshes were effective at decreasing the accumulation of log debris (Figure 12). However, only lattice fences and certain types of string booms (not distinguished from log booms in this study) are under the control of project consultants. Other types of log debris protection structures that are under the control of project consultants, such as tire structures (Image 3) or posts (Image 4), were generally found to be ineffective. Log debris accumulation was not found to differ significantly between marsh design type; however, embayment designed marshes were anecdotally observed to often have an accumulation of log debris at the back of the site (Image 4).

Experimentation is required to determine other types of successful log debris protection and more research is required to determine if marsh design can have a significant impact on lowering log debris accumulation.

It is recommended that future wetland compensation projects first consider river hydrology in site selection to diminish the potential for log debris accumulation and, second, consider the installation of some form of log debris protection, especially if constructing an embayed marsh. However, if log debris removal is required Thomas (2002) suggests leaving well-embedded logs in the high marsh zone where bare ground would be threatened by opportunistic weedy species and focusing log removal efforts in the low to mid marsh zone where *Carex lyngbyei* dominates.

Image 3: Tire log debris protection structure. Compensation site 10-002-A. July 28th, 2015

Image 4: Posts as log debris protection. Compensation site 01-003-B. July 24th, 2015

4.1.9 Waterfowl Grazing

Branta canadensis (Canada geese) are a migratory species that nest in arctic and subarctic regions of Canada, summer in the United States, and pass through southern Canada during spring and fall migration (Environment Canada 2010). In the 1970's non-migratory populations of *B. Canadensis* were introduced to southern Canada for the purpose of hunting and wildlife viewing, but the introduction had unintended negative results. The populations exploded, seeing a rise of 50 times from 1965 to 1995 in the Lower Fraser Valley, putting stress on food and habitat resources (Environment Canada 2010). *B. Canadensis* target crops and grassy plant species for food and prefer to forage near open water (Environment Canada 2010). During the natural migration of *B. Canadensis Carex lyngbyei* is either just emerging or dying back; however, during the summer months *C. lyngbyei* is available for the non-migratory *B. Canadensis* to forage on as it often grows near open water.

B. Canadensis have been known to reduce *C. lyngbyei* in compensatory wetlands to 0% survival after the initial year of planting (Crandell 2001, Adams & Williams 2004). This study found that *C. lyngbyei* mean maximum stem height was significantly shorter (99 cm ± 13) on sites where clear evidence of waterfowl grazing was observed compared with sites that did not have clear evidence (122 cm ± 9). Established stands of *C. lyngbyei* are much more likely to survive *B. Canadensis* grazing due to the below-ground organs of the plant which constitute most of its biomass (Kistritz et al. 1983). This calls to attention the importance to protect and monitor new compensation sites during the initial years of establishment to ensure the survival and healthy establishment of *C. lyngbyei*.

4.2 Riparian Compensation Habitat

Riparian habitats are the narrow ecotone between the aquatic and terrestrial environment and are subject to frequent flooding (Goodwin et al. 1997). 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 (Barling & Moore 1994, Donat 1995, Hood & Naiman 2000, Richardson et al. 2007). 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 (Naiman & Decamps 1997, Richardson et al. 2007, Guglielmo et al. 2008). 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 (Knopf & Samson 1994).

4.2.1 Area

This study attempted to assess riparian compensation sites based on the proportion of target habitat established, but found it was too variable due to the historical data available. Despite all areas being reported in square meters, notes indicate that at the time of compensation many projects were measured in linear meters. For example, a site may report to have created 100 m², but in reality 100 linear meters were created. Upon field inspection we would find 400 m² (100 m long by 4 m wide), creating a discrepancy of four times. In Figure 15 we report discrepancies of sites measured in linear meters compared with our linear meter findings; however, they were only calculated for sites in which we were able to confirm that linear measurements were used. Other sites with high area discrepancies were likely compensated using linear meters, but this could not be confirmed.

4.2.2 Species Composition

Achieving 100% native species in both the overstory and understory strata was considered a realistic goal for riparian compensation projects. Eighty-one percent of sites containing trees had a high proportion of native species (81-100%) in their overstory strata and 58% of sites had a high proportion of native species in their understory strata. Non-native species in the overstory often included European mountain-ash), *Betula pendula* (European birch), and *Prunus cerasifera* (purple leaf plum). *Sorbus. aucuparia* and *B. pendula* may have been planted intentionally (both species are available commercially and have ornamental value), or were confused with native *Sorbus sitchensis* (Sitka mountain-ash) and native *Betula papyrifera* (paper birch) by restoration practitioners. *Prunus cerasifera* was likely planted intentionally as a decorative ornamental.

The most common non-native understory shrub species was invasive *Rubus armeniacus (Himalayan blackberry) and exotic Rosa rugosa (Rugosa rose).* Exotic *R. rugosa* was likely planted as a substitute to native Rosa sp., as it has higher ornamental value, and does not exhibit the rapid expansive growth of native roses, which can prove problematic near public trails. *Rubus armeniacus* is an aggressive invasive, and likely entered sites through seed dispersal by avian species. To better replicate natural riparian habitats, and achieve 100% native species, it is advised that future riparian compensation projects select only native species and include active invasive species management, particularly for *R. armeniacus*. Astley (2010) recommends that dense planting of native species may help to limit *R. armeniacus* establishment.

Rubus armeniacus was the most problematic invasive species encountered in riparian compensation sites with one site containing 75% total cover. The species was introduced to the Pacific Northwest in 1885 and by 1945 was naturalized along the West Coast (Bennett 2006, Boersma et al. 2006). Today, *Rubus armeniacus* is known to aggressively invade disturbed sites as well as riparian habitats (Invasive Species Council of British Columbia 2014) making early successional riparian compensation sites highly susceptible to invasion. Additionally, *R. armeniacus* creates dense thickets that can prevent the establishment of planted native trees and shrubs, and inhibit the natural colonization of other native species. *Populus balsamifera* (black cottonwood) and *Alnus rubra* (red alder), two of the most common riparian habitat species, are relatively short lived; therefore, when they die in *R. armeniacus* thickets they will not be replaced. Although *R. armeniacus* does provide some habitat value, it is an inferior riparian species for restoration, as it does not contribute large woody debris and does not provide sufficient shade to the aquatic environment (Bennett 2006). *Rubus armeniacus* has been observed to provide habitat, nesting sites, and food for a number of species (Bennett 2006); however, it was found that breeding birds will preferentially select non-*R. armeniacus* habitats for nesting sites (Astley 2010) and the food and habitat functions provided by *R. armeniacus* can be easily replaced by fruit-bearing native species (Green & Klinka 1994).

4.2.3 Diversity and Density

Preliminary analysis suggests that compensatory riparian habitats have less understory species diversity and richness than reference sites (data not shown). This is corroborated by Matthews et al. (2009) which also found that there was generally less species richness in compensatory riparian habitats compared with reference sites. This is likely due to deficiencies in planting strategy or cost saving measures. Regardless of reason, it is important to plant riparian compensation habitats with several native understory species, and (where possible) leave existing trees to create a structurally complex habitat with high species diversity (Dreesen et al. 2002).

The number of stems per hectare observed at compensatory riparian habitats varied greatly, from 0 to 16,840, and the median stems per hectare was 157.2 stems/ha. The number of stems per hectare in the reference site was 733 and 74% of the compensation sites had less stems per hectare than the reference site. Overall, it was observed that overstory species were often underrepresented in riparian plantings, which limits the resemblance of compensation habitats to that of reference conditions.

Seventy-nine percent of the riparian compensation habitats had greater understory percent cover than the reference site; however, understory percent cover can vary greatly based on successional stage. The reference site used in this study was a late-successional riparian habitat with a mature canopy, while most compensation sites were in an early-successional stage. Succession, in the case of riparian habitats, is a much slower process than in marsh habitats, which are capable of achieving 100% vegetative cover within a few growing seasons as opposed to several decades in riparian areas. Furthermore, many compensation sites were planted densely, which is recommended, to prevent the establishment of *R. armeniacus* (Astley 2010).

4.2.4 Compensation Design

Compensatory riparian habitat varied greatly in design between sites. The most common design was a thin strip of vegetation, often only 1 m wide, placed between a public walking trail and the riprap dike, at the top of the slope. Another common design included the installation of pots or “pockets” into the riprap slope which were then planted with a tree or shrubs (e.g. compensation site 04-005). Some riparian habitats had large spaces of manicured lawn between vegetation patches and very few had wide areas of vegetation resembling a natural riparian habitat. The vegetation in a number of compensation sites were subjected to hedging resulting in short, dense stands. It was observed that many shrub and even sometimes tree species were being trimmed and hedged in public parks and near residential developments to maintain sightlines and preserve aesthetic value. Hedging understory species causes the plant to grow densely, 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.

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, strategically planting trees to limit sightline loses, and not including manicured lawns in compensation calculations.

Riparian compensation sites often occurred at the top of riprap slopes where they will very rarely, if ever, get inundated by flooding (a technical requirement for a habitat to be considered riparian). 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 better replicates the ecological functions of true riparian habitat, it has limitations. Planting mortality was high in these pockets and trees and shrubs have not been recommended on dike slopes, as root penetration may cause cracking, loosening, wind throw holes, and seepage (BC Ministry of Water Land and Air Protection 2003). A solution to this may be to consider terracing compensation marsh benches with an armoured marsh foreshore, as well as an elevated, armoured riparian bench along the backshore. More research and experimentation is required to address these limitations and improve compensation design.

Most riparian compensation habitats observed in this study did not accurately replicate natural riparian vegetation, and these deficiencies were not well-described through the current compensation assessment measures. Most riparian compensation projects assess success based on plantings survival (Matthews & Endress 2008); however, this too would not assess how well the habitat replicates a natural environment. The most common deficiencies observed were unnatural habitat structure due to hedging, lack of overstory species, presence of manicured lawns, isolation from the aquatic environment, and high elevation. It is understandable that recreational and aesthetic values need to be preserved for the public, but these pseudo-riparian habitats should not be considered as compensation at a 1:1 ratio, and fail to validate the guiding no-net-loss (NNL) principle.

4.3 Limitations

4.3.1 Description of Compensation Actions

Important information such as baseline conditions, compensation actions, and monitoring results were often absent or incomplete in the BIEAMP-FREMP legacy site records. Because of this, it was difficult to comment on or evaluate certain levels of compensation success. For example, it was not possible to evaluate the longevity of original site plantings, as many legacy site descriptions did not include a species list, or were too vague (e.g. *Carex* spp., *Juncus* spp.). Similarly, it was not possible to compare sites that were planted to sites that were left to naturally colonize, as such planting strategies were rarely described.

4.3.2 Precision of Compensation Site Mapping

The imprecision of compensation site polygons in the FREMP-BIEAP legacy records hindered monitoring actions. The mapping precision of each FREMP-BIEAP legacy site record is presented in one of 4 precision ranks: (d) definite location based on coordinates, (h) definite location based on orthoimagery, (i) inexact location but very close and (u) uncertain location. Of the 130 legacy records, only 44% of sites were mapped to a definitive level, 52% were considered inexact but very close, and 4% of site locations were uncertain. As a fundamental resource for monitoring efforts, this level of imprecision is problematic, particularly when considering that many of the inexact polygon boundaries (52% of all sites), were estimated through aerial photo interpretation and remain unconfirmed.

This limitation was realized over the course of this project. Of the 54 sites ground-truthed, only 32% were considered precise enough to have absolute confidence in the area measurement**.** This uncertainty proved especially problematic when trying to evaluate the no-net-loss principle, which is dependant on acquiring accurate area measurements for a compensation site.

In some cases, the inaccuracy of BIEAMP-FREMP polygons significantly influenced monitoring results. For example, site 02-006 was sampled in July 2015, but upon corresponding with Fisheries and Oceans Canada, it was discovered that the sample area was incorrect, and the data were unusable (Image 5). The site had to be re-sampled in August 2015.

Image 5: Example of an incorrect FREMP-BIEAMP legacy polygon (red) and true compensation site boundaries confirmed by Brian Naito (Department of Fisheries and Oceans) (blue).

4.3.3 A Need for Knowledge Collation & Acquisition

These challenges outline a need for knowledge collation among practitioners, proponents, and government agencies previously involved in FREMP. Since its disbandment in 2013, no single entity has taken the role of data and resource collation, resulting in the dispersal of FREMP documents among several agencies, practitioners, and the BCIT River's Institute. Without an entity working to manage and acquire relevant FREMP files, it is likely that these resources will become increasingly scarce, and monitoring will become increasingly difficult.

Within the current state of affairs, significant effort should be made to acquire compensation site plans well-before commencing any monitoring actions, as they contain much of the information required for effective monitoring, and were noticeably absent from physical and digital libraries used in this project. The site plans used in this project were acquired through direct correspondence with project proponents including the City of Surrey, Ministry of Transportation, and Fisheries and Oceans Canada.

5 Recommendations

5.1 Marsh Compensation Habitat

5.1.1 Future Compensation Projects

- **Increase monitoring effort and invasive species management budget from West to East.**
    - Compensation sites are more susceptible to invasive and exotic species invasion along a West to East gradient, likely due to the effect of salinity. Monitoring efforts should reflect susceptibility of site to invasive or exotic species invasion.
- **Ensure appropriate elevation is established for marsh habitat and appropriate substrate used in creation of compensation wetland.**
    - Compensation sites were found to have a higher mean site wetland indicator status (WIS) than reference sites. Increasing site WIS correlates with exotic species. Higher site WIS may be attributed to low submergence time caused by the site being at too high an elevation, or poor water retention by soil.
- **Increase monitoring of *Carex lyngbyei* in initial years of compensation and consider grazing protection measures to ensure survival and establishment.**
    - There is significantly less *C. lyngbyei* in compensation sites compared to reference sites.
    - *Carex lyngbyei* has significantly shorter stem height in the presence of waterfowl grazing, particularly *Branta Canadensis* (Canada Geese). New compensation sites have been known to lose all *C. lyngbyei* plantings in the first year due to geese graze.
- **Consider salinity tolerance of plant species dependant of distance within or to the Fraser River salt wedge.**
    - Most dominant native species observed included: *Carex lyngbyei*, *Juncus balticus, Carex obnupta, Juncus articulatus,* and *Typha latifolia*
    - *Carex lyngbyei* and *Juncus balticus* dominance decreases with distance from the mouth of the river.
    - *Carex obnupta* increases with distance from the mouth of the river.
    - *Juncus articulatus* and *Typha latifolia* dominance did not differ with distance from the mouth of the river.
- **Consider river hydrology in site selection to limit potential impacts of log debris. Install log debris protection when possible or utilize existing structures, especially if constructing an embayed marsh.**
    - Excessive log debris build up can severely impact plant growth and site productivity.
    - The presence of a log-boom, marina, or lattice fence significantly reduces the amount of log debris accumulation.
    - Embayed marshes were observed to have greater accumulation of leg debris.
- **Combine compensatory wetlands with riparian habitat**
    - Riparian buffers surrounding wetlands have been associated with increased wetland health (Wray & Bayley 2006). Therefore, combining wetland compensation with existing riparian habitat or incorporating a riparian buffer as part of the compensation may improve the quality and functioning of the wetland habitat.
    - Several existing compensation projects contain both riparian and wetland compensation, but the two habitats are isolated from each other due to a steep riprap slope. Consider new designs that better integrate riparian vegetation into marsh interface (e.g. terrace system).

- **Establish baseline data prior to compensation actions**
    - Lack of baseline data or pre-impact conditions limits the ability to determine success or failure and to conclude if no-net-loss has been achieved (Kentula et al. 1992, Cole & Shafer 2002, Harper & Quigley 2005, Quigley & Harper 2006, Matthews & Endress 2008). Therefore, pre-impact assessment surveys should be conducted using the inventory methods of this study and contributed to the FREMP-BIEAP Habitat Compensation Sites database.

5.1.2 Immediate Actions

- **Control invasive species within individual compensation sites**
    - *Typha angustifolia* and *Typha x glauca* as well as *Phalaris arundinacea* are the most dominant invasive species observed on compensation sites.
    - *Typha angustifolia* and *T. x glauca* as well as *P. arundinacea* tend towards monotype stands that severely decrease ecological functioning.
    - Site descriptions (**Error! Reference source not found.** & **Error! Reference source not found.**) ou tline sites with small, easily controlled patches of invasive species for ease of mitigation action.
- **Remove log debris from impacted sites**
    - Log debris accumulation can severely impact plant growth.
    - Removal of log debris is recommended for sites with excessive log debris accumulation. Site descriptions (Appendix VII – Marsh Compensation Site Descriptions) outline whether log debris accumulation is excessive and requires removal.
    - When removing log debris from a wetland Thomas (2002) suggests leaving embedded logs in the high marsh zone where bare ground would be threatened by opportunistic weedy species and focusing log removal efforts in the low to mid marsh zone where *Carex lyngbyei* dominates.

5.1.3 Research and Development

- **Further analysis with existing dataset**
    - The raw data from this study will be publicly available
    - Data not used includes:
        - Plant species flowering/seed status
        - Species richness/diversity analysis
        - Maximum stem height analysis of *Carex* and *Juncus* spp.
        - Mudflat community analysis
        - Biomass analysis using Robel-pole data or *Carex* and *Juncus* spp. stem height
- **Complete assessments for remaining marsh compensation habitats in FREMP-BIEAP database**
    - This study assessed 39 of the 96 marsh compensation habitats in the FREMP-BIEAP database
- **Species with unknown origin investigation**
    - Some genera have native and non-native species that occupy similar habitats in the Fraser River region whose differentiating characteristics are either poorly described or only observable under certain conditions; such as while flowering or seeds observed under a microscope.
    - If an unknown species is highly dominant or dominant enough to influence the outcome of the proportion of native species it is recommend that further investigation be carried out to determine its origin.
- **Threatened species analysis**

- Threatened, native plant species were identified in this study.
- This data can be used to look at distribution and abundance of threatened species as well as identify vital habitat.

- **Log debris protection experimentation**
  - The presence of a log-boom, marina, or lattice fence significantly reduces the amount of log debris accumulation; however only lattice fences and some string booms are under the control of compensation consultants.
  - Some other forms of log debris protect have been shown to be ineffective.
  - More research and experimentation is recommended to determine more log debris protection options.
- **Marsh design for minimization of log debris accumulation**
  - Log debris accumulation did not differ between marsh design types; however, embayed marshes were anecdotally observed to have more accumulation.
  - Further research is required to determine if marsh design can influence log debris accumulation.

5.2 Riparian

5.2.1 Future Compensation Projects

- **Combine riparian and wetland compensation habitats**
  - Riparian buffers surrounding wetlands have been associated with increased wetland health (Wray & Bayley 2006). Therefore, combining wetland compensation with existing riparian habitat or incorporating a riparian buffer as part of the compensation may improve the quality and functioning of the wetland habitat. In several existing compensation projects created riparian habitat is isolated from created marsh due to steep riprap slopes. Consider new designs that better integrate riparian vegetation into marsh interface (e.g. terrace system).
- **Plant riparian habitat with a high diversity of native species (Dreesen et al. 2002)**
  - Riparian compensation sites were observed to, on average, have a low diversity of species, inhibiting site resilience to ecological threats and changes over time.
- **Plant native fruit-bearing species**
  - Fruit bearing native species have a higher habitat value for many animals that feed on them.
- **Initial understory plantings should be dense**
  - Dense plantings may help to limit the establishment of *R. armeniacus* (Astley 2010).
- **Plant more trees**
  - Riparian compensation sites were observed to, on average, have lower stem density than the reference site.

- **Include wildlife trees where possible**
  - Very few snags/wildlife trees were observed in compensatory riparian habitats.
  - Snags/wildlife trees provide habitat for cavity nesting species and forage for many different species.
- **Monitor riparian habitats for long period of time**
  - Riparian habitats have a much longer establishment time than wetlands and progress through various successional stages. Therefore, they require a long-term monitoring strategy.

Effective monitoring plans will reduce monitoring frequency, but increase monitoring time period.

- **A balance of anthropogenic and habitat values in compensatory riparian habitats**
  - Some riparian compensation sites have manicured vegetation to maintain views and aesthetic appeal; however, dense manicured vegetation can act as a barrier to wildlife.
  - Incorporate "pockets" of manicured vegetation between sections of more "wild" vegetation.
- **Determine a standardized method to measure area**
  - Some riparian compensation sites were created based on linear meters, but recorded in square meters resulting in an inability to assess compliance.
- **Do not include lawns or manicured vegetation as riparian habitat at a 1:1 ratio**
  - Some riparian compensation sites included lawns or heavily manicured vegetation in compliance calculations. These types of habitat do not possess the same ecological value or function as natural riparian habitat.
- **Actively control invasive species**
  - The most problematic invasive species to riparian habitats is *R. armeniacus*, which can invade and establish during any successional stage, but is of the highest threat immediately following disturbance.
  - Monitoring and control of *R. armeniacus* should continue until a more mature successional stage has been reached.

5.2.2 Immediate Actions

- **Plant trees**
  - Most compensation sites contained a stem density lower than the reference site
  - Compensation sites containing no trees or a low stem density should be planted with additional native trees
- **Control invasive species**
  - *R. armeniacus* was the most problematic invasive species observed in riparian compensation sites. The highest percent cover of *R. armeniacus* encountered was 75%.
  - *R. armeniacus* on existing compensation sites should be controlled. Site description forms in Appendix VIII) detail which sites contain *R. armeniacus*
- **Alter landscaping methods**
  - Some riparian compensation sites have manicured vegetation to maintain views and aesthetic appeal; however, dense manicured vegetation can act as a barrier to wildlife.
  - Sites currently receiving landscaping treatments should alter those methods to incorporate "pockets" of manicured vegetation between sections of more "wild" vegetation. Sites containing manicured vegetation are detailed in Appendix VIII.

5.2.3 Research and Development

- **Reassess success criteria to consider all facets of riparian habitat**
  - Riparian areas are complex habitats that have a number of dynamic variables. Therefore, assessment criteria should consider the following factors (in relation to reference sites where possible):
    - Size, age, and complexity of trees
    - Presence of snags/wildlife trees
    - Density requirements dependent on successional stage of habitat

        - Anthropogenic influences such as landscaping
        - Flood frequency
        - Contribution of shade and nutrients to aquatic environment
- **Complete assessments for remaining riparian compensation habitats in FREMP-BIEAP database**
    - This study assessed 18 of the 68 riparian compensation habitats in the FREMP-BIEAP database
- **Research and experimentation with bioengineering for riprap slopes**
    - Most compensation sites encountered were created at the top of riprap walls where they will rarely, if ever, get flooded, a technical requirement for a habitat to be considered riparian
    - Planting on dike slopes is generally not recommended as root penetration may cause cracking, loosening, wind throw holes, and seepage (MOE 2003)
    - More research and experimentation with different types of bioengineering for riprap slopes, such as terraced riparian strips, is recommended

5.3 Other Estuary Compensation Habitats

The FREMP-BIEAP database contains 7 different type of estuarine compensation habitats. While marsh and riparian habitats make up the majority of the compensation types there are also 9 sites containing subtidal mudflat, 28 sites containing intertidal mudflats, 1 site containing eelgrass bed habitat, 2 sites containing subtidal/intertidal rock/reef and 9 sites containing intertidal stream channels. It is recommended that future studies be conducted to assess these different types of compensation habitats, and whether the no-net-loss (NNL) principle was truly achieved.

6 Closing Statement

The FREMP-BIEAP database contains 130 projects representing wetland, riparian, mudflat, eelgrass bed, rock/reef, and stream channel habitat. Due to time constraints, this study only assessed wetland and riparian habitats and only surveyed 39 projects. Wetland compensation projects were the primary focus of the study, though important insights into riparian compensation were also established.

Monitoring and assessment methods for wetlands were adapted from similar studies and carefully described in this document to allow for (1) replication in future studies and (2) result comparisons with similar projects. Compensation site descriptions and raw data from this study have been updated in the FREMP-BIEAP database and are publicly available. This information provides baseline data that may be used for future studies and analysis.

The site description of each compensation site provides details about the current plant communities, impacts to the site (e.g. log debris, waterfowl grazing, invasive species), and comprehensive details regarding the site's history and current state. These individual reports will provide habitat managers with the information necessary for making monitoring and mitigation decisions.

The analysis included in this study will deepen the understanding of marsh and riparian compensation site dynamics, as well as compensation compliance in the Fraser River Estuary. Only 33% of wetland compensation sites surveyed were classified as successful based on criteria assessing compliance area and proportion of native species. Deficiencies in area can be attributed to a lack of compliance; however, deficiencies in the proportion of native species is a dynamic and complex issue.

Limitations on the proportion of native species may be impacted by the site's location in relation to the mouth of the river and/or the site's Wetland Indicator Status (WIS) (see section 2.6.2.4). *Carex lyngbyei* was the most common species used in compensation site plantings; however, it is less-established in compensation sites compared with natural reference environments. This is an indication that a component of compensation activities is limiting *C. lyngbyei* establishment. This could be due to competition from exotic species, waterfowl grazing in the initial years after compensation, or poor site design favouring species that tolerate drier conditions. It was also found that compensation sites that utilized a form of log debris protection had less log debris accumulation. The results found in this study helped to establish a list of evidence based recommendations for future compensation projects, mitigation actions for existing sites that are functioning poorly, and continued research and development.

Since the 1980's habitat managers have been trying to establish no-net-loss (NNL) of impacted habitat in the Fraser River Estuary but have been unsuccessful. This study found that 2/3^{rds} of compensation sites did not achieve NNL. Studies in Canada, the United States, and across the world have found similar results, that created wetlands are not functioning as well as natural wetlands (Kunz et al. 1988, Zedler 1996, Brown & Veneman 2001, Quigley & Harper 2006, Moreno-Mateos et al. 2012). However, lessons can be learned from the 1/3rd of sites that did achieve NNL as well as from the analysis of the shortcomings. Canada contains approximately 1/4th of the world's wetland habitat (Rubec 1994); therefore, it is important to build upon research and continue to improve habitat compensation.

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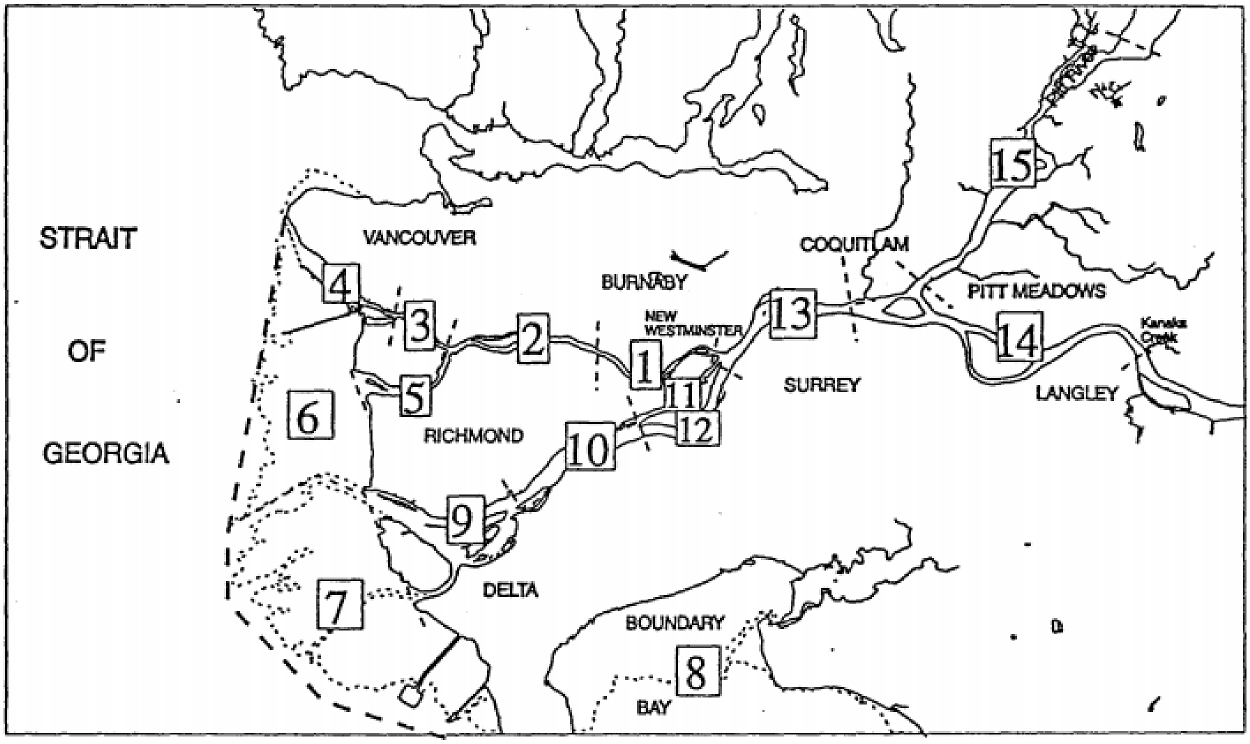
Appendix I – FREMP habitat management units



Appendix II – Species Classified as Invasive

Scientific	Common	Supporting Literature
Buddleja davidii	butterfly bush	(Klinkenberg 2013)
Cirsium arvense	Canada thistle	(Ralph et al. 2014; Perzoff 2008)
Clematis vitalba	traveler's joy	(ISCMV 2013)
Convolvulus arvensis	field bindweed	(Ralph et al. 2014; Perzoff 2008)
Cytisus scoparius	Scotch broom	(Ralph et al. 2014; Perzoff 2008)
Hypericum perforatum	common St. John's-wort	(Ralph et al. 2014; Perzoff 2008)
Ilex aquifolium	English holly	(Perzoff 2008; ISCMV 2013)
Iris pseudacorus	yellow iris	(Ralph et al. 2014;Perzoff 2008)
Lythrum salicaria	purple loosestrife	(Ralph et al. 2014; Perzoff 2008)
Phalaris arundinacea	reed canarygrass	(Perzoff 2008; ISCMV 2013)
Rubus armeniacus	Himalayan blackberry	(Klinkenberg 2013; ISCMV 2013)
Rubus laciniatus	evergreen blackberry	(ISCMV 2013)
Solanum dulcamara	European bittersweet	(Ralph et al. 2014; Perzoff 2008)
Tanacetum vulgare	common tansy	(Ralph et al. 2014; Perzoff 2008)
Typha angustifolia	lesser cattail	(Selbo & Snow 2004)
Typha x glauca	hybrid cattail	(Selbo & Snow 2004)

Appendix III – Prescribed Wetland Indicator Status for Species absent from Lichvar et al. (2014)

Scientific	**Common**	**Assigned Wetland Indicator status**	**Numeric Value**
Artemesia vulgaris	common mugwort	UPL	5
Bidens connate	purplestem beggarticks	OBL	1
Carex sitchensis	Sitka sedge	OBL	1
Ceratophyllum echinatum	spring hornwort	OBL	1
Convulvulus arvensis	field bindweed	FAC	3
Crepis tectorum	annual hawksbeard	FACU	4
Festuca occidentalis	western fescue	FACU	4
Festuca sp.	ornamental fescue	UPL	5
Festuca sp.	fine fescue	FACU	4
Glyceria maxima	giant mannagrass	OBL	1
Glyceria sp.	unknown mannagrass	OBL	1
Hieracium lachenaliii	European hawkweed	FACU	4
Juncus bolanderi	Bolander's rush	FACW	2
Lapsana communis	nipplewort	FACU	4
Lotus pedunculatus	stalked bird's-foot trefoil	FACU	4
Lycopus sp.	unknown horehound	OBL	1
Lythrum portula	European water-purslane	OBL	1
Mazzaella sp.	mazzaella	OBL	1
Melilotus alba	owl sweet clover	FACU	4
Myriophyllum ussuriense	Ussurian water-milfoil	OBL	1
Persicaria minor	Asian knotweed	FAC	3
Persicaria sp.	unknown persicaria	OBL	1
Philonotis fontana	spring moss	OBL	1
Poa confinis	beach bluegrass	FACU	4
Poa sp.	exotic bluegrass	FAC	3
Rosa multiflora	rambler rose	FACU	4
Salix sp.	unknown willow	FACW	2
Sonchus oleraceus	common sow-thistle	FACU	4
Tanacetum vulgare	common tansy	FACU	4
Veronica beccabunga	American speedwell	OBL	1
Vicia cracca	tufted vetch	FAC	3
n/a	aquatic algae	OBL	1
n/a	unknown moss	FAC	3
n/a	unknown mustard	FAC	3
n/a	exotic turf grass	FACU	4

Appendix IV – Marsh Compensation Assessment Methods

Example Site 02-001

Criterion 1: Proportion Target Habitat Established

Field measurements indicated that only 10,824 sqm (70% of FREMP legacy goal) is functioning as mid to high marsh habitat. The other habitats, community 2 (vegetated mudflat) and community 3 (sandbar) comprise the remainder. These other habitats provide complexity to the site, but were not the target habitats of the compensation project and are more susceptible to invasive and exotic species. As a result, they were not included in the assessment, and the site received a fair rank.

	Poor	**Fair**	Good
percent range	0 - 64	**65 - 84**	85 +

Criterion 2: Proportion Native Species

Success standards were based on data from the two nearest upstream and downstream reference sites:

- REF-05-001 % cover native species = 89%
- REF-02-001 % cover native species = 83%

Therefore, target relative % cover native species for compensation site 02-001 = 87% (average of reference sites).

This new target of 87% represents a relativized 100%. 100/87 = gives us a conversion rate of 1.149 to calculate the upper and lower bounds of the poor, fair, and good categories, adapted from the parameters used in Criterion 1:

- Poor: 64 ÷ 1.149 = 55
- Fair: 84 ÷ 1.149 = 73
- Good: 100 ÷ 1.149 = 87

Site 02-001 had a relative % cover native species of 59%, so the site would receive a fair rank for this criterion.

	Poor	Fair	Good
percent range	0 - 64	65 - 84	85 +
conversion based on reference Sites	0 - 55	56 - 73	74 +